Niches in Bedrock: Towards Integrating Bedrock Mortars into a Niche Construction Framework

by

David H. Price

A thesis submitted to
Sonoma State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

in

Cultural Resource Management

Committee Members:

Alexis Boutin, PhD., Chair

Margaret Purser, PhD.

Mark Selverston, M.A.

August 10, 2016

.

Authorization for the Reproduction of Master's Thesis

Niches in Bedrock: Towards Integrating Bedrock Mortars into a Niche Construction Framework

Thesis by

David Price

Abstract

Purpose of Study: This thesis investigates the ability to use bedrock mortar depth to reliably infer resource processing goals of the prehistoric peoples that utilized Browns Valley Ridge, California. The study area is a portion of a Sierra foothill formation at the eastern margin of the Sacramento Valley, with a particularly high density of bedrock mortars. Traditionally, bedrock mortar depth has been assumed to be a result of use-wear. The purpose of this study is to analyze the depth patterns of the mortars for evidence of manufacture to desired specifications that can be linked to intended processing goals.

Methods: This study utilizes archival data, field survey, and statistical analysis. Archival data include ethnographic and archaeological evidence of bedrock mortar use. Field methods include the intensive pedestrian survey of the study area and detailed recording of bedrock milling features. Statistical analyses involved Kolmogorov-Smirnoff and Shapiro-Wilks tests for normality; hypothetical frequency distribution comparisons; and data correction and transformation techniques including kernel density estimate, logarithmic transformation, and differential binning. The combination of the three methods create the ability to analyze bedrock mortar depth frequency datasets for meaningful patterns.

Findings: The 1,274-acre study area on Browns Valley Ridge contains over 74 bedrock milling loci comprised of at least 722 milling features on 240 bedrock outcrops. The bedrock mortar depth-frequency distribution of the study area is a highly non-normal, strongly multi-modal, and heavily right-skewed. The distribution does not match the results of hypothetical use-wear patterns, and the depth-frequency distributions of bedrock mortars at the locus and outcrop scales are highly variable. Data correction shows that the modes of the study area distribution are indicative of meaningful data, and not the result of data smoothing or recording errors.

Conclusion: The multi-modality, non-normality, and skew of the depth frequency distribution in the study area show that it is not the result of natural processes or use wear. The robust modes of the distribution display desired depths of those who manufactured them. Given the substantial investment in time and place of bedrock mortar manufacture, it is highly likely that the depth distribution of the study area represents a design indicative of processing goals.

Acknowledgements

This paper could not have been written without the help of numerous people. First and foremost, I would like to thank my committee members Alexis Boutin, Margie Purser, and Mark Selverston. Their insight and clarity guided me through the kind of boulder-strewn labyrinthine paths that I tend to get lost on. A special thanks to Mark for getting me involved on Saddleback Ranch. It's still hard to believe how lucky I was to have been around to volunteer on that first survey effort. A very special thanks go to Carol and Ned Spieker, owners of Saddleback Ranch, for their generosity, curiosity, and hospitality. I will never be able to thank them enough for letting us in to their beautiful ranch, and only hope that this research helps to shed light on some of its unique story. Many thanks to the Anthropological Studies Center for providing me the tools and experience necessary to perform the work needed for this thesis, and for the volunteer crews that helped me do it. Of course, I have to make special mention of my graduate cohort, many of whom were walking alongside me from outcrop to outcrop through three field seasons.

My family deserves much of the credit for this paper getting finished. I am especially thankful to my mother and father, who despite their efforts and sincere warnings, paved my way directly into archaeology. You both found that delicate balance of being supportive, giving space, and *just* pushing enough to encourage me to finish this paper in a somewhat respectable timeframe. Finally, a thousand thanks to my wonderful fiancé, who planned most of a wedding, kept our home livable, and cleaned behind my ears when I retreated from my sense of personal hygiene in the name of getting a chapter finished. I couldn't have done it without you.

Table of Contents

ABSTRACT .... **IV**

ACKNOWLEDGEMENTS .... **V**

LIST OF FIGURES .... **VII**

CHAPTER 1. INTRODUCTION **1**

CHAPTER 2. BACKGROUND **14**

The Constituents of Bedrock Milling Infrastructure 14
Acorn Processing and Bedrock Mortar Use 17
Modern Ethnographic Insights 18
A Niche Construction Framework 20
Physical Setting 22
Prehistoric Context 25
Ethnographic Context 34
Theoretical Context 38

CHAPTER 3. METHODS **48**

Archival Research 48
Field Survey and Recording 49
Analysis 50

CHAPTER 4. FINDINGS AND ANALYSIS **56**

Findings 56
Landscape Scale 56
Bedrock Mortar Outcrop Scale 62
Milling Locus Scale 65
Analysis 69
Null Hypothesis 1: Mortar Depth is Random 69
Null Hypothesis 2: Mortar Depth is a Function of Use-Wear 70
Test Hypothesis: Mortar Depth is a Function of Design 78
Discussion 84
A Niche Construction Approach to the Study of Bedrock Mortars 87

CHAPTER 5. CONCLUSION **94**

Future Studies 97

REFERENCES CITED **100**

APPENDIX 1 .... **112**

APPENDIX 2 .... **139**

APPENDIX 3 .... **148**

List of Tables

TABLE 1: RESULTS OF NORMALITY TESTS 69

List of Figures

FIGURE 1: STUDY AREA VICINITY MAP 7
FIGURE 2: NICHE CONSTRUCTION PATHWAYS (FROM O'BRIEN AND LALAND 2012:446)... 46
FIGURE 3: STUDY AREA MAP 57
FIGURE 4: LANDSCAPE SCALE DEPTH FREQUENCY HISTOGRAM........ 58
FIGURE 5: DIFFERENTIAL DATA BINNING 58
FIGURE 6: SMOOTHED DEPTH FREQUENCY HISTOGRAM 60
FIGURE 7: DEPTH FREQUENCY BOXPLOT 60
FIGURE 8: BEDROCK MORTAR OUTCROP MAP........ 61
FIGURE 9: OUTCROP SCALE CUMULATIVE MORTAR DEPTH FREQUENCY BOXPLOT 62
FIGURE 10: OUTCROP SCALE MORTAR COUNT FREQUENCY BOXPLOT........ 62
FIGURE 11: OUTCROP SCALE CUMULATIVE MORTAR DEPTH FREQUENCY HISTOGRAM 63
FIGURE 12: OUTCROP SCALE MORTAR COUNT FREQUENCY HISTOGRAM 63
FIGURE 13: MORTAR DEPTH FREQUENCIES OF INDIVIDUAL BEDROCK MORTAR OUTCROPS 64
FIGURE 14: MILLING LOCUS MAP 66
FIGURE 15: MILLING LOCUS SCALE OUTCROP COUNT FREQUENCY HISTOGRAM 67
FIGURE 16: MILLING LOCUS SCALE MORTAR COUNT FREQUENCY HISTOGRAM 67
FIGURE 17: MILLING LOCUS SCALE CUMULATIVE MORTAR DEPTH FREQUENCY HISTOGRAM 67
FIGURE 18: MORTAR DEPTH FREQUENCY OF INDIVIDUAL MILLING LOCI 68
FIGURE 19: REPRESENTATIVE HISTOGRAMS FOR SCENARIO 1........ 72
FIGURE 20: REPRESENTATIVE HISTOGRAMS FOR SCENARIO 2........ 73
FIGURE 21: REPRESENTATIVE HISTOGRAMS FOR SCENARIO 3........ 75
FIGURE 22: SMOOTHED MORTAR DEPTH HISTOGRAMS SHOWING POSSIBLE MODES 80
FIGURE 23: MORTAR DEPTH HISTOGRAM WITH SUPERIMPOSED KERNEL DENSITY ESTIMATE CURVE 82
FIGURE 24: HISTOGRAM OF LOG10 DATA WITH SUPERIMPOSED KERNEL DENSITY ESTIMATE CURVE 83

Chapter 1. Introduction

The bedrock mortar (BRM) is one of California archaeology's most iconic symbols. The distinctive depressions are observed throughout the state, from the west coast to the east side of the Sierra Nevada. California's aboriginal peoples manufactured BRMs almost everywhere there was suitable rock to do so, in contexts ranging from a single mortar on a small isolated boulder to hundreds on numerous large outcrops. Ethnographic accounts of BRM use in California indicate the importance of the technology to Native Californians for the purpose of food processing, as well as for both the ceremonial and informal processing of non-food resources. Bedrock mortars are often the only remaining physical evidence of the prehistoric and protohistoric activities of Native Californians in a given area, especially in primarily erosional landscapes or those with poor soil preservation. Despite the importance of BRMs to both Native Californians and the archaeological record, archaeologists have paid relatively little attention to the role of the technology itself in the lives and cultures of the people who made them. Instead, researchers have largely focused on the resource best known to have been processed within BRMs: the acorn.

The archaeological discourse about BRMs has revolved around acorn processing for several reasons. First, they are difficult to put into a context for study (e.g., Stevens 2002). There is no known method of directly dating individual BRMs. There are methods for directly testing what specific resources were processed in a given mortar; however, they are relatively new, not widely known or used, expensive, and still being refined. Further, BRMs are created in natural outcroppings and large boulders, media which are rarely buried and seldom allow for indirect dating or clear association with the rest of the archaeological record. As a result, it is difficult to address questions of diachronic change in the technology or its relationship to unknown aspects of prehistoric life.

On the other hand, there is a long record of ethnographers mentioning the use of BRMs during modern and protohistoric times, and while they do mention other resources, all report that indigenous Californians primarily used the technology to grind acorn into flour (Gifford 1936; Kroeber 1925; McCarthy et al. 1985; Powers 1877; Ortiz 1991; Schulz 1980). At the time of European contact, nearly every Californian culture had an acorn-centered diet (Gifford 1936; Kroeber 1925; Powers 1877), which Gifford (1936) called balanophagy. Early anthropologists ascribed such a high value to acorn as a food source that they believed any Native American group with abundant access to it would inevitably adopt balanophagy. These observers saw subsistence shift as an important focus of cultural study, while the development of BRM technology was just a corollary to achieving that end.

Later, archaeologists (e.g., Basgall 1987; Baumhoff 1963; Bettinger 1976; Binford 1968) carried the idea of the BRM as a corollary to balanophagy while they developed and refined the theoretical frameworks commonly used for examining subsistence strategies in California. These frameworks are generally based on biological theory rooted in neo-Darwinism, which views adaptation as a response to environmental stimuli (Lewontin 1983)— when the environment changes, the mechanism of natural selection chooses for successful adaptations. Since it proved logical and productive to analyze subsistence strategies in terms of varying forms of adaptive fitness, other cultural phenomena were examined mostly in their capacity to affect the adaptive fitness of those strategies (Ames 1992; Basgall 1987; Bettinger 1976; Bettinger and Baumhoff 1982; Bettinger et al. 1997; Binford 1968, 1980; Codding et al. 2012; Gremillion 2002; Haney 1992; Hildebrandt and McGuire 2002; Jackson 1991; Jones 1996; McGuire and Hildebrandt 1994; Metcalfe and Barlow 1992; Morgan 2012; Raab 1996; Smith 1983; Tushingham and Bettinger 2013; Whelan et al. 2013). The automatic correlation of BRMs with balanophagy fit nicely within this developmental scheme.

The process of analyzing the shift to balanophagy under neo-Darwinian frameworks began in the middle of the 20th century. Anthropologists such as Baumhoff (1963) and Bettinger (1976) connected intensified acorn use to Flannery's (1969) Broad Spectrum Revolution, a seemingly worldwide trend that involved diet breadth expansion from primarily large game to various plant and animal resources. By the late 1980s, anthropologists such as Basgall (1987), Metcalfe and Barlow (1992), and Broughton (1994) demonstrated that acorn was not the obviously exceptional resource previously thought, due to the intensive labor required to make acorn edible. These authors helped to develop the field of human behavioral ecology (HBE), the most prevalent theoretical framework for analyzing prehistoric subsistence practices in California, from the neo-Darwinian-based field of behavioral ecology (Nettle et al. 2013; Winterhalder and Smith 2000). Working under the framework of HBE, they calculated the adaptive fitness of eating "low-ranked" foods such as acorn in terms of caloric costs and benefits, and found that it was less efficient than focusing on "high-ranked foods" such as large game, which required less processing (Smith 1983). Human behavioral ecologists argue that population growth caused a shortage of high-ranked resources, which spurred intensification around low ranked foods (Ames 1992; Basgall 1987; Baumhoff 1963; Bettinger et al. 1997; Broughton 1994; Broughton et al. 2010; Gremillion 2002; Holly Jr. 2005; Raab 1996; Wohlgemuth 1996, 2004). In his influential 1987 paper, Basgall applies this concept to California balanophagy and argues that the development of BRMs in the Sierra Nevada occurred as a response to the need to efficiently process acorn due to increased production requirements (Basgall 1987:41). Other cultural implications were also connected with diet breadth expansion under the framework of HBE, including increased political complexity (Ames 1992), increased sedentism (Binford 1980; Tushingham and Bettinger 2013; Whelan et al. 2013), food storage (Bettinger et al. 1997; Metcalfe and Barlow 1992; Morgan 2012; Tushingham and Bettinger 2013), and the development of gender-differentiated labor roles (Jackson 1991; McGuire and Hildebrandt 1994).

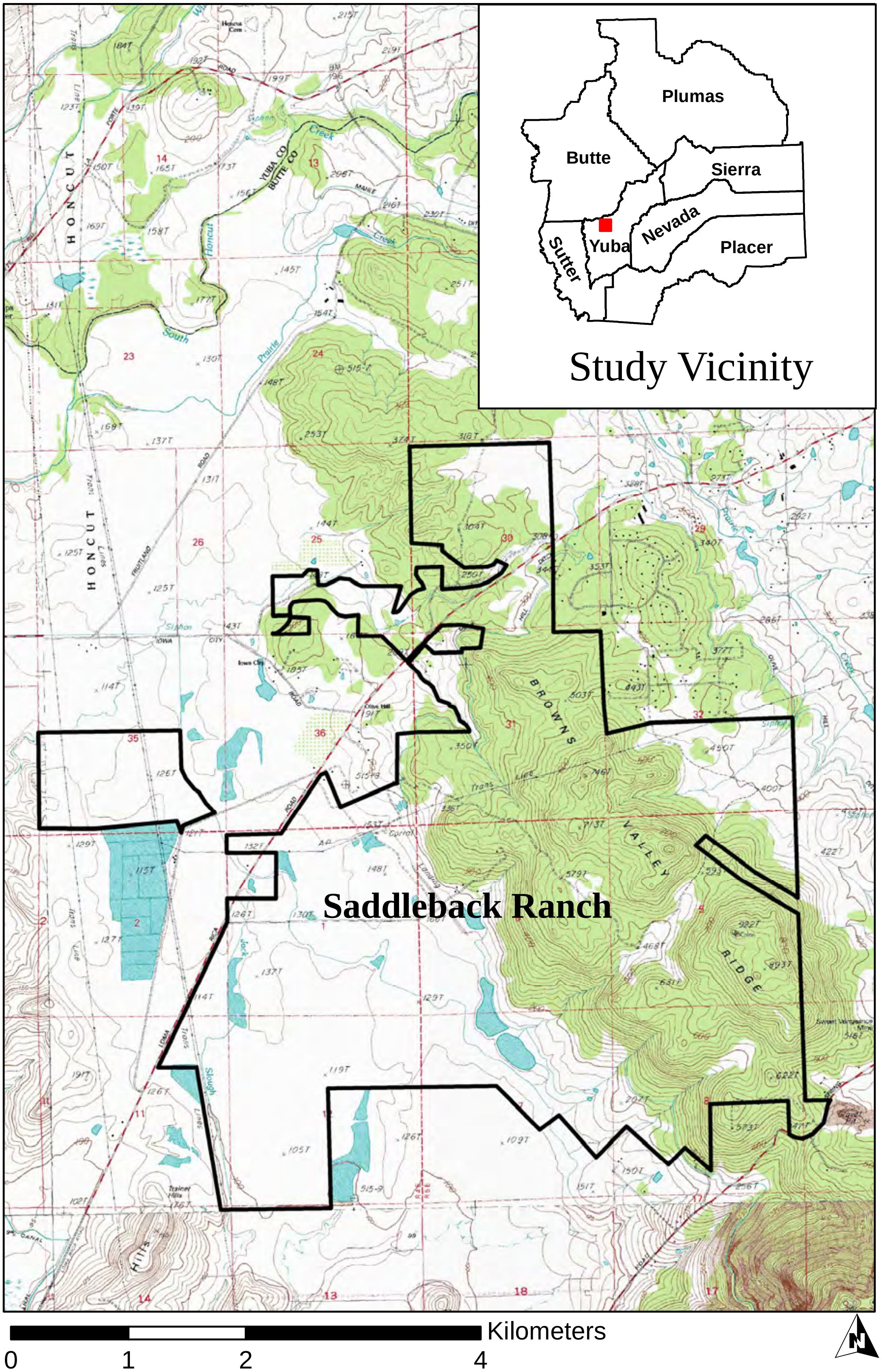
While there are many insights that HBE has brought to archaeology, recent authors have begun to criticize the approach, specifically its tendency to focus on population pressure and resultant resource shortages as the prime causes for cultural evolution (Gremillion 2002; Tushingham and Bettinger 2013; Whelan et al. 2013; Zeder 2012). Alternatively, using the theoretical framework of niche construction theory (NCT), researchers are taking approaches that focus on the role of changing relationships between biological, cultural, and environmental factors as causal mechanisms in cultural evolution (Bleed and Matsui 2010; Bliege Bird et al. 2008; Laland and O’Brien 2010; Odling-Smee et al. 2003; O’Brien and Laland 2012; Riel-Salvatore 2010; Zeder 2012). Niche construction theory is a relatively new field within evolutionary biology that introduced the mechanism of niche construction: the ability of organisms to alter their environment in a way that modifies natural selection (Odling-Smee et al. 1996:641; O'Brien and Laland 2012:434). Where anthropological frameworks based on neo-Darwinian evolutionary theory view cultural adaptation as a one-way process of natural selection based on environmental stimuli, NCT argues that niche construction creates an additional selective force— ecological inheritance— that is just as influential as natural selection (Odling-Smee et al. 1996; Scott-Phillips et al. 2013). Ecological inheritance refers to the cultural, biological, and natural environments inherited by successive generations that have been influenced by niche constructing activities (Laland and O'Brien 2010; O'Brien and Laland 2012). NCT views adaptation as a recursive process between culture, environment, and biology.

Niche construction theory has major benefits for anthropology over neo-Darwinism. Since many cultural phenomena involve direct or indirect alterations to the environment in some way, the mechanism of niche construction and ecological inheritance provides a theoretically rigorous way to integrate culture as a causal force in an evolutionary model (Lewontin 1983; Laland and O'Brien 2010; Odling-Smee et al. 1996, 2003; O'Brien and Laland 2012; Zeder 2012). Using NCT, anthropologists can examine cultural adaptations like the development of BRM technology in new contexts, as being influential in the course of history, and as being a process of human choice rather than necessity. Niche construction theory thus allows archaeologists to continue to move away from the auspices of environmental determinism, while maintaining scientific rigor.

This thesis will demonstrate the utility of NCT by applying it to a study of BRMs in Saddleback Ranch, a private reserve on a low-elevation isolated Sierra Nevada foothill formation called Browns Valley Ridge (see Figure 1). Browns Valley Ridge sits at an intersection between biological and geological landscapes, as well as at the intersection between linguistic and cultural variants of protohistoric Maidu speaking Native Californians. It is bio-diverse, rich in food resources, and has a high density of BRMs throughout the formation.

Much of the modern archaeological investigation into subsistence practices conducted in the foothills of the Sierra Nevada has been anchored in HBE (Basgall 1987; Broughton et al. 2010; Leftwich 2010; Raab 1996; Wohlgemuth 1996). As discussed above, the discourse has revolved around resource intensification as an adaptation to population growth and resulting resource imbalances, with BRM technology acting as a corollary necessity to efficiently process acorn. Applying this treatment to Browns Valley Ridge is problematic for several reasons. First, no prior archaeological investigations have been carried out there. As Zeder points out in her 2012 analysis of HBE, the conclusions of the framework are not as widely applicable as has been argued by its proponents (e.g., Nettle et al. 2013; Winterhalder and Smith 2000). She and other authors such as Bleed and Matsui (2010), Collard et al. (2013), and McCluire (2007) are increasingly demonstrating, among other things, that intensification often happens in resource-rich areas with no evidence of imbalance between population and high-ranked foods. The Sierra Nevada foothills are among the most bio-diverse and resource rich areas in California (Diekmann et al. 2007; Jepson 1925; Storer et al. 2004), and evidence of resource-population imbalance is lacking in the major archaeological studies performed nearest to Browns Valley Ridge (i.e. Humphreys 1969 and Ritter 1970).

Figure 1: Study vicinity map



It is therefore not a given that Basgall's (1987) conclusions, based on excavations that took place hundreds of miles away from Browns Valley Ridge and in different environmental and cultural contexts, should be applied. It follows that the motivations and causes of technological development should be examined in their own contexts as well.

Just as problematically, HBE models expect major dietary choices and technological developments to be based entirely on caloric efficiency— the shift to balanophagy was necessary because high-ranked foods became scarce and so BRMs were manufactured to accommodate that shift. It is easily demonstrable that humans today make dietary choices based on factors such as taste, variety, and cultural taboos, and the choices do not always coincide with biological health or adaptive fitness. It is reasonable to assume that the prehistoric inhabitants of Browns Valley Ridge made similar choices, for better or for worse. Just because people could best avoid starvation by eating nothing but big, slow moving game they might still desire to eat a variety of other foods, even if it meant large expenditures of energy and low caloric efficiency. The material culture that people developed to process their food should be examined in light of these potential choices.

Finally, the tendency of HBE practitioners to automatically correlate BRMs with balanophagy ignores the non-subsistence roles that they were known to fulfill. Both early and modern ethnographers such as Kroeber (1925), Gifford (1936), and McCarthy et al. (1985) acknowledge the use of BRMs to process medicines, pigments, and substances used in ceremonial contexts. This oversight may be especially relevant at Saddleback Ranch, which is situated at the margin of the Central Valley and the Sierra Nevada foothills, and whose western flanks are provided a unique view of the Sutter Buttes, a spiritually significant landform for the protohistoric Maidu. While no primary ethnographic work was conducted for this study, a large number of mortars were observed in Saddleback Ranch that suggest ceremonial, rather than subsistence-related, use. These were isolated or hidden, present in or adjacent to rock shelters, far from sources of water, and were in locations with a clear view of the Sutter Buttes. A study of BRM use under an HBE framework is not well suited to analysis outside of subsistence-related contexts, and would thus potentially overlook a significant aspect of the lives of the Maidu and their ancestors.

This thesis takes first steps toward integrating BRM use in Saddleback Ranch into a NCT framework. It hypothesizes that BRM technology was a major element of ecological inheritance on Browns Valley Ridge. As such, their function, morphology, and meaning would have been shaped by both the environment and the cultural practices of the people who made them. Perhaps more importantly, they would have played an active part themselves in shaping the environment and cultural practices of both the people who made them and the successive generations that inherited them. This concept of ecological inheritance— a recursive relationship between culture and environment— will aid in the formation of a more meaningful narrative of BRMs because it can separate them from the assumption that they were developed out of the necessity to adopt balanophagy and instead address other hypotheses. Instead of a response to the *need* to intensify subsistence practices, perhaps BRMs created an incentive to do so, regardless of resource availability. Perhaps BRMs had been used for ceremonial purposes for thousands of years before they were adopted for subsistence purposes. Perhaps it was the opposite, and shamanic men adopted the technology from food processing women. Perhaps the inhabitants of Saddleback Ranch manufactured all of the mortars in a short amount of time for the purpose of processing acorn, or perhaps they built the complex milling infrastructure over numerous generations for multiple reasons. Perhaps there were even multiple developmental aspects to BRM use that were taking place side by side. Using an NCT framework, anthropologists can address these hypotheses while respecting the active role that the Maidu of Browns Valley Ridge played in California history.

The creation of a niche construction model that address hypotheses like those listed above requires the formulation of the relationships of dozens, if not hundreds, of different cultural and environmental elements. Such a goal is far beyond the scope of the current study. However, to incorporate BRM infrastructure into a niche construction model, a recursive relationship between it and other aspects of the model must be established. This involves formulating a metric by which variation in BRMs can be tested to relate to variation in those other elements.

This thesis proposes that the depth of a BRM serves as such a metric. More specifically, this thesis proposes that the combination of BRMs of different depths and contexts in a given landscape constitutes a measurable design of milling infrastructure that can indicate different processing goals of the people that manufactured them. These processing goals, whether for food, medicine, ceremony, utilitarian, or combinations of the four, can be studied in conjunction with other elements of a niche construction framework to address hypotheses about potential subjects like those listed above. Unfortunately, formulating the actual processing goals indicated by the design of the milling infrastructure in Saddleback Ranch is outside of the scope of this thesis but could be a direction for future research.

This thesis thus begins integrating BRM technology into a niche construction model by showing that BRM depth is a reliable metric for formulating the design of milling infrastructure in a way that can be used to deduce the processing goals of the former inhabitants of Saddleback Ranch. It accomplishes this by addressing two research questions that revolve around an existing discourse about BRMs. The first question is whether BRM depth is primarily a result of use wear. It is prompted by an ethnographic study by Barrett and Gifford (1933:143), who mention that BRMs were abandoned after they had worn past a certain depth through use. This concept was continued by influential anthropologists such as Baumhoff (1963) and Elsasser (1960), and continues to this day as evidenced by personal discussions between the author and his peers. The second question is whether BRMs were purposefully manufactured to specific depths. It is prompted by three modern ethnographic studies (i.e. Grinnel 2004; McCarthy et al. 1985; Ortiz 1991) which show that the modern descendants of the Native Californians who inhabited Yosemite and the higher-elevation central Sierra Nevada foothills used BRMs of set depth ranges to process specific sets of resources.

This study addresses the question of whether BRM depth in Saddleback Ranch is a result of use-wear and eventual abandonment through a comparison of the existing mortar depth distributions, observed through intensive survey, with a series of hypothetical distributions. These hypothetical distributions are developed through varying assumptions of how use-wear rate and population would affect the observed mortar-depth combinations were they the primary causal factor in BRM morphology.

The results of this analysis suggest that the BRM depth distributions observed in Saddleback Ranch were not primarily determined through use-wear and abandonment.

This thesis addresses the question of whether BRM depth is a factor of design through an analysis of the multimodality in characteristics of the observed mortar-depth distribution. The analysis focuses on the robustness of the observed modes of the distribution when subjected to various methods of data correction and transformation. The results of this analysis strongly suggest that the inhabitants of Saddleback Ranch manufactured BRMs based on preferred depths, and that the apparent preference does not appear to have been influenced by the abandonment of mortars at a certain depth.

The following chapters are organized into background, methods, findings and analysis, and conclusion sections. The background section includes a brief synthesis of the environmental, cultural, archaeological, and theoretical information that supports the present study. The methods section includes information on how the field survey and data collection was conducted, and the process used for preparing and analyzing the data. The findings and analysis section includes the results of the data collection and analysis, and a discussion of their implications for the study of BRM technology and life at Saddleback Ranch. The conclusions section includes a final synthesis of the study, as well as a discussion of potential directions for future investigations.

The ability to reliably connect the design of bedrock milling infrastructure to subsistence strategies other than balanophagy will greatly benefit anthropology. Anthropologists have a long history of studying subsistence practices, and developing a robust material indicator of such practices in an area where soil preservation and erosion often result in sparse direct evidence is immediately applicable to a large number of academic pursuits. However, the integration of that milling infrastructure into a niche construction framework will allow a more inclusive story about its relationship to pre- and proto-historic life. It will be inclusive in the sense that it can examine the relationship of the technology to as wide-ranging a set of subjects as ceremonialism, genetic evolution, and dietary choices; but also inclusive in that it maintains the active presence of the Maidu and their ancestors in that story and gives them credit and responsibility for the choices they made. It is the hope of the author that what follows is just the first step in a long and fruitful journey to that end.

Chapter 2. Background

This chapter provides the information necessary to support this specific study, as well as preliminary information for developing a niche construction framework for future studies on Browns Valley Ridge. The objective of this thesis is to demonstrate that patterns in the morphology of the BRMs in the study area show that they were manufactured according to desired specifications that represent processing goals. The following sections provide a discussion of the constituents of BRM infrastructure and ethnographic observations of the use of BRM technology necessary to fulfill that objective. However, the ultimate goal of this approach is to create a framework for evaluating numerous cultural adaptations according to the specific contexts in which they occurred— one that will help both archaeologists and their audiences to understand what those adaptations meant to the individuals that made them. For this reason, following the discussion of BRM technology and its ethnographic-era use, this chapter includes a brief synthesis of natural and cultural contextual information in which to place the findings of this thesis. While much of the information isn't necessarily integral to the immediate goals of the study, it is critical for eventually developing the context in which cultural adaptations occur— the niche construction framework— and finding meaning in those adaptations.

The Constituents of Bedrock Milling Infrastructure

The basic unit of bedrock milling infrastructure is the bedrock mortar. While another milling feature, commonly known as a milling slick, is often present in varying forms and frequencies alongside it, the BRM is far more common. Milling slicks can also be difficult for archaeologists to recognize, so they are often not included in milling records when they are present. Further, no metric is commonly known to connect milling slicks with varying subsistence practices. As a result, this study is primarily focused on BRMs.

Bedrock milling features are manufactured on natural bedrock outcrops or boulders (BRM outcrops). Native Californians have created as many as a thousand BRMs in a single outcrop, though they are more often found to contain between one and a dozen. BRM outcrops themselves range in groupings from a single small boulder in isolation to several dozen large outcrops in close proximity. While BRM outcrops may sometimes be quite small, they are never considered “portable” and cannot be moved to different locations without the use of modern machinery.

Closely grouped BRM outcrops are usually documented together within a single archaeological site boundary. Creating archaeological site boundaries is a relatively straight forward process. They are more often used to aid in the management of all the resources in a given space than to delineate an area of related activities such as food processing. Archaeologists often use an arbitrary 50 meter buffer around an artifact or feature; that is, if another artifact or feature is within the 50 meter buffer, they are grouped together in a single site. If a third resource is within 50 meters of either one of them, all three are grouped together, and so it goes until there are no other known artifacts or features within a 50 meter radius of any others.

While the above approach to site recording may be effective for managing a large database of resources, it presented a problem for the purposes of this study, which uses data collected from a survey which also included the recording of many historic-era resources. When the survey efforts were complete, site boundaries were developed in the manner described above. This resulted in the designation of several sites that included BRM outcrops which would not otherwise have been associated with each other.

One large site, for example, whose main constituents comprised an historic-era residential and agricultural complex, also included three individual BRM outcrops. These outcrops were each over 150 meters apart, were not visible from each other, and were on different general landforms (one in a flat meadow and two on opposite faces of a toe-slope). These outcrops would not have been recorded as part of the same site had there not been any historic features or artifacts to connect them, and ethnographic evidence strongly suggests that the outcrops were not associated with the historic-era features. It would unreasonably bias a site-level analysis of BRMs to associate these outcrops with each other in a single site, when similar groupings may exist throughout the study area that would not be associated.

This study instead uses “milling loci” in place of traditional sites to avoid this setback. Several methods were tested in an attempt to create statistically and spatially significant milling loci. These included forms of density and grouping analyses in ESRI ArcMap software, which resulted in differing potential groups of milling features. As it turns out, using a 50 meter buffer around each milling outcrop in a similar fashion to normal site designation, but based on the presence of milling features only, resulted in the most intuitive milling loci for an initial study such as this one. Consequently, milling locus boundaries were ultimately designated largely based on proximity and landform context. These loci create a good baseline unit for analyzing groups of milling features.

Future studies will be able to build off the results and, perhaps, develop ways of grouping milling features that are less dependent upon proximity.

Acorn Processing and Bedrock Mortar Use

The food resource most commonly associated with bedrock milling infrastructure is acorn. It is well documented that acorn was the main dietary staple of most protohistoric native California cultures (Baumhoff 1963; Dixon 1905; Gifford 1936; Kroeber 1925, 1929; Powers 1877). Acorn use remains an important part of the lives of modern Native Americans as well. As a result, several excellent accounts of the process of collecting and preparing acorns are available (Gifford 1936; Grinnel 2004; Ortiz 1991).

Acorn was usually harvested in the fall, when the nuts were ripe. It was sometimes knocked out of trees, but more often was simply collected from the ground once it had already fallen (Gifford 1936). As Jackson (1991:304) notes, the logistics of acorn harvesting can be quite complex; certain species of oak produce acorn yields over different cycles of one or two years, and different groves produce differently within species. Additionally, acorn from different oak species was not valued equally. Many accounts in the Sierra Nevada report that black oak was preferred over others, often for its high fat content (Baumhoff 1963; Gifford 1936; Ortiz 1991).

Once the acorns were collected they had to be transported back to a camp or village, or they were stored and dried in remote locations. The investment in time and energy for this would logically depend on the distance from the tree to the storage site, and on the amount of weight being carried. In the central southern Sierra Nevada, acorn was harvested in the higher altitudes near summer camps, where black oak was plentiful, and transported down to lower-altitude winter camps for use during the winter and spring (Jackson 1991). An additional investment in time and resources was required for the construction and maintenance of granaries, which were usually built near bedrock mortar outcrops (Basgall 1987:89; Jackson 1991:305).

Turning acorn into a foodstuff was an intensive process and varied from place to place, culture to culture, and sometimes even between families and individual people (Baumhoff 1963; Gifford 1936; Ortiz 1991:39). However, there was a progression that was necessary to render the acorn edible, which resulted in certain similar techniques observed throughout California. Acorn first had to be shelled, then pounded into a fine flour, and finally leached multiple times with water. The bedrock mortar was the main implement used in the pounding of acorn to produce flour. Many sources indicate the intensive and time consuming nature of this process (Baumhoff 1963; Gifford 1936; Grinnel 2004; Kroeber 1925; Ortiz 1991). This intensive pounding and grinding of acorn and other resources in BRMs is largely what led anthropologists and archaeologists such as Barrett, Baumhoff, Gifford, Elsasser to conclude that BRMs deepened with use.

Modern Ethnographic Insights

As part of the Crane Valley Hydroelectric Project, McCarthy et al. (1985) performed extensive research on the relationship between the historic function and morphology of bedrock mortars in the central Sierra Nevada. Based on primary ethnographic work and analysis of existing mortars, they concluded that, contrary to popular belief, mortars did not significantly deepen with age or use. Instead, McCarthy et al. (1985:341–343) argue that bedrock mortars were purposefully manufactured to specific depths, depending on the intended use of the mortar in processing a specific type or group of resources. This conclusion is consistent with Grinnel's (2004) and Ortiz's (1991) modern accounts of the preparation of acorn for leeching. They documented the process as it was performed by different modern Native Californians, who were sure to leave enough acorn meal coating the sides and bottom of the mortar to prevent the pestle from making any contact with its inner surface.

McCarthy et al.'s ethnographic informants described a form-to-function relationship of bedrock mortars in the Sierra Nevada based on depth (McCarthy et al. 1985:342). They delineated three ranges of bedrock mortar depth involved in different aspects of food processing. Mortars from less than a centimeter to approximately 5.5 centimeters deep were used for the initial pounding of whole, shelled acorns into a coarse flour. Mortars from approximately 5.5-9.5 cm deep were used to pound the coarse flour into a fine flour suitable for leeching and cooking. The ethnographic informants claimed that the extra depth of the mortar was necessary because the pounding force was greatly increased in this phase, which increased the amount of meal that would fly out of a shallower mortar (McCarthy et al. 1985:317). Mortars that were deeper than 9.5 cm were reported to have been used for the processing of hard seeds, berries, and other foodstuffs. According to the informants, such a deep mortar did not allow for efficient pounding of acorn due to the nut's oily nature and tendency to cake at the bottom (McCarthy et al. 1985:317). Instead, deep mortars were used to pound hard seeds that were prone to flying out of a shallower mortar, as well as to grind seeds, berries, and other resources in a circular motion.

A Niche Construction Framework

The Native Californian informants involved in Grinnel’s (2004), McCarthy et al.’s (1985), and Ortiz’s (1991) publications provide invaluable insight into the potential morphological-functional relationships of bedrock milling technology, and thus offer a foundation on which to base the current study. However, a NCT approach requires that a context should be built from scratch, including ecological and cultural elements that are specific to the location in which an adaptation like BRM technology is being studied, creating a framework of recursive relationships that is not unduly limited by preconceived assumptions. Without one, archaeologists either risk making inappropriate or unfounded generalizations about the technology, or come to inaccurate or incomplete conclusions. This paper argues that HBE includes these pitfalls with regard to its treatment of bedrock milling technology, and thus provides a narrow or altogether inaccurate narrative of BRM technology on Browns Valley Ridge— that like everywhere else in California, it was simply an adaptation to resource scarcity creating a need to efficiently process acorn. This isn’t suggesting that the informants in the above studies were somehow wrong— the BRMs they used were an aspect of their specific ecological inheritance. As such, researchers should expect BRMs in their study area to have evolved both in form and function, as well as have shaped the thinking and practices of those who grew up using them. However, archaeologists shouldn’t simply superimpose information from one area to another. Alternatively, they should approach their study of BRM technology as an aspect of ecological inheritance specific to their own region of study.

Instead of taking McCarthy et al.'s findings and applying them to BRMs on Browns Valley Ridge, this thesis proposes to test whether depth is a reliable metric from which to infer resourcing processing goals of the Native Californians who manufactured them there. In the same vein, the ultimate goal of this approach is to create a niche construction framework that can challenge, or at least expand, the resource scarcity narrative. The primary factor in challenging the narrative is that Browns Valley Ridge is a landscape that exists at the territorial margins of both environmental and cultural zones. It straddles the transition between the Upper and Lower Sonoran Life Zones; sits between the central and northern Sierra Nevada culture areas, between Central Valley and Sierra Nevada Foothill culture regions, and between Delta and Northern Sacramento Valley culture regions; and falls directly within the Nisenan-Northwest Maidu (or Konkow) linguistic transition, a contested boundary that has been discussed by early anthropologists such as Kroeber (1929) and Littlejohn (1929), and continues to be discussed in ethnographic studies by authors such as Blount et al. (2008) and Siskin et al. (2007). In their influential (2003) study, Turner et al. show locations such as these to be areas of substantial abundance, both in terms of natural resources and of cultural capital. While Turner et al.'s study discusses this abundance as an adaptive advantage during times of stress, a NCT approach will allow archaeologists to create a framework for studying cultural adaptation at all times. The following sections provides some preliminary information that will aid in eventually creating this niche construction framework.

Physical Setting

Saddleback Ranch is a 5,041-acre property in Yuba County, on the western flanks of the Sierra Nevada foothills. It falls within Township 16 North, Range 5 East and Township 17 North, Range 5 East, MDBM, as depicted on the Loma Rica, California USGS 7.5-minute topographic quadrangle. Just over half of the ranch is on Browns Valley Ridge, a northwest-southeast trending foothill formation, which rises to a maximum height of 922 ft. above mean sea level (amsl) at Chinn Peak. The study area utilized in this paper is confined to Browns Valley Ridge; the remainder of the ranch lies on the valley floor to the west. Browns Valley Ridge is part of a Mesozoic geologic formation that overlies the western edge of the Sierran Basement. It consists of volcanic and meta-volcanic bedrock that formed from Jurassic-period pyroclastic flows (Saucedo and Wagner 1992). The Prairie Creek Fault Zone, created by a shear transform fault, separates Browns Valley Ridge from the gradually rising Sierra Nevada foothills to the east (Saucedo and Wagner 1992). The bedrock of the ridge is overlain by the shallow gravelly loams of the Auburn-Sobrante complex (United States Department of Agriculture 2015a). The underlying bedrock is exposed in numerous locations, forming thousands of outcrops on topographic features and along the shallow drainages that wind their way through Browns Valley Ridge. The soils of the adjacent valley are formed of a much deeper quaternary alluvium, with relatively few areas of exposed bedrock (United States Department of Agriculture 2015a).

The majority of the study area is within the Honcut Headwaters-Lower Feather River watershed, though its southeastern-most extent falls within the Upper Yuba River watershed (United States Department of Agriculture 2015b). The Yuba River is approximately 2.7 miles to the south, and South Honcut Creek is approximately 2 miles to the north. Dry Creek runs approximately 2 miles to the southeast of Saddleback Ranch and drains into the Yuba River directly to the south. The Lower Feather River meanders down the Sacramento Valley approximately nine miles west of Browns Valley Ridge. Several small unnamed seasonal drainages have their headwaters in Browns Valley Ridge, mostly draining into Jack Slough to the southwest, which then drains into the Feather River.

The study area falls within C. Hart Merriam's well-known (1889) Lower and Upper Sonoran Life Zones. Jepson (1925:4) divides the Lower Sonoran into three geographical subsets— the Colorado, the Mojave, and the Valley Sonoran— each characterized by high summer temperatures, low rainfall, and low humidity. The Valley Sonoran, in which fall the parts of the study area up to approximately 500 ft. amsl, experiences greater rainfall and lower temperature variability than its Mojave and Colorado Desert counterparts (Jepson 1925:5). Fauna commonly encountered in the Valley Sonoran include jackrabbit, brush rabbit, fox, coyote, mule deer, numerous reptiles, abundant waterfowl, valley quail, mourning dove, turkey, various woodpeckers, and other birds (Moratto 1984:23). Pronghorn, tule elk, and grizzly bear would also have been prominent before European contact (Moratto 1984:23).

Jepson describes the plant community of the Valley Lower Sonoran as mostly grassland, comprised of annual grasses and wildflowers that germinate with winter rains and grow to maturity through late spring and early summer (Jepson 1925:5). Woodlands of sycamore, cottonwood, valley oak, and willows grow along riparian (Jepson 1925:6; Moratto 1984:23). Before the arrival of Europeans and the subsequent diversion or damming of major river systems, regular flooding created a vast wetland dominating the Sacramento Valley between the study area and the Sutter Buttes to the west, supporting vast tule marsh communities.

The parts of the study area that are above 500 ft. amsl fall within the Upper Sonoran. Jepson (1925:6) divides the Upper Sonoran into two biotic subregions: the lower foothill belt and the chaparral belt. He describes the lower foothill as a grassland formation, averaging between 500 and 1,000 ft. amsl, with similar species as those of the Lower Sonoran, sometimes with stands of blue or Englemann oak. The chaparral belt consists of xeric fire-adapted brush lands with manzanita, Ceanothus species, and mountain mahogany (Jepson 1925:6). These are located on steeper slopes with shallower and better drained soils than the lower foothill belt, between 1,000 and 4,000 ft. amsl. While the study area does not reach 1,000 ft. amsl, areas of steep slope, open exposure, and shallow soils accommodate the growth of chaparral communities much lower.

While grassland and chaparral communities are present, by far the most common vegetation community in the study area consists of blue oak woodlands. Besides blue oaks, these woodlands commonly also include live oak, Englemann oak, valley oak, and buckeye, and form an almost continuous band along the Sierra Nevada foothills between 900 and 2,280 ft. amsl (Barbour et al. 2007:318). In the study area, the gentle slopes and valleys are comprised almost entirely of a dense blue oak overstory that extends down as low as 200 ft. amsl. Live oak, bull pine, buck brush, and buckeye are interspersed throughout these woodlands at varying densities, with annual grasses composing most of the understory. On the steeper slopes or in riparian zones, the blue oak stands are patchier, with riparian woodland or chaparral in between. The highest elevations of

Browns Valley Ridge also support foothill pine-blue oak communities. In these areas, foothill (or grey) pine grow in patches, though blue oaks still dominate the canopy. The foothill woodland biotic community was one of the most important and abundant zones in prehistory. Johnson and Theodoratus (1978:374–383) note the use of numerous resources in the area in protohistoric times, including blue oak acorn, buckeye, foothill pine nuts, wild carrot, wild onion, wild garlic, wild potatoes and other tubers, gumweed, twitweed, manzanita berries, coffee berry, chokecherries, wild grape, buckberry brush, blackberry, elderberry, various mushrooms, grasshopper, yellow jacket larvae, various fowl, antelope, deer, rabbits, lizards, and frogs. The presence of multiple geological and biological regions in close proximity created an abundant and resilient ecosystem that would likely have provided plentiful resources, even in times of potential environmental stresses.

Prehistoric Context

Though ground stone technology, of which bedrock mortars are a subset, has been observed in artifact assemblages dating back to the Terminal Pleistocene and early Holocene periods (from the initial peopling of the new world to approximately 8000 BP), it is rarely a significant part of the toolkit. The author knows of no instances of portable or bedrock mortars to have been discovered in these early assemblages. However, the inception of the Archaic period (8000 BP to European contact) is marked by a substantial shift in archaeological assemblages from flaked-stone to primarily ground stone. The following sections describe the Archaic cultural sequences developed near the study area. They include those late-period cultures variously described as ethnographic, emergent, and protohistoric; most of the sequences described below include these late cultures as part of longer series that extend back to the mid-Archaic. Because this study focuses on prehistoric use of BRM technology by Native Americans, a discussion of European use of Saddleback Ranch is not provided.

Around 8000 BP populations seemed to be shifting away from a heavy reliance on flaked stone tool assemblages to an extensive use of ground milling stones. Many archaeologists consider this to represent a shift from a diet centered largely on animal resources to a broader diet based mostly on plant resources that required more processing than those eaten previously (Fitzgerald and Jones 1999; McGuire and Hildebrandt 1994). This "Millingstone Horizon" is often compared to the broad spectrum revolution of the Levant identified by Flannery (1969). It is composed of a distinct archaeological assemblage that includes ground millingstones and mullers, a lack of formal projectile points, and burials that are covered by cairns of groundstone. The Millingstone Horizon was originally thought to be limited to southern California, but is now shown to have stretched at least as far north as Clear Lake (Fitzgerald and Jones 1999; McGuire and Hildebrandt 1994; Sutton 1993). Frederickson ascribes the early Borax Lake Pattern as part of, or companion to, the Millingstone Horizon (Frederickson 1974:42–44). Deep deposition in the Central Valley and shallow acidic soils in the Sierra Nevada have resulted in a relative dearth of known Millingstone Horizon sites near the study area (Glassow 1992:210).

Contrary to the preceding Millingstone Horizon, a large sample of highly variable sites that date from approximately 5,000-6,000 B.P onward have been found near Browns Valley Ridge. Many of these sites were discovered during large salvage archaeology projects that led to the creation of influential studies (e.g., Frederickson 1974; Lillard and

Purves 1936; Moratto 1984; Ritter 1970) and resulted in the creation of several regionalized cultural chronologies near the study area. The chronologies were generally attributed to specific geological provinces, notably either the Central Valley floor or the Sierra Nevada foothills; however, the transitional setting of Saddleback Ranch makes it difficult to place into any existing regional category. As has been discussed by several authors (Fitzgerald and Jones 1999; Frederickson 1974; Glassow 1992; Leftwich 2010; Meighan 1987; Moratto 1984), the timing and concept of the periods, phases, eras, patterns, horizons, and other commonly used ideas in the cultural sequences are complicated and often used improperly and interchangeably, and do not account for the considerable diversity observed even within the supposed delineations. Saddleback Ranch likely contains elements from multiple culture sequences, and discovering those elements that are specific to the ridge itself will eventually allow archaeologists create an appropriate framework for comparing material culture to other elements of a niche construction framework. Nonetheless, Browns Valley Ridge exists within a larger network of prehistoric culture, and the following discussion of the archaeological sequences that have been developed near the study area is important for its eventual comparison to broader cultural patterns that the people of the region were a part of.

Lillard and Purves (1936) created the first of the Central Valley cultural sequences near the study area based on excavations they performed outside of Sacramento. Their Early, Transitional, and Late periods were differentiated by mortuary practices, as well as artifacts of shell, bone, and stone (Lillard et al. 1939; Siskin et al. 2007:12). Portable mortars have been observed in assemblages from all three periods (Moratto 1984:180), though bedrock mortars are not discussed and dating the individual periods has been fraught with problems. Beardsley (1954) expanded this sequence to include the San Francisco Bay region and solidified the culture sequences into the Central California Taxonomic System (CCTS). The CCTS described discrete and successive culture changes, known as the Early, Middle, and Late Horizons, that were argued to be applicable across the Central Valley (Moratto 1984:181).

Two major investigations in the foothills near the study area resulted in the development of culture sequences that are very often used in by modern researchers. Ritter (1970) developed the first and most commonly used chronology based on several archaeological assemblages discovered during projects around Lake Oroville, just north of Saddleback Ranch and only slightly higher in elevation. His Mesilla, Bidwell, Sweetwater, and Oroville Complexes span the time between 3000 BP and European contact. The following is adapted from Moratto's (1984:297–301) summary of Ritter's (1970) synthesis, unless noted otherwise.

Mesilla Complex assemblages span between 3000 and 2000 BP and may represent seasonal or sporadic occupation of the foothills. Selverston (2005) and Moratto (1984) write that these sites contain numerous handstones and milling stones with a paucity of mortars and pestles, though at least some, are present. This may be a result of these sites being located in the foothills, where plentiful bedrock suitable for mortar construction may have lessened the need for "portable" mortars. Leaf-shaped, side-notched, and stemmed dart points suggest the continued importance of hunting. Olivella and Haliotis beads are both common ornaments found in the Mesilla Complex. Several elements of these assemblages show contact with Central Valley cultures, including charmstones and bone pins and spatulae.

The Bidwell Complex spans from 2000 BP to 1200 BP and is characterized by more permanent settlements in the foothills, with smaller logistical sites in the surrounding areas. Evidence of hunting with the atlatl is still present, though Siskin et al. (2007:15) note that projectile points now range in size from small to large and are composed primarily of basalt stemmed and corner notched types. Fishing with nets is evidenced by grooved and notched sinker stones. Milling slabs are present in Bidwell Complex assemblages, but Moratto (1984) infers that wooden mortars were used to process acorn. Presumably this is due to a lack of stone bowl mortars found in Bidwell assemblages. Burials in this complex most often consist of flexed, dorsal or lateral position interment.

The Sweetwater Complex, which occurs between 1200 BP and 500 BP, was identified by the increased presence of certain Olivella and Haliotis shell ornament forms, as well as an established steatite cup, platter, bowl, and pipe industry. Projectile points changed from larger atlatl dart forms to smaller Eastgate, Rose Spring, and Gunther Barbed forms, indicating the adoption of the bow and arrow during this period. Siskin et al. (2007:15) note an increase in the presence of bowl mortars and pestles, with a major decrease in the presence of milling slabs and handstones. They also note an increase in bone implements such as fish gorges, spatulae, tubular beads, and pins (Siskin et al. 2007:15). The increase in ornamentation and specialized tools is suggested to have accompanied craft specialization and increasing social complexity and stratification (Siskin et al. 2007:15–16). Burials in the Sweetwater Complex shifted from flexed to extended or semi-flexed positions.

The Oroville Complex is associated specifically with the Konkow Maidu, but is also representative of later-period sites across California. Though likely used before Oroville Complex times, the bedrock mortar was central to acorn processing during this period. The presence of other plant-milling tools from the previous complex continued unchanged. The adoption of Desert series projectile points happens near the earliest times of the Oroville Complex. Numerous fish hooks and gorges are evidence of fishing intensification (Siskin et al. 2007:16). Other distinctive elements of Oroville assemblages include incised bird bone tubes, gaming shells, gorge hooks, and clamshell disk beads. The deceased were often buried on their sides, in tightly-flexed positions. Siskin et al. (2007:16) write that evidence of resource intensification during the Oroville Complex, including bedrock milling technology, was the result of population growth and subsequent resource competition.

Humphreys (1969) developed the second most widely used foothill chronology based on excavations at three sites near New Bullards Bar, approximately 30 km northeast of the study area at an elevation of 1800 ft. amsl. He found a sequence that closely resembles the Mesilla, Bidwell, and Sweetwater Complexes (Moratto 1984:300–301; Compas et al. 2003). The first, Bullards Bar I, dates from 5275-3041 BP and includes milling slabs, handstones, and large stemmed and leaf-shaped projectile points. This assemblage closely resembles those of the Martis Complex higher in the Sierra Nevada and suggests cultural interactions between them and foothill populations (Compas et al. 2003:8; Humphreys 1969:85–92). Bullards Bar II dates to approximately 2400 BP, based on obsidian hydration readings (Compas et al. 2003:8). This assemblage consists of Gunther-type projectile points and steatite artifacts. Bullards Bar III spans

1000-434 BP and is characterized by Desert series projectile points, the use of petrified wood in stone tool manufacture, and bedrock mortars (Compas et al. 2003:8). Bullards Bar III is associated with the protohistoric Nisenan and Konkow Maidu (Hamusek and Dreyer 1991:4).

Several authors have criticized the rigid cultural sequences described above as, among other things, being unable to account for temporally overlapping Horizons, conflicting archaeological assemblages, and gradual cultural adaptation (Frederickson 1974:41; Moratto 1984:199; Siskin et al. 2007:11). In Frederickson's landmark synthesis of Borax Lake archaeology, he argues that a "unilineal sequence of culture types does not provide an adequate model for understanding the changes which appear to have taken place" in California (Frederickson 1974:41). Frederickson advances the idea of cultural "patterns", which are not based on sequential timing, but on specific groups of technological, economic, social, and other adaptations. This accounts for gradual and regional change, which helps to explain the differences in timing, specific tool kits, mortuary practices, and other variations observed across central California, while still creating a comparative framework for the area. The Windmiller, Berkeley, and Augustine Patterns that he identified are commonly applied to the study area, and provide an improved method of integrating future findings from the study area.

The Windmiller Pattern, which spans the period from 5000 BP to 2500 BP, is named after the Windmiller culture first identified by Lillard et al. (1939) and is divided into the Early, Middle, and Late Windmiller. Assemblages in this pattern point to a mixed economy of hunting and foraging. They contain numerous projectile points that include large obsidian concave-base and stemmed points, as well as bone fishing hooks and spears. Faunal evidence suggests that elk, deer, pronghorn, rabbits, waterfowl, sturgeon, salmon, and numerous other fish were consumed regularly. Numerous handstones and millingstones are observed, indicating the importance of plant resources. Mortar fragments are common in some Windmiller sites, and Moratto suggests that this could represent the relative importance of grinding acorn in those localities (Moratto 1984:201). Large numbers of baked clay balls are also present in Windmiller assemblages, which may have been used as heating rocks for basket-cooking acorn. Other distinctive artifacts include square Olivella beads, a unique trident fishing spear, and baked clay objects thought to have been fishing line sinkers. Moratto notes that the Windmiller Pattern reflects seasonal transhumance, with winter habitation in the valley and summer camps in the foothills (Moratto 1984:206)

Frederickson (1974:44) grouped several earlier cultural sequences and assemblages found to occur between 2500 BP and 1300 BP into the Berkeley Pattern, so named because the earliest manifestations of the pattern first appeared in the San Francisco Bay Area. The lowest levels of the West Berkeley Mound contain assemblages that stylistically match the Windmiller Pattern and show a gradual but essential change in cultural practices. Population size tends to be larger in the Berkeley pattern, but with less evidence of wealth, at least in burial sites (Moratto 1984:210). Frederickson notes that the Berkeley Pattern assemblages are observed in the Central Valley beginning sometime between 1,500 and 3000 BP (Frederickson 1974:44). These assemblages are similar to Windmiller Pattern assemblages, but show a shift in predominance from milling slabs and hand stones to mortars and pestles, which is interpreted to indicate an increase in importance of the acorn as a food resource (Moratto 1984:210; Siskin et al. 2007:14).

Large projectile points and atlatls are still common in Berkeley Pattern assemblages, indicating the continued importance of hunting (Frederickson 1974). By 1,500 BP, the Berkeley Pattern was well established throughout the Sacramento Valley (Frederickson 1974:44).

Frederickson's final phase, the Augustine Pattern period marks the transition in economic and land-use patterns to those observed in ethnographic times between 1300 BP and Eurpoean contact. Throughout central California evidence of increasingly elaborate ritual and social activity and dense population is evidenced by intricate mortuary remains, assemblages, and activities such as pre-internment burning of offerings (Moratto 1984:211–212). Shaped mortars and pestles, as well as hopper mortars, are the dominant grinding implements, and again, many authors attribute this to a shift to balanophagy (Basgall 1987; Bettinger et al. 1997; Frederickson 1974; Glassow 1992; Hildebrandt and McGuire 2012; Jackson 1991; Moratto 1984; Schulz and Johnson 1980). Evidence for intensified fishing and hunting is also present in the Augustine Pattern assemblages (Moratto 1984:211) through faunal remains. The bow and arrow was introduced during this pattern, and in the Central Valley, an established pottery industry is evidenced by the remains of "rolled, coiled, and pinched clay, as well as rim and body sherds" (Moratto 1984:213). This is also when clam disk bead money was introduced to central California (Frederickson 1974:49). Settlement patterns suggested by Augustine Pattern sites match those observed by early ethnographers, with permanent winter villages in the Central Valley or lower elevation foothills, and temporary summer camps at higher elevations (Siskin et al. 2007:14).

Ethnographic Context

At the time of European contact, the study area was inhabited by Maidu speaking peoples. Maidu is postulated to be a member of the Penutian language stock and was spoken everywhere from the Sacramento River east to the crest of the Sierra Nevada (Kroeber 1925:391). Ethnographic Maidu is composed of three language groups. The Mountain (or Northeast) Maidu, the Konkow (or Northwest Maidu), and the Nisenan (or Southern Maidu). The Mountain Maidu inhabited the upper reaches of the North and Middle forks of the Feather River, where the normally-continuous wall of the Sierra Nevada is broken up and interspersed with numerous flat valleys (Kroeber 1925:392). This territory is northeast of the study area and much higher in elevation. The Konkow inhabited the valley floor and low hills from the Chico area to as far south as the Yuba River. According to Kroeber (1925), the Konkow attributed their name to the term *koyo.mkawi*, which refers to the meadow lands west of Chico and Oroville (Siskin et al. 2007:18). The Nisenan inhabited the whole of the American River drainage, along with the Yuba and Bear Rivers, which technically are tributaries of the Feather River (Kroeber 1925:939). The Nisenan occupied elevations from the valley floor up to the crest of the Sierra Nevada, abutting territories of the Mountain Maidu to the north and the Washoe to the east (Blount et al. 2008:19). This vast range of topography and elevation likely went hand-in-hand with linguistic and cultural differences, but the data on which early ethnographers based their delineations is very sparse (Kroeber 1925:393). Thus, the Nisenan were likely not the homogenous group that they are often represented to be.

In their comprehensive study of cultural resources within Caltrans District 3, Blount et al. (2008) compiled ethnographic research from numerous sources such as

Powers (1877), Dixon (1905), Kroeber (1925, 1929), Littlejohn (1929), and Wilson and Towne (1978). According to ethnographers, Nisenan and Konkow are mutually unintelligible languages, yet the two were connected by intermediate gradations (Blount et al. 2008:24–26). They noted that neighboring groups of Maidu people had similar enough dialects to understand each other, but could not understand groups that were farther away (Blount et al. 2008:25). Blount and his colleagues postulate a Nisenan-Konkow transition zone, noting that it is a result of their inability to delineate an actual boundary based on ethnographic accounts (Blount et al. 2008:24). Browns Valley Ridge rises between the Yuba River, immediately to the south, and Honcut Creek, immediately to the north. It falls directly within the Nisenan-Konkow transition, as delineated by Blount et al. (2008), which extends up the Yuba River into the high-Sierra. Additionally, it is an isolated foothill ridge at the margin of the Central Valley. Thus, the study area is not only a transitional zone between Nisenan and Konkow, but between Valley and Hill subgroups of each.

The Valley Nisenan and Valley Maidu generally conformed to Kroeber's (1925, 1929) "tribelet" political organization. Unlike the large, politically organized tribes observed in other parts of North America, many native California groups organized and identified themselves based on smaller "village communities" (Kroeber 1925:228). These communities were composed of a primary village with several surrounding settlements. Each of these tribelets thought of themselves as "people of villages A, B, and C, or the people of chiefs X and Y" (Kroeber 1925:161). Thus, while they shared many cultural and linguistic traits of bordering peoples, the individualized nationality associated with "tribes" is absent (Kroeber 1925:162). Blount et al. (2008:21) describe tribelets as having “fixed territories, a single head person, and a large enough population (200 or more people) to have been at least 50% endogamous.”

Blount et al. (2008) differentiate the Hill Nisenan and Hill Konkow political organization as different from that of their valley floor neighbors. Instead of tribelets with a fixed territory, Hill Nisenan and Konkow lived in “Small Sedentary Village Communities”, composed of 40-100 people scattered along ridges and in favorable valleys (Blount et al. 2008:21). Instead of being formed of a principal village and several surrounding suburbs that identified with a centralizing figure or geographical feature, these smaller village communities each had their own head people and ceremonial centers, and their marriage networks overlapped.

Besides the differences in political organization, a main difference between Valley and Hill Nisenan was the lack of the formal Kuksu Societies in the Hill subcultures (Kroeber 1929:267). The Kuksu religion was an elaborate ceremonial system that was practiced in northern California from the Sacramento Valley to the Pacific coast. While the specific practices varied based on location, it was generally composed of two main elements— secret societies whose members embodied Kuksu, a god-like spirit, as well as other supernatural beings, and dances and rituals ceremonies connected to the spirit world. Certain elements similar to Kuksu ceremonies were incorporated into Hill cultures late in history, but ethnographers noted a lack of the secret societies integral to the religion (Kroeber 1929:267). This lack of a major religious institution serves to separate the Hill from the Valley Nisenan more than the variations in language that early ethnographers used to separate different tribelets.

Despite the differences that likely arose due to broad geographic differences in Maidu occupation areas, there were many similarities between the neighboring Maidu groups. Both Valley and Hill subgroups of Nisenan and Konkow engaged in similar subsistence practices and had similar material cultures (Blount et al. 2008:43–44; Kroeber 1929; Littlejohn 1929). They followed yearly gathering cycles, travelling higher in elevation during the summer months to hunt and collect resources, while moving to lower elevations in the winter. The obvious overlap of territories that this seasonal transhumance implies is not addressed. Differences in topography and elevation dictated what resources were available, but neighboring groups traded with each other (Siskin et al. 2007:19; Kroeber 1925:300; Blount et al. 2008:46–47). The acorn was the most important plant staple to the Maidu. It was collected communally by hand during the fall, carried in burden baskets, and kept in acorn granaries until needed (Blount et al. 2008:47). Acorn was processed in bedrock mortars, wood or stone slab hopper mortars, and bowl mortars (Kroeber 1925:411).

While Kroeber (1925:393) argues that the differences between the Northwestern, Northeastern, and Southern Maidu languages were sufficient to designate them as distinct, he also claims that they were not wholly unintelligible, that there were transitional dialects between each, and that neighboring groups of Maidu had similar languages and similar material cultures (Kroeber 1925, 1929; Littlejohn 1929). Indeed, as mentioned above, Kroeber differentiates the Valley and Hill Nisenan as cultures more than he does the Valley Nisenan and Valley Konkow (Kroeber 1925, 1929). As a result, modern researchers like Hamusek and Dreyer (1991:6) and Sisken et al. (2007:18) describe the peoples living along Honcut Creek as either speaking a transitional dialect between Konkow and Nisenan, or inhabiting the area as separate cultural groups. In reality, as Powers claimed long ago, there was likely never a true distinction or border to begin with (Powers 1877:315). Instead, the Maidu language, like the cultures that spoke them, likely consisted of a constant gradation, affected by geography and interaction with neighboring groups. The farther away one got from their home territory, the less one would recognize the language or the culture.

Browns Valley Ridge is part of a landscape of natural and cultural margins. It straddles biological ecotones, material and ethnographic culture regions, and ethno-linguistic transitions. This setting created both an abundance of natural resources and cultural practices, as well as a completely unique context in which cultural adaptations would have taken place. Bedrock milling technology in the study area would have developed as part of this unique context, and the following sections provide a discussion of the theoretical frameworks that have shaped the approach this thesis used to begin investigating that development.

Theoretical Context

Modern investigations of prehistoric subsistence activities and their concomitant processing technologies in California have largely been framed in one of several subsets of Human Behavioral Ecology. This study provides an alternate theoretical framework—Niche Construction Theory— which may provide a better approach to learning both about and *from* bedrock milling technology. Niche construction theory is a relatively recent theoretical framework developed in the field of evolutionary biology, which provides a powerful model to account for the important role that bedrock mortar technology itself could have in shaping cultural and biological adaptations. Below are discussions of both frameworks, which will demonstrate the increased utility of a niche construction approach.

Modern subsistence investigations in California are largely built upon anthropological studies that examined the causes of the adoption of agriculture throughout much of the world, and biological studies that explored evolution in animals. Binford's (1968) influential work regarding post-Pleistocene subsistence changes and Flannery's (1969) research on plant domestication in the Levant are the two landmark anthropological works that began such inquiry. Binford postulated that the major changes evident in the diet of post-Pleistocene populations across much of the world, including the advent of agriculture, had to be the result of an outside pressure that upset the balance between population levels, the productive levels of the environment, and technology. This was in direct opposition to earlier hypotheses that attributed the changes to human ingenuity and growing knowledge of local resources (Zeder 2012:242). Binford instead argued that sea level rise in the terminal Pleistocene increased territorial pressure on coastal inhabitants. The reduction in foraging and hunting area forced residents into a more sedentary lifestyle, which they had to supplement by incorporating seasonal resources into their diet. As populations continued to grow, people were forced into more and more marginal habitats, forcing them to develop technological and productive innovations to again reach balance with the carrying capacity of the land (Binford 1968).

Flannery (1969) drew upon Binford's core concept, but focused more on population equilibrium than environmental pressures. He postulated that the Levant of the Terminal and post-Pleistocene consisted of a patchwork of more and less productive environments in which people could choose to live. As populations in the more productive areas grew, small groups broke off and relocated, helping to keep the productive capacity of their original areas in balance. Their migration eventually threw off the balance of populations in less productive environments, however, forcing the inhabitants to resort to a "broad spectrum" of less valuable food resources (Flannery 1969:74). The availability and reliability of the less attractive foods proved to be such a boon to subsistence strategies that they were even eventually adopted in higher productivity areas. Flannery argued that the innovations required to harvest and process these foods eventually led to early cultivation.

The field of evolutionary biology bolstered Binford's and Flannery's conclusions. The traditional understanding of evolution revolved around Darwinian or Lamarckian concepts, whereby organisms adapt to their environments through natural selection and genetic drift (Dawkins 1990; Lewontin 1983). Traits that are beneficial to adaptive fitness in a given environment are passed on to successive generations with greater frequency than harmful traits. The result was an evolutionary process where populations adapt to changes in their environment, which naturally meshed with Binford's and Flannery's work.

Behavioral Ecology (BE) is a subset of evolutionary biology that was originally developed in the 1960s to explain foraging activity in animals (Nettle et al. 2013). It studies how measurable variation in ecological conditions predicts variation in the behavioral strategies of individuals, as well as the adaptive and reproductive fitness of those behavioral strategies (Nettle et al. 2013:1031–1032). Behavioral ecology measures the fitness of behavioral strategies in proxies such as mating success, survival, or energetic returns (Broughton et al. 2010; Nettle et al. 2013:1032; Codding et al. 2012). The typical approach of BE is to formulate models of what an individual will "gain, in fitness terms, by doing A rather than B, and using these models to make predictions either about how variation in ecological conditions will affect the prevalence of behaviors A and B, or about what the payoffs to individuals doing A and B will be, in some currency related to fitness" (Nettle et al. 2013:1032). Influential anthropologists such as Baumhoff (1963), Bean and Lawton (1976), and Bettinger (1976) adapted this framework to archaeology as human behavioral ecology, which allowed the study of human behavior from an adaptive standpoint and added theoretical rigor to their inquiry into the foraging activities of hunter-gatherers. This led to the development of Optimal Foraging Theory (OFT), which uses energetic return as the main proxy for fitness and postulates that hunter-gatherers will be "selected to behave so as to maximize the net rate of return (energy or nutrients) per unit of foraging time" (Smith 1983:626).

Since the 1980s, numerous studies in California have been conducted under the frameworks of HBE, OFT, and their various models and sub-models. Most prevalent among these are diet breadth models, which use cost benefit analyses to predict resource procurement choices made by individuals and groups (see Basgall 1987; Baumhoff 1963; Bean and Lawton 1976; Codding et al. 2012; Jackson 1991; Jones 1996; McGuire and Hildebrandt 1994; Nettle et al. 2013; Raab 1996; Schulz 1980; Wohlgemuth 1996). In most of these works, the broad spectrum revolution as described by Binford and Flannery has become a common example of optimal foraging in action. Diet extensification and intensification are viewed as adaptations to outside pressures which humans make to increase fitness (that is, caloric intake). While many practitioners of HBE discuss several areas and social aspects of subsistence choices, the same themes run through their studies: 1) food resources are ranked based largely on caloric yields, and 2) shifts in diet, from narrow and focused on "high ranked" resources to broad and inclusive of "low ranked" resources (Smith 1983), are generally attributed to one form or another of resource depression based on population pressure or environmental change (Basgall 1987; Raab 1996; Broughton et al. 2010). Under this framework, technology is generally only treated as a factor in the net caloric output of a food resource. In the case of bedrock milling, the technology was a necessary development to process enough acorn in a certain amount of time to make it a viable food source for supporting large populations.

Like HBE, Niche Construction Theory (NCT) stems from evolutionary biology (Laland and O'Brien 2010; Odling-Smee et al. 2003, 1996). Niche construction, however, adds "the process whereby organisms, through their metabolism, their activities and their choices, modify their own and/or each other's niche" (Odling-Smee et al. 2003:419). Instead of a one-way process where organisms adapt to their environment, as in HBE, NCT looks at adaptation as a "two-way process involving organisms both responding to their environments, and changing their environments" (Odling-Smee et al. 2003:240). In anthropology, this approach includes the cultural transmission recognized in HBE, but adds the effects that landscape modification (niche construction) has on current and future generations. In other words, while HBE recognizes the effect of the environment on shaping cultural adaptations, NCT sees cultural adaptations, landscape alteration, and other forms of niche construction, as active evolutionary processes themselves, forming recursive relationships with future adaptations (Laland and O'Brien 2010; Odling-Smee et al. 1996).

A very simple example of niche construction can be demonstrated in the lives of earthworms. Through the digestion, casting, and incorporation of organic and inorganic materials into the soil in which they live, earthworms affect the chemistry of that soil. When those earthworms breed, future generations are born into the new soil conditions, and continue altering the soil. Eventually, new generations of earthworms can be born into radically different environments, subject to new selective pressures. This can result in both genotypic and phenotypic changes within that earthworm population. Thus, the activities of the earthworm at least partially drove its adaptation.

Of course, for humans, it is more complicated. Laland and O'Brien (2010:313–318) provide a good example of human niche construction. They use the classical arguments for the prehistoric shift to agriculture, which include environmental change and population pressure, in areas where the availability of "high return" undomesticated foods was low (Laland and O'Brien 2010:315). However, areas of early plant and animal domestication frequently occurred in resource-rich zones where population pressure was not sufficient to cause resource depression (Zeder 2012). The traditional concept of Darwinian evolution does not provide a strong theoretical explanation for this observed data; a phenotypic adaptation such as plant domestication should be the result of an environmental stimulus such as resource depression. Laland and O'Brien argue that niche construction theory provides an understanding of how such an adaptation can occur. They view plant domestication as coeval with human evolution, involving both cultural and natural selection. Human niche construction activities such as selective collection of large seeds, incidental tilling of the ground, and creating organically rich dump areas, caused phenotypic changes in the plants that humans viewed as beneficial.

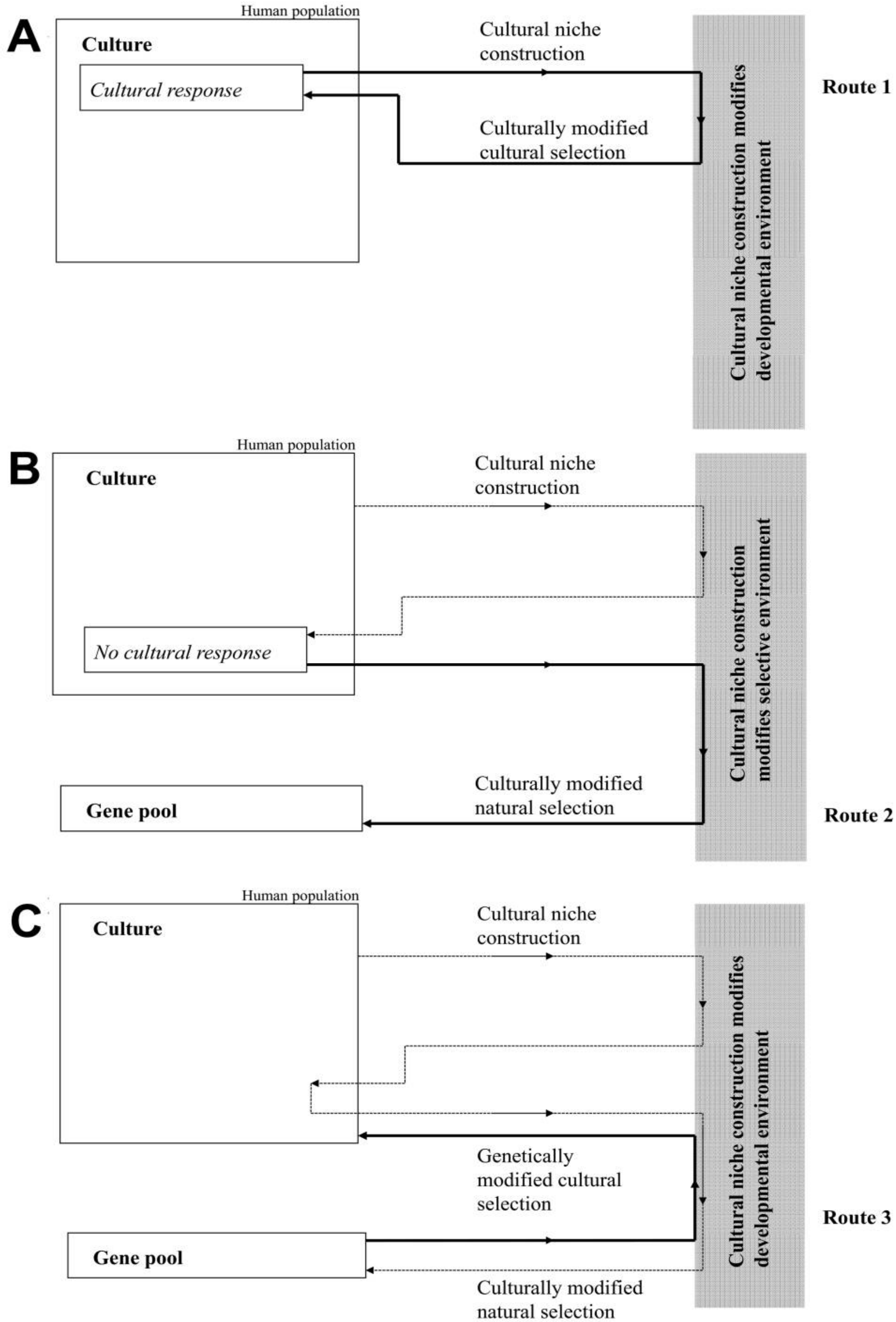
These changes included an increase in seed size, simultaneous ripening of seed crop, and loss of delayed seed germination, and they resulted in increasing the yield of the plant community. The increased yield of edible plant material then increased fitness in the human population, as well as selected for various genetic traits such as the ability to better digest starches. These adaptations fed back and in turn favored activities that selected for reinforcing the plant community (Laland and O'Brien 2010:315–316). Eventually, this relationship became full-fledged agriculture.

The complicated web of niche construction does not stop at relationships between a species and an activity, or even between two species. As Odling-Smee et al. (2003) point out in a discussion of dam building as niche construction in beaver populations, beavers are affecting much more than the genes that select for dam building or the populations of trees they use. They are also modifying nutrients and decomposition in the water, vegetation populations in the river and lake zones, and materials that are transported downstream. In doing so, beavers are affecting the selection of several of their own traits, as well as those of potentially thousands of other species. Humans have the ability to engage in niche construction on an exponentially larger scale, and much of the cultural phenomena of interest to archaeologists is a part of one or many niche constructing activities. The niche construction perspective allows for the formulation of a "biologically and culturally informed, yet general evolutionary framework suited to the kind of cost-benefit analyses carried out by archaeologists" (Laland and O'Brien 2010:316).

Figure 2 (from O'Brien and Laland 2012:446) displays three potential pathways in a niche construction model. Model A describes a scenario in which a cultural process, acting at a population level, modifies the environment. The population responds to the modified environment through further cultural niche construction activities. Model B describes a scenario in which there is no cultural response to the modified environment, which triggers a genetic response in the population. Model C describes how a changed genetic constitution in a population can lead to new innovation and cultural development.

A niche construction activity such as the creation of bedrock mortars should not simply be viewed as a behavioral adaptation responding to the need to efficiently process acorn, as HBE would argue. Instead, bedrock mortars can themselves be viewed as playing a role in the evolving socio-biological and socio-ecological settings of those who manufactured them. Their presence may have had any number of consequences, from the perceived need to change fire regimes to enhance the growth of plant and animal foods, to genetic changes allowing the human body to better digest starchy foods (Odling-Smee et al. 1996, 2013). These changes could result in different uses of bedrock mortars, which could then result in yet more biological and cultural adaptations based on new niches the BRMs created. Niche construction theory provides a framework in which to place these recursive relationships; however, as there has been no application of the framework to bedrock mortars in the Sierra Nevada foothills, this example is only hypothetical as of yet.

Figure 2: Niche construction pathways (from O'Brien and Laland 2012:446)



The field of HBE has provided, and will continue to provide, valuable insight into many choices made by past populations. However, it is not well equipped to account for the important roles that technological developments play in those choices. This study takes the first step in demonstrating the utility of a niche construction framework in developing a more complete understanding of the role of bedrock milling technology on Browns Valley Ridge. It will work from the central hypothesis that the development of bedrock milling infrastructure was not a unidirectional behavioral adaptation, but rather a part of an interconnected set of feedback mechanisms. Together, these mechanisms formed the complex web of recursive relationships between biology, culture, and environment that shaped and gave meaning to the lives of the Maidu that lived there.

Chapter 3. Methods

To begin the process of integrating BRM technology into a niche construction model, this study shows that BRM depth is a reliable metric for inferring a preferred function that the Maidu had in mind when manufacturing it. Taking this step will allow future studies to infer what that function actually was, and thus develop the relationship of milling infrastructure design to processing strategies. To collect the necessary data, the author and several teams of volunteer and professional archaeologists conducted archival research, field survey, and field recording between 2013 and 2015. A brief description of the methods used for data collection is provided below, followed by a discussion of the methods used for data analysis.

Archival Research

The Anthropological Studies Center (ASC) at Sonoma State University began archaeological investigations at Saddleback Ranch in 2012. They were not mandated by legal compliance, but were motivated purely by the interest of the landowner in the history of his property. The landowner originally asked the ASC to investigate historic-era developments on the ranch and its surrounding properties. At this prompt, ASC staff conducted an archival record search at the North Central Information Center at California State University, Sacramento. The purpose of the record search was to identify all previous studies and previously recorded sites within one mile of the Saddleback Ranch boundary. While the current study is unrelated to the purpose of the original investigations, a new record search was unnecessary. The current study area falls entirely within the boundaries of the original record search, and communication with the landowner ensured that no additional surveys or sites have been recorded and reported to the Information Center since.

The results of the records search included several large survey reports, as well as numerous previously recorded cultural resources. Most of these were prehistoric sites composed primarily of BRMs, many of which fell inside the current study area. Unfortunately, the differences in the methods and consistency of recording BRMS, outcrops, and sites by these the authors of these studies precluded use of their raw data. However, the field crews involved in this study used the locational data of the previously recorded sites to relocate and rerecord them to acceptable standards.

Field Survey and Recording

Anthropological Studies Center volunteer crews, under the supervision of the author and ASC staff archaeologists, performed surveys during three separate field seasons: the first in May of 2013, the second in April of 2014, and the third in October of 2015. The survey was intended to relocate and update previously recorded resources, as well as identify and record unknown resources. Pedestrian transects were spaced between 15 and 20 meters, and all exposed bedrock outcrops were inspected. Field crews recorded individual BRM depth information to the closest quarter-centimeter. They accomplished this by laying a ruler or other plane across the top lip of the mortar and measuring to the bottom of the cup with a measuring tape. The crews generally left soil, rocks, leaves, and other materials found filling the mortars in place to facilitate potential future special studies such as residue analysis. In the cases where these materials inhibited measuring the depth of the mortar with a tape, the crews marked their depth using a stiff wire or pinflag. Field crews created scale drawings of each BRM outcrop, including the placement of individual mortars, and recorded their dimensions on Department of Parks and Recreation (DPR) 523F Milling Station Records. Due to the large scale of the study area, the location of each BRM outcrop was collected using Trimble Geo-series GPS mapping units. The recorders assigned each individual mortar on a specific outcrop with the same locational data as the outcrop. The author assigned milling locus designations by using ESRI ArcMap software to determine 25 meter-radius buffers around each BRM outcrop and combine those whose buffer overlapped.

Analysis

Ideally, to investigate whether a certain mortar depth or range of depths was associated with a specific type or group of resources, a study would directly test what kind of resources were processed in a sample of BRMs. The researcher could then calculate a regression that tested the strength of association between depth and resource. Methods of testing directly for resource residues in BRMs do exist, but unfortunately were not available for use in this study. Instead, this study tests the hypothesis that depth is a reliable metric for deducing whether the Maidu of Saddleback Ranch designed their milling infrastructure with specific processing goals in mind. It does so by evaluating the test hypothesis against two nullifying hypotheses— that mortar depth displays no patterning at all, or that is a function of use-wear and abandonment. As far as this author is aware, the methods used for performing these analyses are novel to this application, insofar as they comprise a mix of qualitative comparison of descriptive statistics and quantitative statistical tests. The author performed all graphing, tests, and descriptive computations using OriginPro statistical software. The methods for performing these analysis are described below.

The first null hypothesis— that the mortar sample displays no patterning— is evaluated by running the depth-frequency distribution data through the Kolmogorov-Smirnov and Shapiro-Wilks statistical tests for normality. Both evaluate their own test hypothesis, that the sample distribution is derived from a non-normal population, against their null hypothesis that the sample distribution is derived from a normal population. According to the central limit theorem of statistics, a random sample of a continuous variable (such as depth) usually assumes the very recognizable normal distribution (Rumsey 2010:61), which is the standard bell curve shape commonly used for calculating probability in basic statistics. Since the survey of the study area is assumed to have located all BRMs within, a normal depth-frequency distribution would indicate a random process of depth formation. If the two normality tests' hypotheses prove insignificant, then the null hypothesis cannot be rejected, and the sample distribution would be assumed to have derived from a normal population. This study would then conclude that the depth-frequency distribution of the sample does not display sufficient patterning to indicate preferred BRM morphology, and that depth could thus not be claimed to be a reliable metric for inferring processing strategy in the milling infrastructure of the study area.

If the first null hypothesis can be rejected, then this study will test the second— that BRMs deepened with age and were abandoned when they reached an undesirable depth. Archaeologists do not have any widely accepted method of testing the age of BRMs, nor the intensity or regularity of their use. Testing the second null hypothesis is thus a difficult prospect. This study attempts to do so by comparing the observed depth-frequency distributions of the real sample data to a series of possible distributions from hypothesized sample data. The hypothetical distributions represent what should be observed in the real sample data if mortar depth is assumed to be a function of use-wear.

This author created the hypothetical depth-frequency distributions based on varying scenarios of how the rate of use-wear would have affected mortar depth over time and how the population of BRM users affected the frequency of those depths in the sample. These scenarios each represent different diachronic use-wear-to-population growth ratios over a series of progressive time periods. Scenario 1 assumes a stable population (no growth or decline) and begins with an initial population of five BRM users. In this scenario, the rate of use wear proved to be insignificant in the resulting distributions. Scenario 2 assumes a slow population growth-to-use-wear ratio. It begins with an initial single BRM user, a population growth rate of one BRM user per period, and a use-wear rate of 1 cm per period. Scenario 3 represents a faster population growth-to use-wear ratio. It also begins with a single BRM user and population growth of one user per period, but mortar depth only increases by 1 cm every five periods.

The resulting depth-frequency distributions are a series of synchronic snapshots of a diachronic process that can be compared to the observed real sample from the study area. Each scenario was carried through enough progressions to demonstrate all the possible distributions to expect if use-wear and abandonment were the primary factors in shaping depth-frequency distributions. These progressions are estimable because BRM depth is assumed to be a function of use over time. The study made additional assumptions and generalizations for simplicity's sake, as well as due to its scope. Mortar use is assumed to remain relatively consistent throughout the progressions, both in spatial distribution and in intensity. As a result, all mortars in the hypothetical populations are assumed to be used at around the same time and to be subject to the same wear patterns. Each scenario uses a depth range from 0.1 - >5 cm, where 5 cm is the deepest desirable depth. When a BRM reaches a depth of >5 cm, it is considered too deep for use and abandoned and replaced with a new mortar. These are admittedly significant oversimplifications, but nonetheless illustrative of the trends likely to be observed if depth is in fact a function of use-wear. If the observed depth-frequency distributions of the real sample do not match any of the hypothetical distributions created through the above scenarios, then this hypothesis can be rejected, and it can be confidently argued that the appearance of preferred depths in the BRM infrastructure of Saddleback ranch is not a result of use-wear and mortar abandonment.

This study assesses the test hypothesis— that the inhabitants of Saddleback Ranch manufactured BRMs to preferred depths or depth ranges based on intended processing uses— through an analysis of the modality of the observed depth-frequency distributions in the study area. If this hypothesis is correct, then the frequency distributions should exhibit strong modality, preferably multimodality, in accordance with those desired ranges. A determination of multimodality is preferable because of the same concept in the central limit theory of statistics that was applied to the test for randomness. The central limit theorem shows that a sample of observations from a non-normally distributed population will still tend to form a normal distribution (Rumsey 2010:56). For this reason, a highly skewed and multimodal depth-frequency distribution will offer the strongest indicator of preferred BRM depths or depth ranges.

The resulting distributions from the hypothesized processes discussed in the scenarios above provide an example of how a desired range of depths may skew distributions to non-normal shapes. In that case, the abandonment of mortars after their depths became undesirable would create heavy left skew and strong modality at the deepest edge of the distributions. A highly skewed distribution, but one with observably different modality characteristics than those hypothesized above, would thus offer strong evidence that the mode or modes represented purposefully manufactured and desired depth ranges, rather than a range of undesirable depths.

To test for the strongest possible modes, the raw data creating the distribution will be smoothed through binning techniques, as well as with a kernel density estimation. Binning essentially refers to the process of rounding data up to a certain point, and allows for smoothing non-meaningful variation out of a distribution. Additionally, the data will be transformed to a logarithmic base 10 function, and modality of the resulting distribution will be compared to the smoothed data. These are widely accepted methods of "bump hunting" (Mukhopadhyay 2015:1), used in data driven sciences to search for important phenomena among large sets of variables (Hall and York 2001; Jann 2007; Minnotte 1997; Mukhopadhyay 2015). The bumps to which the term refers are modes in data distributions. Meaningful modes should be robust enough to maintain presence throughout these techniques. If no potential modes prove robust enough to be visible through the smoothing and transformation processes, then this study will conclude that the data collected does not provide enough information to make the claim that depth is a reliable metric of milling infrastructure design for inclusion into a niche construction model.

If robust modes become apparent through the smoothing and transformation techniques, they will first be compared to the hypothesized results from the use-wear function scenarios. If the resulting modes strongly resemble the hypothetical distributions from the use-wear function analysis, then it will not be possible to differentiate the modes from the two potential processes. In this situation, the study will have to conclude that while the data may suggest a maximum desired depth, they do not contain enough information to reliably relate depth as a metric for specific resource goals in milling infrastructure. If robust modes are identified that differ greatly from those hypothesized in the use-wear distribution analysis, then the test hypothesis that the modes are representative of specific design cannot be rejected. In this case, it can be confidently argued that the modes present in the sample depth-frequency distribution are representative of preferred depths, and the reliability of depth as a metric for infrastructure design can be inferred.

The methods described in this chapter provide a way to test whether mortar depth can be used to associate mortar morphology to an intended function. They do this by first examining two hypotheses that nullify this hypothesis— that mortar depths in Saddleback Ranch are completely random, and that mortar depth is a result of use-wear. By rejecting these null hypotheses, this study can test the modality of observed sample depth distributions for robust modes— indicators of preferred depths that do not correlate with use-wear or random processes. The following chapter provides the results and a discussion of these analyses.

Chapter 4. Findings and Analysis

Field crews surveyed a total of 1,278 acres of Saddleback Ranch (which constitutes the study area) over three field seasons (see Figure 3). The efforts resulted in the recording of 722 bedrock milling features on 240 bedrock outcrops, distributed across the surveyed area in 74 milling loci. Of the 722 milling features, 23 are classified as milling slicks, while eight of the 240 milling outcrops contain only milling slicks. As discussed earlier, this study uses only the sample of BRMs (n=699) and outcrops with BRMs (n=232). Appendix 1 contains the raw BRM data used for this study.

Findings

Landscape Scale

An initial examination of the raw data shows a severe rounding error, especially in the lower depth ranges. The rounding error is due to both the limited accuracy allowed by the measurement techniques in the field, as well as the tendency for the individual recorders to favor round numbers. Figure 4 shows the resulting depth-frequency distribution of the raw data, which displays substantial variation between values that are not representative of reality. The data thus had to be smoothed, which was accomplished by binning it to the 1-cm depth range. As mentioned above, binning is the process of rounding data to certain intervals, creating distinct “bins” into which the data fall.

Figure 3: Study area map

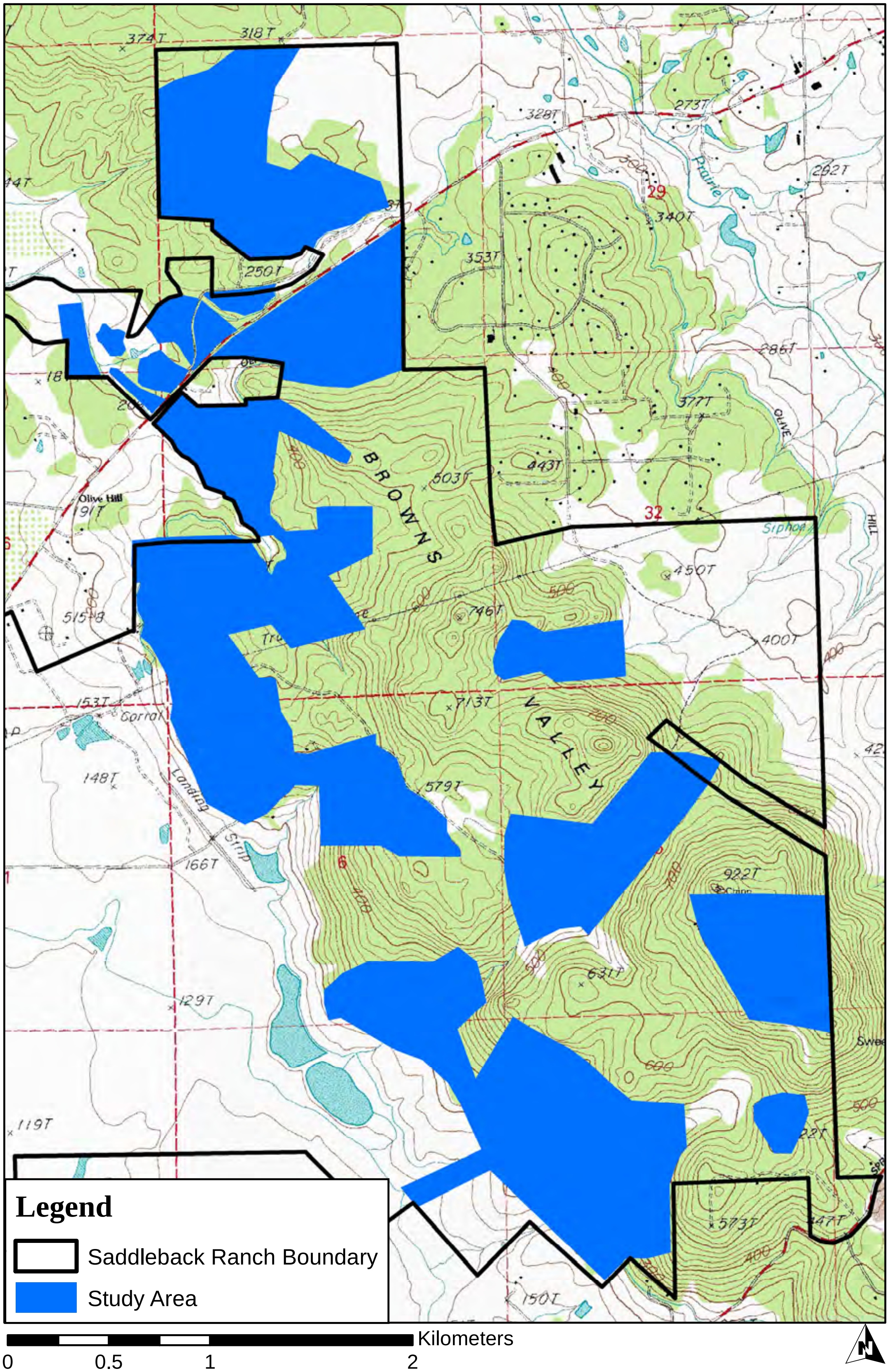


Figure 4: Landscape scale depth frequency histogram

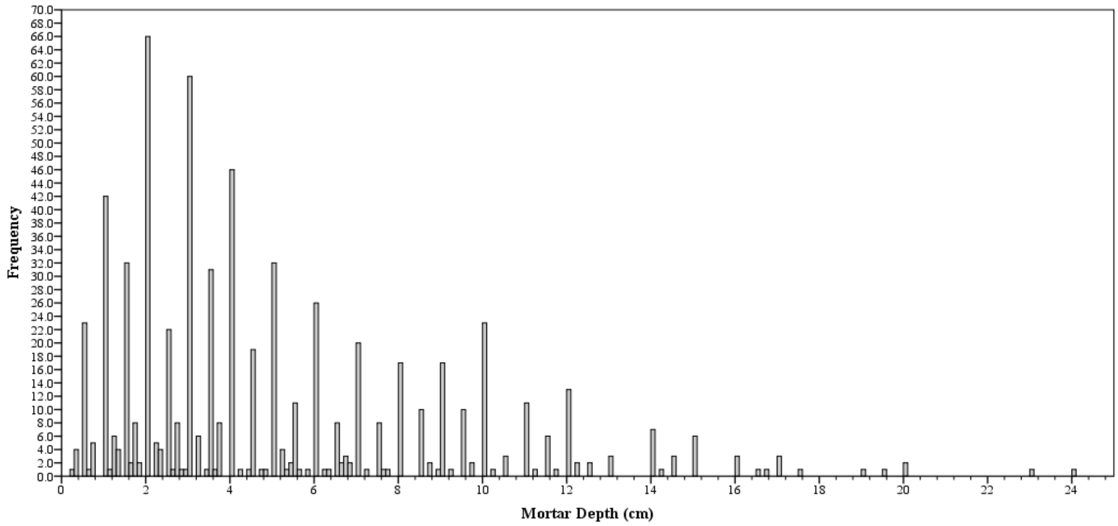
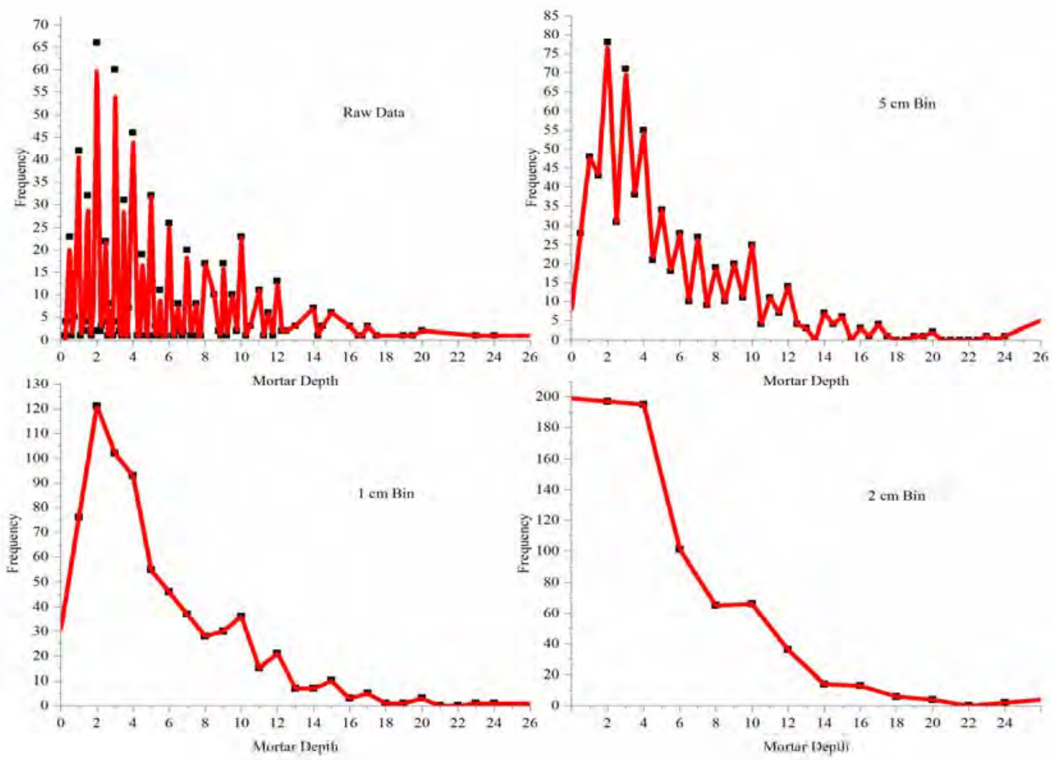


Figure 5: Differential data binning



In this case, all mortars that measured up to 1 cm deep were counted as 1-cm BRMs, creating a 1-cm bin. This interval of bin represents the least rounding error, while maintaining enough accuracy to represent real variation. Figure 5 exemplifies this concept. It displays the raw data, as well as data binned at the .5-, 1-, and 2-cm range, with linear interpolation lines to aid in visualizing the variation between values.

Figure 6 is a histogram of the smoothed depth data. Appendix 2 contains the mortar depth frequencies and summary descriptive statistics for the sample. Despite the large range of BRM depths (1-24 cm), 75% of the sample is less than 7 centimeters deep. Further, the range between the 25th and 75th percentile (the interquartile range) is between 2 and 7 centimeters deep, which means that 50% of the total BRM sample occupies a range of only five centimeters. This concentration is noteworthy because it implies that a non-random process helped to shape distribution at the BRM sample scale.

Figure 7 emphasizes the concentration of mortars in the lower range of depth values in the distribution. This boxplot visualization of data helps to compare it to the outcrop and milling locus samples. The tick of the left whisker indicates the minimum depth of the sample, the leftmost edge of the box represents the 25th percentile (first quartile), the center line of the box represents the median depth value (50th percentile, second quartile), the right edge of the box represents the 75th percentile (third quartile), and the tick of the right whisker marks 1.5 interquartile ranges from the third quartile. When present, the marks to the right of the right whisker represent depth values that are considered to be outliers or extreme outliers relative to the rest of the distribution. The furthest right mark of any boxplot is the maximum depth value of the sample.

Figure 6: Smoothed depth frequency histogram

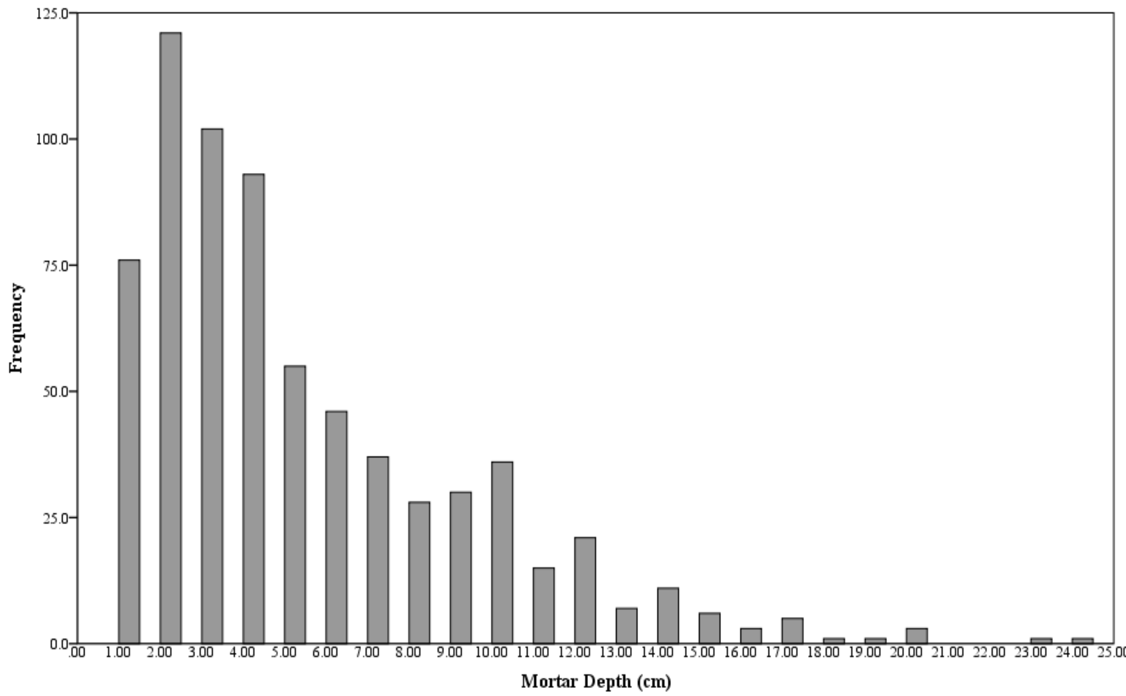


Figure 7: Depth frequency boxplot

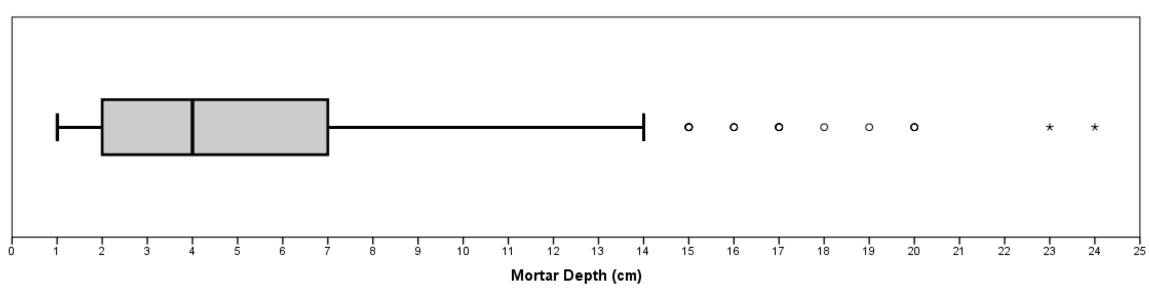
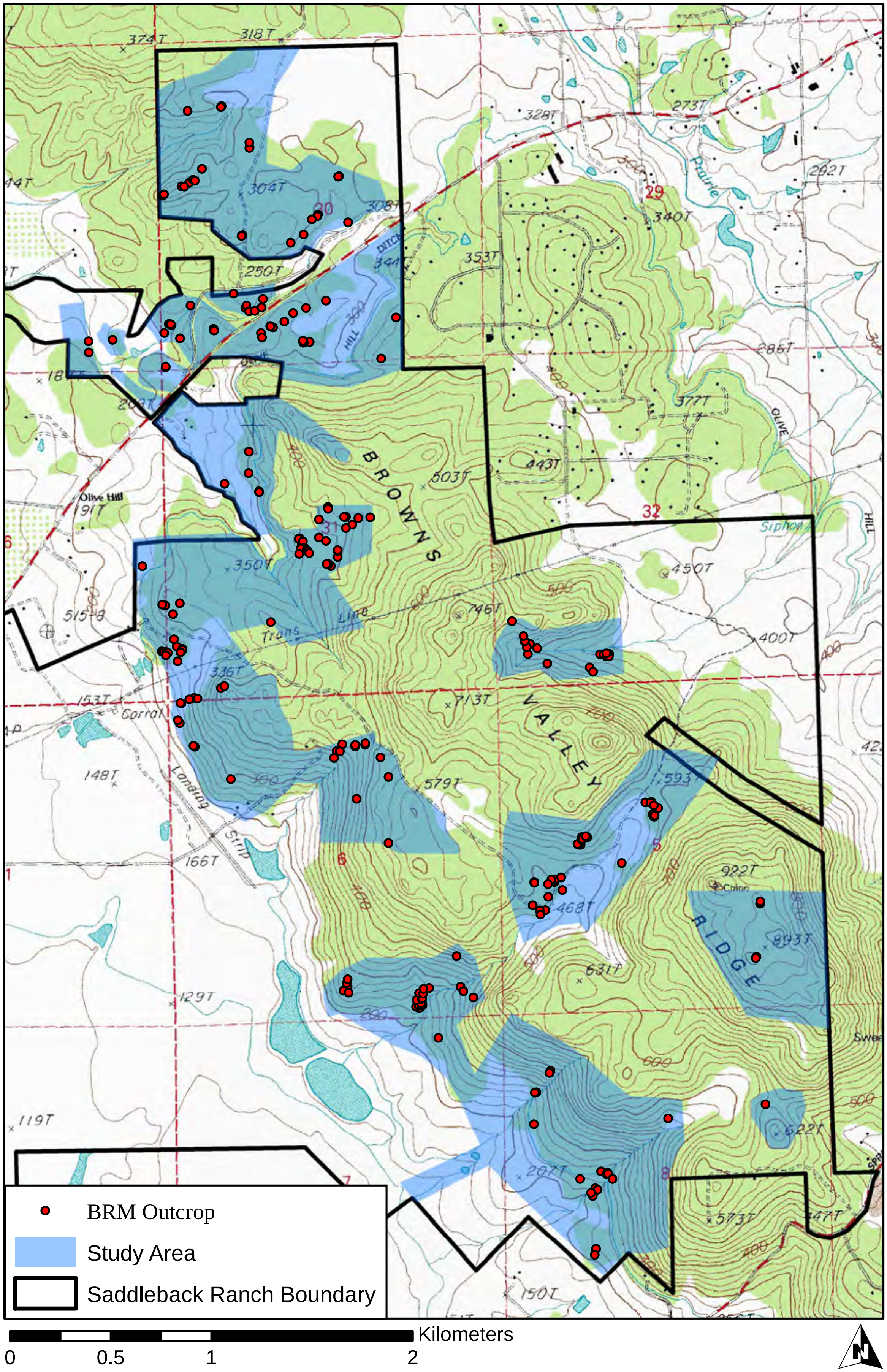


Figure 8: Bedrock mortar outcrop map



Bedrock Mortar Outcrop Scale

The field crews observed 232 bedrock outcrops that contain BRMs in the study area (see Figure 8). The outcrops range in BRM count from 1-20, with a cumulative BRM depth ranging between 1 and 171 centimeters. Like the depth distribution of the landscape-scale sample, both the BRM count distribution and the cumulative BRM depth distribution at the outcrop scale, shown below in Figures 9, 10, 11, and 12, are concentrated in the low range of their values. The interquartile range of the cumulative BRM depth per outcrop is between 4 and 16 centimeters, with a median of 8 centimeters. Of particular note, however, are the mortar depth frequencies per individual outcrop. These are presented below in Figure 13, and exhibit high variability and apparent randomness. This suggests that different determinants of mortar depth were active at the outcrop scale than at the BRM sample scale, which is relevant to the analyses and discussions below. Appendix 2 contains the summary descriptive statistics and depth frequencies for the BRM outcrop sample.

Figure 9: Outcrop scale cumulative mortar depth frequency boxplot

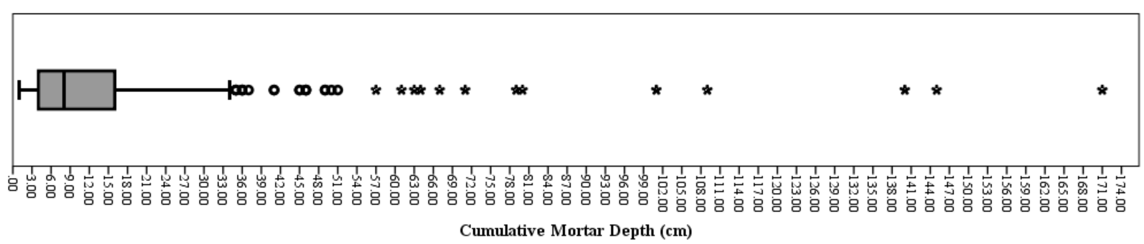


Figure 10: Outcrop scale mortar count frequency boxplot

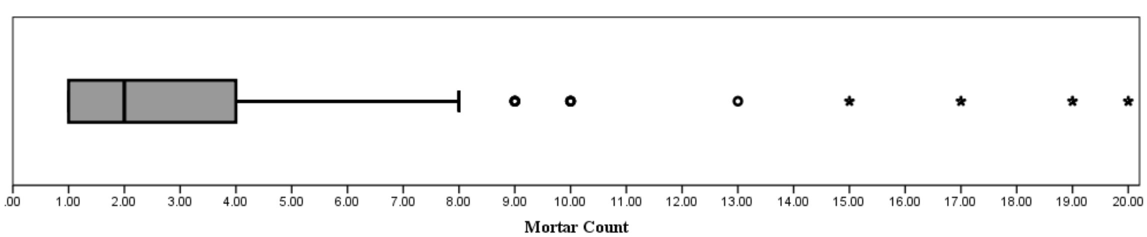


Figure 11: Outcrop scale cumulative mortar depth frequency histogram

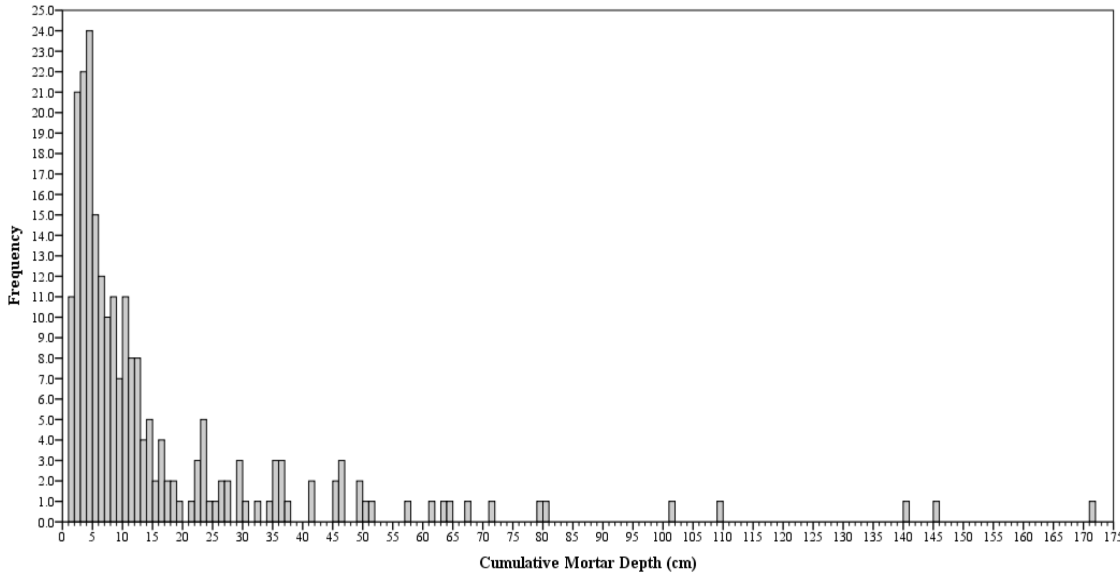


Figure 12: Outcrop scale mortar count frequency histogram

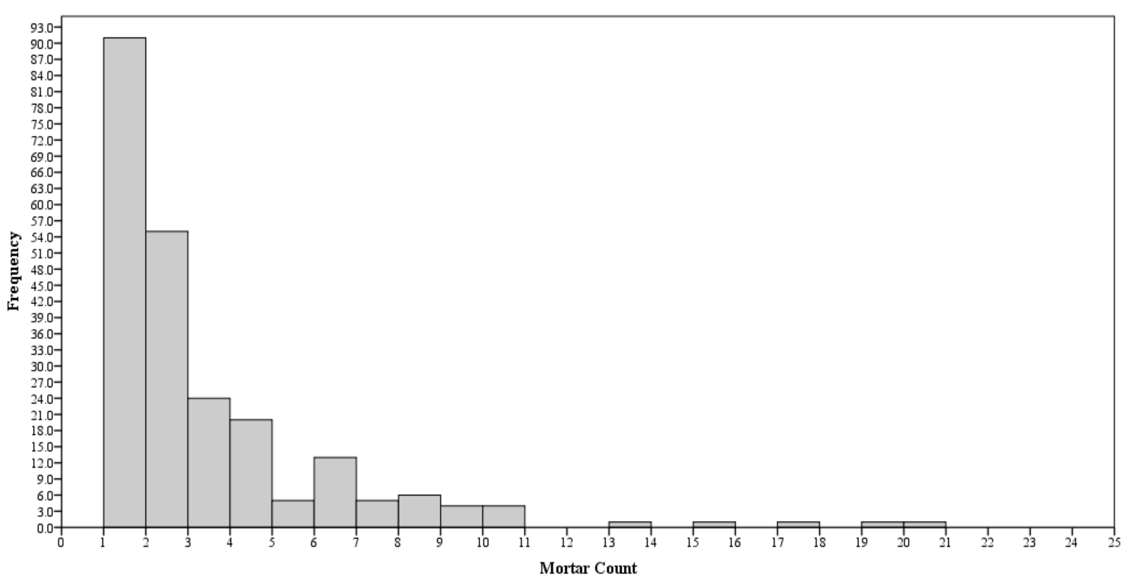
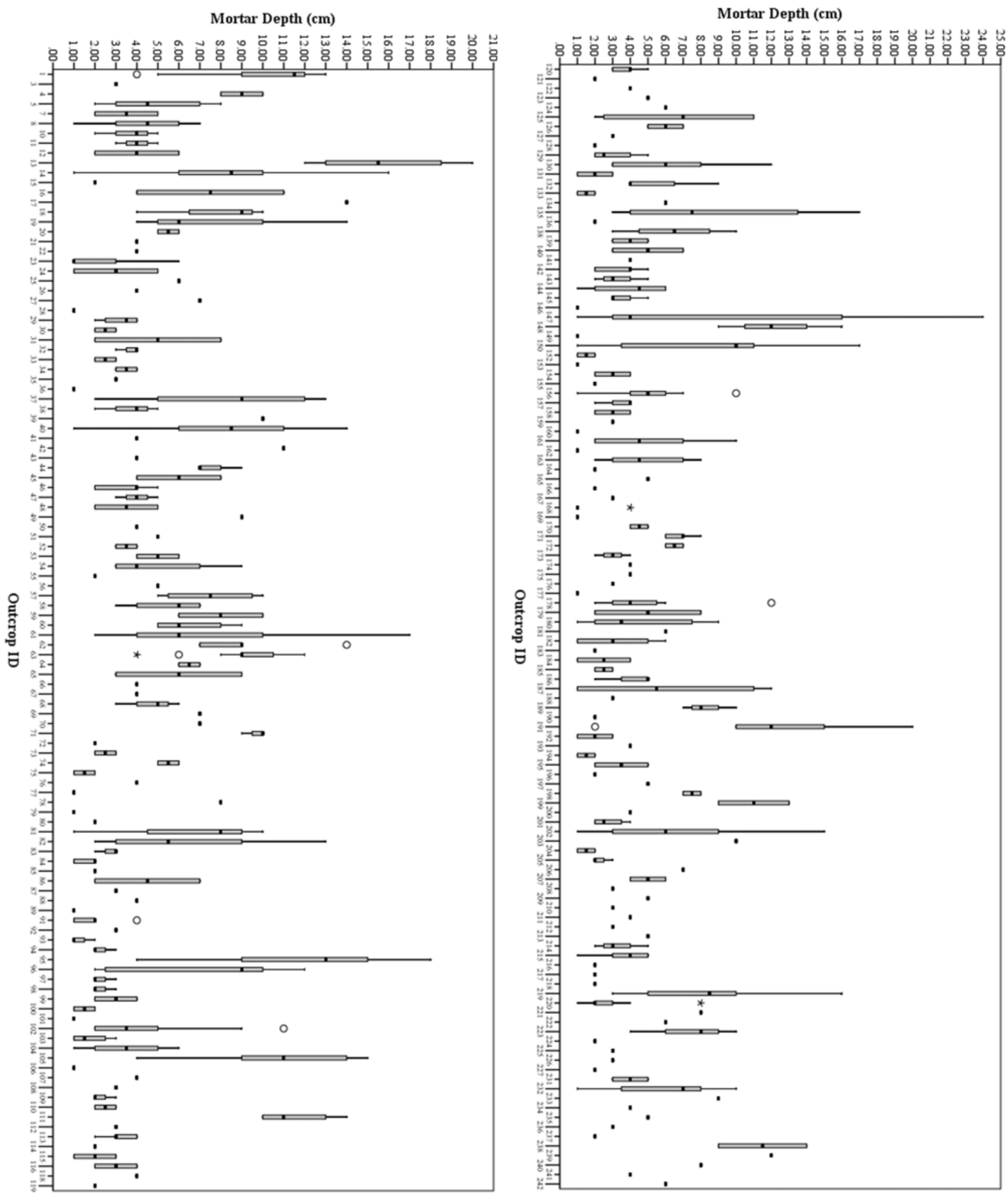


Figure 13: Mortar depth frequencies of individual bedrock mortar outcrops



Milling Locus Scale

A total of 74 milling loci were developed from the results of the survey effort (see Figure 14). They range from a single BRM outcrop with a single shallow mortar to a cluster of 33 outcrops with 115 mortars. Appendix 2 contains the summary statistics for the outcrop, mortar, and cumulative mortar depths of the milling loci as well as the BRM depth frequencies data per milling locus. Figures 15, 16, and 17 are histograms of the BRM outcrop count per milling locus, mortar count per locus, and cumulative mortar depth per locus, respectively. As with the outcrop and BRM samples, the data exhibits a clear concentration of all three of the above categories in the lower range of observed values. However, similarly to the BRM outcrops, the individual milling loci exhibit a wide range of BRM depth-frequency distributions when plotted side by side. Figure 18 is a boxplot of the BRM depth-frequency distributions that illustrate this difference. Like the outcrop sample, this is suggestive of different formational processes affecting BRM depth at the milling locus scale as compared to the BRM sample scale.

Figure 14: Milling locus map

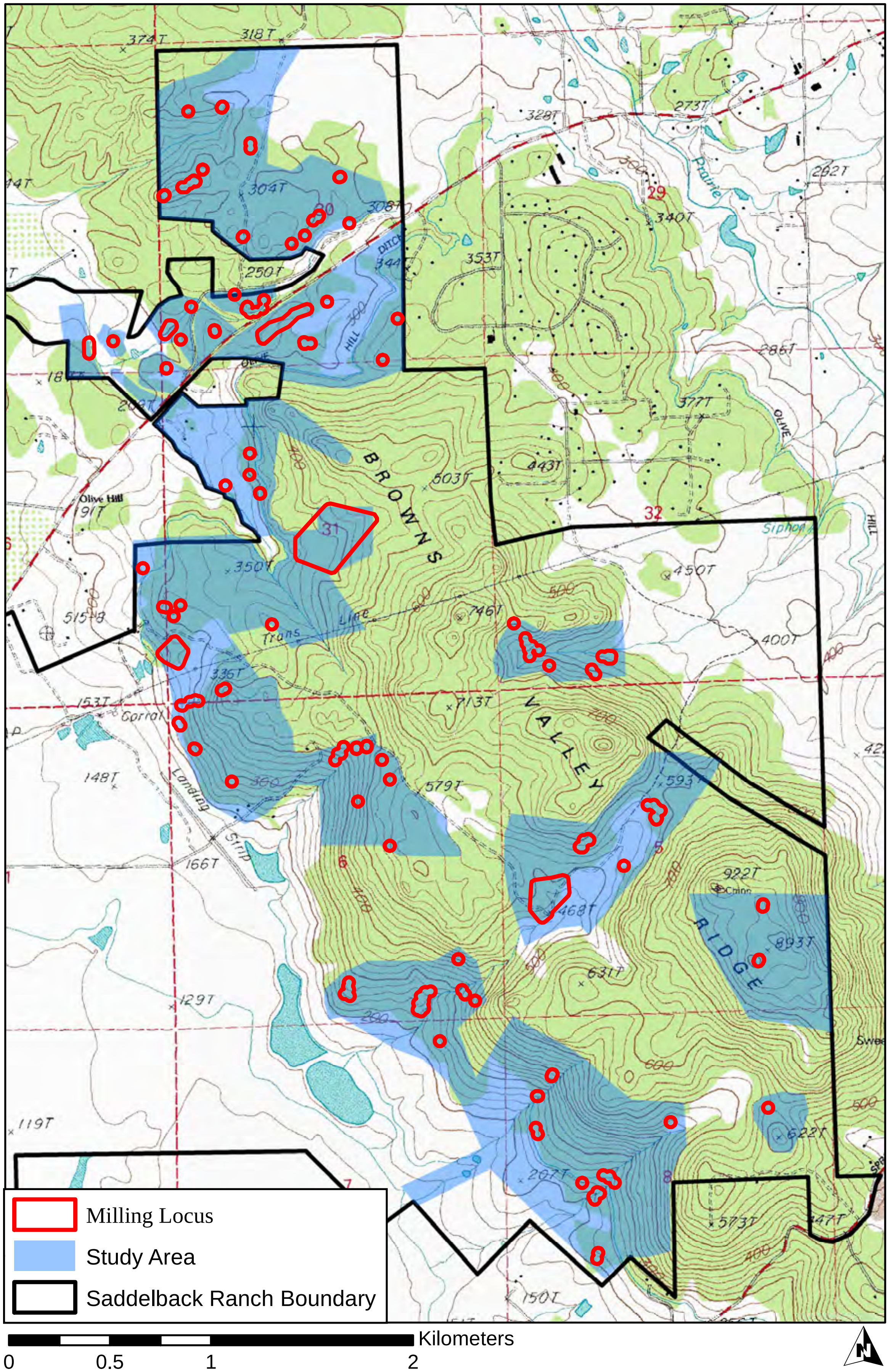


Figure 15: Milling locus scale outcrop count frequency histogram

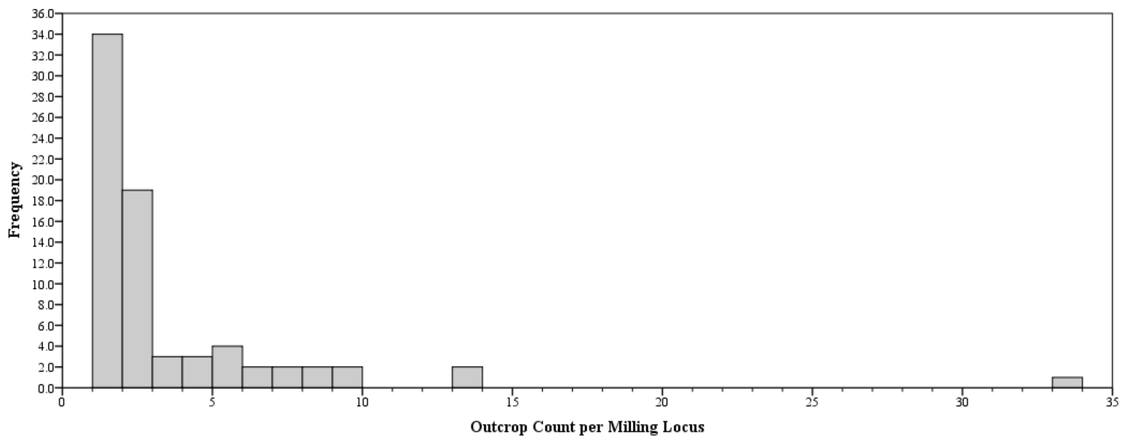


Figure 16: Milling locus scale mortar count frequency histogram

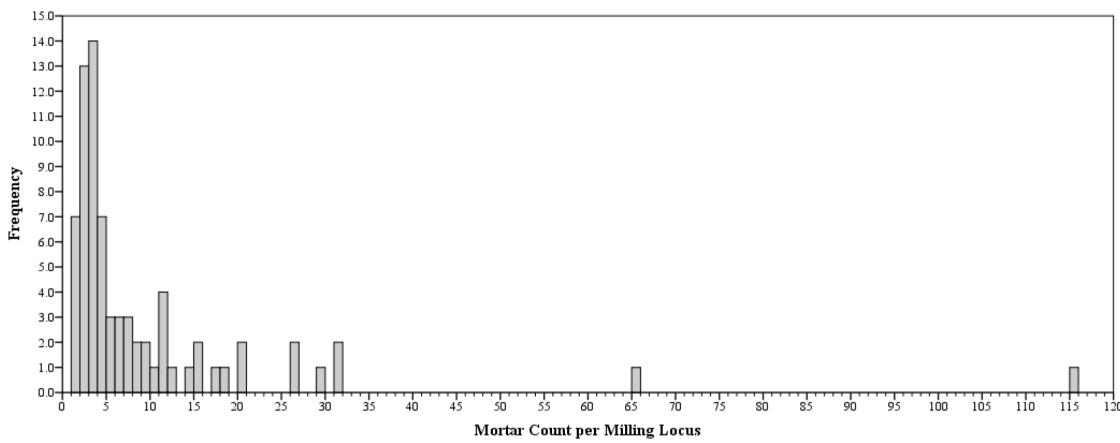


Figure 17: Milling locus scale cumulative mortar depth frequency histogram

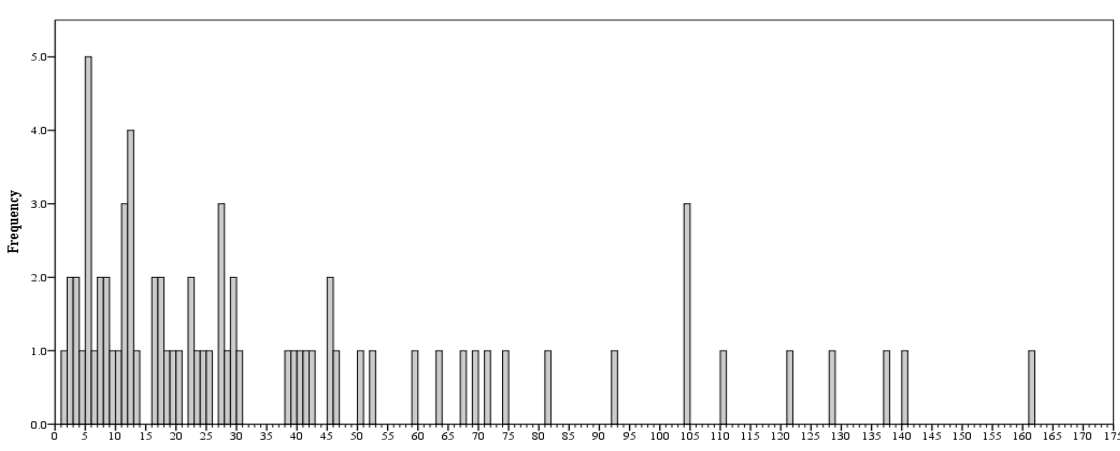
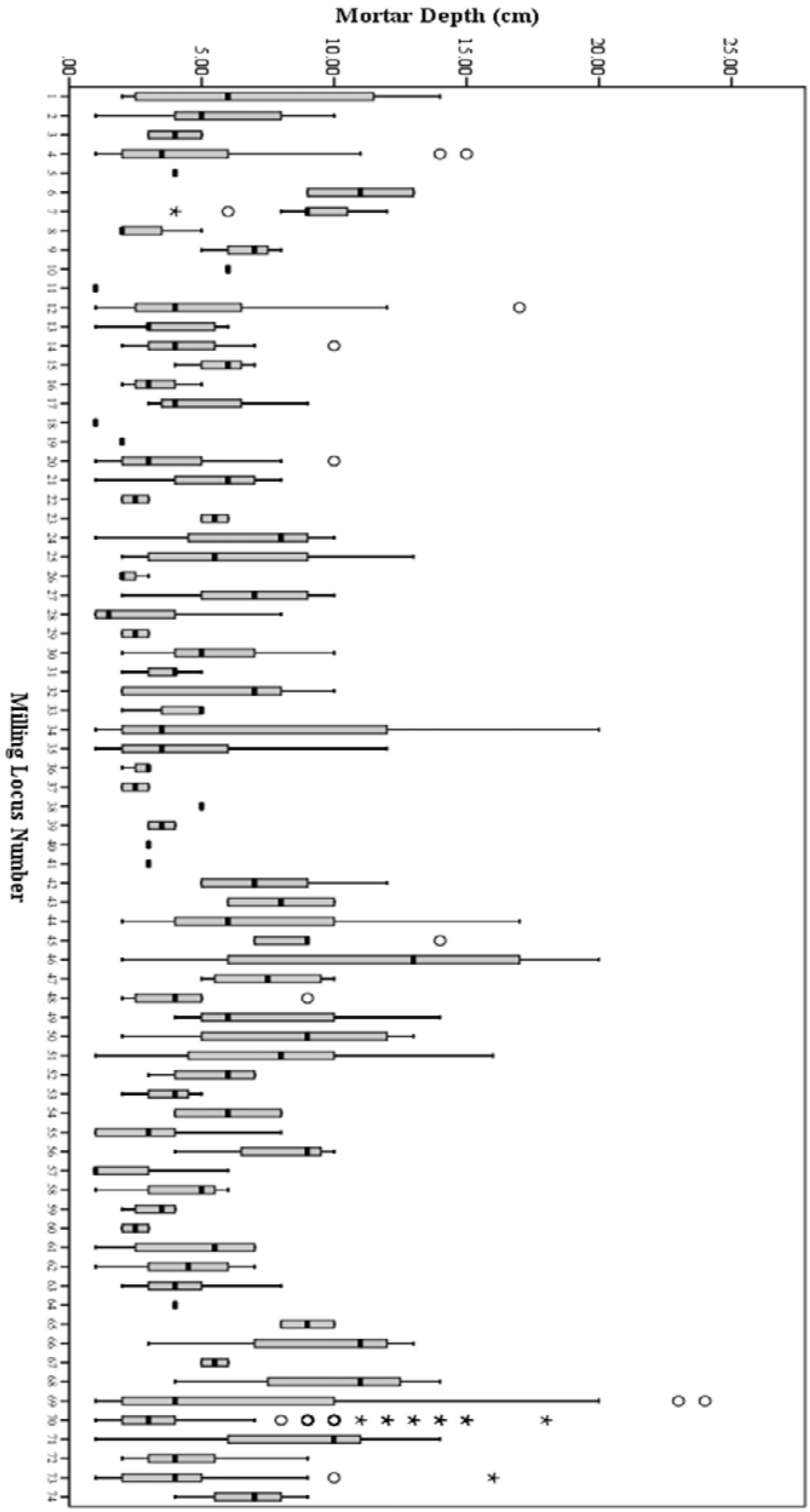


Figure 18: Mortar depth frequency of individual milling loci



Analysis

Null Hypothesis 1: Mortar Depth is Random

As described above, this hypothesis is tested through a comparison of the BRM depth-frequency distribution to a normal distribution. If the observed distribution tests to be demonstrably normal, then the observed BRM depths cannot be argued to be the result of a preferential process. This comparison was accomplished by running the depth frequency data through the Kolmogorov-Smirnov and Shapiro-Wilk tests, the results of which are displayed in Table 1. Both processes evaluate a test hypothesis— that the sample distribution is derived from a non-normal (i.e. designed) population— against a null hypothesis that it is derived from a normal (or random) population. If the null hypothesis cannot be rejected, then the study will have to assume that the data collected do not provide enough information to test whether the BRM depths in the study area reflect a preferred depth, whether that preference is a result of abandonment because of excessive depth or deliberate manufacture to a specific set of depths.

Table 1: Results of normality tests

Shapiro-Wilk Test		Kolmogorov-Smirnov Test	
Statistic	p-value	Statistic	p-value
.868	.000	.188	.000

Both tests result in a p-value of zero, which relates to the significance of the sample distribution's relationship to a normal distribution. The sample distribution can thus be confidently regarded as *strongly* non-normal. This was expected, given the significant skew and variation already observed in the sample frequency distribution, despite the fact that it was binned to 1-cm ranges. This study does not then have to reject the hypothesis that depth is a function of design based on initial statistical testing and can proceed with testing null hypothesis 2.

Null Hypothesis 2: Mortar Depth is a Function of Use-Wear

This study approached testing null hypothesis 2 by comparing the observed BRM sample data with a series of hypothetical distributions created under various assumptions of use-wear and population growth. Each resultant hypothetical scenario is discussed below, followed by comparisons with the real BRM sample data.

Scenario 1: This example represents a stable population, with no growth or decline (exact population replacement). In this scenario a 1 cm per period use-wear rate was used for simplicity, though any rate would have returned similar results. This example assumed that a single population of 10 BRM users each began utilizing a single mortar at concurrent times. Thus, the P_1 BRM depth-frequency distribution is composed of only ten 1-cm deep mortars. During each period use-wear caused the entire population of BRMs to increase in depth by a single centimeter, so that P_2 has a distribution of ten 2-cm deep BRMs, P_3 has a distribution of ten 3-cm deep BRMs, and so on until P_6. At the beginning of P_6, the initial BRM population reached >5 cm and was no longer considered usable. The users then created new 1-cm mortars, and the resultant frequency distribution includes ten 1-cm mortars and ten >5-cm mortars. As the cycle continued, ten new >5-cm deep BRMs accumulated every five periods, while a new group of ten progressed through the depth ranges.

The resulting trends from Scenario 1 were well established by P_{21}. Except for the first six progressions, this series of distributions show both strong bimodality and a considerable left skew (the major mode is on the right extreme of the distribution curve, causing a long tail to the left). The left skew is due to the majority of BRMs occupying the deepest range of the distribution, which was the result of the accumulation of abandoned BRMs that reached the >5-cm range. The strong bimodality was caused by the fact that only one range of BRM depth is populated in any given time, other than those that were abandoned and are no longer subject to processes that alter depth. Appendix 3 provides the frequencies for each progression in Scenario 1, and Figure 19 provides representative histograms.

Scenario 2: In this example, the BRM user population began at a single person and increased by one per period, while the use-wear rate equated to 1 cm per period. This example represents a moderate population growth rate to use-wear rate ratio. Unlike Scenario 1, the introduction of new BRM users maintained a relatively uniform BRM depth-frequency distribution across the ranges through the first ten or so progressions. At that point, however, the >5 cm depth frequency started increasing exponentially, causing the distribution to again skew heavily left, as in Scenario 1. Unlike Scenario 1, however, the influx of new BRM users maintains a relatively uniform distribution of usable mortars, keeping the overall frequency distribution generally unimodal. The trends resulting from Scenario 2 were also readily apparent by P_{21}. Appendix 3 contains the hypothetical depth frequencies for each progression in this analysis, and Figure 20 shows representative histograms.

Figure 19: Representative histograms for Scenario 1

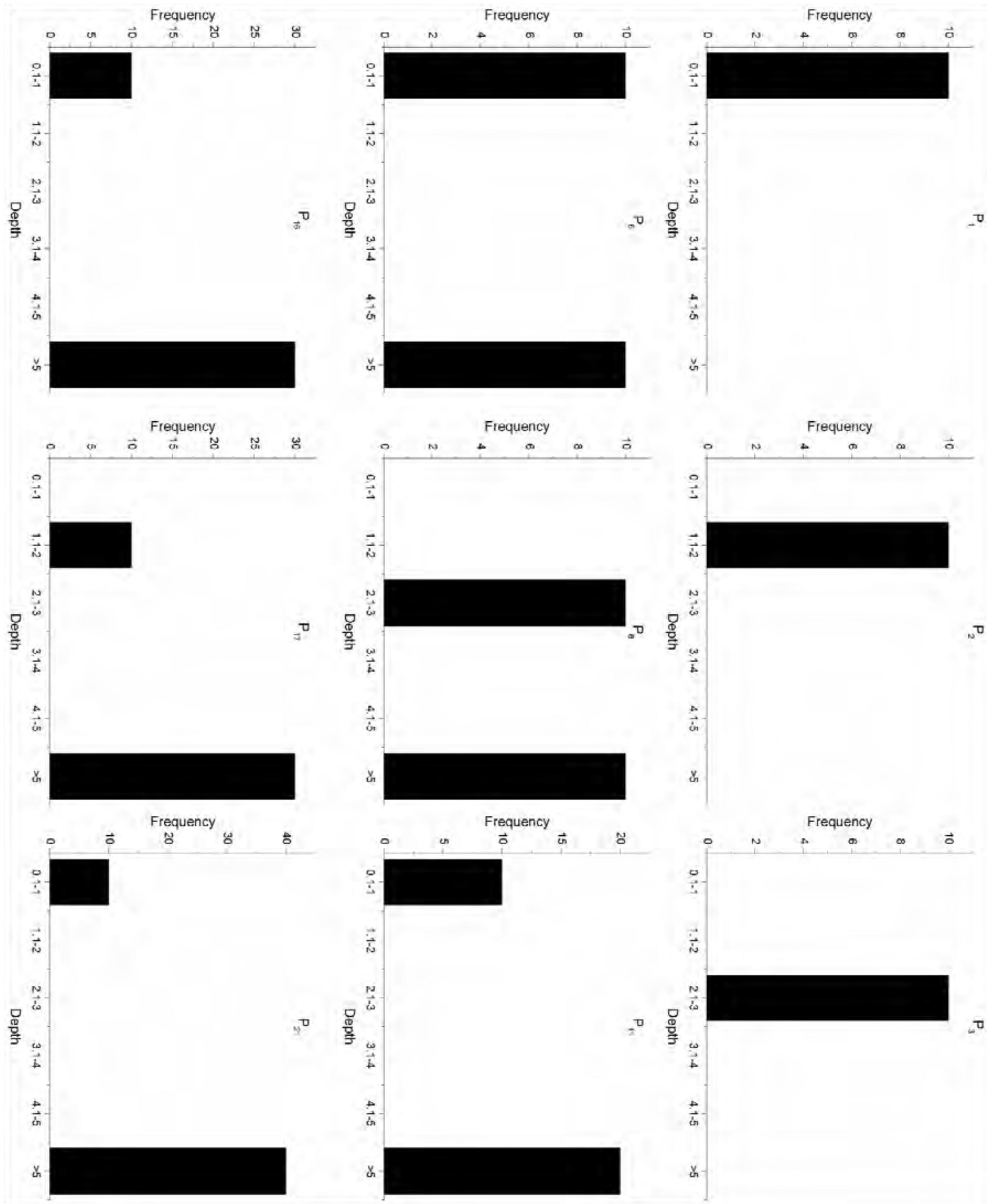
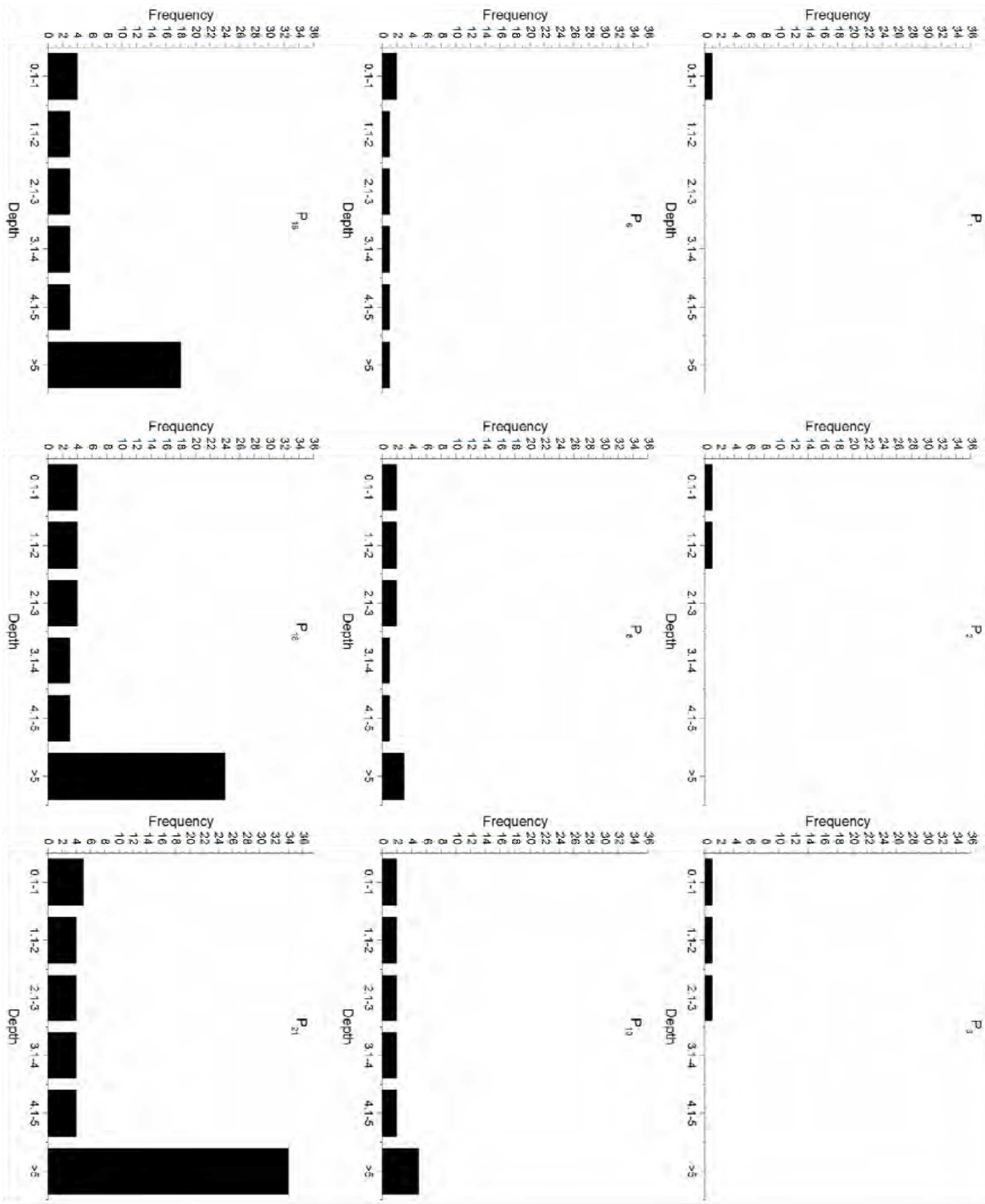


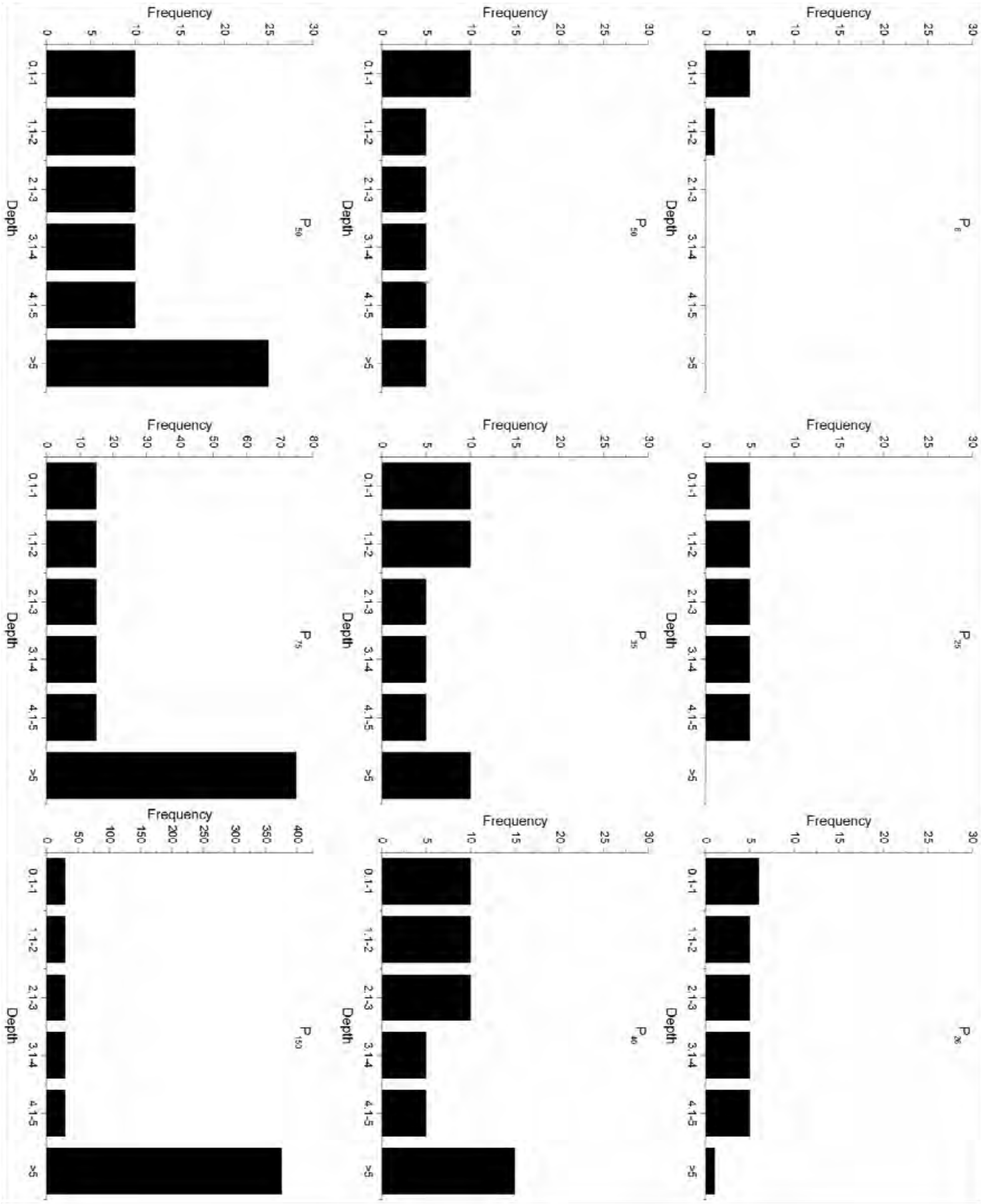
Figure 20: Representative histograms for Scenario 2



Scenario 3: This progression represents either faster population growth or a slower rate of use-wear relative to Scenario 2. It assumed that BRM depth only increased by 1 cm every five periods, while the BRM user population still increased by one every period. It is thus not until P_6 that the initial user's BRM reaches the 2-cm range. The progression of Scenario 3 is similar to Scenario 2, only taking longer. The distribution fluctuated between right skewed unimodal and uniform in the early periods, and the initial mortar did not reach the >5-cm range until P_{26}. From there, the relatively high amount of new BRM users per period only maintained the right-skewed unimodality for a short time. By P_{31} the steady introduction of new BRMs began to be outpaced by the rapid increase in abandoned BRMs, briefly causing polar bimodality in the distribution, and then a clear left skew by $P_{40.}$ By $P_{50,}$ the distribution is clearly unimodal and heavily left-skewed, and remains so ad infinitum. Appendix 3 contains the depth frequency results for Scenario 3, and Figure 21 displays a set of representative histograms.

In each of the above scenarios, the BRM depth frequencies tended towards strongly unimodal and left-skewed distributions over time. Short periods of right skew and polar bimodality were dependent on population growth, but were only observable early in the progressions. Steady population decline modeled similarly to Scenario 2, though became heavily left-skewed earlier as a result of fewer and fewer new BRM users maintaining the balance of new to abandoned BRMs over time.

Figure 21: Representative histograms for Scenario 3



Comparison to Observed Sample Distribution. As discussed earlier, the three hypothesized scenarios tended toward strongly left-skewed frequency distributions over time. This was a result of the accumulation of abandoned mortars that rapidly, often exponentially, increased with time. In Scenario 1, the progression of distributions began as right-skewed and strongly unimodal, until the first generation of mortars reached the depth at which they were abandoned. From there, the progressions took the form of polar bimodal distributions, and the continuing accumulation of abandoned mortars caused them to skew more and more to the left, ad infinitum. No distributions within Scenario 1 resemble the observed depth-frequency distribution of the mortars in the study area. It is thus unlikely that the two assumptions of the scenario—static population and a use-wear to mortar depth correlation—were significant factors in shaping the morphology of the milling infrastructure in Saddleback Ranch.

In Scenario 2, moderate population growth created a relatively uniform population of usable mortars early in the progression. As soon as the first generations of mortars reached abandonment depth, however, the distributions began to rapidly become more and more left-skewed. In this case, either population growth was too slow or the rate of use-wear was too fast to create a right-skewed distribution, and the exponentially increasing rate of abandoned mortars eventually precluded the possibility. As in Scenario 1, no distributions in the progression of Scenario 2 resemble that of the observed distribution of the mortar sample in the study area. It is thus unlikely that the assumptions of the scenario—a moderately growing population of BRM users and a use-wear to mortar depth relationship—played a significant role in shaping the morphology of the milling infrastructure in Saddleback Ranch.

Scenario 3 represents either a greatly increased rate of population growth, a significantly reduced use-wear rate, or both. In this hypothetical situation, a similar trend to the previous scenarios eventually takes place, with even faster exponential growth of the abandoned mortar population once the initial generations of BRMs become too deep for use. However, the higher rate of new BRMs, for a short period of the progression between P_{26} and P_{30}, creates a slightly right-skewed distribution that does not include a second mode in the far right. It is conceivable, given the correct population fluctuations due to circumstances such as epidemic disease, natural disaster, or mass migration, that this stage of the progression could come to resemble the observed distribution of the mortar sample from the study area.

An examination of the outcrop and milling locus samples addresses the possibility that the observed BRM sample distributions resulted from similar processes to those in Scenario 3, resulting in similar distributions to P_{26}–P_{30}. As discussed earlier, it was hypothesized that if depth is a function of use-wear, then the depth-frequency distribution of the mortar population as a whole should resemble the BRM depth distribution frequencies of the outcrop milling loci throughout the study area. This is based on the assumption that BRM use was relatively consistent across the landscape over time. This does not mean that mortars had to be used concurrently at all times, but it assumed that BRM users were not taking part in a staggered pattern of mortar and outcrop use at the scale of the milling locus.

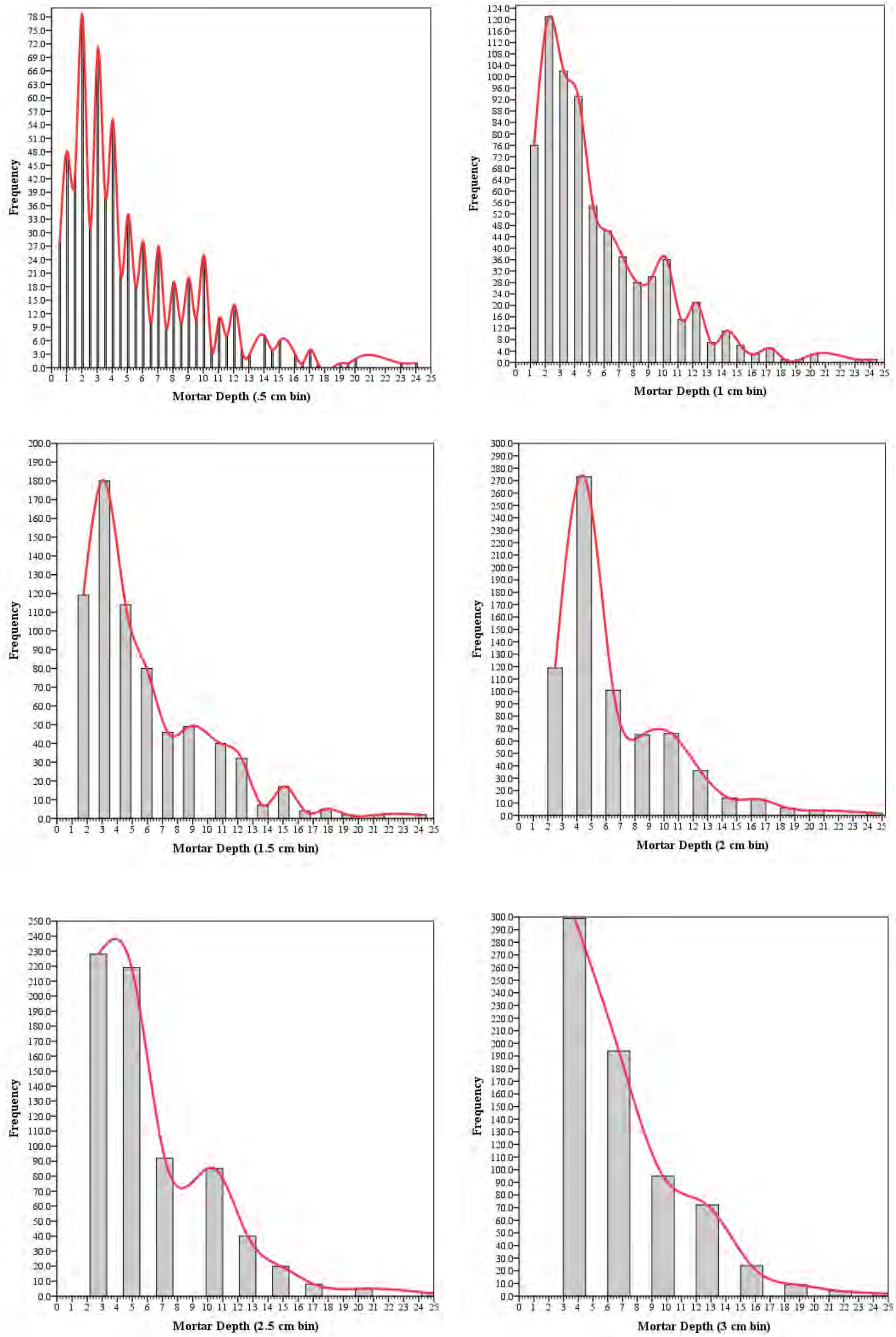
While the *cumulative* BRM depth frequencies of the outcrop and milling locus samples exhibit a similar distribution to the total BRM sample — right-skewed with gradually decreasing values as depth increases — the BRM depth frequencies at the locus and outcrop level clearly exhibit widely variable distributions. For these depth frequencies to have developed as a result of use-wear, an unusually complex, or more likely random, pattern of land use at the milling locus scale would have had to be in effect.

Ethnographic studies such as those performed by Beals (1933), Gifford (1936), Gifford and Barrett (1933), Kroeber (1925, 1929), Littlejohn (1929) and Powers (1877) suggest that the protohistoric Maidu conformed to relatively regular patterns of migration, site occupation, and land use. Studies performed by modern archaeologists and ethnographers like Grinnel (2004), McCarthy et al. (1985), Ortiz (1991), and Osborne (1998), and Jackson (1994) show that there was a substantial time investment involved in creating BRMs and that they engendered a sense of ownership, inheritance, and continuity in the women that used and inherited them from their mothers and grandmothers. Given these factors, it is unlikely that a use-wear and abandonment process would have resulted in highly variable patterns observed at the milling locus and outcrop scales. It is thus unlikely that the processes described in Scenario 3 shaped the morphology of the milling infrastructure in the study area, despite the resemblance of P_{26}–P_{30} to the BRM sample depth-frequency distribution. This null hypothesis is therefore rejected..

Test Hypothesis: Mortar Depth is a Function of Design

This study hypothesizes that, in the absence of use-wear as the main determinant of mortar depth, *meaningful* modality in the BRM depth-frequency distribution of the study area is an indicator of purposeful design by the BRM makers. Meaningful modality would be caused by concentrations of mortars of specific depths, or within close ranges, that represent real decision-making by the manufacturers of the BRMs for specific functionality. However, as noted above, it was not possible to obtain perfectly consistent measurements of the mortars, nor was it likely that the Maidu were using sensitive measuring equipment to obtain exact depths. As a result, the distribution curve of the raw data contains numerous fluctuations and modes, much of which is probably not representative of a potential decision-making process. To correct for the fluctuation in measurement, this study binned the depth data to 1 cm, originally shown in Figure 6. However, this process can lead to inaccurate or artificial modes in the distribution curve because mortars may be improperly grouped together. To test for modes that more accurately represent the depths desired by the Maidu in that inhabited the study area, this study “bump hunted” through different smoothing and transformation techniques. The first smoothing technique was to create histograms of the data smoothed to different bins, presented below in Figure 22. Cubic spline interpolation lines have been superimposed on the histograms to identify modes.

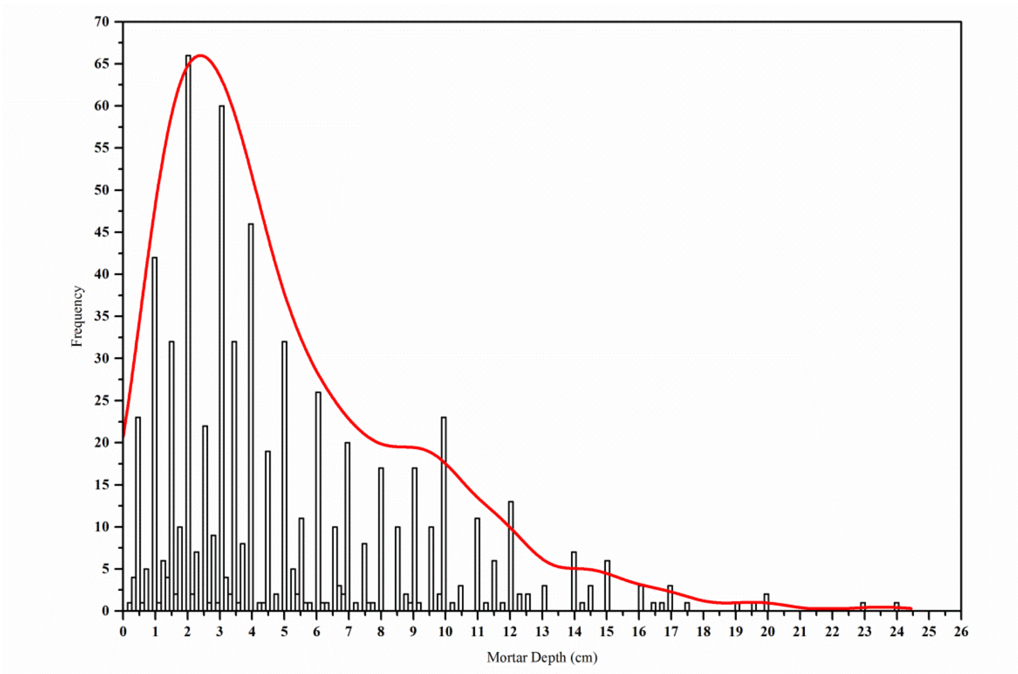
Figure 22: Smoothed mortar depth histograms showing possible modes



The histograms suggest two robust modes in the 2–4 and 9–10 cm depth ranges, up through 2.5-cm binning, after which the process smoothed out all modality. The histograms indicate the possibility of a third mode in the 14–15 cm range up through 1.5-cm binning. The continuity of the first two modes up to 2.5-cm binning suggests that they are potentially reflective of real modes in the data. The third mode persists long enough in the process to remain a possibility, though with less probability than the first two.

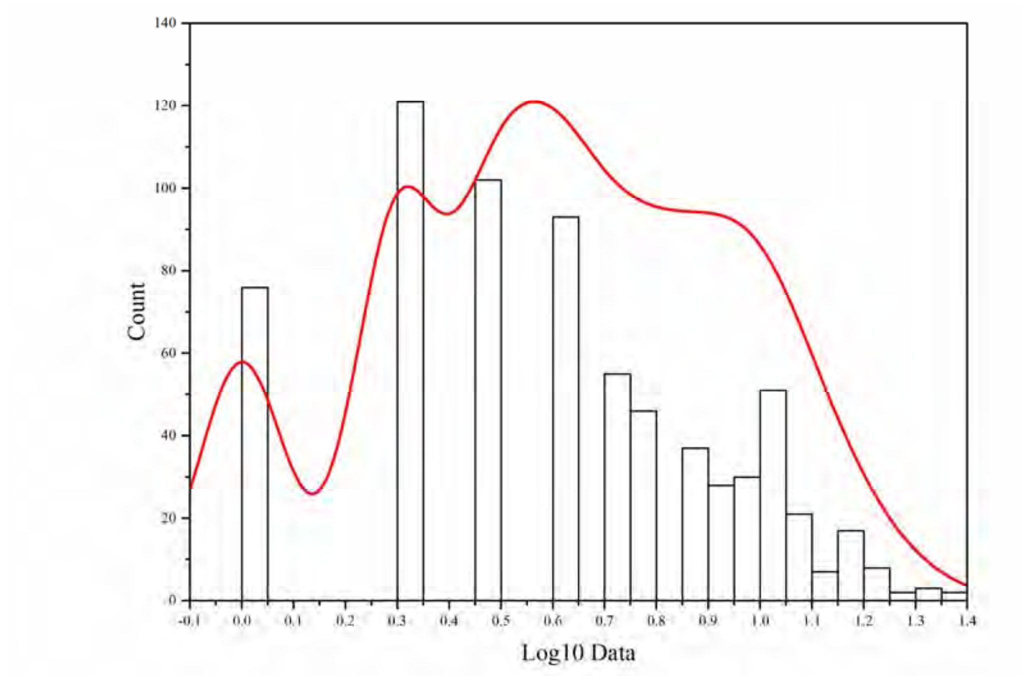
To further test the robustness of the modes, this study used an adaptive kernel density estimate (KDE) to interpolate the raw data. KDEs use a method similar to binning for data smoothing called bandwidth estimation; however, it is actually a process of numerous iterations that adaptively finds the optimal smoothing width (or kernel) for the data (Jann 2007; Mukhopadhyay 2015). Figure 23 provides the raw data with the KDE curve superimposed. The KDE curve shows two robust modes at about 2.5 and 9.5 cm, correlating closely to the binned histograms in Figure 6. The KDE curve also suggests the possibility of a third mode in 15 cm range. While the 14–15 cm peak in the KDE curve is not very pronounced, it still correlates with the mode observed in the binning process and so slightly reinforces its reflection of a real mode.

Figure 23: Mortar depth histogram with superimposed kernel density estimate curve



To continue testing the robustness of the modes identified above, the 1-cm bin data was transformed to a log base 10 distribution and interpolated with a KDE curve. Log base 10 transformations are made by multiplying the data by Log base 10 and are often used to transform non-normally distributed data to a normal distribution, so that a researcher can use statistical tests that assume normal parametric distributions. The strength of the multi-modality of a distribution curve, a sign of non-normality, is thus naturally tested by the procedure, and the robustness of individual modes is indicated by their persistence through the transformation. Figure 24 shows the result of the transformation and KDE procedure.

Figure 24: Histogram of log10 data with superimposed kernel density estimate curve



The histogram of the Log 10 data shows two clear modes at the 0.3 and 1.0 value, while the KDE curve shows three modes at the 0.0, 0.3, 0.6 values, with a potential mode at the .95-1.0 range. When converted back into standard notation, the 0.0, 0.3, 0.6, 0.95, and 1.0 values translate to 1, 2, 4, 9, and 10 cm depths, respectively. The histogram thus shows modes at 2 and 10 cm, while the KDE curve shows modes of 1, 2, and 4 cm, with a potential mode at 9-10 cm. Neither indicates the persistence of a 14–15 cm mode.

The histogram and KDE curve of the Log base 10 data strongly reinforces the probability that the 2-4 and 9-10 cm modes identified in the smoothed data are not artifacts of the binning process, but intentionally manufactured depths, while suggesting less probability that the 15-cm mode is meaningful. The KDE curve of the raw data suggests modes of 2.5, 9.5, and 15 cm, further bolstering the 2-4 and 9-10 cm modes, but also indicating possible meaning in the 15-cm mode. Altogether, these tests strongly indicate the presence of two real modes in the data between 2–4 and 9-10 cm, while indicating the possibility of a third 14–15 cm mode. Given that use-wear and natural processes were not likely to have been the main factor in determining BRM morphology in the study area, the finding that real and robust modes exist in the depth distribution of the sample strongly suggests that the pre- and protohistoric Maidu of Browns Valley Ridge purposefully manufactured mortars to specific depths, with a preference for the depth ranges identified above.

Discussion

This study argues that use-wear does not explain the BRM depth frequencies observed in the study area, while deliberate manufacture does. The observation made by Barrett and Gifford (1933), that mortars were abandoned after they had worn past a certain point, implies the active processes of both use-wear and abandonment. The concept of BRM abandonment may have stemmed from a misunderstanding of the idea that they were no longer used for acorn, as McCarthy et al. (1985) learned from their Mono consultants. That BRMs were abandoned at a certain depth altogether, however, is unlikely in this study area. In most potential cases this would have led to an accumulation of abandoned mortars across the landscape, which would have been apparent as a major mode of deep mortars within a narrow range of the depth-frequency distribution. This would have created the opposite image of distribution that was observed in the study area, one that was left skewed.

This thesis does not argue that use-wear had no influence whatsoever on the morphology of individual BRMs in the study area. It is very likely that pounding or grinding caused at least some wear over time, and other processes were likely at work as well. McCarthy et. al (1985:317) describe their Mono consultants repeatedly dragging their pestles up over the lip of a mortar when taking a break or shifting sitting positions on the outcrop, for example. The type of resource being processed, the rock-type of the pestle, natural exfoliation, or other unknown processes also probably had an effect on BRM morphology.

For the distribution observed in the study area to have resulted from use-wear at all, BRM abandonment would either have to not yet have substantially begun or never have been practiced in the first place. In either case, the heavy concentration of shallow mortars could only be explained by a large introduction of new BRMs after the technology had already been established in the study area (as represented by the considerable number of deeper BRMs). A similar process would also be necessary to explain the clear mode of 9–10 cm mortars in the middle range of BRM depths. Presumably, the fluctuating BRM frequencies would be indicative of fluctuating population in the study area. In this case the small number of mortars in the 15+ cm range would indicate a small population when BRM technology was first established. The rising mortar count as depth decreases in the distribution curve would indicate generally increasing, though fluctuating, population through time. The major concentration of very shallow mortars would suggest a large increase in population near the end of Maidu utilization of BRMs in the study area.

While the parameters described above are possible, and could explain the depth frequencies observed in the BRM sample as a whole, they are not supported by the widely variable patterns in mortar depth frequencies observed at the outcrop and milling locus levels. Under the assumption that use-wear was the main shaper of BRM depth, frequency patterns at the scale of the study area should be relatively similar to those observed at the milling locus and outcrop scales. Otherwise, a complex and staggered pattern of BRM use in individual outcrops and milling loci would be necessary to lead to the considerable variation observed in the depth frequencies. Such variation may be likely from region to region, or even foothill to foothill; however, early ethnographers' accounts of Native land use suggest much more uniformity at the scales of the outcrop or individual site. Future archaeological studies can test whether intrasite land-use patterns could have occurred in a way that caused BRM use-wear to result in the depth frequencies observed at both the locus and landscape scales. In their absence, though, it is reasonable to reject the hypothesis for a simpler, yet still effective, explanation of the frequency patterns observed at the three scales.

The hypothesis that the observed depth frequencies are reflective of the deliberate manufacture of individual BRMs by the inhabitants of Browns Valley Ridge satisfies those conditions. It is simpler than the complex small-scale land use patterns implied by the use-wear assumption, takes into account the data supplied by the consultants in Grinnel's (2004), McCarthy et. al's (1985), and Ortiz's (1991) studies, and is still supported by the heavily right-skewed and strongly multi-modal depth-frequency distribution of the study area sample. More importantly, the hypothesis better explains the wide variability of mortar depth frequencies at the outcrop and milling locus sample scales, as well as their lack of similarity to that of the landscape scale. Given the numerous resources known to be processed in mortars, the milling infrastructure at the outcrop and locus scales should reflect varying processing goals related to those resources, manifested in variable depth frequencies. As the scale of the sample gets larger, the milling infrastructure would represent broader, more generalized processing strategies, and the depth frequencies of the total sample of BRMs would change accordingly. A large scale processing strategy would thus not necessitate morphologically similar milling infrastructure all scales; rather, it would be built upon differing BRM depth-combinations that acted as specialized parts within a larger system.

The result of the analysis is that complex and unsubstantiated intrasite use patterns would be necessary to explain use-wear as the primary determinant of the varying BRM depth-frequency distributions observed in the study area, while the distributions are an expected result of form-to-function mortar creation. The insights gleaned from the ethnographic research of Grinnel, McCarthy et al., and Ortiz show that Native Californians preferred certain depths for processing specific resources, and that they were careful to avoid introducing broken rock material into the foods they processed, thus actively working to avoid heavy use-wear. Given these findings, this study concludes that the Browns Valley Ridge Maidu manufactured BRMs to desired depths based on intended functions.

A Niche Construction Approach to the Study of Bedrock Mortars

This thesis proposes that BRM depth-frequency distributions, like those used in the analyses above, are particularly well-suited for integrating mortars into a niche construction model. Depth-frequency distributions are statistical representations of the design of milling infrastructure and can thus be developed into measurable and comparable descriptions of processing goals. Niche construction theory provides a way to use depth-frequency distributions to explore the relationships between processing goals and other parts of prehistoric life, without restricting them to the subsistence-related caloric cost-benefit analyses and resulting assumptions inherent in HBE. This concept is exemplified by comparing McCarthy et al.'s study, which makes conclusions structured by HBE, against a proposed niche construction approach.

McCarthy et al.'s ethnographic research resulted in the designation of starter, finisher, and seeder mortars based on the depth ranges that their Mono consultants preferred for processing acorn and hard seeds (McCarthy et al. 1985:329). They developed a depth-frequency distribution for 111 BRMs recorded in the study area, divided it into the consultants' functional depth ranges, and found a 52.3%–18.9%–28.9% starter–finisher–seeder ratio, respectively (McCarthy et al. 1985:331). They propose that this ratio generally "represents the typical bedrock mortar technology required for food processing in substantive settlements in [their] environmental zone." (McCarthy et al. 1985:331).

The Mono that took part in the study were consistent in their functional designations, and McCarthy et al. had good reason to incorporate them. However, the application of the functional designations to the depth-frequency distribution in their study area highlights the limitations of HBE for examining BRM technology: it provides no mechanism for studying the technological adaptation outside of an already assumed subsistence narrative. McCarthy et al. correlated the development of bedrock milling infrastructure in their study area to HBE's balanophagy account. Because their Mono consultants used and remembered the BRMs in the specific context of intensified acorn with supplemental seed processing, McCarthy et al. had no occasion to consider that other processing goals may have potentially helped determine the design of the milling infrastructure. Human behavioral ecology's balanophagy narrative offered no motivation to study diachronic change in the design of milling infrastructure or in the processing goals that it was used for, and HBE offered no mechanism for studying the non-subsistence resources McCarthy et al. knew to be processed in BRMs. As a result, they simply divided the depth-frequency distribution into the starter–finisher–seeder depth ranges and then assumed the resulting ratio to be an accurate representation of the overall design. This treatment of the depth-frequency distribution prematurely imposed functional designations that could lead future studies to identify inaccurate processing goals, as well as effectively limiting archaeologists' understanding of milling technology to a synchronic development that Native Californians only developed to adapt to changing subsistence needs. In contrast, a NCT approach would first encourage a researcher to evaluate whether the technological adaptation had morphological-functional relationships in the specific study area, as this study has done, and then to develop a method for inferring those relationships based on data from that context.

Niche construction theory provides a framework for anthropologists to create a better understanding of bedrock milling technology. An NCT approach involves developing a location- and context-specific niche construction model, built from a set of cultural, environmental, and biological variables. Milling infrastructure is just one element of a niche construction model, and depth-frequency distributions can act as a kind of incipient structure on which to build the context-specific processing goals required for the model. Researchers can only develop accurate and meaningful relationships with other elements of a niche construction model *after* sufficient understanding of the milling infrastructure in a given area is established.

Depth-frequency distributions are quantitative descriptive statistical devices that do not embody any inherent resource-specific functional associations. Instead, anthropologists can focus on studying the milling technology itself to develop functional associations in the context of individual study areas, rather than impose assumed associations. Recent methodological advances in residue analysis make this approach feasible because researchers can test individual BRMs for the presence of specific resources—often to the genus or species level—to make functional associations related to the larger design of the milling infrastructure.

Depth-frequency distributions are especially useful for representing the design of milling infrastructure because they can show broad patterns of resource-specific processing that provide a more complete understanding than looking at individual results. For example, if acorn residue is found in BRMs that seem to span the depth-range of a study area, analyzing the acorn residue at landscape-, milling locus-, or outcrop-scale depth-frequency distributions could shed light on a number of questions. For example, was there simply no preferred BRM depth for acorn processing? Are there potentially meaningful gaps in the depth-range where no acorn residue was found? How do the results relate to the modality of the distribution? Was there a specific location or environmental context where a certain resource was only being processed in a certain depth range, or alongside others? Depth-frequency distributions will help researchers to infer processing goals that are related to more than just specific depth-function associations. They can develop a set of processing goals that are informed by contextual relationships with BRM depth and other elements of a niche construction model. While recent methodological advances make the approach feasible, it is NCT that provides a framework for analyzing the potential resources found, whether they are related to subsistence or not, and for discovering their relationships to other parts of prehistoric life.

The relationships of processing goals to other parts of a niche construction model structure and give meaning to a narrative for milling infrastructure. These other parts might include different technologies, available foods resources, ceremonial practices, migration patterns, or the gene that codes for the enzyme that allows humans to digest complex starches. Adaptation is a recursive process in which changes in one part of a model alter the others. The meaning of these relationships comes from the fact that they are both experienced by and shaped by people.

The potential examples of niche construction relationships are numerous and wide ranging, and they must be developed according to individual study areas. For example, imagine a local food taboo as a hypothetical element in a niche construction model. That taboo could have resulted in several outcomes, such as a lack of milling infrastructure designed to process the food. Over time, the milling infrastructure, partially structured by the taboo, could prove to be useful for processing a set of resources for which it was not originally intended. This could lead to changing the local population's perceptions of the resource's importance, and to different processing goals. Those different processing goals could eventually alter the original food taboo, and the process would continue on. If approached in the correct manner, the milling infrastructure in a study area can help to tell this story.

This example is obviously hypothetical, though not far-fetched. In a real model, the two elements would have relationships with other cultural and natural elements as well, which would have complicated the story considerably. Nonetheless, the example demonstrates a potential recursive relationship that is not necessarily based on transactions of caloric efficiency. The example also demonstrates the concept of ecological inheritance acting as a selective pressure. Successive generations of people would inherit their ancestors' taboos and milling infrastructure, which would shape related views and cultural practices. Continuing changes in those views and practices could shape the taboos and milling infrastructure that they then passed on to the next generation, and the process would continue as long as they inhabited the area. In this way people are responsible for shaping their own history and future, even when they are related to subsistence choices that are required to maintain a minimum caloric output.

An example for the utility of NCT in the study of milling infrastructure on Browns Valley Ridge is prompted by observations that the author and survey crews made during survey of the study area. As mentioned earlier, several of the BRM outcrops that the crews recorded contained one or two shallow mortars, were isolated from water sources and other milling loci, and were in or adjacent to rock shelters with a clear view of the Sutter Buttes. Ethnographic research has revealed the spiritual importance of the Buttes to the Maidu, as the place where the spirits of the dead went before ascending to heaven, as well as the origin of spiritual dances (see Button 2009 for and excellent synthesis of Maidu spiritual associations with the Sutter Buttes). While it is difficult to find written evidence that bedrock mortars were used in specific spiritual practices related to the Buttes, it is very likely that shamans used them to prepare resources for use in ceremonial practices. If these BRMs were not created for subsistence purposes, then their inclusion in analyses of subsistence-related processing goals would lead to inaccurate conclusions. Further, the relationships that this aspect of the milling infrastructure had with ceremonial practices, spiritual beliefs, and the non-spiritual world would be lost.

Niche construction theory encourages anthropologists to consider context-specific adaptation. Use of a niche construction model shows the relationships between different aspects of the cultural, biological, and environmental world in which an organism lives. Unlike HBE, NCT does not require these relationships be confined to trade-offs in caloric efficiency and so allows for a more inclusive analysis. When applied to the study of humans, these relationships can be explored to find their meaning to the people who were part of the world that the niche construction model describes. Niche construction theory thus not only allows anthropologists to address hypotheses, but to form a more meaningful narrative of a part of prehistoric life.

Chapter 5. Conclusion

Bedrock milling technology is an integral part of the material culture of prehistoric California. It is a highly visible and practically permanent system of infrastructure, often the only remaining evidence of the activities of prehistoric people in an area. This permanence and visibility would have caused the technology to play a huge part in the lives of those people, both shaping and being shaped by their culture and environment.

Despite the considerable importance to the people that made and inherited it, the role of BRM technology is often an afterthought in anthropological studies. It is usually regarded as simply a development of the necessity to efficiently process acorn. This is largely a product of the theoretical frameworks widely utilized by California archaeologists. These frameworks, usually based on neo-Darwinian evolutionary theory, offer important insights into the influence of selective pressures on prehistoric behavior and diet originating from the outside environment. However, neo-Darwinian theory is poorly adapted to the exploration of selective pressures from internal sources such as technology. As a result, the people who developed technology as a strategy for shaping their own lives are rarely given the credit or responsibility for doing so under neo-Darwinian anthropological frameworks.

Niche construction theory (NCT) is a development in the field of evolutionary biology that allows the incorporation of internal selective pressures into these studies. NCT offers the mechanism of niche construction, through which an organism alters elements of its own environment and behavior, as a causal mechanism in evolution.

These elements form a recursive relationship called a niche construction model. Because they are recursive, the niche construction model allows us to see how changes in one element can affect changes in any of the others. Humans have a unique and elevated tendency to alter our own environment, behavior especially though technology. We are thus extremely effective niche constructors.

Niche construction theory offers a more powerful way to explore the relationship of bedrock milling technology to elements of the culture, biology, and environment than more commonly used theoretical frameworks of California archaeology. These factors composed the environment in which the people who used BRMs were born and lived their lives— their ecological inheritance. Niche construction theory provides a way to analyze how peoples' ecological inheritance influences cultural adaptation, and how that adaptation influences further ecological inheritance. However, a mechanism for the technology's interaction with the rest of the elements of the niche construction model first had to be developed. This mechanism has to be a metric whose variation can be representative of meaningful changes in the technology.

This study proposed that BRM depth is a metric that can be used to reliably infer processing goals from the design of the BRM infrastructure in Saddleback Ranch. Processing goals, whether based on subsistence or non-subsistence activities, are well known and well understood to interact with other elements of culture and environment, so would prove an effective mechanism for interaction with other elements of a niche construction model. This hypothesis was tested against two null hypotheses. The first was that BRM depth was the result of a random process and could not be reliably connected to preferred depths. The second was that an appearance of preferred BRM depth was the product of use-wear and eventual abandonment. Analyses of BRM depth frequency data led to each of these hypotheses being rejected. The data was subjected to the Kolmogorov-Smirnov and Shaprio-Wilk tests for normality to test for randomness in the BRM depth-frequency distribution. Each found that the BRM depth-frequency distribution observed in Saddleback Ranch was highly non-normal and was thus not likely derived from a random process.

Having rejected the null hypothesis that BRM depths in the study area were random, the author next evaluated the hypothesis that the apparent design to the BRM frequency distribution was the result of a process of use-wear. The null hypothesis was tested by comparing the BRM, outcrop, and milling locus sample data to a series of hypothetical distributions that were developed based on varying assumptions of the use-wear rate and population variation. None of the resulting hypothetical distributions proved to be correlated sufficiently with the observed BRM, outcrop, and milling locus data when analyzed in conjunction, and so this null hypothesis was rejected.

This thesis evaluated the test hypothesis—that the prehistoric and protohistoric inhabitants of BRM Saddleback Ranch manufactured mortars to desired depths—by analyzing the modality of the observed BRM depth-frequency distribution. Methods of differential binning, KDE smoothing, and Log base 10 data transformation indicated very robust modes in the distribution of the 2-4 and 9-10 cm BRM depth ranges, and a third less robust but potential mode around 15 cm. The robustness of these modes, in conjunction with the rejection of the null hypotheses, strongly suggests that BRMs in Saddleback Ranch were manufactured by the Browns Valley Maidu with specific processing goals in mind. The author proposes that these processing goals vary between the landscape, outcrop, and milling locus scales. Resource processing goals are an important and meaningful part of culture and are widely interactive with other elements of culture, environment, and biology. They are thus prime factors for inclusion in a niche construction framework. Bedrock milling technology, then, can be used for powerful explorations of prehistoric life, rather than treated as a postscript to them.

Future Studies

Future studies in Saddleback Ranch should be geared towards developing a usable niche construction model for Browns Valley Ridge. This will involve inferring and describing processing goals based on the observed depth-frequency distributions, refining them for use in the niche construction model, and identifying the other elements that are potentially related to resource processing. Eventually, researchers can use this model to address hypotheses about any number of topics.

The next step in the process of refining a method for the inclusion of BRM technology into a niche construction framework is to develop processing goals. It will be necessary to collect a sufficient number of residue-analysis samples to confidently associate certain depth with specific resources to do this. The subsequent refining of the depth-frequency distributions will largely be conducted through statistical analyses. It will be necessary to perform various types of regression and other statistical analyses to associate the residue results with depth ranges, as well as to describe their relationship to the shape and modality of the distribution.

One interesting potential avenue of investigation on this front revolves around the multimodal nature of the landscape-scale distribution. Mixture modeling in statistics is a field that explores the fact that non-normal multi-modal distributions like those in the study area are often mixed sets of normally-shaped distributions (e.g., Banfield and Raftery 1993; Freeman and Dale 2013; Lee and McKachlan 2013; Zivkovic 2004). This would imply that the multimodality of the depth-frequency distribution from the study area could be a combination of the modes of multiple unimodal frequency distributions that are related to separate processing goals. A researcher could tease these apart using mixture modeling, with potentially very interesting and informative results.

One very exciting prospect that can come from results of discovering specific processing goals based on residue analysis and mixture modeling will be an approach to investigating diachronic change in milling infrastructure and potentially even a method of indirectly dating the technology in the study area. As mentioned above, residue analysis can often identify resources to a genus or species level. If sufficient residue analysis can be conducted, subsequent studies have the potential to associate and separate depth-frequency distributions that are designed to facilitate genus- or species-specific processing goals from the larger distribution. The resulting associations would not simply be single resources with specific BRM depths, but potentially sets of resources that strategically designed milling infrastructure was designed to process. Researchers can then perform archaeobotanical investigation such as that done by Wohlgemuth (1996, 2004) and Lepofsky and Lyons (2003) to develop resource-specific density-distribution curves of the archaeobotanical remains found in the study area. These resource-processing signatures can easily be compared and analyzed with the depth-frequency distribution curves of the milling infrastructure. If the right process for obtaining this information can be developed, then future studies can compare how archaeobotanical resource-density distributions changed through time and associate the changes with variation in the milling infrastructure. Archaeologists may have a chance at then indirectly dating the manufacture of the milling infrastructure if they can connect dateable archaeobotanical signatures in sediments to sets of BRMs that display corresponding processing goals.

Further ethnographic investigation, review of the literature, archaeological excavation, and other disciplinary approaches will help develop elements of the niche construction model for Browns Valley Ridge. Contextual clues, such as the effect of ceremonial mortar use, will guide the discovery and development of these elements. Varying research hypotheses will probably structure the way forward, but the principles of NCT throw open the doors for learning about the prehistoric Maidu in numerous ways. Niche construction theory allows future studies to test hypotheses about a number of topics in Saddelback Ranch that have nothing to do with caloric fitness. More importantly, though, NCT will help those future studies to acknowledge a narrative of choices, changes, and meaning that structured life for the Browns Valley Ridge Maidu. A crucial aspect of ensuring that narrative accomplished this will be through joining the archaeological findings with input from the living ancestors of the Browns Valley Ridge Maidu to illustrate a history inclusive of both Native and anthropological views. Doing so will bridge the gap between science and story-telling in archaeology and will thus make it an endeavor that has great value to all of society.

References Cited

Ames, K.
1992 The Northwest Coast: Complex Hunter-Gatherers, Ecology, and Social Evolution. *Annual Review of Anthropology* 23(1): 209–229.

Banfield, J.D, and A.E. Raftery
1993 Model-Based Gaussian and Non-Gaussian Clustering. *Biometrics* 49(3): 803-821.

Barbour, M., T. Keeler-Wolf, and A. Schoenherr (editors).
2007 *Terrestrial Vegetation of California*. University of California Press, Berkeley.

Barrett, S.A., and E.W. Gifford
1933 Miwok Material Culture. *Bulletin of the Public Museum of the City of Milwaukee* 2(4): 117–376.

Basgall, M.
1987 Resource Intensification among Hunter-Gatherers: Acorn Economies in Central California. *Research in Economic Anthropology* 9: 21–52.

Baumhoff, M.
1963 Ecological Determinants of Aboriginal California Populations. *University of California Publications in American Archaeology* 49: 155–236.

Beals, R.
1933 Ethnology of the Nisenan. *University of California Publications in American Archaeology and Ethnography* 31(6): 335–414.

Bean, L.J., and H.T. Lawton
1976 Some Explanations for the Rise of Cultural Complexity in Native California with Comments on Proto-Agriculture and Agriculture. In *Native Californians: A Theoretical Perspective*, edited by L.J. Bean and T.C. Blackburn, pp. 19–48. Ballena Press, Ramona, California.

Beardsley, R.
1954 Temporal and Areal Relationships in Central California Archaeology. *Berkeley: University of California Archaeological Survey Reports* 24, 25.

Bettinger, R.
1976 *Hunter-Gatherers, Archaeology and Evolutionary Theory*. Plenum Press, New York.

Bettinger, R., and M. Baumhoff
1982 The Numic spread: Great Basin Cultures in competition. *American Antiquity* 47: 485–503.

Bettinger, R., R. Mahli, and H. McCarthy
1997 Central Place Models of Acorn and Mussel Processing. *Journal of Archaeological Science* 24: 887–899.

Binford, L.
1968 Post-Pleistocene Adaptations. In *New Perspectives in Archaeology,* edited by L. Binford and S. Binford, pp. 313–341. Aldine, Chicago.

1980 Willow Smoke and Dog's Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. *American Antiquity* 45(1): 4–20.

Bleed, P., and A. Matsui
2010 Why Didn't Agriculture Develop in Japan? A Consideration of Jomon Ecological Style, Niche Construction, and the Origins of Domestication. *Journal of Archaeological Method and Theory* 17(4): 356–370.

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

Blount, C., S. Davis-King, and R. Milliken
2008 *Native American Geography, History, Traditional Resources, and Contemporary Communities and Concerns*. Cultural Resources Inventory of Caltrans District 3 Rural Conventional Highways. California Department of Transportation.

Broughton, J.M., M.D. Cannon, and E.J. Bartelink
2010 Evolutionary Ecology, Resource Depression, and Niche Construction Theory: Applications to Central California Hunter-Gatherers and Mimbres-Mogollon Agriculturalists. *Journal of Archaeological Method and Theory* 17(4): 371–421.

Broughton, J.M.
1994 Late Holocene Resource Intensification in the Sacramento Valley, California: The Vertebrate Evidence. *Journal of Archaeological Science* 21(4): 501–514.

Button, M.
2009 Multiple Ways of Seeing One Place: Archaeological and Cultural Landscapes of the Sutter Butters, California. Unpublished Master's Thesis, California State University, Chico.

Codding, B., D. Bird, and T. Jones
2012 A Land of Work: Foraging Behavior and Ecology. In *Contemporary Issues in California Archaeology*, pp. 115–131. Left Coast Press.

Collard, M., B. Buchanan, M. J. O'Brien, and J. Scholnick
2013 Risk, mobility or population size? Drivers of technological richness among contact-period western North American hunter-gatherers. *Philosophical Transactions of the Royal Society B: Biological Sciences* 368(1630): 20120412–20120412.

Compas, L., M. Baloian, and S. Flint
2003 *Cultural Resource Inventory for Pacific Gas and Electric's Proposed Colgate -Smartsville #1 60 kV Transmission System Replacement Project.* Unpublished Draft Cultural Resource Inventory. Pacific Gas and Electric Company, Sacramento.

Dawkins, R.
1990 *The Extended Phenotype: The Long Reach of the Gene*. University Press, Oxford.

Diekmann, L., L. Panich, and C. Striplen
2007 Native American Management and the Legacy of Working Landscapes in California: Western Landscapes were Working Long before Europeans Arrived. *Rangelands* 29(3): 46–50.

Dixon, R.B.
1905 The Northern Maidu. *Bulletin of the American Museum of Natural History* 17(3): 199–346.

Elsasser, A.B.
1960 *The Archaeology of the Sierra Nevada in California and Nevada*. University of California Archaeological Surveys. Berkeley.

Fitzgerald, R., and T. Jones
1999 The Milling Stone Horizon Revisited: New Perspectives from Northern and Central California. *Journal of California and Great Basin Anthropology* 21(1): 67–93.

Flannery, K.
1969 Origins and Ecological Effects of Early Domestication in Iran and the Near East. In *The Domestication and Exploitation of Plants and Animals*, edited by P. Ucko and G.W. Dimbleby, pp. 73–100. Duckworth, London.

Frederickson, D.A.
1974 Cultural Diversity in Early Central California: A View from the North Coast Ranges. *Journal of California Anthropology* 1(1): 41–53.

Freeman, J.B., and R. Dale
2013 Assessing Bimodality to Detect the Presence of a Dual Cognitive Process. *Behavior Research Methods* 45(1): 83–97.

Gifford, E.W.
1936 California Balanophagy. In *Essays Presented to A.L. Kroeber,* edited by R. Lowie, pp. 87–89. University of California Press, Berkeley.

Glassow, M.
1992 Archaic Cultural Development in California. *Revista de Arqueología Americana* (5). Las Sociedaded Americanas del Postpleistoceno Temprano: 201–229.

Gremillion, K.J.
2002 Foraging Theory and Hypothesis Testing in Archaeology: An Exploration of Methodological Problems and Solutions. *Journal of Anthropological Archaeology* 21(2): 142–164.

Grinnel, E.
2004 Making Acorn Bread in Yosemite. In *Food in California Indian Culture*, edited by I. Jacknis, pp. 137–142. Phoebe Hearst Museum of Anthropology, Berkeley.

Hall, P., and M. York
2001 On the Calibration of Silverman's Test for Modality. *Statistica Sinica* 11: 515–536.

Hamusek, B., and W. Dreyer
1991 *A Cultural Resource Survey of the Proposed Prairie Creek Planned Unit Development, Yuba County, California*. Research Associates, Fair Oaks, California.

Haney, J.
1992 Acorn Exploitation in the Eastern Sierra Nevada. *Journal of California and Great Basin Anthropology* 14(1): 94–102.

Hildebrandt, W., and K. McGuire
2002 The Ascendance of Hunting during the California Middle Archaic: An Evolutionary Perspective. *American Antiquity* 67(2): 231–256.

2012 A Land of Prestige. In *Contemporary Issues in California Archaeology*, edited by T. Jones and J. Perry, pp. 133–151. Left Coast Press.

Holly Jr., Donald
2005 The Place of “Others” in Hunter-Gatherer Intensification. *American Anthropologist* 107(2): 207–220.

Humphreys, S.E.
1969 *The Archaeology of New Bullard's Bar*. National Park Service, San Francisco.

Jackson, T.L.
1991 Pounding Acorn: Women's Production as Social and Economic Focus. In *Engendering Archaeology*, edited by J. Gero and M. Conkey, pp. 301–325. Blackwell Publishers, Oxford.

Jann, B.
2007 Univariate Kernel Density Estimation. Unpublished e-print repository. Available at fmwww.bc.edu/repec/bocode/k/kdens.pdf. Accessed 03-2016.

Jepson, W.L.
1925 *A Manual of the Flowering Plants of California*. University of California Press, Berkeley.

Johnson, J., and D. Theodoratus
1978 *Cultural Resources of the Marysville Lake, California Project (Parks Bar Site), Yuba and Nevada Counties, California.* Prepared for United States Army Core of Engineers, Sacramento.

Jones, Terry
1996 Mortars, Pestles, and Division of Labor in Prehistoric California: A View from Big Sur. *American Antiquity* 61(2): 243–264.

Kroeber, A.L.
1925 *Handbook of the Indians of California*. Bureau of American Ethnology Bulletin 78. University of California Press, Berkeley.

1929 The Valley Nisenan. *University of California Publications in American Archaeology and Ethnology* 24(4): 253–290.

Laland, K., and M. O'Brien
2010 Niche Construction Theory and Archaeology. *Journal of Archaeological Method and Theory* 17: 303–322.

Lee, S., and G.J. McKachlan
2013 Model-based clustering and classification with non-normal mixture distributions. *Statistical Methods and Applications* 22(4): 427–454.

Leftwich, B.M.
2010 Set in Stone: Bedrock Mortars and Behavior in the North-Central Sierra Nevada. Unpublished Dissertation, University of California, Santa Barbara.

Lepofsky, D. and N. Lyons
2003 Modeling Ancient Plant Use on the Northwest Coast: Towards an Understanding of Mobility and Sedentism. *Journal of Archaeological Science* 30(11): 1357–1371.

Lewontin, R.
1983 Gene, Organism, and Environment. In *Evolution from Molecules to Men*, edited by D. Bendall, pp. 273–285. Cambridge University Press, Cambridge.

Lillard, J.B., R.F. Hezier, and F. Fenenga
1939 *An Introduction to the Archaeology of Central California*. Sacramento Junior College, Department of Anthropology, Bulletin 1.

Lillard, J.B., and W.K Purves
1936 *The Archaeology of the Deer Creek-Cosumnes Area, Sacramento County, California*. Sacramento Junior College, Department of Anthropology, Bulletin 1.

Littlejohn, H.W.
1929 Nisenan Field Notes. Bancroft Library, University of California, Berkeley.

McCarthy, H., C. Blount, and R. Hicks
1985 *Appendix F: A Functional Analysis of Bedrock Mortars: Western Mono Food Processing in the Southern Sierra Nevada.* Cultural Resources of the Crane Valley Hydroelectric Project Area. Theodoratus Cultural Research, Inc., Sonora and Fair Oaks, California.

McClure, S.
2007 Gender, Technology, and Evolution: Cultural Inheritance Theory and Prehistoric Potters in Valencia, Spain. *American Antiquity* 72(3): 485–508.

McGuire, K., and W. Hildebrandt
1994 The Possibilities of Women and Men: Gender and the California Milling Stone Horizon. *Journal of California and Great Basin Anthropology* 16(1): 41–59.

Meighan, C.W.
1987 Reexamination of the Early Central California Culture. *American Antiquity* 52(1): 28–36.

Merriam, C.H.
1889 *Life Zones and Crop Zones of the United States*. Government Printing Office, Washington D.C.

Metcalfe, D., and R. Barlow
1992 A Model for Exploring the Optimal Trade-off between Field Processing and Transport. *American Anthropologist* 94(2): 340–356.

Minnotte, M.C.
1997 Nonparametric Testing of the Existence of Modes. *The Annals of Statistics* 25(4): 1646–1660.

Moratto, Michael
1984 *California Archaeology*. Academic Press, Orlando.

Morgan, Christopher
2012 Modeling Modes of Hunter-Gatherer Food Storage. *American Antiquity* 77(4): 714–736.

Mukhopadhyay, S.
2015 Large-Scale Mode Identification and Data-Driven Sciences. Unpublished e-print repository. Available at http://www.arxiv.org/pdf/1509.06428. Accessed 04-2016.

Nettle, D., M. A. Gibson, D. W. Lawson, and R. Sear
2013 Human behavioral ecology: current research and future prospects. *Behavioral Ecology* 24(5): 1031–1040.

O'Brien, M., and K. Laland
2012 Genes, Culture, and Agriculture: An Example of Human Niche Construction. *Current Anthropology* 53(4): 434–470.

Odling-Smee, F., D. Erwin, E. Palkovacs, M. Feldman, and K. Laland
2013 Niche Construction Theory: A Practical Guide for Ecologists. *The Quarterly Review of Biology* 88(1): 3–28.

Odling-Smee, F., L. Hawkes, K. Lupo, and N. Blurton-Jones
2003 *Niche Construction*. Monographs in Population Biology 37. Princeton University Press, Princeton.

Odling-Smee, F., K. Laland, and M. Fieldman
1996 Niche Construction. *The American Naturalist* 147(4): 641–648.

Ortiz, B.
1991 *It Will Live Forever: Traditional Indian Acorn Preparation*. Heyday Books, Berkeley.

Osborne, R.H.
1998 The Experimental Replication of a Stone Mortar. *Lithic Technology* 23(2): 116–123.

Powers, S.
1877 *Tribes of California*. Vol. 3. Contributions to North American Ethnology. Government Printing Office, Washington D.C.

Raab, L.M.
1996 Debating Prehistory in Coastal Southern California: Resource Intensification Versus Political Economy. *Journal of California and Great Basin Anthropology* 18(1): 64–80.

Riel-Salvatore, J.
2010 A Niche Construction Perspective on the Middle–Upper Paleolithic Transition in Italy. *Journal of Archaeological Method and Theory* 17(4): 323–355.

Ritter, E.W.
1970 Northern Sierra Foothill Archaeology: Culture History and Culture Process. *University of California, Center for Archaeological Research at Davis, Publications* 2: 171–184.

Rumsey, D.J.
2010 *Statistics Essentials for Dummies*. For dummies. Wiley Publications, Inc., Indianapolis, IN.

Saucedo, G.J., and D.L. Wagner
1992 Geologic map of the Chico quadrangle. Regional Geologic Map 7A. California Division of Mines and Geology.

Schulz, P., and J. Johnson
1980 An Early Acorn Cache from Central California. *Journal of California and Great Basin Anthropology* 2(1): 127–128.

Schulz, P.D.
1980 Osteoarchaeology and Subsistence Change in Prehistoric Central California. Unpublished Ph.D. Dissertation, University of California, Davis.

Scott-Phillips, T., K. Laland, D. Shuker, T. Dickins, and S. West
2013 The Niche Construction Perspective: A Critical Appraisal. *Evolution* 68(5): 1231–1243.

Selverston, M., M.J. Markwyn, and M. Walker
2005 *Archaeological and Historical Resource Inventory Report: Oroville Facilities Relicensing.* Unpublished Technical Report. California Department of Water Resources.

Siskin, B, B. Texier, C. Ward, and A. McCarthy
2007 *Archaeological Survey and Inventory for the Table MTN-Colgate-Rio Oso 230 KV Transmission Line Reconductor and Tower Modification Project.* Unpublished Technical Report. Pacific Gas and Electric Company.

Smith, E.
1983 Anthropological Applications of Optimal Foraging Theory: A Critical Review. *Current Anthropology* 24: 625–651.

Stevens, N.
2002 Spatial and Temporal Patterning of Bedrock Mortar Sites in the Southern Sierra Nevada: A Regional Exploration. *Proceedings of the Society for California Archaeology* 16: 175–182.

Storer, I., R.L. Usinger, and D. Lukas
2004 *Sierra Nevada Natural History*. University of California Press, Berkeley.

Sutton, M.
1993 On the Subsistence Ecology of the "Late Inland Millingstone Horizon" in Southern California. *Journal of California and Great Basin Anthropology* 15(1): 134–140.

Turner, N., I. Davidson-Hunt, and M. O'Flaherty
2003 Living on the Edge: Ecological and Cultural Edges as Sources of Diversity for Social-Ecological Resilience. *Human Ecology* 31(3): 439–461.

Tushingham, S. and R.L. Bettinger
2013 Why Foragers Choose Acorns before Salmon: Storage, Mobility, and Risk in Aboriginal California. *Journal of Anthropological Archaeology* 32(4): 527–537.

United States Department of Agriculture
2015a Web Soil Survey Application. United States Department of Agriculture. Available at http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. Accessed 4-2015.

2015b Watershed Boundary Dataset. USDA Watershed Boundaries. United States Department of Agriculture: Geospatial Data Gateway. Available at https://gdg.sc.egov.usda.gov. Accessed 4-2015.

Whelan, C., A. Whitaker, J. Rosenthal, and E. Wohlgemuth
2013 Hunter-gatherer Storage, Settlement, and the Opportunity Costs of Women's Foraging. *American Antiquity* 78(4): 662–678.

Wilson, N., and A. Towne
1978 Nisenan. In *Handbook of North American Indians, Vol. 8*, edited by R.F. Heizer. Smithsonian Institution Press, California.

Winterhalder, B., and E.A. Smith
2000 Analyzing Adaptive Strategies: Human Behavioral Ecology at Twenty-Five. *Evolutionary Anthropology* 9: 51–72.

Wohlgemuth, E.
1996 Resource Intensification in Prehistoric Central California: Evidence from Archaeobotanical Data. *Journal of California and Great Basin Anthropology* 18(1): 81–103.

2004 The Course of Plant Food Intensification in Native Central California. Unpublished Dissertation, University of California, Davis.

Zeder, M.A.
2012 The Broad Spectrum Revolution at 40: Resource diversity, intensification, and an alternative to optimal foraging explanations. *Journal of Anthropological Archaeology* 31: 241–264.

Zivkovic, Z.
2004 Improved Adaptive Gaussian Mixture Model for Background Subtraction. IEEE Xplore. Available at http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1333992. Accessed 04-2016.

Appendix 1

Milling Locus Number	Outcrop Count	Mortar Count	Cumulative Mortar Depth
1	3	4	27.5
2	4	11	59.25
3	1	2	7.5
4	7	26	127
5	1	1	4
6	1	2	22
7	1	15	135.5
8	2	3	8
9	2	3	19.5
10	1	1	5.5
11	1	2	1
12	13	31	155.1
13	2	7	27
14	5	15	64.4
15	2	3	16.5
16	1	3	9.8
17	2	3	15.5
18	1	1	1
19	1	1	1.5
20	8	29	95.9
21	8	20	99.2
22	1	2	4
23	1	2	10
24	1	4	26.5
25	1	8	46.75
26	2	3	7
27	5	9	56.25
28	5	6	14.05
29	2	2	4.5
30	5	7	38
31	2	7	23
32	2	5	27.5
33	1	3	11
34	6	18	120.2
35	7	26	104.1
36	1	3	6.75
37	1	2	4.5
38	1	1	5
39	2	2	7
40	1	1	3
41	1	1	2.5

Milling Locus Number	Outcrop Count	Mortar Count	Cumulative Mortar Depth
42	2	5	36.5
43	1	2	15.25
44	1	6	45
45	1	5	45.5
46	2	6	71
47	1	4	28.25
48	4	11	42.5
49	1	3	24
50	1	8	63.5
51	2	11	81
52	1	4	21.5
53	1	3	10
54	1	2	11
55	6	14	39
56	1	3	22.5
57	1	17	37.5
58	2	3	12
59	1	4	13
60	1	2	5
61	3	4	19
62	2	10	40.5
63	3	12	49.5
64	2	3	12
65	1	2	18
66	2	11	101.4
67	1	2	11
68	2	3	29
69	13	65	425.8
70	33	115	477.5
71	4	9	72.5
72	9	20	84.75
73	9	31	129.9
74	2	4	26

Outcrop Context Number	Outcrop ID	Millling Locus Number	Mortar Count	Cumulative Mortar Depth
13-0001	1	66	10	98.9
13-0005	3	66	1	2.5
13-0007	4	65	2	18
13-0008	5	63	6	27.5
13-0014	7	62	2	7
13-0015	8	62	8	33.5
13-0027	10	63	3	10.5
13-0028	11	63	3	11.5
13-0030	12	46	2	8
13-0031	13	46	4	63
13-0032	14	51	10	79
13-0033	15	51	1	2
13-0103	16	68	2	15
13-0104	17	68	1	14
13-0109	18	56	3	22.5
13-0129	19	49	3	24
13-0201	20	67	2	11
13-0202	21	64	2	8
13-0203	22	64	1	4
13-0204	23	57	17	37.5
13-0208	24	58	2	6
13-0209	25	58	1	6
13-0210	26	61	1	4
13-0211	27	61	2	14
13-0212	28	61	1	1
13-0213	29	59	4	13
13-0215	30	60	2	5
13-0216	31	55	2	10
13-0217	32	55	3	11
13-0218	33	55	2	5
13-0219	34	55	2	7
13-0222	35	55	1	3
13-0224	36	55	4	3
14-1002	37	50	8	63.5
14-1006	38	53	3	10
14-1008	39	71	1	9.5
14-1009	40	71	6	49
14-1010	41	71	1	3.5
14-1011	42	71	1	10.5
14-1015	43	74	1	3.5

Outcrop Context Number	Outcrop ID	Millling Locus Number	Mortar Count	Cumulative Mortar Depth
14-1016	44	74	3	22.5
14-1020	45	54	2	11
14-1024	46	48	5	15.5
14-1026	47	48	3	11.5
14-1027	48	48	2	6.5
14-1029	49	48	1	9
14-1030	50	72	2	7
14-1031	51	72	1	5
14-1033	52	72	4	12.75
14-1036	53	72	2	9
14-1037	54	72	7	32.75
14-1038	55	72	1	2
14-1039	56	72	1	4.5
14-1041	57	47	4	28.25
14-1042	58	52	4	21.5
14-1049	59	43	2	15.25
14-1054	60	42	4	25
14-1055	61	44	6	45
14-1056	62	45	5	45.5
14-1065	63	7	15	135.5
14-1067	64	15	2	12.5
14-1068	65	17	2	12
14-1069	66	17	1	3.5
14-1071	67	15	1	4
14-2001	68	27	3	13.25
14-2002	69	27	1	6.5
14-2003	70	27	1	7
14-2004	71	27	3	28
14-2005	72	27	1	1.5
14-2010	73	22	2	4
14-2012	74	23	2	10
14-2015	75	28	2	2
14-2016	76	28	1	3.5
14-2017	77	28	1	0.75
14-2018	78	28	1	7.5
14-2019	79	28	1	0.3
14-2024	80	19	1	1.5
14-2028	81	24	4	26.5
14-2029	82	25	8	46.75
14-2030	83	36	3	6.75

Outcrop Context Number	Outcrop ID	Millling Locus Number	Mortar Count	Cumulative Mortar Depth
14-2042	84	70	6	8
14-2043	85	70	1	1.5
14-2044	86	70	2	8.5
14-2045	87	70	1	2.25
14-2046	88	70	1	3.5
14-2047	89	70	1	1
14-2049	91	70	7	11
14-2050	92	70	1	2.5
14-2051	93	70	4	4
14-2052	94	70	4	7.5
14-2053	95	70	9	107.5
14-2054	96	70	8	55.25
14-2055	97	70	7	14.25
14-2056	98	70	3	5.75
14-2058	99	70	6	16.25
14-2059	100	70	2	2
14-2060	101	70	1	1
14-2061	102	70	10	42
14-2063	103	70	4	5.5
14-2064	104	70	4	13
14-2065	105	70	6	63.5
14-2067	106	70	1	0.5
14-2068	107	70	1	3.5
14-2069	108	70	1	2.5
14-2070	109	70	4	7.5
14-2071	110	70	2	4.25
14-2072	111	70	4	44.75
14-2073	112	70	2	6
14-2075	113	70	6	17.75
14-2076	114	70	1	2
14-2077	115	70	2	3.75
14-2079	116	70	2	5.5
14-2081	118	70	1	3.75
14-2096	119	31	1	1.5
14-2098	120	31	6	21.5
14-2100	121	30	1	1.75
14-2101	122	30	1	4
14-2102	123	30	1	4.75
14-3010	124	10	1	5.5
14-3011	125	12	4	27

Outcrop Context Number	Outcrop ID	Millling Locus Number	Mortar Count	Cumulative Mortar Depth
14-3013	126	12	2	11.5
14-3015	127	12	1	3
14-3016	128	12	1	2
14-3017	129	12	4	12
14-3019	130	12	5	29.8
14-3021	131	12	2	4
14-3023	132	12	3	17
14-3024	133	12	2	3
14-3029	134	12	1	5.6
14-3030	135	12	4	33
14-3032	136	12	1	2
14-3037	138	14	4	24.3
14-3038	139	14	2	8
14-3039	140	14	2	9.1
14-3040	141	14	1	4
14-3041	142	14	6	19
14-3043	143	16	3	9.8
14-3049	144	13	4	16
14-3051	145	13	3	11
14-3055	146	11	2	1
14-3057	147	69	20	168.4
14-3058	148	69	3	37
14-3059	149	69	1	1
14-3060	150	69	19	144.5
14-3067	152	69	2	3
14-3069	153	69	1	1
14-3070	154	69	2	6
14-3071	155	69	1	2
14-3072	156	69	9	46
14-3073	157	69	3	8.7
14-3074	158	69	2	5.5
14-3076	159	69	1	2.2
14-3084	160	69	1	0.5
14-3093	161	20	10	45.6
14-3094	162	20	2	2
14-3095	163	20	6	28.3
14-3096	164	20	1	2
14-3097	165	20	1	5
14-3098	166	20	3	4.6
14-3099	167	20	1	3

Outcrop Context Number	Outcrop ID	Millling Locus Number	Mortar Count	Cumulative Mortar Depth
14-3100	168	20	5	5.4
14-3102	169	21	1	1
14-3103	170	21	2	9
14-3104	171	21	9	58.1
14-3105	172	21	2	13
14-3106	173	21	3	7.9
14-3107	174	21	1	3.2
14-3108	175	21	1	4
14-3109	176	21	1	3
14-3110	177	18	1	1
14-3111	178	35	7	35
14-3112	179	35	2	8.75
14-3113	180	35	8	33.1
14-3114	181	35	1	6
14-3115	182	35	5	15
14-3116	183	35	1	2
14-3117	184	35	2	4.25
14-3119	185	37	2	4.5
14-3120	186	33	3	11
14-3121	187	34	6	36
14-3122	188	34	1	3
14-3123	189	32	3	24.5
14-3124	190	32	2	3
14-3125	191	34	6	71
14-3126	192	34	2	4
14-3127	193	34	1	3.2
14-3128	194	34	2	3
15-0101	195	8	2	6
15-0102	196	8	1	2
15-0105	197	9	1	4.5
15-0106	198	9	2	15
15-0113	199	6	2	22
15-0118	200	5	1	4
15-0120	201	4	4	10.5
15-0121	202	4	13	79.5
15-0122	203	4	1	10
15-0123	204	4	2	3
15-0124	205	4	3	7
15-0125	206	4	1	7
15-0127	207	4	2	10

Outcrop Context Number	Outcrop ID	Millling Locus Number	Mortar Count	Cumulative Mortar Depth
15-0129	208	40	1	3
15-0130	209	38	1	5
15-0132	210	39	1	3
15-0134	211	39	1	4
15-0138	212	41	1	2.5
15-0139	213	73	1	5
15-0140	214	73	3	9
15-0143	215	73	9	33.5
15-0150	216	73	1	2
15-0154	217	73	1	2
15-0157	218	73	1	2
15-0158	219	73	6	50.5
15-0166	220	73	8	18.4
15-0167	221	73	1	7.5
15-0169	222	30	1	5.5
15-0170	223	30	3	22
15-0172	224	26	2	4
15-0173	225	26	1	3
15-0175	226	29	1	2.5
15-0176	227	29	1	2
15-0030	231	3	2	7.5
15-0031	232	2	7	38.5
15-0032	233	2	1	9
15-0033	234	2	2	7.25
15-0034	235	2	1	4.5
15-0036	236	1	1	3
15-0037	237	1	1	2
15-0038	238	1	2	22.5
14-1072	239	72	1	11.5
14-1073	240	72	1	7.75
14-1074	241	42	1	4
14-3014	242	12	1	5.2

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
13-0001.01	13-0001	1	66	4.5
13-0001.02	13-0001	1	66	8.9
13-0001.03	13-0001	1	66	4
13-0001.04	13-0001	1	66	12
13-0001.05	13-0001	1	66	10
13-0001.06	13-0001	1	66	13
13-0001.07	13-0001	1	66	12
13-0001.08	13-0001	1	66	11.5
13-0001.09	13-0001	1	66	12.5
13-0001.10	13-0001	1	66	10.5
13-0005.01	13-0005	3	66	2.5
13-0007.01	13-0007	4	65	8
13-0007.02	13-0007	4	65	10
13-0008.01	13-0008	5	63	8
13-0008.02	13-0008	5	63	7
13-0008.03	13-0008	5	63	4.5
13-0008.04	13-0008	5	63	2.5
13-0008.05	13-0008	5	63	2
13-0008.06	13-0008	5	63	3.5
13-0014.01	13-0014	7	62	5
13-0014.02	13-0014	7	62	2
13-0015.01	13-0015	8	62	4
13-0015.02	13-0015	8	62	2.5
13-0015.03	13-0015	8	62	1
13-0015.04	13-0015	8	62	6
13-0015.05	13-0015	8	62	5.5
13-0015.06	13-0015	8	62	2.5
13-0015.07	13-0015	8	62	7
13-0015.08	13-0015	8	62	5
13-0027.01	13-0027	10	63	2
13-0027.02	13-0027	10	63	5
13-0027.03	13-0027	10	63	3.5
13-0028.01	13-0028	11	63	4.5
13-0028.03	13-0028	11	63	3
13-0028.04	13-0028	11	63	4
13-0030.01	13-0030	12	46	6
13-0030.02	13-0030	12	46	2
13-0031.01	13-0031	13	46	12
13-0031.02	13-0031	13	46	14.5
13-0031.03	13-0031	13	46	20

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
13-0031.04	13-0031	13	46	16.5
13-0032.01	13-0032	14	51	10
13-0032.02	13-0032	14	51	16
13-0032.03	13-0032	14	51	8
13-0032.04	13-0032	14	51	6
13-0032.05	13-0032	14	51	1
13-0032.06	13-0032	14	51	6
13-0032.07	13-0032	14	51	3
13-0032.08	13-0032	14	51	10
13-0032.09	13-0032	14	51	10
13-0032.10	13-0032	14	51	9
13-0033.01	13-0033	15	51	2
13-0103.01	13-0103	16	68	4
13-0103.02	13-0103	16	68	11
13-0104.01	13-0104	17	68	14
13-0109.01	13-0109	18	56	3.5
13-0109.02	13-0109	18	56	10
13-0109.03	13-0109	18	56	9
13-0129.01	13-0129	19	49	14
13-0129.02	13-0129	19	49	4
13-0129.03	13-0129	19	49	6
13-0201.01	13-0201	20	67	6
13-0201.02	13-0201	20	67	5
13-0202.01	13-0202	21	64	4
13-0202.02	13-0202	21	64	4
13-0203.01	13-0203	22	64	4
13-0204.01	13-0204	23	57	2.5
13-0204.02	13-0204	23	57	2
13-0204.03	13-0204	23	57	2
13-0204.04	13-0204	23	57	1
13-0204.05	13-0204	23	57	4
13-0204.06	13-0204	23	57	0.5
13-0204.07	13-0204	23	57	0.5
13-0204.08	13-0204	23	57	0.5
13-0204.09	13-0204	23	57	0.5
13-0204.10	13-0204	23	57	1
13-0204.11	13-0204	23	57	1
13-0204.12	13-0204	23	57	0.5
13-0204.14	13-0204	23	57	6
13-0204.15	13-0204	23	57	3

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
13-0204.16	13-0204	23	57	6
13-0204.19	13-0204	23	57	6
13-0204.20	13-0204	23	57	0.5
13-0208.01	13-0208	24	58	5
13-0208.02	13-0208	24	58	1
13-0209.01	13-0209	25	58	6
13-0210.01	13-0210	26	61	4
13-0211.01	13-0211	27	61	7
13-0211.02	13-0211	27	61	7
13-0212.01	13-0212	28	61	1
13-0213.01	13-0213	29	59	4
13-0213.02	13-0213	29	59	4
13-0213.03	13-0213	29	59	3
13-0213.04	13-0213	29	59	2
13-0215.01	13-0215	30	60	2
13-0215.02	13-0215	30	60	3
13-0216.01	13-0216	31	55	8
13-0216.02	13-0216	31	55	2
13-0217.01	13-0217	32	55	4
13-0217.02	13-0217	32	55	3
13-0217.03	13-0217	32	55	4
13-0218.01	13-0218	33	55	3
13-0218.02	13-0218	33	55	2
13-0219.01	13-0219	34	55	3
13-0219.02	13-0219	34	55	4
13-0222.01	13-0222	35	55	3
13-0224.01	13-0224	36	55	1
13-0224.02	13-0224	36	55	0.5
13-0224.03	13-0224	36	55	0.5
13-0224.04	13-0224	36	55	1
14-1002.01	14-1002	37	50	9.5
14-1002.02	14-1002	37	50	12.25
14-1002.03	14-1002	37	50	3.75
14-1002.04	14-1002	37	50	11.5
14-1002.05	14-1002	37	50	11.75
14-1002.06	14-1002	37	50	1.75
14-1002.07	14-1002	37	50	7.5
14-1002.08	14-1002	37	50	5.5
14-1006.01	14-1006	38	53	2
14-1006.02	14-1006	38	53	3.5

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-1006.03	14-1006	38	53	4.5
14-1008.01	14-1008	39	71	9.5
14-1009.01	14-1009	40	71	7
14-1009.02	14-1009	40	71	14.5
14-1009.03	14-1009	40	71	6
14-1009.04	14-1009	40	71	9.5
14-1009.05	14-1009	40	71	11
14-1009.06	14-1009	40	71	1
14-1010.01	14-1010	41	71	3.5
14-1011.01	14-1011	42	71	10.5
14-1015.01	14-1015	43	74	3.5
14-1016.01	14-1016	44	74	9
14-1016.02	14-1016	44	74	6.5
14-1016.03	14-1016	44	74	7
14-1020.01	14-1020	45	54	3.5
14-1020.02	14-1020	45	54	7.5
14-1024.01	14-1024	46	48	3.5
14-1024.02	14-1024	46	48	3.5
14-1024.03	14-1024	46	48	5
14-1024.04	14-1024	46	48	1.5
14-1024.05	14-1024	46	48	2
14-1026.01	14-1026	47	48	4
14-1026.02	14-1026	47	48	5
14-1026.03	14-1026	47	48	2.5
14-1027.01	14-1027	48	48	4.5
14-1027.02	14-1027	48	48	2
14-1029.01	14-1029	49	48	9
14-1030.01	14-1030	50	72	3.5
14-1030.02	14-1030	50	72	3.5
14-1031.01	14-1031	51	72	5
14-1033.01	14-1033	52	72	3.5
14-1033.02	14-1033	52	72	3
14-1033.03	14-1033	52	72	3
14-1033.04	14-1033	52	72	3.25
14-1036.01	14-1036	53	72	3.5
14-1036.02	14-1036	53	72	5.5
14-1037.01	14-1037	54	72	2.25
14-1037.02	14-1037	54	72	5.25
14-1037.03	14-1037	54	72	3.75
14-1037.04	14-1037	54	72	8.5

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-1037.05	14-1037	54	72	2.25
14-1037.06	14-1037	54	72	8
14-1037.07	14-1037	54	72	2.75
14-1038.01	14-1038	55	72	2
14-1039.01	14-1039	56	72	4.5
14-1041.01	14-1041	57	47	5.25
14-1041.02	14-1041	57	47	9.75
14-1041.03	14-1041	57	47	8.75
14-1041.04	14-1041	57	47	4.5
14-1042.01	14-1042	58	52	4.5
14-1042.02	14-1042	58	52	7
14-1042.03	14-1042	58	52	3
14-1042.04	14-1042	58	52	7
14-1049.01	14-1049	59	43	9.75
14-1049.02	14-1049	59	43	5.5
14-1054.01	14-1054	60	42	5
14-1054.02	14-1054	60	42	7
14-1054.03	14-1054	60	42	8.5
14-1054.04	14-1054	60	42	4.5
14-1055.01	14-1055	61	44	17
14-1055.02	14-1055	61	44	8
14-1055.03	14-1055	61	44	4
14-1055.04	14-1055	61	44	4
14-1055.05	14-1055	61	44	2
14-1055.06	14-1055	61	44	10
14-1056.01	14-1056	62	45	14
14-1056.02	14-1056	62	45	9
14-1056.03	14-1056	62	45	7
14-1056.04	14-1056	62	45	6.5
14-1056.05	14-1056	62	45	9
14-1065.01	14-1065	63	7	9.5
14-1065.02	14-1065	63	7	9
14-1065.03	14-1065	63	7	10
14-1065.04	14-1065	63	7	11.5
14-1065.05	14-1065	63	7	10
14-1065.06	14-1065	63	7	8.5
14-1065.07	14-1065	63	7	10.5
14-1065.08	14-1065	63	7	11.5
14-1065.09	14-1065	63	7	8.5
14-1065.10	14-1065	63	7	12

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-1065.11	14-1065	63	7	9
14-1065.12	14-1065	63	7	8.5
14-1065.13	14-1065	63	7	8
14-1065.14	14-1065	63	7	5.5
14-1065.15	14-1065	63	7	3.5
14-1067.01	14-1067	64	15	7
14-1067.02	14-1067	64	15	5.5
14-1068.01	14-1068	65	17	9
14-1068.02	14-1068	65	17	3
14-1069.01	14-1069	66	17	3.5
14-1071.01	14-1071	67	15	4
14-1072.01	14-1072	239	42	11.5
14-1073.01	14-1073	240	72	7.75
14-1074.01	14-1074	241	72	4
14-2001.02	14-2001	68	27	4.25
14-2001.04	14-2001	68	27	6
14-2001.05	14-2001	68	27	3
14-2002.01	14-2002	69	27	6.5
14-2003.01	14-2003	70	27	7
14-2004.02	14-2004	71	27	8.5
14-2004.03	14-2004	71	27	9.5
14-2004.04	14-2004	71	27	10
14-2005.01	14-2005	72	27	1.5
14-2010.01	14-2010	73	22	2.5
14-2010.02	14-2010	73	22	1.5
14-2012.01	14-2012	74	23	4.5
14-2012.02	14-2012	74	23	5.5
14-2015.01	14-2015	75	28	1.5
14-2015.02	14-2015	75	28	0.5
14-2016.01	14-2016	76	28	3.5
14-2017.01	14-2017	77	28	0.75
14-2018.01	14-2018	78	28	7.5
14-2019.01	14-2019	79	28	0.3
14-2024.01	14-2024	80	19	1.5
14-2028.01	14-2028	81	24	10
14-2028.02	14-2028	81	24	8
14-2028.03	14-2028	81	24	8
14-2028.04	14-2028	81	24	0.5
14-2029.01	14-2029	82	25	1.5
14-2029.02	14-2029	82	25	5

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-2029.03	14-2029	82	25	10.25
14-2029.08	14-2029	82	25	12.25
14-2029.09	14-2029	82	25	6.75
14-2029.10	14-2029	82	25	5.25
14-2029.11	14-2029	82	25	3
14-2029.12	14-2029	82	25	2.75
14-2030.01	14-2030	83	36	2.75
14-2030.02	14-2030	83	36	1.25
14-2030.03	14-2030	83	36	2.75
14-2042.01	14-2042	84	70	1
14-2042.02	14-2042	84	70	1.25
14-2042.03	14-2042	84	70	2
14-2042.04	14-2042	84	70	1.5
14-2042.05	14-2042	84	70	1.5
14-2042.06	14-2042	84	70	0.75
14-2043.01	14-2043	85	70	1.5
14-2044.01	14-2044	86	70	6.5
14-2044.02	14-2044	86	70	2
14-2045.01	14-2045	87	70	2.25
14-2046.01	14-2046	88	70	3.5
14-2047.01	14-2047	89	70	1
14-2049.01	14-2049	91	70	3.75
14-2049.02	14-2049	91	70	0.75
14-2049.03	14-2049	91	70	1.25
14-2049.04	14-2049	91	70	1
14-2049.05	14-2049	91	70	2
14-2049.06	14-2049	91	70	0.75
14-2049.07	14-2049	91	70	1.5
14-2050.01	14-2050	92	70	2.5
14-2051.01	14-2051	93	70	0.75
14-2051.02	14-2051	93	70	0.5
14-2051.03	14-2051	93	70	1
14-2051.04	14-2051	93	70	1.75
14-2052.01	14-2052	94	70	2.5
14-2052.02	14-2052	94	70	1.5
14-2052.03	14-2052	94	70	1.75
14-2052.04	14-2052	94	70	1.75
14-2053.01	14-2053	95	70	13
14-2053.02	14-2053	95	70	15
14-2053.03	14-2053	95	70	15

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-2053.04	14-2053	95	70	3.5
14-2053.05	14-2053	95	70	8
14-2053.06	14-2053	95	70	14
14-2053.07	14-2053	95	70	9
14-2053.08	14-2053	95	70	17.5
14-2053.09	14-2053	95	70	12.5
14-2054.01	14-2054	96	70	1.75
14-2054.02	14-2054	96	70	8.5
14-2054.03	14-2054	96	70	2
14-2054.04	14-2054	96	70	3
14-2054.05	14-2054	96	70	11.25
14-2054.06	14-2054	96	70	10
14-2054.07	14-2054	96	70	10
14-2054.08	14-2054	96	70	8.75
14-2055.01	14-2055	97	70	1.5
14-2055.02	14-2055	97	70	3
14-2055.03	14-2055	97	70	2.75
14-2055.04	14-2055	97	70	1.5
14-2055.05	14-2055	97	70	1.5
14-2055.06	14-2055	97	70	2
14-2055.07	14-2055	97	70	2
14-2056.01	14-2056	98	70	1.5
14-2056.02	14-2056	98	70	2.75
14-2056.03	14-2056	98	70	1.5
14-2058.01	14-2058	99	70	3
14-2058.02	14-2058	99	70	2.5
14-2058.03	14-2058	99	70	2
14-2058.05	14-2058	99	70	3.25
14-2058.06	14-2058	99	70	3.5
14-2058.07	14-2058	99	70	2
14-2059.01	14-2059	100	70	0.5
14-2059.02	14-2059	100	70	1.5
14-2060.01	14-2060	101	70	1
14-2061.01	14-2061	102	70	2
14-2061.02	14-2061	102	70	3.5
14-2061.03	14-2061	102	70	2.5
14-2061.04	14-2061	102	70	11
14-2061.05	14-2061	102	70	2
14-2061.06	14-2061	102	70	1.5
14-2061.07	14-2061	102	70	3

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-2061.08	14-2061	102	70	8.5
14-2061.09	14-2061	102	70	3.5
14-2061.10	14-2061	102	70	4.5
14-2063.01	14-2063	103	70	0.5
14-2063.02	14-2063	103	70	0.5
14-2063.03	14-2063	103	70	3
14-2063.04	14-2063	103	70	1.5
14-2064.01	14-2064	104	70	5.5
14-2064.03	14-2064	104	70	3
14-2064.04	14-2064	104	70	1
14-2064.05	14-2064	104	70	3.5
14-2065.01	14-2065	105	70	8.5
14-2065.02	14-2065	105	70	15
14-2065.03	14-2065	105	70	10
14-2065.04	14-2065	105	70	12
14-2065.06	14-2065	105	70	14.5
14-2065.07	14-2065	105	70	3.5
14-2067.01	14-2067	106	70	0.5
14-2068.01	14-2068	107	70	3.5
14-2069.01	14-2069	108	70	2.5
14-2070.01	14-2070	109	70	1.5
14-2070.02	14-2070	109	70	1.5
14-2070.03	14-2070	109	70	1.5
14-2070.04	14-2070	109	70	3
14-2071.01	14-2071	110	70	2.5
14-2071.02	14-2071	110	70	1.75
14-2072.01	14-2072	111	70	11.5
14-2072.02	14-2072	111	70	9.5
14-2072.03	14-2072	111	70	9.5
14-2072.04	14-2072	111	70	14.25
14-2073.01	14-2073	112	70	3
14-2073.02	14-2073	112	70	3
14-2075.01	14-2075	113	70	3
14-2075.02	14-2075	113	70	1.5
14-2075.03	14-2075	113	70	3
14-2075.04	14-2075	113	70	4
14-2075.05	14-2075	113	70	2.5
14-2075.06	14-2075	113	70	3.75
14-2076.01	14-2076	114	70	2
14-2077.01	14-2077	115	70	2.75

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-2077.02	14-2077	115	70	1
14-2079.01	14-2079	116	70	1.5
14-2079.02	14-2079	116	70	4
14-2081.01	14-2081	118	70	3.75
14-2096.01	14-2096	119	31	1.5
14-2098.01	14-2098	120	31	3.5
14-2098.02	14-2098	120	31	3
14-2098.03	14-2098	120	31	5
14-2098.04	14-2098	120	31	3.5
14-2098.05	14-2098	120	31	4
14-2098.06	14-2098	120	31	2.5
14-2100.01	14-2100	121	30	1.75
14-2101.01	14-2101	122	30	4
14-2102.01	14-2102	123	30	4.75
14-3010.01	14-3010	124	10	5.5
14-3011.01	14-3011	125	12	2
14-3011.02	14-3011	125	12	11
14-3011.03	14-3011	125	12	11
14-3011.04	14-3011	125	12	3
14-3013.01	14-3013	126	12	6.5
14-3013.02	14-3013	126	12	5
14-3014.01	14-3014	242	12	5.2
14-3015.01	14-3015	127	12	3
14-3016.01	14-3016	128	12	2
14-3017.01	14-3017	129	12	2
14-3017.02	14-3017	129	12	2
14-3017.03	14-3017	129	12	3
14-3017.04	14-3017	129	12	5
14-3019.01	14-3019	130	12	8
14-3019.02	14-3019	130	12	5.3
14-3019.03	14-3019	130	12	12
14-3019.04	14-3019	130	12	2.3
14-3019.05	14-3019	130	12	2.2
14-3021.01	14-3021	131	12	1
14-3021.02	14-3021	131	12	3
14-3023.01	14-3023	132	12	9
14-3023.02	14-3023	132	12	4
14-3023.03	14-3023	132	12	4
14-3024.01	14-3024	133	12	2
14-3024.02	14-3024	133	12	1

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-3029.01	14-3029	134	12	5.6
14-3030.01	14-3030	135	12	4.5
14-3030.02	14-3030	135	12	16.7
14-3030.03	14-3030	135	12	9.5
14-3030.04	14-3030	135	12	2.3
14-3032.01	14-3032	136	12	2
14-3037.01	14-3037	138	14	6.5
14-3037.02	14-3037	138	14	2.6
14-3037.03	14-3037	138	14	6
14-3037.04	14-3037	138	14	9.2
14-3038.01	14-3038	139	14	3
14-3038.02	14-3038	139	14	5
14-3039.01	14-3039	140	14	2.3
14-3039.02	14-3039	140	14	6.8
14-3040.01	14-3040	141	14	4
14-3041.01	14-3041	142	14	4
14-3041.02	14-3041	142	14	1.5
14-3041.03	14-3041	142	14	4.5
14-3041.04	14-3041	142	14	3.5
14-3041.05	14-3041	142	14	3.5
14-3041.06	14-3041	142	14	2
14-3043.01	14-3043	143	16	2
14-3043.02	14-3043	143	16	4.8
14-3043.03	14-3043	143	16	3
14-3049.01	14-3049	144	13	3
14-3049.02	14-3049	144	13	6
14-3049.03	14-3049	144	13	1
14-3049.04	14-3049	144	13	6
14-3051.01	14-3051	145	13	5
14-3051.02	14-3051	145	13	3
14-3051.03	14-3051	145	13	3
14-3055.01	14-3055	146	11	0.5
14-3055.02	14-3055	146	11	0.5
14-3057.01	14-3057	147	69	3
14-3057.02	14-3057	147	69	3
14-3057.03	14-3057	147	69	2
14-3057.04	14-3057	147	69	2.8
14-3057.05	14-3057	147	69	2.5
14-3057.06	14-3057	147	69	0.5
14-3057.07	14-3057	147	69	3

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-3057.08	14-3057	147	69	4
14-3057.09	14-3057	147	69	3.6
14-3057.10	14-3057	147	69	5
14-3057.11	14-3057	147	69	17
14-3057.12	14-3057	147	69	14
14-3057.13	14-3057	147	69	23
14-3057.14	14-3057	147	69	15
14-3057.15	14-3057	147	69	1
14-3057.16	14-3057	147	69	1
14-3057.17	14-3057	147	69	5.5
14-3057.18	14-3057	147	69	24
14-3057.19	14-3057	147	69	19
14-3057.20	14-3057	147	69	19.5
14-3058.01	14-3058	148	69	16
14-3058.02	14-3058	148	69	9
14-3058.03	14-3058	148	69	12
14-3059.01	14-3059	149	69	1
14-3060.01	14-3060	150	69	12
14-3060.02	14-3060	150	69	11
14-3060.03	14-3060	150	69	5
14-3060.04	14-3060	150	69	11
14-3060.05	14-3060	150	69	10
14-3060.06	14-3060	150	69	17
14-3060.07	14-3060	150	69	10
14-3060.08	14-3060	150	69	5
14-3060.09	14-3060	150	69	1.5
14-3060.10	14-3060	150	69	11
14-3060.11	14-3060	150	69	10
14-3060.12	14-3060	150	69	5
14-3060.13	14-3060	150	69	11
14-3060.14	14-3060	150	69	12
14-3060.15	14-3060	150	69	7
14-3060.16	14-3060	150	69	1
14-3060.17	14-3060	150	69	2
14-3060.18	14-3060	150	69	1
14-3060.19	14-3060	150	69	2
14-3067.01	14-3067	152	69	2
14-3067.02	14-3067	152	69	1
14-3069.01	14-3069	153	69	1
14-3070.01	14-3070	154	69	4

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-3070.02	14-3070	154	69	2
14-3071.01	14-3071	155	69	2
14-3072.01	14-3072	156	69	4
14-3072.02	14-3072	156	69	4
14-3072.03	14-3072	156	69	6
14-3072.04	14-3072	156	69	10
14-3072.05	14-3072	156	69	5
14-3072.06	14-3072	156	69	7
14-3072.07	14-3072	156	69	1
14-3072.08	14-3072	156	69	6
14-3072.09	14-3072	156	69	3
14-3073.01	14-3073	157	69	3.2
14-3073.02	14-3073	157	69	3.5
14-3073.03	14-3073	157	69	2
14-3074.01	14-3074	158	69	3.5
14-3074.02	14-3074	158	69	2
14-3076.01	14-3076	159	69	2.2
14-3084.01	14-3084	160	69	0.5
14-3093.01	14-3093	161	20	2.3
14-3093.02	14-3093	161	20	2.5
14-3093.03	14-3093	161	20	6.6
14-3093.04	14-3093	161	20	2
14-3093.05	14-3093	161	20	5.4
14-3093.06	14-3093	161	20	7
14-3093.07	14-3093	161	20	9.5
14-3093.08	14-3093	161	20	1.8
14-3093.09	14-3093	161	20	6.7
14-3093.10	14-3093	161	20	1.8
14-3094.01	14-3094	162	20	1
14-3094.02	14-3094	162	20	1
14-3095.01	14-3095	163	20	5
14-3095.02	14-3095	163	20	4
14-3095.03	14-3095	163	20	1.3
14-3095.04	14-3095	163	20	8
14-3095.05	14-3095	163	20	3
14-3095.06	14-3095	163	20	7
14-3096.01	14-3096	164	20	2
14-3097.01	14-3097	165	20	5
14-3098.01	14-3098	166	20	1.3
14-3098.02	14-3098	166	20	2

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-3098.03	14-3098	166	20	1.3
14-3099.01	14-3099	167	20	3
14-3100.01	14-3100	168	20	0.5
14-3100.02	14-3100	168	20	0.3
14-3100.03	14-3100	168	20	0.3
14-3100.04	14-3100	168	20	0.3
14-3100.05	14-3100	168	20	4
14-3102.01	14-3102	169	21	1
14-3103.01	14-3103	170	21	5
14-3103.02	14-3103	170	21	4
14-3104.01	14-3104	171	21	5.8
14-3104.02	14-3104	171	21	6.2
14-3104.03	14-3104	171	21	7.6
14-3104.04	14-3104	171	21	6.8
14-3104.05	14-3104	171	21	6.7
14-3104.06	14-3104	171	21	5.4
14-3104.07	14-3104	171	21	6.6
14-3104.08	14-3104	171	21	6
14-3104.11	14-3104	171	21	7
14-3105.01	14-3105	172	21	7
14-3105.02	14-3105	172	21	6
14-3106.01	14-3106	173	21	3.4
14-3106.02	14-3106	173	21	2.5
14-3106.03	14-3106	173	21	2
14-3107.01	14-3107	174	21	3.2
14-3108.01	14-3108	175	21	4
14-3109.01	14-3109	176	21	3
14-3110.01	14-3110	177	18	1
14-3111.01	14-3111	178	35	3
14-3111.02	14-3111	178	35	2
14-3111.03	14-3111	178	35	3
14-3111.04	14-3111	178	35	5
14-3111.05	14-3111	178	35	6
14-3111.06	14-3111	178	35	12
14-3111.07	14-3111	178	35	4
14-3112.01	14-3112	179	35	1.25
14-3112.02	14-3112	179	35	7.5
14-3113.01	14-3113	180	35	1.1
14-3113.02	14-3113	180	35	6.3
14-3113.03	14-3113	180	35	2.9

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-3113.04	14-3113	180	35	3.7
14-3113.05	14-3113	180	35	9
14-3113.06	14-3113	180	35	1
14-3113.07	14-3113	180	35	7.5
14-3113.08	14-3113	180	35	1.6
14-3114.01	14-3114	181	35	6
14-3115.01	14-3115	182	35	5
14-3115.02	14-3115	182	35	6
14-3115.03	14-3115	182	35	3
14-3115.04	14-3115	182	35	0.5
14-3115.05	14-3115	182	35	0.5
14-3116.01	14-3116	183	35	2
14-3117.01	14-3117	184	35	4
14-3117.02	14-3117	184	35	0.25
14-3119.01	14-3119	185	37	2
14-3119.02	14-3119	185	37	2.5
14-3120.01	14-3120	186	33	5
14-3120.02	14-3120	186	33	4.4
14-3120.03	14-3120	186	33	1.6
14-3121.01	14-3121	187	34	8
14-3121.02	14-3121	187	34	3
14-3121.03	14-3121	187	34	12
14-3121.04	14-3121	187	34	11
14-3121.05	14-3121	187	34	1
14-3121.06	14-3121	187	34	1
14-3122.01	14-3122	188	34	3
14-3123.01	14-3123	189	32	8
14-3123.02	14-3123	189	32	6.5
14-3123.03	14-3123	189	32	10
14-3124.01	14-3124	190	32	1.5
14-3124.02	14-3124	190	32	1.5
14-3125.01	14-3125	191	34	2
14-3125.02	14-3125	191	34	12
14-3125.03	14-3125	191	34	15
14-3125.04	14-3125	191	34	10
14-3125.05	14-3125	191	34	12
14-3125.06	14-3125	191	34	20
14-3126.01	14-3126	192	34	1
14-3126.02	14-3126	192	34	3
14-3127.01	14-3127	193	34	3.2

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
14-3128.01	14-3128	194	34	2
14-3128.02	14-3128	194	34	1
15-0030.01	15-0030	231	3	3
15-0030.02	15-0030	231	3	4.5
15-0031.01	15-0031	232	2	7.5
15-0031.02	15-0031	232	2	2.75
15-0031.03	15-0031	232	2	7.5
15-0031.04	15-0031	232	2	1
15-0031.05	15-0031	232	2	6.5
15-0031.06	15-0031	232	2	9.5
15-0031.07	15-0031	232	2	3.75
15-0032.01	15-0032	233	2	9
15-0033.01	15-0033	234	2	3.75
15-0033.02	15-0033	234	2	3.5
15-0034.01	15-0034	235	2	4.5
15-0036.01	15-0036	236	1	3
15-0037.01	15-0037	237	1	2
15-0038.01	15-0038	238	1	14
15-0038.02	15-0038	238	1	8.5
15-0101.01	15-0101	195	8	4.5
15-0101.02	15-0101	195	8	1.5
15-0102.01	15-0102	196	8	2
15-0105.01	15-0105	197	9	4.5
15-0106.01	15-0106	198	9	8
15-0106.02	15-0106	198	9	7
15-0113.01	15-0113	199	6	9
15-0113.02	15-0113	199	6	13
15-0118.01	15-0118	200	5	4
15-0120.01	15-0120	201	4	4
15-0120.02	15-0120	201	4	2
15-0120.03	15-0120	201	4	1.5
15-0120.04	15-0120	201	4	3
15-0121.01	15-0121	202	4	6
15-0121.02	15-0121	202	4	3
15-0121.03	15-0121	202	4	9
15-0121.04	15-0121	202	4	6
15-0121.05	15-0121	202	4	1
15-0121.06	15-0121	202	4	6
15-0121.07	15-0121	202	4	4
15-0121.08	15-0121	202	4	11

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
15-0121.09	15-0121	202	4	14
15-0121.10	15-0121	202	4	3
15-0121.11	15-0121	202	4	15
15-0121.13	15-0121	202	4	1
15-0121.14	15-0121	202	4	0.5
15-0122.01	15-0122	203	4	10
15-0123.01	15-0123	204	4	2
15-0123.02	15-0123	204	4	1
15-0124.01	15-0124	205	4	3
15-0124.02	15-0124	205	4	2
15-0124.03	15-0124	205	4	2
15-0125.01	15-0125	206	4	7
15-0127.01	15-0127	207	4	6
15-0127.02	15-0127	207	4	4
15-0129.01	15-0129	208	40	3
15-0130.01	15-0130	209	38	5
15-0132.01	15-0132	210	39	3
15-0134.01	15-0134	211	39	4
15-0138.01	15-0138	212	41	2.5
15-0139.01	15-0139	213	73	5
15-0140.01	15-0140	214	73	3
15-0140.02	15-0140	214	73	4.5
15-0140.03	15-0140	214	73	1.5
15-0143.01	15-0143	215	73	5
15-0143.02	15-0143	215	73	5
15-0143.03	15-0143	215	73	4
15-0143.04	15-0143	215	73	4.5
15-0143.05	15-0143	215	73	1
15-0143.06	15-0143	215	73	2
15-0143.07	15-0143	215	73	4
15-0143.08	15-0143	215	73	5
15-0143.09	15-0143	215	73	3
15-0150.01	15-0150	216	73	2
15-0154.01	15-0154	217	73	2
15-0157.01	15-0157	218	73	2
15-0158.01	15-0158	219	73	8
15-0158.02	15-0158	219	73	5
15-0158.03	15-0158	219	73	16
15-0158.04	15-0158	219	73	9
15-0158.06	15-0158	219	73	10

Mortar Context Number	Outcrop Context Number	Outcrop ID	Milling Locus Number	Depth (cm)
15-0158.08	15-0158	219	73	2.5
15-0166.01	15-0166	220	73	7.2
15-0166.02	15-0166	220	73	1.7
15-0166.03	15-0166	220	73	2
15-0166.04	15-0166	220	73	0.6
15-0166.05	15-0166	220	73	1.3
15-0166.06	15-0166	220	73	1.2
15-0166.07	15-0166	220	73	3.2
15-0166.08	15-0166	220	73	1.2
15-0167.01	15-0167	221	73	7.5
15-0169.01	15-0169	222	30	5.5
15-0170.01	15-0170	223	30	10
15-0170.02	15-0170	223	30	4
15-0170.03	15-0170	223	30	8
15-0172.01	15-0172	224	26	2
15-0172.02	15-0172	224	26	2
15-0173.01	15-0173	225	26	3
15-0175.01	15-0175	226	29	2.5
15-0176.01	15-0176	227	29	2

Appendix 2

		Outcrop Count	Cumulative Mortar Depth	Mortar Count
Sample Size:	74			
Mean		3.14	49.85 cm	9.45
Median		2	24.5 cm	4
Mode		1	5 cm	3
Std. Deviation		4.45	80.7 cm	15.99
Range		32	508 cm	114
Minimum		1	1 cm	1
Maximum		33	509 cm	115
Sum		232	3689 cm	699
Percentile	25			
	50			
	75			

Outcrop Count	Frequency	Percent	Cumulative Percent
1	34	45.9	45.9
2	19	25.7	71.6
3	3	4.1	75.7
4	3	4.1	79.7
5	4	5.4	85.1
6	2	2.7	87.8
7	2	2.7	90.5
8	2	2.7	93.2
9	2	2.7	95.9
13	2	2.7	98.6
33	1	1.4	100
Total	74	100	

Cumulative Mortar Depth (cm)	Frequency	Percent	Cumulative Percent
1	1	1.4	1.4
2	2	2.7	4.1
3	2	2.7	6.8
4	1	1.4	8.1
5	5	6.8	14.9
6	1	1.4	16.2
7	2	2.7	18.9
8	2	2.7	21.6
9	1	1.4	23
10	1	1.4	24.3
11	3	4.1	28.4
12	4	5.4	33.8
13	1	1.4	35.1
16	2	2.7	37.8
17	2	2.7	40.5
18	1	1.4	41.9
19	1	1.4	43.2
20	1	1.4	44.6
22	2	2.7	47.3
23	1	1.4	48.6
24	1	1.4	50
25	1	1.4	51.4
27	3	4.1	55.4
28	1	1.4	56.8
29	2	2.7	59.5
30	1	1.4	60.8
38	1	1.4	62.2
39	1	1.4	63.5
40	1	1.4	64.9
41	1	1.4	66.2
42	1	1.4	67.6
45	2	2.7	70.3
46	1	1.4	71.6
50	1	1.4	73
52	1	1.4	74.3
59	1	1.4	75.7
63	1	1.4	77
67	1	1.4	78.4
69	1	1.4	79.7

Cumulative Mortar Depth (cm)	Frequency	Percent of Total	Cumulative Percent
71	1	1.4	81.1
74	1	1.4	82.4
81	1	1.4	83.8
92	1	1.4	85.1
104	3	4.1	89.2
110	1	1.4	90.5
121	1	1.4	91.9
128	1	1.4	93.2
137	1	1.4	94.6
140	1	1.4	95.9
161	1	1.4	97.3
432	1	1.4	98.6
509	1	1.4	100
Total	74	100	

Mortar Count	Frequency	Percent	Cumulative Percent
1	7	9.5	9.5
2	13	17.6	27
3	14	18.9	45.9
4	7	9.5	55.4
5	3	4.1	59.5
6	3	4.1	63.5
7	3	4.1	67.6
8	2	2.7	70.3
9	2	2.7	73
10	1	1.4	74.3
11	4	5.4	79.7
12	1	1.4	81.1
14	1	1.4	82.4
15	2	2.7	85.1
17	1	1.4	86.5
18	1	1.4	87.8
20	2	2.7	90.5
26	2	2.7	93.2
29	1	1.4	94.6
31	2	2.7	97.3
65	1	1.4	98.6
115	1	1.4	100
Total	74	100	

		Cumulative Mortar Depth	Mortar Count
Sample Size:	232		
Mean		15.9009 cm	3.01
Median		8 cm	2
Mode		4 cm	1
Std. Deviation		23.57862 cm	3.037
Range		170 cm	19
Minimum		1 cm	1
Maximum		171 cm	20
Sum		3689 cm	699
Percentiles	25	4 cm	1
	50	8 cm	2
	75	16 cm	4

Cumulative Mortar Depth	Frequency	Percent	Cumulative Percent
1	11	4.7	4.7
2	21	9.1	13.8
3	22	9.5	23.3
4	24	10.3	33.6
5	15	6.5	40.1
6	12	5.2	45.3
7	10	4.3	49.6
8	11	4.7	54.3
9	7	3	57.3
10	11	4.7	62.1
11	8	3.4	65.5
12	8	3.4	69
13	4	1.7	70.7
14	5	2.2	72.8
15	2	0.9	73.7
16	4	1.7	75.4
17	2	0.9	76.3
18	2	0.9	77.2
19	1	0.4	77.6
21	1	0.4	78
22	3	1.3	79.3
23	5	2.2	81.5
24	1	0.4	81.9

Cumulative Mortar Depth	Frequency	Percent	Cumulative Percent
25	1	0.4	82.3
26	2	0.9	83.2
27	2	0.9	84.1
29	3	1.3	85.3
30	1	0.4	85.8
32	1	0.4	86.2
34	1	0.4	86.6
35	3	1.3	87.9
36	3	1.3	89.2
37	1	0.4	89.7
41	2	0.9	90.5
45	2	0.9	91.4
46	3	1.3	92.7
49	2	0.9	93.5
50	1	0.4	94
51	1	0.4	94.4
57	1	0.4	94.8
61	1	0.4	95.3
63	1	0.4	95.7
64	1	0.4	96.1
67	1	0.4	96.6
71	1	0.4	97
79	1	0.4	97.4
80	1	0.4	97.8
101	1	0.4	98.3
109	1	0.4	98.7
140	1	0.4	99.1
145	1	0.4	99.6
171	1	0.4	100
Total	232	100	

Mortar Count	Frequency	Percent	Cumulative Percent
1	91	39.2	39.2
2	55	23.7	62.9
3	24	10.3	73.3
4	20	8.6	81.9
5	5	2.2	84.1
6	13	5.6	89.7
7	5	2.2	91.8
8	6	2.6	94.4
9	4	1.7	96.1
10	4	1.7	97.8
13	1	0.4	98.3
15	1	0.4	98.7
17	1	0.4	99.1
19	1	0.4	99.6
20	1	0.4	100
Total	232	100	

Sample Size		699
Mean (cm)		5.2775
Median (cm)		4
Mode (cm)		2
Std. Deviation (cm)		3.95066
Range (cm)		23
Minimum (cm)		1
Maximum (cm)		24
Percentiles	25	2 cm
	50	4 cm
	75	7 cm

Depth	Frequency	Percent	Cumulative Percent
1	76	10.9	10.9
2	121	17.3	28.2
3	102	14.6	42.8
4	93	13.3	56.1
5	55	7.9	63.9
6	46	6.6	70.5
7	37	5.3	75.8
8	28	4	79.8
9	30	4.3	84.1
10	36	5.2	89.3
11	15	2.1	91.4
12	21	3	94.4
13	7	1	95.4
14	11	1.6	97
15	6	0.9	97.9
16	3	0.4	98.3
17	5	0.7	99
18	1	0.1	99.1
19	1	0.1	99.3
20	3	0.4	99.7
23	1	0.1	99.9
24	1	0.1	100
Total	699	100	

Appendix 3

Scenario 1

Period	0.1-1 cm Frequency	1.1-2 cm Frequency	2.1-3 cm Frequency	3.1-4 cm Frequency	4.1-5 cm Frequency	>5 Frequency
P_1	10	0	0	0	0	0
P_2	0	10	0	0	0	0
P_3	0	0	10	0	0	0
P_4	0	0	0	10	0	0
P_5	0	0	0	0	10	0
P_6	10	0	0	0	0	10
P_7	0	10	0	0	0	10
P_8	0	0	10	0	0	10
P_9	0	0	0	10	0	10
P_{10}	0	0	0	0	10	10
P_{11}	10	0	0	0	0	20
P_{12}	0	10	0	0	0	20
P_{13}	0	0	10	0	0	20
P_{14}	0	0	0	10	0	20
P_{15}	0	0	0	0	10	20
P_{16}	10	0	0	0	0	30
P_{17}	0	10	0	0	0	30
P_{18}	0	0	10	0	0	30
P_{19}	0	0	0	10	0	30
P_{20}	0	0	0	0	10	30
P_{21}	10	0	0	0	0	40

Scenario 2

Period	0.1-1 cm Frequency	1.1-2 cm Frequency	2.1-3 cm Frequency	3.1-4 cm Frequency	4.1-5 cm Frequency	>5 Frequency
P_1	1	0	0	0	0	0
P_2	1	1	0	0	0	0
P_3	1	1	1	0	0	0
P_4	1	1	1	1	0	0
P_5	1	1	1	1	1	0
P_6	2	1	1	1	1	1
P_7	2	2	1	1	1	2
P_8	2	2	2	1	1	3
P_9	2	2	2	2	1	4
P_{10}	2	2	2	2	2	5
P_{11}	3	2	2	2	2	7
P_{12}	3	3	2	2	2	9
P_{13}	3	3	3	2	2	11
P_{14}	3	3	3	3	2	13
P_{15}	3	3	3	3	3	15
P_{16}	4	3	3	3	3	18
P_{17}	4	4	3	3	3	21
P_{18}	4	4	4	3	3	24
P_{19}	4	4	4	4	3	27
P_{20}	4	4	4	4	4	30
P_{21}	5	4	4	4	4	34

Scenario 3

Period	0.1-1 cm Frequency	1.1-2 cm Frequency	2.1-3 cm Frequency	3.1-4 cm Frequency	4.1-5 cm Frequency	>5 Frequency
P_1	1	0	0	0	0	0
P_2	2	0	0	0	0	0
P_3	3	0	0	0	0	0
P_4	4	0	0	0	0	0
P_5	5	0	0	0	0	0
P_6	5	1	0	0	0	0
P_7	5	2	0	0	0	0
P_8	5	3	0	0	0	0
P_9	5	4	0	0	0	0
P_{10}	5	5	0	0	0	0
P_{11}	5	5	1	0	0	0
P_{12}	5	5	2	0	0	0
P_{13}	5	5	3	0	0	0
P_{14}	5	5	4	0	0	0
P_{15}	5	5	5	0	0	0
P_{16}	5	5	5	1	0	0
P_{17}	5	5	5	2	0	0
P_{18}	5	5	5	3	0	0
P_{19}	5	5	5	4	0	0
P_{20}	5	5	5	5	0	0
P_{21}	5	5	5	5	1	0
P_{22}	5	5	5	5	2	0
P_{23}	5	5	5	5	3	0
P_{24}	5	5	5	5	4	0
P_{25}	5	5	5	5	5	0
P_{26}	6	5	5	5	5	1
P_{27}	7	5	5	5	5	2
P_{28}	8	5	5	5	5	3
P_{29}	9	5	5	5	5	4
P_{30}	10	5	5	5	5	5
P_{31}	10	6	5	5	5	6

Scenario 3

Period	0.1-1 cm Frequency	1.1-2 cm Frequency	2.1-3 cm Frequency	3.1-4 cm Frequency	4.1-5 cm Frequency	>5 Frequency
P_{32}	10	7	5	5	5	7
P_{33}	10	8	5	5	5	8
P_{34}	10	9	5	5	5	9
P_{35}	10	10	5	5	5	10
P_{36}	10	10	6	5	5	11
P_{37}	10	10	7	5	5	12
P_{38}	10	10	8	5	5	13
P_{39}	10	10	9	5	5	14
P_{40}	10	10	10	5	5	15
P_{41}	10	10	10	6	5	16
P_{42}	10	10	10	7	5	17
P_{43}	10	10	10	8	5	18
P_{44}	10	10	10	9	5	19
P_{45}	10	10	10	10	5	20
P_{46}	10	10	10	10	6	21
P_{47}	10	10	10	10	7	21
P_{48}	10	10	10	10	8	23
P_{49}	10	10	10	10	9	24
P_{50}	10	10	10	10	10	25
P_{51}	11	10	10	10	10	27
P_{52}	12	10	10	10	10	29
P_{53}	13	10	10	10	10	31
P_{54}	14	10	10	10	10	33
P_{55}	15	10	10	10	10	35
P_{56}	15	11	10	10	10	37
P_{57}	15	12	10	10	10	39
P_{58}	15	13	10	10	10	41
P_{59}	15	14	10	10	10	43
P_{60}	15	15	10	10	10	45
P_{75}	15	15	15	15	15	75
P_{100}	20	20	20	20	20	150

Scenario 3

Period	0.1-1 cm Frequency	1.1-2 cm Frequency	2.1-3 cm Frequency	3.1-4 cm Frequency	4.1-5 cm Frequency	>5 Frequency
P_{125}	25	25	25	25	25	250
P_{150}	30	30	30	30	30	375