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A Diachronic Stable Isotope Investigation of Paleodiets, Migration, and the Influence of Climate
on the Indigenous People of the West-Central Sierra Nevada, CA

By

BRYNA E. HULL
DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

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Dedication

This dissertation is dedicated to the Tuolumne Me-Wuk, without whom none of this would have been possible.

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There are so many people who offered me support over the years, it is difficult to find a beginning or end. I want to thank the Tuolumne Me-Wuk for their support of this project, and for all the guidance and interaction offered by Reba Fuller. These are your ancestors, thank you for allowing me to better understand them.

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Abstract

Within the west-central Sierra Nevada, archaeologists have long debated the effects of the Medieval Climate Anomaly (MCA) on the indigenous culture, owing largely to the scant archaeological evidence produced during this period. More broadly, climate events are frequently included within arguments surrounding the reorganization of culture or their inexplicable decline. Within this region, the argument leans towards the former, however, this has led to further questions regarding the nature of this cultural reorganization. The previous cultural pattern of greater residential-than-logistical mobility, and a greater reliance on pine nuts than acorns as a storable staple seems to end around the same time as the droughts start. This dissertation examines the relationships among diet, mobility, and drought in the west-central Sierra Nevada over the last ~4000 years. It asks two related questions: how settlement structure, residential mobility, diet, and climate articulated through time, and how indigenous communities adapted to short- and long-term climatic shifts, especially drought.

While human behavioral ecology theory guides the main hypothesis that water, if treated as a resource patch, was a limiting resource during the MCA, I used stable isotope analysis of paleobotanical, faunal, and human remains within a diachronic framework, together with regional archaeological and environmental evidence to address these questions. The paleobotanical analysis established a local isotopic baseline and demonstrated meaningful differences between angiosperm and gymnosperm resources, allowing the long-term importance of pine nuts to human diets to be more directly evaluated. The faunal analysis established baseline expectations for animal protein and local sulfur isotope ranges and further explored paleoprecipitation estimation from collagen. These lines of evidence were integrated with human

carbon, nitrogen, and sulfur isotope data to evaluate dietary change, residential mobility, and the possibility of non-local movement through time.

The results indicate that substantial social reorganization occurred during the Recent Prehistoric I period (RP I; 1100-610 cal BP), coeval with the MCA droughts. Dietary change was not instantaneous, but the shift toward greater use of angiosperms, and reduced reliance on gymnosperm resources was fully manifest by RP I. Sulfur isotope analysis suggests reduced residential mobility during this interval and does not support a simple replacement model, though some non-local individuals were present. Paleoprecipitation estimates derived from plants, fauna, and humans further suggest that drought-related environmental stress formed an important part of this sequence. Taken together, the evidence supports an interpretation in which drought acted as a catalyst for the initial reorganization of settlement, mobility, and diet, while later territoriality likely helped maintain reduced residential mobility into the Recent Prehistoric II period (RP II; 610-100 cal BP).

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Chapter 1: Introduction

This dissertation examines what human diets can tell us about ancient societies. The focus here is on relationships among human mobility, foraging decisions, and drought. Two main questions drive this research: 1) what are the articulations among settlement structure, human mobility, environment, and diet; and 2) how do humans adapt to short and long-term climatic changes, such as droughts and cold periods? To address these questions, this project used stable isotope analysis of paleobotanical, faunal, and human remains within a diachronic framework centered in the west-central Sierra Nevada. The approach was designed to move beyond indices of food remains and artifacts as these have left us with lingering questions, and instead evaluates long-term relationships among diet, mobility and drought through multiple lines of evidence.

West-central Sierra Nevada hunter-gatherers experienced multiple droughts throughout the last 4000 years. The most intense was an episodic period of droughts known collectively as the Medieval Climatic Anomaly (MCA), ca. 1050– 675 BP (Graham and Hughes 2007; Stine 1994). While this dissertation examines how human diets changed over the last ~4,000 years and evaluates how these changes relate to shifts in residential and logistical mobility, it gives particular focus to whether periods of environmental stress, such as the Medieval Climate Anomaly (MCA), correspond to broader reorganization in subsistence and landscape use.

Previous research in the region suggested a long-term pattern of wide landscape use, high seasonal residential mobility, and a strong reliance on pine nuts for winter storage prior to the MCA (Moratto 2002; Moratto et al. 1988; Rosenthal et al. 2011b; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005). Following the droughts, however, the archaeological record indicates

a reorganized society in which residential mobility had decreased, logistical mobility had increased, and acorns became a more prominent storage resource (Moratto 2002; Moratto et al. 1988; Rosenthal et al. 2011b; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005). Previous research implicates the MCA (e.g., Moratto 1984) as a driving mechanism behind a marked shift in settlement and subsistence patterns, wherein residential mobility decreased, and acorns became a staple food for storage and consumption. On the other hand, other research questions the centrality of the MCA and suggests that greater importance of acorns represents a strategy to increase the quantity of storable foods for winter (Rosenthal 2011a). More recent research explores this shift through changing abundances of paleobotanical remains and suggests that one explanation for the shift from high residential mobility and use of gray pine nuts, to lower residential mobility, greater logistical mobility, and greater acorn use is rising opportunity costs related to women's foraging and childcare (Whelan 2016; Whelan et al. 2013).

This dissertation re-examines these questions with new sources of data. I examine how diets changed over the last 4,000 years, and when these changes took place in relation to settlement strategies, residential mobility, and overall foraging behavior. As diet is a sensitive measure of environmental stress, such as could have been caused during the MCA droughts, I use this information in conjunction with the available archaeological evidence to test ideas about the timing of dietary changes.

In the west-central Sierra Nevada, the MCA is hypothesized to have created a situation where hunter-gatherers reordered the rank of preferred resources for storage from a front-loaded resource (pine nuts) to a back-loaded resource (acorns), and residential mobility became increasingly restricted as the drought continued. Front-loaded resources are those that require significant processing prior to storage, while back-loaded resources are those where processing

costs are delayed until after storage, but prior to use (Bettinger 2009). This reordering suggests that time constraints on foraging versus other activities may have become more pronounced as overall mobility changed. A possible explanation for the reduced residential mobility is that permanent and reliable water sources were targeted for settlement to reduce the risk of being without water, where water is considered as a resource patch. Secondly, it is possible that the MCA period coincides with increases to territoriality within the region, given the interpretation that bedrock mortars may be a signal of claimed territory (Leftwich 2010; Stevens et al. 2019).

As residential mobility decreases, we expect that logistical mobility will increase. This may cause a situation where longer foraging bouts are economically inefficient. Even though pine nuts are higher ranked than acorns, they have a higher pre-storage processing cost as much of the cone is inedible. As well, their utility may decrease as distance from the camp increased with longer foraging bouts. Because acorns can easily be collected and require no processing prior to transport or storage, they may have been more efficient as distance to camp increased with longer logistical foraging bouts. It is expected that as logistical mobility increased, the shift to include more acorns may have been a time-tradeoff between foraging efficiency and the ability to shift the processing costs to the least productive time of year, winter.

This dissertation project begins with an overview of the environment and climate of the west-central Sierra Nevada in Chapter 2. Within this chapter, I discuss the elevation-dependent biotic communities, climate, and vegetation history. I pay special attention to drought and its effect on plants, as the Sierra, like the rest of California, is prone to extended periods of reduced rainfall, which can have cascading effects throughout the mountains and the adjacent Central Valley. This is pertinent since foraging communities' diets are closely linked to environmental conditions and dietary decisions help to structure settlement patterning.

Chapter 3 is an overview of anthropological research within the west-central Sierra Nevada. This chapter begins with a summary of the Central Sierra Me-Wuk culture as it is detailed by ethnographic and linguistic reports, with a primary focus on subsistence and settlement patterns. Next, I cover the history of archaeological research within the region, where I include a discussion on the developments brought by changing state and federal laws as pertains to archaeological research within the area and the subsequent impacts on some sites on which I focus. I also offer a discussion on other avenues of research within the regions, namely chronology building and settlement and subsistence studies. The next section within this chapter is an overview of the region's culture history, which offers insights to links between culture and environment. Last within this chapter, I interpret and discuss a refined chronological placement of the New Don Pedro burials based on this dissertation research, and the broader implications for understanding the region's culture history.

Chapter 4 lays the foundation for understanding $\delta^{13}\text{C}$ of C_3 paleobotanical remains and how signatures of their consumption can be transferred up the food chain. The goal is to extrapolate differential responses of these remains to broad paleo-environmental changes and how this relates to the $\delta^{13}\text{C}$ expected in human and animal remains from the same local region and time frame. This chapter begins with a brief review of carbon circulation across Earth and a short discussion of the different photosynthetic pathways employed by different classes of plants. It then explores more deeply what factors contribute to variation in $^{13}\text{C}/^{12}\text{C}$ of C_3 plants and suggest that the use of a global average of $\delta^{13}\text{C}$ of C_3 plants to understand $\delta^{13}\text{C}$ in C_3 consumer tissues is inadvisable. It further lays out expectations of $\delta^{13}\text{C}$ for different sample types based on previous ecological research. Within this chapter, I illustrate a notable difference between angiosperm and gymnosperm $\delta^{13}\text{C}$ values in tissue types which can be passed onto human and

animal consumers, and from which I build a model to predict $\delta^{13}\text{C}$ of faunal consumers. As well, I show there is a strong correlation between precipitation and angiosperm C_3 plant $\delta^{13}\text{C}$, accomplished through paleoprecipitation modelling from $\delta^{13}\text{C}$ of black oak tree rings, and secondarily paleobotanical remains. As well, I show that this signal is conserved and preserved in paleobotanical materials which could be useful for estimating precipitation during the months of growth of angiosperm paleobotanicals, which could benefit a wide range of analyses.

Chapter 5 asks the basic question, what can stable isotope analysis of faunal remains can tell us about Indigenous cultures, diets, and, more broadly, the environment? I explore the light stable isotope abundances of carbon (C), nitrogen (N), and sulfur (S) in a selection of faunal remains from several sites from the west-central Sierra Nevada in relation to modelled baseline values and expectations in order to predict and better explain the diets and geography of Indigenous peoples dwelling here over the last 4,000 years. I first provide a brief overview of C, N, and S, and their use within paleodietary isotopic analysis studies. Next, I give an overview of the faunal record of the Sierra Nevada, and the utility of incorporating faunal remains within isotopic analyses of human diets. Following this, I discuss the sample selection and identification process, and outline the isotopic expectations based on animal feeding habits and home-range size. I then analyze the data and discuss the results to make predictions about human values, paleo-precipitation, and the local range for $\delta^{34}\text{S}$. Importantly, this chapter sets the stage for analyzing the stable isotopes from the human remains in the next chapter by creating two models, one for $\delta^{13}\text{C}$ (which incorporates the model from the paleobotanicals as well as the faunal results), and one for $\delta^{15}\text{N}$ which is based from the faunal results.

Chapter 6 returns to focus on humans, and evaluates group level C, N, and S patterns within a diachronic framework. The chapter begins with a brief overview of the archaeological,

environmental, and theoretical context of the linkages among diet, mobility, settlement structure and drought and asks the question of how diets changed over the last 4,000 years, and when these changes took place in relation to the MCA. This chapter builds on premises from previous chapters, and incorporates the baseline ranges of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ to understand human diets and mobility patterns. Within the materials and methods section, I offer a brief history of the burial collections used within this project, and importantly, I highlight that all human remains were sampled with permission from the Tuolumne Me-Wuk, who are the most likely descendants of the individuals under study. Within the results section, human diets are interpreted through the use of the two models created within Chapter 5. Model performance and uncertainty for both diet isotope models were evaluated using the same statistical framework. As well, I investigate how mobility changed over time, and the possible relationship to drought or alternatively, territorial behavior. Next, this chapter continues the experimental paleoprecipitation estimation, and explores whether it is possible with $\delta^{13}\text{C}_{\text{collagen}}$ values of omnivorous humans. This chapter concludes with a summary of the interpreted results.

The last chapter, Chapter 7, summarizes and interprets the results of the previous data-based chapters alongside the archaeological and environmental evidence. It next moves beyond the lens of the west-central Sierra Nevada to discuss more broadly the implications of these results for paleodietary studies.

Chapter 2: Environmental Setting of the Central Sierra Nevada Region of California

The Sierra Nevada region is marked by rolling foothills backed by the gently rising slopes of the Sierra Nevada mountains to the east, with the region covering over 53,000 km² (Raumann and Soulard 2012). Approximately 190—290 km east of California’s central coast, the region marks the eastern-most edge of California’s Great Central Valley and acts as a border between the Valley and the Great Basin. The northwest-southeast trending mountain range is only 105 km wide but stretches some 640 km from the Tehachapi Range in the south (35°N) to the north where its granitic backbone eases beneath the Cascades Range at 40°N (Curry 1969; Rundel 2011; Shulgina et al. 2023; Storer and Usinger 1963).

The westerly-facing slopes rise from near sea level to elevations of 4,400 m at the highest peaks along the crest in the south (Millar 1996; Shulgina et al. 2023). In the north, peaks stretch 3400 m above sea level (Shulgina et al. 2023; Storer and Usinger 1963). The unified range is essentially a tilted and faulted granitic block with western slope gradients of only two to six percent (Storer and Usinger 1963; Millar 1996). Eastern slopes, however, are much steeper. On the northern margin of the eastern side, the elevational descent into the valleys and folds of the Great Basin is nearly 1000 m. While, along the edge of Owens Valley in the south, the descent to the east from the southern peaks can plunge nearly 2100 m over only eight km, a slope gradient of 26% (Storer and Usinger 1963).

The differences between the northern and the southern portions of the region make dividing the region into three parts a widespread practice among Sierran researchers. The “central” Sierra is bounded on the northern edge by the Mokelumne River (38.22°N), on the south by the Merced River (37.37°N), and encompasses the drainages of the Stanislaus and

Tuolumne Rivers. It is within this area that ancestral Central Sierra Me-Wuk, the focus of this study, resided (Barrett and Gifford 1933), and their descendants continue to live.

Climate coupled with the different elevations and slope aspects within the central Sierra Nevada foothills and mountains create a heterogeneous environment, rich with varied and seasonal resources. For the people who called this region home prior to European arrival, the seasonal nature of resources necessitated cultural adaptations of seasonal vertical movement up and down slope, as well as the use of storage (Barrett and Gifford 1933; Merriam 1967; Morgan 2012; Whelan et al. 2013).

In this chapter I begin by detailing the environment of the western Sierra Nevada region. I include discussions of the elevation-dependent biotic communities, climate, and vegetation history. I pay special attention to drought and its effect on plants, as the Sierra, like the rest of California, is prone to extended periods of reduced rainfall, which can have cascading effects throughout the mountains and the adjacent Central Valley. This is pertinent since foraging communities' diets are closely linked to environmental conditions and dietary decisions help to structure settlement patterning.

2.1 Environment of the Western Sierra Nevada: Biotic Communities

The biotic communities that evolved in and inhabit the western slope are structured along elevational gradients which correlate with temperature, precipitation, and jet stream patterns (Axelrod 1977; Dettinger et al. 2018; Eardley and James 2024; Major 1977; Millar 1996; Storer et al. 2004; Storer and Usinger 1963). Most floral communities grade into one another, and boundaries are seldom sharp or straight (Storer & Usinger 1963; Storer et al. 2004). These biotic zones are interlaced such that on south facing slopes at ecotone margins vegetation from the

lower elevation biotic zones will reach higher because of the dryer and warmer conditions, whereas on north facing slopes plant types from the higher zone will encroach lower due to the cooler conditions (Storer & Usinger, 1963: 26). Climate affects plant distributions, which in turn affects animal distributions among the biotic zones (Jameson and Peeters 2004; Storer and Usinger 1963).

The timing and length of ripening for edible resources differs among biotic communities due to the differences in precipitation and temperature among the different elevations (Storer & Usinger, 1963). For example, plants in the lower, snow-free elevations have earlier phenology than plants within the cooler and more snow-laden higher elevations. This leads to an elevational gradient of seasonally ripe resources. Variability in precipitation and temperature can lead to wide differences in the exact timing of phenology in plants— in cool, wet years with ample snow, resources will ripen later, while in poor precipitation/warm years resources ripen earlier. This has important dietary implications for residents within the Sierra, as not all resources are available at the same time each year, nor is resource distribution homogenous.

2.1.1 Lower Sonoran Zone- Valley Margin

The lowest foothill elevations, up to about 90 m (300 ft), support mainly a grass and forb savanna from the valley (Schoenherr 2017; Storer & Usinger 1963). This is referred to by ecologists as the Lower Sonoran Zone (Schoenherr 2017; Storer & Usinger, 1963). Species of note within the grass and forb savanna include fascicled tarweed (*Deinandra fasciculata*), hayfield tarweed (*Hemizonia congesta luzulifolia*), blue dicks (*Dichelostemma capitatum*), miniature lupine (*Lupinus bicolor*), purple needlegrass (*Stipa pulchra*), California yarrow (*Achillea millefolium*), California plantain (*Plantago erecta*), beardless wild rye (*Elymus triticoides*), and a few species of Brodiaea lilies (*Brodiaea spp.*) (Lulow and Young 2011; Major

1977). The grass and forb savanna is frequently interspersed with stands of blue oak (*Quercus douglasii*), valley oak (*Q. lobata*), interior live oak (*Q. wislizenii*), and buckeye (*Aesculus californica*) (Major 1977; Storer and Usinger 1963). Near waterways, Fremont cottonwoods (*Populus fremontii*) and various willows (*Salix spp.*) can be found (Major 1977; Storer and Usinger 1963).

Although a variety of animals inhabit the grass and forb savanna of the lowest foothills, some have been extirpated since the Gold Rush era, including grizzly bear (*Ursus arctos*), gray wolf (*Canis lupus*), tule elk (*Cervus elaphus nannodes*), and pronghorn (*Antilocapra americana*) (Schoenherr 2017). Species that are still present, though in various states of federal protection and state monitoring, include the San Joaquin kit fox (*Vulpes macrotis mutica*), the Sacramento Valley red fox (*V. vulpes patwin*), mountain lions (*Puma concolor*), coyotes (*Canis latrans*), badgers (*Taxidea taxus*), and California mule deer (*Odocoileus hemionus californicus*) (Jameson and Peeters 2004; Perrine et al. 2007; Schoenherr 2017). According to historic records, vast herds of mule deer once roamed this habitat, however, as much of the land was transformed to agricultural fields and livestock grazing, mule deer were pushed further east into the foothills and Sierra, where they now seasonally migrate up and down slope (Schoenherr 2017). Other animals that inhabit this community include striped skunk (*Mephitis mephitis*), desert cottontail (*Sylvilagus audubonii*), brush rabbit (*S. bachmani*), black-tailed jackrabbit (*Lepus californicus*), California ground squirrel (*Otospermophilus beecheyi*), Botta's pocket gopher (*Thomomys bottae*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), long-tailed weasel (*Mustela frenata*), California quail (*Callipepla californica*), grouse (*Dendragapus spp*), and numerous small rodents and birds (Jameson and Peeters 2004; Laws 2007; Schoenherr 2017; Storer and Usinger 1963).

Along waterways, waterfowl such as ducks and geese (Anatidae), river otter (*Lutra canadensis*), mink (*Neogale vison*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and western pond turtle (*Actinemys marmorata*) are found (Jameson and Peeters 2004; Laws 2007; Morey 2000; Schempf and White 1974; Schoenherr 2017; Storer and Usinger 1963). Many of these animals also inhabit higher elevations within the foothills and low elevations within the mountains (Jameson & Peeters, 2004; Laws, 2007; Schoenherr, 2017; Storer & Usinger, 1963).

Within Sierran waterways there were once 40 native species of fish, however after numerous modern modifications to streams, rivers and lakes as well as the introduction of non-native fish, twenty-two species are listed as either endangered or in decline (Moyle 2002; Storer et al. 2004). Some of the larger (8- 24+ inches) fish native to the lower elevation waterways include: Sacramento perch (*Archoplites interruptus*), hitch (*Lavinia exilicauda*), hardhead (*Mylopharodon conocephalus*), Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento sucker (*Catostomus occidentalis*), non-migratory rainbow trout (*Oncorhynchus mykiss*), while Pacific lamprey (*Lampetra tridentata*), Chinook salmon (*Oncorhynchus tshawytscha*) and the anadromous steelhead trout (also *Oncorhynchus mykiss*) could be found within the Sacramento River tributaries (Storer et al. 2004). Of interest to archaeologists are the Sacramento perch. Sacramento perch are the most common fish in archaeological assemblages from numerous low elevation valley locations (Hash et al. 2015), however their native home range only extends to the lowest reaches of the foothills below 100 m (328 ft) (Moyle 2002:31, 377), likely explaining why only seven have been recovered from across five sites from Calaveras and Amador county (Gobalet et al. 2004).

The lower elevation waterways are also home to a variety of small (2.5-5 in) fish including the Lohontan redbside (*Richardsonius egregious*), California roach (*Lavinia*

symmetricus), speckled dace (*Rhinichthys osculus*), threespine stickleback (*Gasterosteus aculeatus*), riffle sculpin (*Cottus gulosus*) and the prickly sculpin (*Cottus asper*) (Moyle 2002; Storer et al. 2004). Some of the small fish are restricted to specific rivers, such as the Lohontan redside within the Mokelumne River, while others are widespread (e.g. stickleback and sculpins). Many of these smaller species are thought to have been occasional foods for some Sierran groups. For example, speckled dace once inhabited the foothill streams and rivers between 27-450 m (88-1476 ft) in the San Joaquin drainages (from the Stanislaus River, south) (Moyle 2002:27, 161, 163), however their remains are virtually absent from archaeological assemblages in the foothills, yet they do occasionally show up in Valley assemblages, such as CA-YOL-69, -187 (Gobalet et al. 2004). Of the native fish, few inhabited waters at elevations above 6,000 ft (~1,829 m) (Storer et al. 2004). Those that do are covered separately, below.

Also found within Sierran waterways are a few species of shellfish that occasionally served as food for Native human inhabitants. These freshwater mollusks include western pearlshell mussel (*Margaritifera falcata*), western ridged mussel (*Gonidea angulata*), winged floater (*Anodonta nuttalliana*), California floater (*Anodonta californiensis*), and the Oregon floater (*Anodonta oregonensis*) (Greengo 1952:68–69). The distribution of these species is determined by the availability of suitable fish hosts and the preferred habitat of the mostly sedentary adults (Taylor 1981:141). *M. falcata* and *G. angulata* are found in cool, swift streams, creeks and rivers harboring trout, whereas the three *Anodonta* species prefer lakes, ponds, slow moving rivers and quiet perennial streams (Greengo 1952; Howard 2010; Taylor 1981). Modern field surveys suggest each of these has seen as much as 50% decline in abundance within historical home ranges throughout the waterways flowing into the Valley and beyond (Howard 2010). These species would have been found at higher elevations as well.

2.1.2 Upper Sonoran Zone- Foothill Woodland and Chaparral

The grass and forb savanna of the Lower Sonoran Zone gives way to foothill woodland interfingering with areas of chaparral beginning in the upper foothills. This biotic community is frequently referred to as the Upper Sonoran Zone (Schoenherr 2017; Storer and Usinger 1963). The foothill woodland and chaparral are spread among different elevations, depending on which part of the region is considered. In the north, the foothill woodland and chaparral ranges between 150–915 m (500–3,000 ft) above sea level, while in the central region they range between 243–1,219 m (800–4,000 ft) (Griffin 1972; Storer and Usinger 1963). However, their range is drastically expanded in the southern portion of the region and can be found between 38–1,524 m (125–5,000 ft) in elevation, due to dryer conditions (Storer & Usinger 1963). Chaparral usually occurs on south facing slopes and in soils too shallow to support trees. The foothill woodland zone is characterized by gray pine (*Pinus sabiniana*), blue oak, black oak (*Q. kelloggii*) in the higher elevations, interior live oak, and buckeye (*Aesculus californica*). Foothill chaparral species consist of manzanita (*Arctostaphylos manzanita*, *A. mariposa*, *A. pungens*, and *A. mewukka*), chamise (*Adenostoma fasciculatum*), buck brush (*Ceanothus cuneatus*, and *C. leucodermis*), scrub oak (*Quercus berberidifolia*), spice bush (*Calycanthus occidentalis*), bush poppy (*Dendromecon rigita*), chaparral pea (*Pickeringia montana*), and yerba santa (*Eriodictyon californicum*) (Storer and Usinger 1963).

There are numerous animals within the Upper Sonoran Zone of the foothills and mountains. Along with the migratory California mule deer, another subspecies known as Columbian black tailed deer (*Odocoileus hemionus columbianus*) range within this zone towards the southern end of the Sierra, but do not migrate to the extent of *O.h. californianus* (Anderson and Wallmo 1984; Dasmann and Taber 1956; Schoenherr 2017; Whitaker et al. 2019). Tule elk

occasionally ranged into this zone, although it is not ideal habitat. Evidence for their presence is found archaeologically (Whitaker et al. 2019). Black bear (*Ursus americanus*), along with other carnivore species such as coyote, mountain lion, badgers, gray fox (*Urocyon cinereoargenteus*), and bobcat (*Lynx rufus*) occupy this extremely productive biotic community as did grizzly bear and gray wolf prior to their extirpation (Jameson and Peeters 2004; Schoenherr 2017; Storer and Usinger 1963). Other animals of note within this region include California quail, brush rabbit, desert cottontail, black-tailed jack rabbit, striped skunk, gray squirrels (*Sciurus griseus*), band-tailed pigeons (*Patagioenas fasciata*), mourning dove (*Zenaida macroura*), wood duck (*Aix sponsa*), common merganser (*Mergus merganser*), Merriams chipmunk (*Neotamias merriami*), and the western spotted skunk (*Spilogale gracilis*) (Jameson and Peeters 2004; Laws 2007; Schempf and White 1974; Schoenherr 2017; Storer and Usinger 1963).

2.1.3 Lower Montane – a Mixed Conifer Forest and Mountain Chaparral

On the western slopes of the mountains between 365–2,743 m (1200–9,000 ft) is a mixed conifer forest, once called a “yellow pine belt” and currently referred to as Lower Montane (Griffin 1972; Storer et al. 2004; Storer and Usinger 1963; van Wagtendonk et al. 2018). The Lower Montane forest is frequently interlaced with the foothill woodland vegetation in the lower elevations, and some mountain chaparral on dry, south facing slopes (Griffen 1972; Storer & Usinger 1963). Here, precipitation falls mainly as winter snow (Griffin 1972; Storer and Usinger 1963).

This zone also marks the boundary between freeze-adapted species and those that are more drought adapted (Schoenherr 2017; Storer et al. 2004). It is composed principally of coniferous trees adapted to a summer growing season, which require at least 63 cm (25 in) of precipitation (Schoenherr 2017). This vegetative community consists of variable combinations of

ponderosa pine (*Pinus ponderosa*), incense cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), red fir (*Abies magnifica*), Jeffrey pine (*Pinus jeffreyi*), lodgepole pine (*Pinus contorta*), madrone (*Arbutus menziesii*), currants (*Ribes nevadense*), gooseberries (*Ribes roezlii*), kit-kit-dizzi (*Chamaebatia foliolosa*), and black oak (Griffen 1972; Storer & Usinger 1963). Mountain chaparral frequently consists of holly leaf redberry (*Rhamnus crocea* var. *ilicifolia*), huckleberry oak (*Quercus vacciniifolia*), bush chinquapin (*Castanopsis sempervirens*), as well as buck brush and several species of manzanita (Griffen 1972; Storer & Usinger 1963). In the highest elevations of this biotic zone, white fir gradually becomes the dominant species (Griffen 1972). In the southern portion of the region, relict groves of giant sequoia (*Sequoiadendron giganteum*) occur in and tower above the mixed conifer forest (Griffen 1972).

The mixed conifer forest marks a transition for animal communities, as snow during winter months requires some adaptation or migration (Jameson & Peeters 2004; Schoenherr 2017). While black bears, coyote, mountain lion, bobcats, raccoon, badgers, western spotted skunk, long-tailed weasels, mink, grouse, gray squirrel, Bottas pocket gopher and some resident California mule deer and Columbian black-tailed deer persist year-round, there are many animals from lower elevations, such as the desert rabbit, black tailed jack rabbit, and California quail that do not inhabit areas within and above this mixed conifer forest (Laws 2007). Instead, animals such as Sierra Nevada red fox (*Vulpes vulpes necator*), American marten (*Martes americana*), fisher (*Pekania pennanti*), wolverine (*Gulo gulo luteus* Elliot), porcupine (*Erethizon dorsatum*), ringtail (*Bassariscus astutus*), yellow-bellied marmot (*Marmota flaviventris*), mountain pocket gopher (*Thomomys monticola*), northern flying squirrel (*Glaucomys sabrinus*), Douglas squirrel (*Tamiasciurus douglasii*), California ground squirrel (*Otospermophilus beecheyi*), lodgepole

chipmunk (*Neotamias speciosus*), mountain quail (*Oreortyx pictus*), blue grouse (*Dendragapus obscurus*), and the northern flicker (*Colaptes auratus*) are the residents within this transect (Laws 2007; Schempf and White 1974; Storer et al. 2004; Storer and Usinger 1963). During winter, some animals, such as the northern flicker, mountain quail, mourning dove, and some of the deer will migrate and overwinter below the snowline (Laws 2007; Storer and Usinger 1963). Others, like the yellow-bellied marmot, hibernate (Storer et al. 2004:366).

There are a few fish species native to the cold waters of the higher elevation lakes, streams and rivers. Of note are the medium-sized (up to 16 in) mountain whitefish (*Prosopium williamsoni*) which inhabits high lakes, such as Tahoe and Donner, and rivers flowing down the east side drainages, as well as the large (up to 24 inches) mountain sucker (*Catostomus platyrhincus*) found in streams up to 6,000 ft (Moyle 2002:15; Storer et al. 2004). In the southern Sierra, California golden trout are found in the streams and rivers within and above this elevation zone (Storer et al. 2004). More common species found in the lower elevations, such as riffle sculpin, speckled dace, rainbow trout, hardhead, Sacramento pikeminnow and Sacramento sucker, are also found up into waterways within this elevation transect (Storer et al. 2004; Moyle 2002).

2.1.4 Upper Montane - the Red Fir-Lodgepole Pine Belt

At elevations ranging between 1,676– 3,048m (5,500–10,000ft), the Lower Montane mixed conifer forest grades into the Upper Montane red fir-lodgepole pine belt, representing a Boreal forest (Griffen 1972; Storer & Usinger 1963). This vegetation community, dominated by red fir and lodgepole pine, is also home to Jeffrey pine, silver pine (*Pinus monticola*), Sierra juniper (*Juniperus grandis*), and aspen (*Populus tremuloides*) (Storer & Usinger 1963). In this elevational zone, the areas of mountain chaparral contain huckleberry oak, bush chinquapin,

green manzanita (*Arctostaphylos patula*), and snowbrush (*Ceanothus velutinus*) (Storer & Usinger 1963). Here dense snow covers the ground for months during the winter and spring, with a short growing season lasting about three to four and a half months during summer and early fall (Storer & Usinger 1963).

Many animals inhabit the red fir-lodgepole pine belt. Some that dwell in the mixed conifer forest also call the red fir-lodgepole pine belt home for some months out of the year. These include mountain quail, blue grouse, Sierra Nevada red fox, coyote, American marten, fisher, short-tailed weasel, badger, wolverine, raccoon, porcupine, yellow-bellied marmot, as well as some Columbian black-tailed deer and California mule deer (Laws 2007; Storer & Usinger 1963; Storer et al. 2004). Among the smaller-bodied species which also range throughout this ecotone are the northern flicker, mountain pocket gopher, northern flying squirrel, lodgepole chipmunk, and Douglas squirrel (Laws 2007). There are a handful of animals that are not found below this elevational transect, such as the white-tailed jack rabbit (*Lepus townsendii*), which make high elevation habitats their home. Among these unique species are: snowshoe hare (*Lepus americanus*) which can be found in high elevation forest meadows; the golden mantled ground squirrel (*Callospermophilus lateralis*) which range up into alpine habitats; shadow chipmunk (*Neotamias senex*) who are only found in elevations above 4,800 ft; alpine chipmunk (*Neotamias alpinus*) which prefer open forests above 9,800 ft; and the bushy-tailed woodrat (*Neotoma cinerea*) that can be found in upper elevation conifer forests on rocky outcrops and talus slopes (Laws 2007; Storer & Usinger 1963).

2.1.5 High Sierra- the Sub-Alpine and Alpine Zones

A sparsely-forested subalpine belt has evolved between about 2,100–3,350 m (7,000–11,000 ft), commonly called the High Sierra, and represents the timberline at the highest points within this elevational range (Storer & Usinger, 1963). It is characterized by heavy, persistent winter snow, frosts in any month, and a growing season of only 7–9 weeks (Storer & Usinger 1963). The dominant plant species in this subalpine plant community are lodgepole pine, whitebark pine (*Pinus albicaulis*), foxtail pine (*Pinus balfouriana*), mountain hemlock (*Tsuga mertensiana*), red heather (*Phyllodoce breweri*) and white heather (*Cassiope mertensiana*) (Storer & Usinger 1963).

Above the timberline, at elevations exceeding 3,300m (~11,000ft) and mostly along the highest ridges and peaks, are a community of alpine-dwelling plants— most have low or creeping growth forms attributed to the harsh conditions of the exposed and rocky Sierra crest (Rundel 2011; Storer and Usinger 1963). This alpine zone is rich with various herbaceous perennials, including some grasses and sedges, but is home to few annuals which are likely related to desert species (Rundel 2011; Storer and Usinger 1963). Perennials of note include naked buckwheat (*Eriogonum nudum*), Salmon Creek Indian paintbrush (*Castilleja praeterita*), dwarf alpine Indian paintbrush (*Castilleja nana*), mountain marsh larkspur (*Delphinium polycladon*), and broadleaf lupine (*Lupinus latifolius*)— which represent plants used for foods by indigenous people (Barrett and Gifford 1933; Rundel 2011). In this high-altitude habitat, woody species are limited to dwarf willow (*Salix herbacea*) and members of Ericaceae (heaths and heathers) (Rundel 2011).

Although many animals can be found in these high elevation communities during summer, few are year-round residents. A majority of the animal population in these high

elevations are birds and rodents, such as the yellow bellied marmot, which are adept at dealing with the harsh cold and windy conditions that prevail (Storer et al. 2004). Animals unique to the sub-alpine and alpine zones are big-horned sheep (*Ovis canadensis*)— which graze in alpine meadows and make rocky mountainsides their preferred escape routes— and the pika (*Ochotona princeps*), which are small-bodied relatives of rabbits and hares and who live in the sub-alpine boulder fields and stay active year-round (Laws 2007).

2.2 Climate

The western Sierra Nevada region experiences the seasonal cycle of the northern hemisphere, but its location on the western periphery of the continent determines the type of climate for winter and summer (Storer and Usinger 1963). Since the late Pliocene (~3my BP) the western slopes of the Sierra Nevada, like the rest of California, have experienced a Mediterranean-type climate of warm to hot, dry summers and cool, wet winters and are characterized by large fluctuations in temperature and precipitation at multiple time scales (Axelrod 1977; Dettinger et al. 2011, 2018; Major 1977; Mulch et al. 2008; Storer and Usinger 1963). Temperature and precipitation in this region are dependent on circulation patterns of the Pacific Ocean, latitude, and elevation (Dettinger et al. 2018; Storer and Usinger 1963).

2.2.1 Temperature

Temperature fluctuations are large but mediated by the region's proximity to the Pacific Ocean (Dettinger et al., 2018). The Pacific Ocean acts as a globe-spanning thermal mass that absorbs and buffers both seasonal and year-to-year temperature variations for western North America (Dettinger et al. 2018: 14). In summer, average maximum daytime temperatures in the

Sierra range between 80–100°F (26.6–37.7°C) to a minima of 15–37°F (-9.4– 2.8°C) at night, depending on elevation (Storer and Usinger 1963). In winter, average daily lows can reach 0 to -30°F (-17.8– -34.4°C), while the average highs are between 55– 70°F (12.8– 21.1°C) (Storer & Usinger,1963). Generally, temperature decreases about 1°C per every 162 meter gain in elevation, or about 1°F per every 300 foot gain in elevation (Storer and Usinger 1963).

2.2.2 Precipitation

Precipitation falls in the western Sierra Nevada as rain and snow, depending on elevation, time of year, and temperature. The majority of precipitation, about 95%, falls between October and May, with half falling from January to March (Storer and Usinger 1963). In general, winter precipitation patterns originate off California's central and northern coasts and move eastward, pushing up and over the western slope, bringing rain to lower elevations and snow to elevations typically above 600–900 m (2000–3,000 ft) (Storer and Usinger 1963). Most precipitation is exhausted from storm systems between 1,500–1,800 m (5,000– 6,000 ft) in elevation, and precipitation amounts decline above this point (Dettinger et al. 2018: 14; Storer & Usinger 1963: 12).

However, there are some differences between the northern and southern portions of the range. The northern portion of the range is lower in elevation and has less topographic relief than the central and southern portions, and is more directly in the path of strong North-Pacific storms, so it generally receives greater precipitation amounts as rain and overall is wetter (Dettinger et al. 2018; Storer & Usinger 1963). As the elevation increases to the south, the central and southern regions receive more precipitation as snow and are less wet than the northern portion (Dettinger et al. 2018; Storer and Usinger 1963). Overall, the average precipitation ranges between 38 and 76 cm (15-30 in) in the foothills, and between 69 and 117 cm (27-46 in) in the mid-elevations

(between 1,200 and 2,500 m or 4,000 and 8,000 ft) (Rosenthal 2011a). Average snow accumulation above 1,370 m (4,500 ft) in elevation ranges between 10 and 11.5 meters (33 -38 ft) (Eardley and James 2024). Summer thunderstorms at higher elevations are not uncommon and are often accompanied by hail and lightning—a major ignition source of modern wildfires (Millar 1996; Storer and Usinger 1963). There is some indication that the southern-most portions of the range also receive some summer monsoonal moisture emanating from the southeast in some years, especially in the past (Mulch et al. 2008).

The entire region experiences greater precipitation variability on the order of 50% — 200% of normal precipitation from year to year, as compared to the rest of the country where fluctuations are typically on the order of plus or minus 10– 20%, based on historical records (Dettinger et al. 2011, 2018). For example, in Tuolumne County at the heart of the Central Sierra region, the average precipitation for the period 1900-2022 was 120.9 ± 37.9 cm (47.5 ± 14.9 in) (PRISM Group 2023). As can be seen from the standard deviation of almost 1/3 of the average, observed modern precipitation is highly variable from year to year. This is due to climatic fluctuations coming from the Pacific, such as El Niño-Southern Oscillation (ENSO) events, Pacific Decadal Oscillation (PDO), frontal cyclones, and Atmospheric Rivers (i.e., moisture-laden jets in the lower atmosphere whose storms release significant amounts of precipitation as they rise up and over the mountains, noted as ARs), which happen on varied timescales from weeks, decades, and centuries (Dettinger et al. 2018:14; Mantua and Hare 2002; Newman et al. 2016).

PDO is a cyclical variation in North Pacific sea surface temperatures which affects weather patterns in North America and Asia, with two phases referred to as a positive phase and a negative phase, either of which can last between 20-30 years as based on historical records

(Mantua and Hare 2002; Newman et al. 2016; Wang et al. 2014). The PDO tempers the relationship between ENSO and the global climate, which can influence the strength and intensity of ENSO, and depending on the PDO phase, can affect the jet stream (Newman et al. 2016; Wang et al. 2014). Importantly, AR activity does not seem to be linked to the northern hemisphere temperature gradient and instead may be linked to insolation gradients such as Pacific sea-surface temperatures (Knight et al. 2024), meaning that its fluctuations may be linked to PDO phases. While these are all global-scale climate interactions affecting the Sierra, it is AR activity that is the most apparent in recent and paleoclimate records.

While “Atmospheric Rivers” is a relatively new term, ongoing research suggests that the occurrence of ARs extend into the past for at least 9,000 years and are not a modern occurrence due to anthropogenic climate change (Kirby et al. 2012; Knight et al. 2024). ARs in California are noted as huge precipitation events whose timing and number throughout any one year can bring a surplus of dense snow, or large amounts of warm rain that contribute to early snowmelt and drought conditions in the Sierra, along with widespread flooding in the valley (Dettinger et al. 2011; Knight et al. 2024). Because of the large amount of runoff associated with AR storms, paleoclimatologists have begun linking various lake sediment-climate proxy records (such as siliciclastic sediment, magnetic susceptibility, total organic content, C:N ratios, etc.) with AR activity (e.g. Kirby et al. 2012; Knight et al. 2024). Research on modern AR storms indicates they are responsible for ~40% of California’s snow-water equivalent in wet years (Guan et al. 2013).

One important result of the number and timing of California’s wintertime storms is their impact on the winter snowpack. Snowpacks serve many immediate functions within mountain ecosystems, from insulating tree roots and other organisms from freezing above ground

temperatures to providing sustained soil-moisture as temperatures rise during later seasons (Maurer and Bowling 2014; Penczykowski et al. 2017). Snow influences the timing and length of the growing season as well, and hence is an important factor governing the ecology of mountain ecosystems (Penczykowski et al. 2017; Slatyer et al. 2022). Winter snowpacks function as huge water reservoirs for both the Sierra Nevada and the Central Valley. They feed major rivers and many streams and creeks originating in the Sierra, which flow west downslope into the Sacramento and San Joaquin River drainages and into central California's delta. Typically, the snowpack persists beyond the end of the winter precipitation season and melts beginning in late spring-early summer in phase with peak evapotranspiration and radiative fluxes (Godsey et al. 2014). As the winter snowpack melts and disperses it also serves to recharge groundwaters (Godsey et al. 2014; Lapides et al. 2022; Stewart 2009; Tague and Peng 2013; Viviroli et al. 2007). Low flowing creeks, streams and rivers are then sustained later in the year by this groundwater (Godsey et al. 2014; Stewart 2009; Viviroli et al. 2007).

Warmer winters and warm winter storms brought by La Niña ENSO years and Pineapple Express-ARs in the Sierra Nevada lead to early snowmelts in mid-elevation zones (and occasionally the high elevation zones as well), which have numerous ecological and hydrological consequences. Early snowmelts often lead to early phenology in plants, animals and arthropods (Slatyer et al. 2022). However, early snowmelt also risks late season moisture limitation leading to dryer conditions earlier and for a longer period throughout the year (Slatyer et al. 2022; Westerling et al. 2006) which is correlated with greater wildfire frequency and severity (Westerling et al. 2006). This also has an effect on animals, as early phenology in plants can result in browse and graze shortages later in the year, as well as reduced seed production later in the year as soil moisture deficits are higher— which can lead to starvation, altered timing of

migration, or declines in population density and survival for some animals (Halofsky 2018; Le Corre et al. 2017; Morrison et al. 2009; Penczykowski et al. 2017; Slatyer et al. 2022).

In terms of hydrology, there is a lag between the effects of early snowmelt years on the subsurface water storage that serves to replenish many of the low flow streams, creeks and rivers throughout the Sierra (Godsey et al. 2014; Lapidés et al. 2022; Tague and Peng 2013). The recharge of this subsurface water storage zone is dependent on the local geology as well as the percolation of meltwater, above-ground evapotranspiration, and the use by plants (Godsey et al. 2014; Lapidés et al. 2022; Tague and Peng 2013). Normally, an early snowmelt year will cause a deficit in soil moisture content that persists until the following snowmelt (providing the following snowmelt year is “normal” or “above average”) (Godsey et al. 2014; Lapidés et al. 2022). When subsurface moisture conditions are in a deficit prior to or during snowmelt, often following drought years or warm winter years, evapotranspiration and water demand from plants above ground coupled with the subsurface deficit effectively deplete the subsurface water storage zone (tree-root zone and below) (Godsey et al. 2014; Lapidés et al. 2022; Tague and Peng 2013). Hence, even when an “above average” precipitation year occurs following early melt years and/or below-average precipitation years, the resulting mid-late year streamflow is still reduced from what is normally observed with above average precipitation (Lapidés et al., 2022). This is why above average temperatures, dryer conditions, and the overall climatic variability from year to year can have cascading effects within the Sierra Nevada and contribute to its heterogeneous landscape.

2.2.3 Drought and its Effects

Having a Mediterranean climate, the Sierra Nevada region is predisposed to drought on a periodic basis. Drought is defined here as a condition relative to some long-term average

condition of balance between rainfall and evapotranspiration in a particular area whose consequences are dynamic and depend upon its intensity and frequency (Wilhite and Glantz 1985). All droughts begin with a deficiency of precipitation that results in water shortage for some activity (e.g. plant growth) or for some group (e.g. farmers) (Wilhite and Glantz 1985). Historical records indicate that over the last 120+ years (since 1901), the Sierra region and California as a whole, have experienced seven major droughts lasting anywhere from two to seven years (U.S. Geological Survey). These droughts, although difficult for the modern population and economy, were not anomalous in light of longer climatological proxy records from tree rings and lake sediment cores which suggest that the region has experienced many cycles of droughts and periods of normal or greater precipitation since the last glacial maximum and through the last millennium (Graumlich 1993; Mensing et al. 2004; Street et al. 2012).

While the ecology of the Sierra Nevada has adapted to periodic short-term droughts and low-moderate intensity wildfires (those that do not destroy the forest overstory) (Axelrod 1977; Klimaszewski-Patterson et al. 2023; Major 1977; McKelvey et al. 1996; Parsons 1976; Skinner and Chang 1996; Trouet et al. 2010), periods of multidecadal drought and warmer temperatures are expected to have altered the vegetation structure as has been observed in multiple locations over shorter timescales during the modern era (Bréda et al. 2006; Hill et al. 2023; Kelly and Goulden 2008; McDowell et al. 2008, 2010; van der Molen et al. 2011).

For example, Hill et al. (2023) observed that 19.5% of the conifer forests on the western slopes of the Sierra Nevada are out of congruence with their average climatic parameters based on historic versus modern vegetation and climate surveys. This vegetational lag behind climate creates vulnerabilities in population structure, creating opportunities for invading pests and disease (Guegan et al. 2023; Sturrock et al. 2011). Likewise, Kelly and Goulden (2008) found

that while vegetation cover (overall vegetation biomass) was fairly stable over a thirty-year period (1977-2007) within a transect of Southern California's Santa Rosa Mountains, the distribution of individual species changed markedly, with an average up-slope movement of ~65 meters for nine dominant species from desert, chaparral and montane communities. Given different species adaptations for mesic versus xeric conditions, especially regarding montane structures (slope, aspect, soils), a change in the distribution of species is not remarkable and should be expected when long term drought is being considered. What is remarkable is that these changes have taken place during a period that has only experienced short-term periodic drought.

Drought has also been observed to induce mortality of some species at lower elevation ecotone margins (Allen and Breshears 1998; McDowell et al. 2010), which can have lingering effects including increasing forest fragmentation, erosion, and changing species diversity (Allen et al. 2010; Bréda et al. 2006; van der Molen et al. 2011) as well as creating fuel for forest fires (McKelvey et al. 1996; Trouet et al. 2010). Drought creates short-term changes to plant productivity, such as reduced primary (growth) and secondary (reproduction) productivity in long-lived species (trees and shrubs), and reduced and earlier productivity in most annuals and some perennials (Gray and Brady 2016; Seleiman et al. 2021). At the same time, species with a plasticity for deeper rooting depths outcompete those that have less plasticity and are more shallow-rooted, which leads to a change in both the forest overstory and understory, as well as to changes in chaparral community diversity (Roman et al. 2015; Spriester 2021). Recent studies show that woody species susceptible to cavitation (vapor embolisms) and hydraulic failure during prolonged drought, such as many species of conifers, die at the lower elevation margin and move upslope at the higher elevation ecotone (Bréda et al. 2006; Brodersen et al. 2019; Kelly and Goulden 2008; Savage and Vellend 2015; Willson and Jackson 2006). However, in

drought conditions, trees at the subalpine tree line may receive less snow cover (as insulation from freezing temperatures) and incur freeze damage causing higher mortality rates, which also decreases the abundance and can move the subalpine tree line to a lower elevation (Lloyd and Graumlich 1997). Combined, this can lead to the compression of biotic communities and force unusual inter-species competition where none was previously observed (Alley 1982; de Prado et al. 2022; Xu et al. 2023). This is significant when considering how forest ecosystem structure responds to prolonged drought, as changes in the timing of reproduction can alter species succession, especially when coupled with high mortality of some species at ecotone margins.

While the effects of long-term drought have yet to be recorded during the historic era within the western U.S.—which would provide a more direct accounting of exactly what happens to the vegetation structure—the Sierra does have a well-studied environmental history spanning the last 27,000 years. However, owing to the nature of peering back in time, paleoecologists like archaeologists are faced with incomplete records of past events. As such, the next section seeks to cover the environmental history of the western Sierra, offering numerous lines of evidence for vegetational changes in accordance with drought and glaciation. Humans are not absent from this interaction equation. But, based on archaeological evidence, large scale landscape manipulation (e.g., landscape burning) is likely relatively young within the region, which I cover further in Chapter Three.

2.3 Environmental History

During the last 27,000 years, the Sierra Nevada transitioned from a glacial to an interglacial stage which transformed the environment from a Great Basin-like steppe into a forested landscape (Anderson 1990; Brunelle and Anderson 2003; Clark and Gillespie 1997;

Davis 1999; Davis et al. 1985; Davis and Moratto 1988; Mensing 2001, 2015; Minnich and Padgett 2003; Phillips 2017; Phillips et al. 2009; Porinchu et al. 2003; Smith and Anderson 1992; Street et al. 2012; Wahrhaftig et al. 2019). It also experienced at least two minor glacial advances and at least two, possibly three, periods of warm and dry conditions punctuated by major droughts (Clark and Gillespie 1997; Davis and Moratto 1988; Minnich and Padgett 2003; Osleger et al. 2009; Phillips 2017; Phillips et al. 2009; Porinchu et al. 2003; Stine 1994).

Throughout the latter half of this period (c. 11,000 years ago), humans began making seasonal use of, then settled permanently in this region (Moratto 1984; Rosenthal 2011b). The native people throughout the region eventually employed multiple landscape management practices according to their needs (Blackburn and Anderson 1993). For example, buttonbush and willow were pruned for arrow-shaft material (Anderson and Moratto 1996). Individual shrubs of maple, redbud and oak were set afire to induce long shoots for basketry; stands of bunchgrass, as well as edible bulbs, corms and tubers were burned to enhance quantity and quality and to reduce successional species competition; and landscape-level burning was used to expand black oak communities and prolong the life of dry meadows (Aginsky 1943; Anderson and Moratto 1996; McCarthy 1993). The antiquity of some of these practices is unknown, while others are thought to be fairly recent adaptations coinciding with the cultural florescence of the Central Sierra Me-Wuk. These practices, combined with climate and vegetation history, have led to the vegetation structure that is witnessed today within the western Sierra Nevada.

In this section I focus on climate and environmental changes during the last ~5,000 years, beginning in the Middle Holocene. While only a few individuals within this dissertation date to this early period and experienced the environment of the Middle Holocene, the majority experienced climate from more recent periods and I strive to detail these environmental changes.

The following periods are divided into much longer segments than would be experienced by any one person, owing to the nature of reconstructions. This environmental background serves as the starting point to understand some of the landscape-level changes that humans would have faced and the decisions they made regarding gastric choices and settlement.

2.3.1 The Middle Holocene

The period from about 6,500-3,500 BP is thought to have been one of possible increasing moisture and slight cooling (Brunelle and Anderson 2003; Smith and Anderson 1992; Street et al. 2012) as compared to the early Holocene, which was dry, warm and drought-riddled (Anderson 1990; Davis and Moratto 1988; Lindström 1990; Mensing et al. 2004; Osleger et al. 2009). The Middle Holocene begins warm and dry, but by 5,000 years ago, precipitation begins to increase (Mensing et al. 2004), and by 4,100 a cooling trend is indicated (Benson et al. 2002; LaMarche 1973).

In the south-central western Sierra during the early part of this period, Swamp Lake, Yosemite experienced low lake levels due to reduced runoff (Street et al. 2012). Street et al. (2012) found low C:N ratios in lake sediment cores indicating increased algal contributions to the organic matrix (OM). The reduced runoff was part of a much longer dry period that began ~7,400 years ago (Street et al. 2012). Between 5,500 and 3,200, increasing precipitation is documented by a gradual increase in C:N, indicating a greater contribution from vascular plants to OM (Street et al. 2012:102). At June Lake, nestled within the subalpine forest near the eastern Sierran summit, Lyon et al. (2020:11) indicate high lake levels produced by high effective precipitation especially at the end of this period. Particularly high runoff events are estimated to have happened at $4,280 \pm 45$ and $3,960 \pm 245$ cal BP (Lyon et al., 2020: 11).

Tree stumps located within Lake Tahoe show a trend in lake levels rising during the middle Holocene, with death dates on the trees ranging from 6,304-4,846 cal BP as one moves up the slope of the lake shore margin (Lindström 1990: 150-154). The oldest stumps were submerged no less than four meters below the natural sill at the time of documentation (Lindström 1990: 150-154). The deepest trees were the result of the drying trend of the previous climate phase, which—due to low-flow events and sediment accumulation—also increased the height of the sill where Tahoe overflows into the Truckee River (Lindström 1990:154). However, some of the shallower trees were estimated to only be a few hundred years old at time of death, indicating a slow rise in lake level during this 3,000 year period (Lindström 1990). Sediment cores from Lake Tahoe also record increased turbidity during this period which suggests it was one marked by numerous extreme precipitation events (likely ARs) between ~5,600-3,100 BP (Osleger et al. 2009:116-119), similar to the record at June Lake. At Pyramid Lake, northeast of Tahoe, $\delta^{18}\text{O}$ increased in a step-wise fashion during this period (Benson et al. 2002) indicating that Pyramid Lake was not consistently receiving water from the Tahoe-Truckee River system (Mensing et al. 2004). However, by 3,430 cal BP, pollen and $\delta^{18}\text{O}$ records indicate Pyramid Lake began receiving regular inflow from the Truckee River, a sign that Tahoe had started to overflow its sill (Benson et al. 2002; Mensing et al. 2004).

During this time on the western slope, sub-alpine conifers began to colonize high elevation lakesides, while lower elevation forests grew more dense, replacing the previous pattern of open forests with an understory of shrubs (Anderson 1990; Brunelle & Anderson 2003). Mid elevation sites near 1,500 m (5,000 ft) saw an increase in pine and fir, with decreasing percentages of oak (Smith and Anderson 1992). In the southern Sierra, at the mid elevation site of Balsam Meadow, pine expanded, while fir and oak remained stable in low

numbers (Davis et al. 1985). Davis et al. (1985) suggest the high percentage of pine during this period represents the establishment of pine forest surrounding the meadow. Davis (1999) suggests that, for the area around Tulare Lake to the south and in the Central Valley, oak and mahogany decline and the lake goes dry during this period. Although based on interpretations of lake water levels from pelagic algae, this was true for the early part of this period and by the end of this period, pelagic algae is high, suggestive of deeper, open waters (Davis, 1999).

2.3.2 The Late Holocene

The last 3,500 years of climate in the Sierra have been variable, ranging from above average moisture to extreme drought followed by glaciation. Of note, with such variable conditions comes shifting mosaics of vegetation patterning, which means the vegetation was out of sync with climate conditions at times. From 3,500 to 1,000 years ago the modern vegetation structure of the Sierra began to establish and would have been similar to what is seen today. The regional pollen record for this period is unfortunately rather coarse-grained and prevailing interpretations lump the last ~ 3,500 years or more into one continuous category and analysis (e.g., Anderson 1990; Brunelle and Anderson 2003; Davis et al. 1985; Davis 1999; Davis and Moratto 1988; Smith and Anderson 1992). However, pollen diagrams are often provided along with estimated dates based on sedimentation rates and radiocarbon assays and allow some external interpretation, which I attempt below.

In the High Sierra, Anderson (1990) indicates cooler conditions prevailed around 3,500 years ago, continuing the trend from the previous period. Fir expanded at all high elevation sites, indicating cooler temps (Anderson 1990; Brunelle and Anderson 2003). By 2,500 years ago, mountain hemlock had moved downslope and could be found at the site of Ten Lakes 3, while it

had disappeared from Tioga Pass Pond some 235 m higher in elevation, indicating cooler conditions (Anderson 1990).

Fir and incense cedar also expanded at the expense of oak at mid-elevation sites between 3,500-2,500 cal BP (Smith and Anderson 1992). After this point, oak and incense cedar increase while fir declines, until about 2,000 cal BP (Smith and Anderson 1992:Figure 4). Similarly, Davis et al. (1985) note this period at Balsam Meadow in the southern Sierra as the “*Abies* (red fir) Zone” where increases in fir and oak indicate cooler temperatures and where pine is displaced further downslope, a condition that persisted until ~2,000 cal BP (Davis et al 1985: 328). At the valley location of Tulare Lake, Davis (1999) shows pine expands, which suggests cooler and wetter conditions. However, after about 2,500 years ago the percentages of oak and pine pollen decrease and give way to the expansion of basin-margin saltbrush vegetation, indicating the decline of oak woodland near the lake and dryer conditions (Davis 1999).

A period of highly variable precipitation and temperature oscillations punctuated by extreme and persistent drought conditions is evident by examining multiple climate-proxy records for the past 2,500 years (Ababneh 2008; Adams et al. 2015; Anderson 1987, 1990; Anderson & Stillick 2013; Benson et al. 2002; Brunelle & Anderson 2003; Cook et al. 2004; Davis 1999; Dettinger et al. 2011, 2018; Edlund 1996; Graham & Hughes 2007; Graumlich 1993; Hughes & Brown 1992; Hughes & Funkhouser 2005; Hughes & Graumlich 1996; Kirby et al. 2019; Kleppe et al. 2011; Knight et al. 2024; LaMarche 1973; Lloyd & Graumlich 1997; Meko et al. 2001; Mensing et al. 2004; Scuderi 1993; Smith & Anderson 1992; Stine 1994; Street et al. 2012; Swetnam et al. 2009; Wood 1975). For example, between 2350 and 1850 cal BP, Bristlecone pine tree ring indices from the White Mountains (LaMarche 1973) and high Total Organic Content (TOC) in sediment cores from Swamp Lake, Yosemite (Street et al. 2012)

indicate warmer temperatures and above average winter-spring temperatures. Frequent AR activity estimated from deposition of siliciclastic elements in Leonard Lake, CA (Knight et al. 2024) paired with the estimated warmer temperatures by LaMarche (1973) and Street et al. (2012), suggest that winter snowpacks may have been less than historical averages, which could have led to reduced spring runoff.

Benson et al. (2002: 675-676) note that during the same period, Pyramid Lake, Nevada was shallower. Increased wetness or abrupt lake level rises may be responsible for the transport of magnetite-bearing sediments to the deeper part of the lake, as indicated by increased $\delta^{18}\text{O}$ coupled with peaks in magnetic susceptibility of lake core sediments (Benson et al. 2002). At June Lake, this period is represented by spikes in Total Inorganic Carbon (TIC) and declines in lake level which Lyon et al. (2020:14) interpret as representing an interval of periodic droughts. Further evidence for an altered winter precipitation regime comes from Fallen Leaf Lake, CA where now-submerged trees dated to between 1988-1615 cal BP were found to have once lived on an exposed paleoshoreline during the early part of the late Holocene (Kleppe et al. 2011). Trees once grew above the modern subalpine treeline and increased in abundance during this era (Lloyd and Graumlich 1997). At Balsam and Dinkey Meadows, a warm and dry climate is indicated by the invasion of the meadow bogs by fir and suggests that the bogs may have dried during this period (Davis and Moratto 1988: 141). Following this warm interval, the climate cooled (LaMarche 1973; Scuderi 1993) and lake levels rose (Kleppe et al. 2011).

The next major climate change in the Sierra was a dry period punctuated by extreme droughts occurring approximately from the tenth to the thirteenth-fourteenth centuries (1,050-675 cal. BP) during what is called the Medieval Climatic Anomaly (MCA) (Anderson and Stillick 2013; Cook et al. 2004; Graham and Hughes 2007; Graumlich 1993; Kleppe et al. 2011;

MacDonald et al. 2008; Millar et al. 2006; Stine 1994; Street et al. 2012). The droughts were not continuous and were separated by a short interval of cooler and wetter conditions between 840 and 740 BP (Stine 1994) or between 916 and 800 BP (Cook et al. 2004). Temperatures in the Sierra during the MCA are estimated to have been between 0.5-3.2°C warmer than at present (Graumlich 1993; Millar et al. 2006). More recent research (e.g. Kleppe et al. 2011) indicates that the MCA also entailed lower precipitation totals accompanying the warmer temperatures. The MCA droughts, when compared to modern precipitation records, are projected to have lasted multiple decades, some spanning 80 or more years, and entail reconstructed precipitation amounts of no more than 60-65% of what is considered normal (Graham and Hughes 2007; Kleppe et al. 2011; Stine 1994). Of importance is that while the MCA is generally regarded as a period of higher temperature in the northern hemisphere (Mann et al. 1999), higher temperatures in the Sierra during winter mean lower snowpack totals (and lower snow-to-water equivalency) earlier in the year, which translate to greater moisture deficits in the soil earlier in the year, and dryer conditions in the valley and the entire Sierra as less water runs through rivers, creeks and streams due to reduced snow pack and less meltwater (Belmecheri et al. 2016; Dettinger et al. 2011, 2018; Shulgina et al. 2023). The combination of warmer temperatures and reduced precipitation exacerbates the negative effects of each and has cascading effects that would have impacted those living in the Sierras, from plants and animals to humans.

Lowering of lake levels, decreased waterflow, and soil moisture deficits are a region-wide trend during this period. Multiple tree ring records from throughout the Sierra Nevada and White Mountains document lower precipitation and soil moisture deficits during the MCA (Ababneh 2008; Graumlich 1993; Hughes and Brown 1992; Hughes and Graumlich 1996; LaMarche 1973). As well, fire frequency increased during this era, likely due to the moisture deficit which

created increased fuel loads, such as dead and fallen trees and branches (Brunelle and Anderson 2003; Swetnam et al. 2009). Lloyd and Graumlich (1997) found that the alpine tree line lowered during this time due to die-off at the upper ecotone margin, which they speculate was due to reduced precipitation. Mono and Tenya Lakes (Stine 1994), as well as Fallen Leaf Lake (Kleppe et al. 2011) have relict trees which grew on now-submerged paleo shorelines during the MCA, indicating lowered lake water levels. Lower lake levels are also recorded for Lake Elsinore (Kirby et al. 2019) and Pyramid Lake (Benson et al. 2002; Mensing et al. 2004). At Swamp Lake, Yosemite during the MCA, high lake productivity and active organic matrix cycling correspond to the warmer and drier climate (Street et al. 2012). At Tulare Lake, Davis (1999: 253, figure 3) shows that there is a sharp decline in pelagic algae at this time (indicating stagnation, reduced inflow and lowering of lake levels), as well as an increase in deteriorated pollen (indicative of pollen desiccated by heat/lack of moisture), although she does not discuss the MCA directly. More recently, Adams et al. (2015) demonstrate extreme low flows in the Kings, Kaweah, Tule and Kern Rivers coming from the southern Sierra Nevada during the MCA and link these to extreme low stands within Tulare Lake. The Merced River also experienced low flows during this time (Graham and Hughes 2007). Similarly, Meko et al. (2001) demonstrated the flow of the Sacramento River was reduced twice for long periods of time during the MCA interval (1050-600 BP) indicating that river levels were below anything witnessed historically. Meko's (2001: 1035) reconstructed low flows are stated as lasting for a half a century at a time, ending at 1175 A.D. (775 cal BP) and 1400 A.D. (550 cal BP). While the timing of the droughts varies somewhat between areas north or south of 40°N latitude—a latitude recognized by many researchers as a switching point for storm tracks between positive and negative PDO phases

(Dettinger et al. 1998)—the timing of the MCA drought south of 40°N largely correlates with the estimates of Cook and colleagues (2004) for the Western U.S.

The period of extreme drought conditions of the MCA was followed by cooler temperatures and increased glacial activity during the Little Ice Age (LIA) from ~450-50 yr BP (1500- 1900 CE) (Clark and Gillespie 1997; Phillips et al. 2009). The climate conditions of the LIA are reminiscent of terminal Pleistocene conditions and the Recess Peak glacier advance of 14,000-12,000 years ago (Clark and Gillespie 1997; Phillips et al. 2009). The maxima of the Little Ice Age glaciers, referred to as the Matthes glaciers, reached their peak between 1880 and 1897 CE (Clark and Gillespie 1997; Curry 1969). This set in place the forest ecotone positions observed for most of the 20th century. However, during the LIA within the Sierra, there was a decline in the abundance and changes in the position of the subalpine tree line, indicated from relict stands of subalpine trees (Lloyd and Graumlich 1997). Mid-elevation locations saw an increase in fir (*Abies spp.*) species indicative of overall cooler conditions during this period (Anderson 1990). The frequency of fire did not decline in meadow settings, signaling the use of cultural low intensity burning of the landscape by Native American communities (Anderson and Stillick 2013; Brunelle and Anderson 2003).

Since the end of the LIA, the glaciers have been in retreat as the climate again has warmed (Moore and Moring 2013; Phillips et al. 2009), while more recently the high-elevation tree line is moving upslope, as are the many other ecotone boundaries (Hill et al. 2023; Kelly and Goulden 2008). California, and the Sierras, have experience multiple cycles of short intermittent drought, with some, such as 2015, indicating snow-water equivalency is the lowest it has been in the last 500 years (Belmecheri et al. 2016).

While the elevational positioning of biotic communities first documented in the Sierra beginning in the 1850s was the result of the most recent glacial advance, the structure of the forests, meadows, and grasslands was the combined result of natural processes such as wildfires, drought, glaciation, deglaciation, plant succession, regrowth, and reproduction as well as the land-use and management practices of the Me-Wuk and their ancestors. While it is rare that humans learn lessons from the past, it is hopeful that by peering back through the looking glass at what adaptations and innovations served the Native communities well during drought, we might find similar solutions to our own similar problems.

2.4 Chapter Summary and Discussion

In this chapter, I have covered the environment of the Sierra, detailing the geography, elevation-dependent biotic communities, climate, and vegetation history to lay the foundation of the environment for later chapters. I began with a general description of the west slope of the region, stating that it covers over 53,000 km² (Raumann and Soulard 2012). Noting the differences between the northern and the southern portions of the region, I—like many other Sierran researchers—chose to divide the region into three parts, and mainly focus on the west central portion between 38.22-37.37 °N, bounded on the northern edge by the Mokelumne River, on the south by the Merced River, and encompassing the drainages of the Stanislaus and Tuolumne Rivers. This area is the region of focus, as it encompasses the traditional territory of the Central Sierra Me-Wuk, the people under study within subsequent chapters.

Next, I detailed the biotic communities, explaining that they are structured according to elevational gradients, which are further correlated with temperature, precipitation, and jet stream patterns (Axelrod 1977; Dettinger et al. 2018; Eardley and James 2024; Jameson and Peeters

2004; Major 1977; Millar 1996; Storer et al. 2004; Storer and Usinger 1963). Of importance is that the western Sierra has six elevation-dependent biotic communities that grade into each other: the Lower Sonoran (0-90m); Upper Sonoran (38–1,524 m); Lower Montane (365–2,743 m); Upper Montane (1,676-3,048); Sub-Alpine (2,100-3,350); and Alpine (above 3,300 m) (Griffin 1972; Storer et al. 2004; Storer and Usinger 1963; van Wagtendonk et al. 2018).

These biotic communities are rich with varied resources such as many edible greens, bulbs, corms, berries, fruits, nuts, and small seeds. Animals within these communities and important to Sierran human diets include mule deer, black-tailed deer, antelope, elk, a variety of rabbit, hare and ground squirrels, and quail. Although fish inhabit waters below 6,000 ft, their importance to prehistoric human diets with the Sierra is debatable—yes, the people fished, but fish do not have a strong presence archaeologically. Important to understanding dietary decisions is the premise that the west-central Sierra is a patchy environment—not every resource is available in every zone, nor is time of ripening commensurate across all zones (Storer and Usinger 1963).

Following the detailed descriptions of the biotic communities, I covered the general climate. I explain that with the Mediterranean-type climate, the Sierra is characterized by large fluctuations in temperature and precipitation at multiple time scales (Axelrod 1977; Dettinger et al. 2011, 2018; Major 1977; Mulch et al. 2008; Storer and Usinger 1963). In this section I paid particular attention to precipitation, snowpack, and drought, detailing some of the major drivers behind this variability such as PDO, ENSO events, frontal cyclones, and Atmospheric Rivers (Dettinger et al. 2018:14; Mantua and Hare 2002; Newman et al. 2016). Of note is AR activity has been traced back to at least 9,000 years (Kirby et al. 2012; Knight et al. 2024), and in modern times is shown to be responsible for up to ~40% of California’s snow-water equivalent in wet

years (Guan et al. 2013). The most salient point regarding winter snowpacks is they serve as water reservoirs and are responsible for sustaining waters flowing from the Sierra into the central valley and Great Basin (Godsey et al. 2014; Penczykowski et al. 2017; Slatyer et al. 2022; Stewart 2009; Viviroli et al. 2007). As well, the timing of the snowmelt is a critical determinant of whether Northern California will be thrown into drought, as the region is greatly dependent on the Sierra snowpack and meltwaters flowing into rivers and moisture-depleted soils during the hot summer months (Godsey et al. 2014; Lapidés et al. 2022; Tague and Peng 2013; Viviroli et al. 2007).

I next focused on a further discussion of drought, and explained that widespread, short-term droughts lasting one-three years, and long term droughts lasting multiple decades, although less frequent, have happened numerous times throughout the last 11,000 years (Rodney S. Anderson 1990; Davis and Moratto 1988; Dettinger et al. 2018; Graumlich 1993; Mensing 2001; Mensing et al. 2004; Osleger et al. 2009; Street et al. 2012; U.S. Geological Survey). The region has evolved to deal with short term droughts, such as those recorded historically (Axelrod 1977; Major 1977).

This discussion continued with a listing of the consequences of short-term droughts, such as forest fragmentation, destructive wildfires, changing species abundance and diversity, pest and disease susceptibility, erosion, upslope movement of biotic zones, reduced plant productivity, reduced river flows, drying of perennial streams and creeks, reduced inputs to subsurface water tables, and altered species succession (Allen et al. 2010; Allen and Breshears 1998; Bréda et al. 2006; Lapidés et al. 2022; McDowell et al. 2008, 2010; van der Molen et al. 2011). Of importance is that consequences of long-term droughts are less well known, but are expected to have altered the vegetation structure as has been observed in multiple locations over shorter

timescales during the modern era (Hill et al. 2023; Kelly and Goulden 2008; McDowell et al. 2008, 2010; van der Molen et al. 2011). Long-term droughts are expected to amplify each of these concomitants, which would have affected the base resource structure in the region. As such, questions arise as to how this may have affected human foraging decisions and settlement patterns within the west-central Sierra.

Last, I covered the environmental history of the western Sierra focusing on the last ~5,000 years, as it is the most relevant to my research. I began with a general overview of changes that took place over the last 27,000 years to set the scene for the more in-depth discussion of Middle and Late Holocene climate and vegetation history.

To summarize, the Middle Holocene (6,500-3,500 BP) began warm and dry, with lake low-stands documented throughout the region (Benson et al. 2002; Lindström 1990; Lyon et al. 2020; Mensing et al. 2004; Osleger et al. 2009; Street et al. 2012). However, the overall trend is one of cooling and increasing precipitation as compared to the Early Holocene, with evidence for large-scale precipitation events commencing between 5,000-4,000 years ago (Lyon et al. 2020; Osleger et al. 2009; Street et al. 2012). Importantly, the vegetation structure of the Sierra was slowly morphing from open forests with a shrub understory to a more closed-canopy type, with previously-rare mesic species (e.g., most pines, fir) becoming more prominent across the landscape while more xeric-adapted species (e.g., oak, manzanita) became more restricted (Rodney S. Anderson 1990; Brunelle and Anderson 2003; Davis et al. 1985; Smith and Anderson 1992).

I next attempted a thorough discussion of the Late Holocene (3,500-present), which can be characterized as highly variable, with an emphasis on both terms. The Late Holocene begins as cool and wet, with pine, fir, and cedar expanding across many elevations and moving

downslope in some instances (Rodney S. Anderson 1990; Brunelle and Anderson 2003; Davis 1999; Davis et al. 1985; Smith and Anderson 1992). After 2,500 BP, multiple lines of evidence point to periodic droughts and highly variable precipitation and temperature oscillations.

The first drought took place between 2350-1850 BP, and, although the duration and intensity are unknown, it was enough to create declines in lake levels on both sides of the Sierra, dry out meadow bogs on the west slope near Yosemite, and may have been due to reduced snowpack totals from warmer winter temperatures lasting for more than two centuries (Benson et al. 2002; Davis and Moratto 1988; Kleppe et al. 2011; LaMarche 1973; Lyon et al. 2020; Street et al. 2012). This drought is frequently overlooked in archaeological literature of the Sierra, although some Great Basin researchers have noted its widespread occurrence mainly below 42-40°N latitude (e.g., Mensing et al. 2013), which is relevant to my study area which lies below this point. More “normal” conditions returned following this drought, lasting until the well-documented MCA began around 1,100 BP (Kleppe et al. 2011; LaMarche 1973; Scuderi 1993).

The MCA was a period of above average temperatures throughout the northern hemisphere (Mann et al. 1999), however, for the Sierra it spelled drought. The droughts were not continuous and were separated by a short interval of cooler and wetter conditions between 840 and 740 BP (Stine 1994) or between 916 and 800 BP (Cook et al. 2004), with drought conditions continuing until about 600 BP. Of importance to my research is that the conditions during the MCA were extreme enough to force a major die off at the upper treeline (Lloyd and Graumlich 1997), reduce river flows beyond anything witnessed historically (Adams et al. 2015; Graham and Hughes 2007; Meko et al. 2001), lower lake levels (Benson et al. 2002; Kirby et al. 2012; Kleppe et al. 2011; Mensing et al. 2004; Morgan 2006:64–66; Stine 1994) and in some cases allow trees to grow along the new lower-elevation shores of those lakes (Kleppe et al. 2011;

Morgan 2006:64–66; Stine 1994). Numerous studies have also documented water deficits in soil moisture during the MCA, as measured by tree ring widths, and upticks in the occurrence of major forest fires (Ababneh 2008; Graumlich 1993; Hughes and Brown 1992; Hughes and Graumlich 1996; LaMarche 1973). Apparent water-deficits aside, the MCA also entailed warmer temperatures, documented in tree rings from the Sacramento watershed, south to the White Mountains (Graumlich 1993; Meko et al. 2001; Millar et al. 2006).

While the MCA was two droughts separated by a return to cooler and moist conditions, the post MCA climate caused vegetation whiplash and led to a short period of glaciation, during the LIA, beginning around 450 BP and lasting until ~50 BP. The LIA set in place the forest ecotone positions observed for most of the 20th century.

To put the MCA conditions in perspective, given earlier discussion of snowpacks and drought, major water shortages that reduced river flows and caused major drops to lake levels would have certainly been noticeable to the people living in the Sierra at the time, as would have been any concurrent vegetational changes such as die-offs, upslope movements, reduced secondary production (seeds, nuts, fruiting), etc. If we consider the reduced river flows as valid, then we also need to consider that the many perennial streams and seasonal creeks may have also been affected, as most contribute to river flows. If this is the case, then we might also consider that sites located away from streams and rivers in the lower elevations may have become disused or abandoned during the MCA, and that more reliable water sources, such as the major rivers, were sought out as better suited locations from which to forage. This sentiment echoes that of Wohlgemuth (2005) and Rosenthal (2011c:235–236), who have also suggested the MCA drought may have affected settlement patterns in areas located away from major rivers.

Chapter 3: History of Anthropological Research in the West-Central Sierra Nevada

The history of anthropological investigation in the Sierra Nevada began amidst anthropologists' mounting concerns over further loss of Indigenous cultural practices due to colonization, and, to a lesser extent, with debates over the antiquity of humans in the western Sierra Nevada. These two reasons brought the first anthropologists into the region around 1900.

Although some reports of Sierra Miwok culture from various sources pre-date 1900, few investigations focused on recording the culture or language, and none of the researchers had any formal training to do so. These early reports, notes, and newspaper articles offer unique insights on Native lifeways as they were encountered, but they are “off the cuff” observations and thus, are typically not considered in ethnographic accounts, although Stephen Powers (1877) provides an interesting source of information on Me-Wuk lifeways prior to 1900. One exception is Clinton Hart Merriam, who was concerned over the welfare of Native Californians and language loss. Some of Merriam's (1904, 1967) work took him into the Sierra Nevada. His 1904 publication mainly discusses the languages of Native Californians in the southern Sierra Nevada and San Joaquin Valley, while the post-humous 1967 publication lends some insight on Sierra Me-Wuk lifeways near the turn of the last century (Merriam 1904, 1967:325–363).

Ethnography of the Sierran peoples came about during the first half of the 1900s, with a peak before 1930 and slowly tapered off thereafter. Ethnographic reports and linguistic analyses by “trained observers” documented the Sierra Miwok cultures, such as the works of William Henry Holmes (1902:170–173), E.W. Gifford (1944, 1916, 1917a, 1926), Alfred L. Kroeber (1908, 1922, 1925), Samuel A. Barrett (1908; Barrett and Gifford 1933), Bernard Aginsky (1943), Catherine Callaghan (Broadbent and Callaghan 1960; 1972, 1977, 1979, 1987, 1997),

Lucy S. Freeland (1951; Freeland and Broadbent 1960), Victor Golla (2011), and Richard Levy (1978). While the works of the many of aforementioned authors have been invaluable as reference points from which to frame questions regarding human behavior, they fail to account for changes in culture—treating much of Me-Wuk culture as static or unchanged. The exceptions are the linguists who worked on understanding the evolution of the Miwok language during the middle half of the 20th century and later. Because the purview of salvage ethnography revolved around the persistence of memory—some notion of what culture “used to be like”—we have a distorted view of the norms of behavior as often only a few informants remembered them. These behaviors and relationships have become conflated among large geographical areas and over time. In this regard, the works of Barrett (1908) and Gifford (Barrett and Gifford 1933; Gifford 1944, 1916, 1917a, 1926) freely acknowledged their own works as occurring after Sierran lifeways were unimaginably altered following missionization and the gold-rush. They do not consider cultural evolution or adaptation prior to this time. Wobst (1978) understood the danger of extracting human behavior from the salvage ethnographies, and warned of archaeology that only served to reinforce what ethnographies said, rather than as based on true anthropological theory.

During those first fifty years, archaeologists were generally uninterested in the western Sierra Nevada, only occasionally investigating cave sites (Mercer and Hawver Caves) and reports of human remains of “Early Man” (e.g., Holmes 1901, 1902; Nelson et al. 1910) and Pleistocene fauna (Stock 1917), and instead focused on other regions of California such as the rapidly developing San Francisco Bay area and the disappearing shellmounds (Gifford 1917b; Nelson 1909, 1910; Uhle 1907). However, just as ethnographic research was dwindling in the

Sierra Nevada, the passage of the Flood Protection Act of 1944 brought a new surge of interest, this time from archaeologists (Moratto and Riddell 2016).

Similar to the earlier concerns felt by the ethnographers and linguists, California archaeologists became concerned with the potential loss of buried cultural information that was likely to commence following the passage of the Flood Control Act. Numerous proposed dam and reservoir sites throughout the Sierra Nevada were surveyed (Drucker 1948a, 1948b, 1949; Fenenga 1947, 1950; Fredrickson 1949; Osborne 1948), with archaeologists volunteering to ensure minimal loss of information (Moratto and Riddell 2016). During the second half of the 1900s, more laws—the Reservoir Salvage Act of 1960, the National Historic Preservation Act of 1966, the National Environmental Preservation Act of 1970, Archaeological and Historic Preservation Act of 1974, Archaeological Resources Protection Act of 1979, and the Native American Graves Protection and Repatriation Act of 1990—were passed, enacting further protection for archaeological sites (King 2013). The progression of archaeology within the Sierra Nevada is closely tied to these laws, their interpretations, how they were enacted, and the development of Cultural Resource Management (CRM) archaeology. The bulk of material for this dissertation derives from several CRM projects within the region over several decades.

This chapter begins with a summary of the Central Sierra Me-Wuk culture as it is detailed by ethnographic and linguistic reports, with a primary focus on subsistence and settlement patterns. I begin with a review of the ethnographic sources, followed by a review of linguistic geography, and then a discussion of social organization, settlement patterns, and subsistence-related information. Throughout this section I use “Miwok” in reference to the language and its speakers in a broad sense, while I reserve the use of “Me-Wuk” specifically for those who inhabited, and continue to inhabit, the central Sierra Nevada. In the following section, I cover the

history of archaeological research within the region, noting differences between initial “archaeology” and later developments brought by changing federal and state laws. I will discuss how this legal shift had an impact on some sites. Further, I examine other avenues of inquiry stemming from CRM projects, namely chronology building, and settlement and subsistence studies. Finally, I provide an overview of the region’s culture history, and then I interpret and discuss a refined chronological placement of the New Don Pedro burials based on my research, and the broader implications for our understanding of the region’s cultural history.

Throughout this and later chapters I refrain from using the word “prehistory,” as it is derogatory (see Fuller 2011). Instead, I refer to the period preceding European “contact” in a general sense as the cultural history, which should not be confused with the Culture History approach used by early archaeologists throughout the Americas. However, please note I am using names for period divisions coined by Rosenthal (2008a, 2011b), which do include the word “prehistoric.”

3.1 The Ethnography of the Central Sierra Me-Wuk

The ethnography presented below represents an amalgamation of various sources that documented Me-Wuk culture in the Sierra Nevada from the early historic period, circa 1870s through the 1930–40s. Sources range from newspaper articles and the published musings of early visitors to California, to amateur reports, to professional ethnographies and linguistic analyses. Each of these source-types varies in the quality, aspect, and scope of information, just as they vary in terms of when and why they were published. Unlike the California Native groups living in coastal regions, and to some extent the Central Valley, those in the Sierra Nevada did not experience forced missionization, early maritime explorers, nor French and Russian coastal fur

traders and trappers (Hull 2012:19; Kroeber 1925:VI, 278, 445, 546–547; Levy 1978:400–401). Those earliest sources of cultural information so frequently sought by anthropologists do not exist for Sierran groups.

Instead, local newspapers, which sprang up during the Gold-Rush era, are some of the earliest sources documenting Sierra Miwok culture. For example, the *Columbia Gazette*, a small mining-town newspaper from Tuolumne County, published a reader's account of a local Me-Wuk mourning ceremony following the tragic and unexpected death of a local tribal member (*An Indian Funeral, a Horrible and Affecting Scene* 1854). In the recounting, the letter-writer details the emotional turmoil of the small Native group, their reactions to the body, how the body was prepared and laid out for cremation, the cremation as it unfolded, and the process of mourners attending the ceremony. Although not profoundly informative, accounts such as this capture certain aspects of unprompted Sierra Me-Wuk culture in action, which was rare for later ethnographers and linguists.

Among the most informative sources are ethnographic reports by the myriad of anthropologists who, prompted by the common concern of the time over the continual loss of Native cultures, made their way into the Sierra Nevada. These include Edward W. Gifford (1916, 1917a, 1926), Alfred L. Kroeber (1908, 1922, 1925), C. Hart Merriam (1918), Samuel A. Barrett (1908; Barrett and Gifford 1933), and Bernard Aginsky (1943). Their works are the primary sources for contact-era Sierra Miwok culture. However, much information is also missing from their published notes and reports, such as seasonal movements.

Linguists too have contributed a wealth of knowledge through their unravelling of unwritten languages—the works of Catherine Callaghan (Broadbent and Callaghan 1960; 1972, 1977, 1979, 1987), Lucy S. Freeland (Freeland 1951; Freeland and Broadbent 1960), Stephen

Powers (1877), and Victor Golla (2011) stand out. Levy (1978) provides a valuable summary of much of this earlier work as well as a discussion of history. Together, these sources paint an impressionist picture of lived experiences shared among Sierra Miwok groups during the historic period, and from which the ethnography of the Central Sierra Me-Wuk can be drawn out.

The ethnography of the Sierra Miwok-speakers is not without issues. It is a blurred picture of Indigenous lifeways within the Sierra Nevada during the contact period. It is blurred to some extent because not all cultural information is meant for etic audiences (Fuller 2011), ethnographic coverage is spotty among locations as well as in information, and because these ethnographic accounts treat culture as a static entity as based on memories (Barrett and Gifford 1933:359; Gifford 1926:391–392; Heizer 1955:51; Hull 2012:122, 124; Levy 1978:400–401). The ethnography of the Sierran Miwok groups is viewed within this historical context. Importantly for this dissertation, the ethnographic information serves as a starting point for ascertaining subsistence and settlement patterns of the Central Sierra Me-Wuk, as it allows the observations of the ethnographies to be tested.

3.1.1 Miwok Linguistic Geography

“Miwok” is not how the Native peoples who spoke the language defined themselves—it instead translates from Eastern Miwok to English as “people” or “people of” as it is the plural of *miwü*, an Eastern Miwok word for “person” (Kroeber 1925:443). Powers (1877:346–347) was the first to apply the term to the speakers of this language, however he reserved it for his discussion of those encountered in the Central Valley and the Sierra Nevada. It was later applied to all groups who spoke a dialect of Miwok, regardless of location or their actual word for “people” (Nelson 2021:469). Ironically, during early studies of Native Californian languages, a language was frequently named by its own word for “people” or “person” (e.g., “Maidü” is

Maiduan for “person”; “Yana” means “person” in the Yana language). This practice engendered entire cultures to be referred to by their own linguistic term for “people”, sometimes followed or preceded by a locational distinction (e.g., Central Sierra Miwok). Kroeber (1925:444) notes when Miwok referred to one another, it was by village name or a general directional term, such as northerners. Today the progeny of the ethnographic Central Sierra Miwok distinguish themselves as Tuolumne Me-Wuk and Central Sierra Me-Wuk and prefer to be referred to as such by others. As pertains to coastal groups speaking a dialect of the same language, avoiding this term would be preferred (Nelson 2021:469).

In modern usage, the term Miwok broadly refers to seven distinct languages of the Miwokan subgroup of the Penutian language family (Golla 2011:156; Levy 1978:398). During the historic period, the Miwok languages were spread across California from the San Francisco Bay area to the Sierra Nevada, with the Sierran subgroup being comprised of three languages, North, Central, and Southern—each further differentiated by numerous dialects (Broadbent and Callaghan 1960; Freeland 1951; Golla 2011; Levy 1978). Callaghan (1987:5), an expert on Miwok languages, likens the three Sierra Miwok languages to being as close to each other as are Swedish, Danish and Norwegian—mutually intelligible, but distinct.

Language and dialect differentiation have long been used to track the spread of groups into new territories and to estimate the relative antiquity of language families. Glottochronology often consults archaeology to refine its timeframe. Based on such data, current interpretations of the antiquity of the Eastern branch of the Miwok language family—which includes Bay, Plains, and the three Sierra Miwok languages—suggests it split from the Western branch of Miwok between 2,500 to 3,000 years ago (Callaghan 1997:18; Golla 2011:156). If this linguistic split reflects population movement, it suggests Western Miwok speakers moved west towards the Bay,

while Eastern Miwok speakers moved east into the Central Valley prior to 2,500-3,000 years ago (Callaghan 1997:18). I suggest that the separation of these languages may also reflect a reduction in population movement, as groups began settling more permanently into place

Lexical data for Sierra Miwok suggest it separated linguistically from Plains Miwok sometime between 2,000-1,500 years ago (Golla 2011:253; Levy 1978:399). Again, this implies some movement away from a “central mass”, thought to have been located in the Central Valley, with populations moving easterward toward, if not fully into, the Sierra Nevada foothills. It is possible the Sierra branch retained ties with the Plains branch until circa 2,000 to 1,500 years ago, after which population movement was reduced as people settled within more defined territories.

I suggest the lexical data indicate a long standing pattern of use of the western Sierra Nevada by Miwok speakers, among others (e.g., Yokuts, Paiute, Washo, Nisenan), and it was only after territoriality became a more clearly established that the true dialectical differentiation within Sierra Miwok became visible, as geographic “catchment” areas became culturally defined. Sierra Miwok began differentiating dialectically sometime between 500-800 years ago (Golla 2011:253; Levy 1978:398, 399). Golla (2011: 253) suggests it is plausible that after the Sierra-Plains split, Sierra Miwok speakers “remained in a small, linguistically undifferentiated area for several centuries” before speakers moved south and developed the observed dialect boundaries. This begs the questions of exactly when and where the Sierra Miwok first settled, and has sparked ongoing debate.

The “small area” referred to by Golla (2011) is unknown. However, before Golla (2011), Moratto (1984:560–562) suggested it lay in the foothills between the American and Calaveras Rivers (Figure 3.1). More recent archaeological analysis from the central Sierra Nevada suggests

the cultural system associated with the Central Sierra Me-Wuk was in place by 610 cal BP, with apparent shifts in settlement systems, diet, and technology possibly beginning much earlier, around 1,100 cal BP (Rosenthal 2011b). Taken together, the parsimonious interpretation is people speaking a form of Sierra Miwok were responsible for the shifts in culture seen in the west-central Sierra Nevada beginning around 1,100 years ago. By 600 years ago, Sierra Miwok appear to have established themselves within their dialectical bounds of the ethnographic era. This idealized population movement and linguistic separation is shown in Figure 3.2.

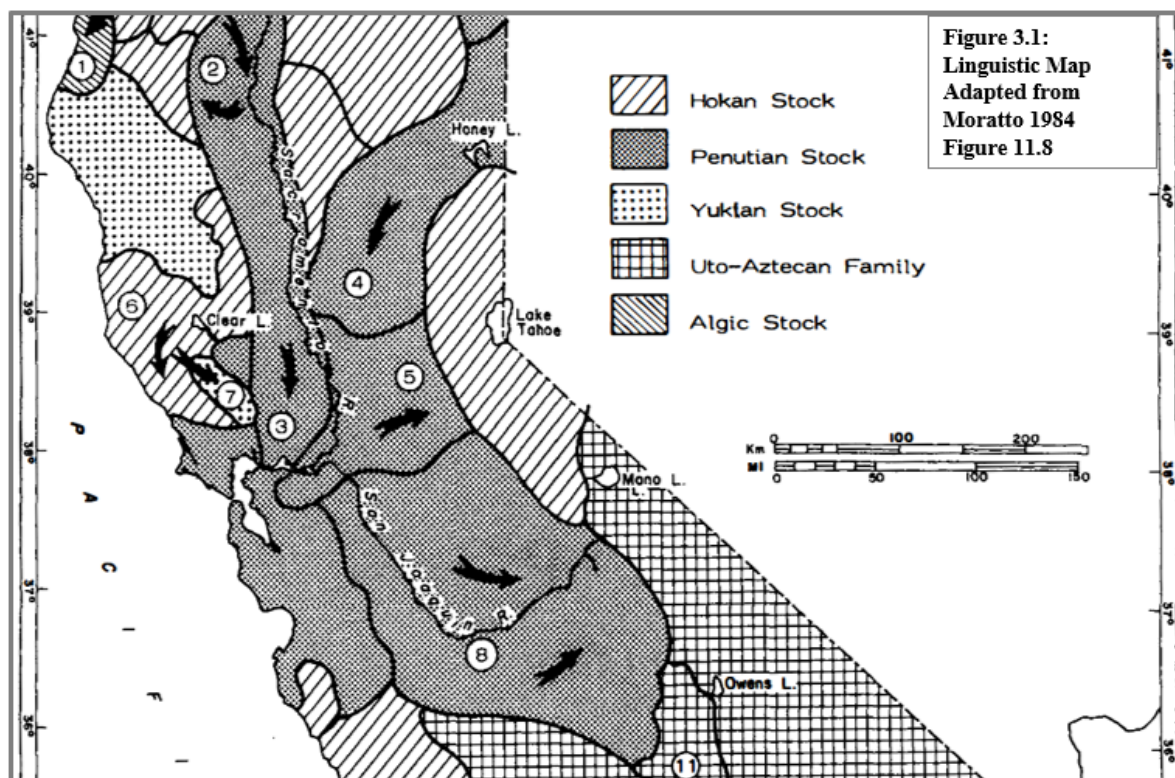


Figure 3.1 Linguistic Map (adapted from Moratto 1984: Fig. 11.8)

Map shows the expansion and movement of Penutian languages across northern California happening in multiple waves. Map indicates the spread of Penutian speakers from a Central Valley Population (wave 5), moving east, and then eventually south (wave 8) as based on Moratto's 1984 research. Wave 8 was associated with the spread of Sierra Me-Wuk.

During the early historic era, speakers of Central Sierra Miwok inhabited the foothills and mountains of the western Sierra Nevada, to the east of the southern Sacramento-northern San Joaquin Valley margin (Aginsky 1943; Barrett 1908; Barrett and Gifford 1933; Kroeber 1925;

Levy 1978). Ethnographers indicate their traditional territorial boundaries were ill-defined, fluid, and encompassed a large portion of land that is today Tuolumne County, and parts of Calaveras County (Aginsky 1943; Barrett 1908; Kroeber 1908, 1925). Their home range encompassed the drainages of the Tuolumne and Stanislaus Rivers from their points of origin in the Sierra Nevada in the east, to the lowest foothills along the valley margin (Barrett 1908: map 3; Barret and Gifford 1933).

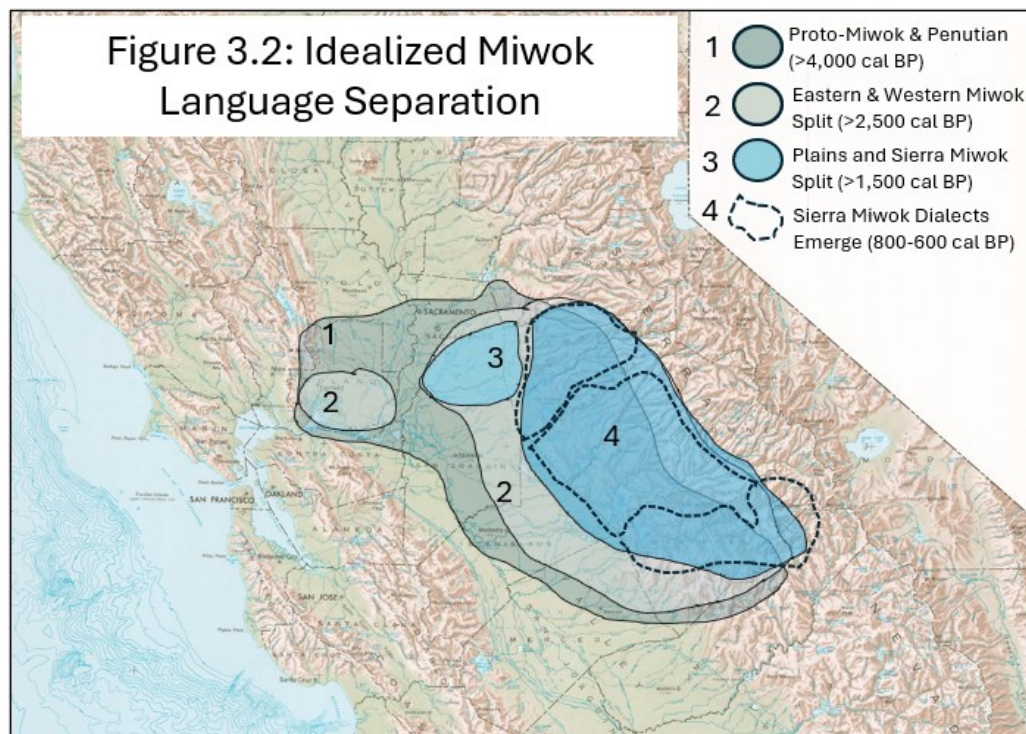


Figure 3.2 Idealized Miwok Language Separation

Map of central California with the idealized movement and linguistic separation of the Miwok languages suggested in the text. In Phase 1, much of the Central Valley, part of the Bay, and the western Sierra Nevada are envisioned to have been occupied by Penutian speakers, with Prot-Miwok speakers among them prior to 4,000 cal BP. During Phase 2, this graphic depicts the separation of Eastern and Western Miwok languages, envisioned as a type of condensing of the population; and is thought to have occurred before 2,500 cal BP. Phase 3 indicates the Separation of Plains Miwok from Sierra Miwok, sometime prior to 1,500 cal BP, and is further envisioned as another contraction of these populations. During Phase 4, dashed lines indicate the emergence of the Sierra Miwok dialects, which is thought to have occurred sometime between 800-600 cal BP. Importantly, rather than broad population movements into new regions, Figure 3.2 shows how territorial circumscription may influence linguistic separation and evolution. The information for this graphic draws heavily from the authors mentioned in the text in section 3.1.1., but any inaccuracies are my own.

The linguistic and ethnographic derivation of territorial boundaries comes from parsing out statements provided by Native informants from the Central Sierra Miwok and adjacent linguistic groups (Aginsky 1943; Barrett 1908; Kroeber 1908). Central Sierra Miwok territory was bounded by many neighboring groups which include the Northern Sierra Me-Wuk to the north, Washo to the northeast, Southern Sierra Me-Wuk to the south in the Yosemite region, the Paiute of the Eastern Sierra Nevada to the east, Yokuts to the west and southwest, and the Plains Miwok to the northwest (Barrett 1908; Kroeber 1925). This is shown in Figure 3.3, a map indicating the scope of the traditional territory as well as that of neighboring groups.

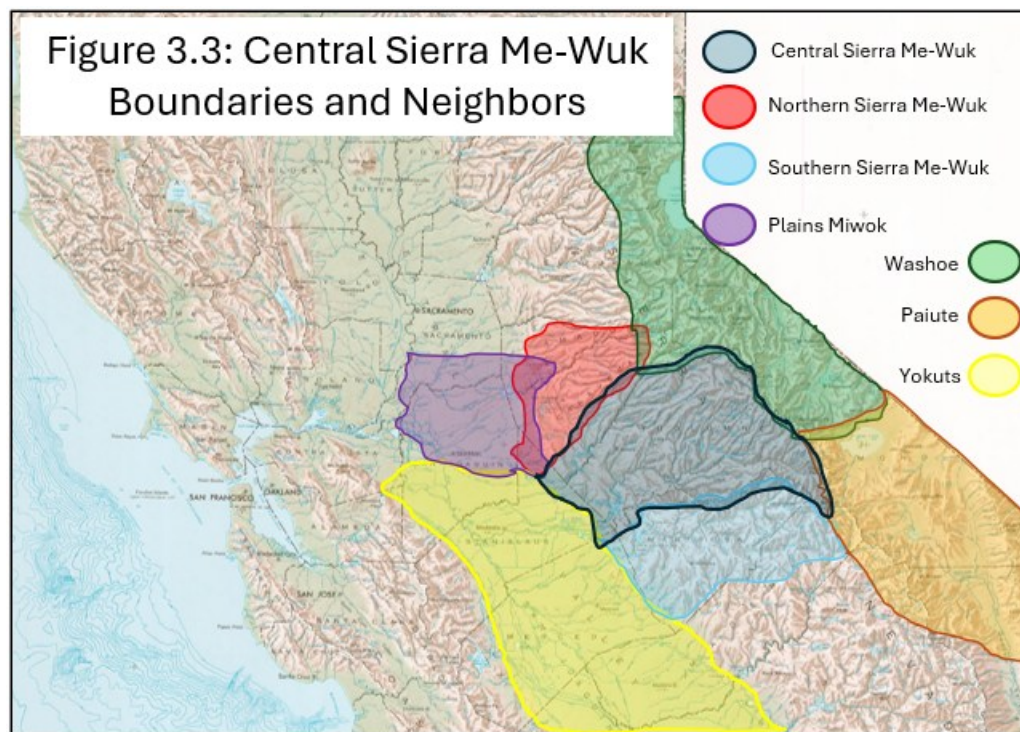


Figure 3.3 Central Sierra Me-Wuk Boundaries and Neighbors Map
A modern culture-area map highlighting the territory of the Central Sierra Me-Wuk in relation to their neighbors. Central Sierra Me-Wuk area (light blue) is shown in the center of six other cultural groups: (moving clockwise from the North) the Northern Sierra Me-Wuk (red), the Washoe (green), the Paiute (orange), the Southern Sierra Me-Wuk (blue), the Valley Yokuts (yellow), and the Plains Miwok (purple).

3.1.2 Sociopolitical Organization and Settlement Structure

Central Sierra Me-Wuk social structure revolved around the concept of the *nena*—a term with the dual meaning of patriline and the ancestral home of the patriline (Gifford 1926:389; Levy 1978:399, 410). Although patrilineages are the main element of social structure, more broadly each *nena* was associated with one of two moieties, land or water, and marriage was exogamous among the moieties (Gifford 1916; Merriam 1967:347). Descent within the moieties was patrilineal (Gifford 1926:389). The land side moiety commonly identified as the bluejay or deer, while the frog stood for the water side (Gifford 1916:140; Merriam 1967). In Sierra Miwok worldview, the world was made up of these two halves, land and water (Levy 1978:411). Within the moieties there was no further separation (Gifford 1916:141). However, personal names of the Central Sierra Me-Wuk were defined by their moiety, and usually entailed the name of an object or animal associated with their moiety (Gifford 1916:142–143; Levy 1978:411). Quite interesting is that occasionally men from outside the group, such as a Yokuts man, would live with the Miwok and take a Miwok wife—he would be assigned to the moiety opposite his wife's, and receive a Miwok name accordingly (Gifford 1916:148).

The moieties functioned in a few ceremonies, among the most famous of which is the *pota* (Gifford 1926:390; Levy 1978:411). The *pota* was also closely connected to the lineages (Gifford 1926:390; Levy 1978:411). Briefly, the lineage holding a *pota* erected three poles with effigies of lineage members attached, then people from the opposite moiety attacked the effigies, which were defended by the lineages of the same moiety as the host (Gifford 1926:390; Levy 1978:411). Although I could find little information for the broader function of the *pota*, it may have served as an affirmation that bound the lineages together within their moiety, reinforcing their relationship amongst one another, as well as connecting them to their moiety and their half

of the world. Gifford (1926:390) suggests during the historic era, the *pota* served as a reminder of the *nená* from which people came, especially after so many people from different *nená* coalesced into some village locations and rancherías following increasing colonial pressure and forced removal from traditional village locations.

Each *nená* was made of all the male members of a patriline, their wives, and children (Gifford 1926:389–390; Levy 1978:411). Decent within the *nená* was patrilineal, as it was for the moieties (Gifford 1926:389; Merriam 1967). A *nená* always included a main settlement, named for the *nená* that arose from it, and outlying hamlets (which were also named) (Gifford 1926:390–391; Levy 1978:398–399, 410). Levy (1978:398–399) estimates there were on average 25 people within each of the major settlements. The post-marital residence pattern was patrilocal, where the marrying-in women would reside in the *nená* of their husbands (Gifford 1926:389). Gifford (1926:390) suggests the patrilines maintained friendly relations with each other, especially in the case of the *nená* from which a man's wife came. Kinship was of the Omaha type, where cross-cousin marriage was allowable, or where a man could marry his mother's brother's daughter (Gifford 1916:188; Levy 1978:411).

Political organization was also structured around the *nená*, where the entirety of the *nená* was regarded by anthropologists as a tribelet (Gifford 1926; Levy 1978). The tribelets were referred to by the name of the principal settlement of their *nená* (Levy 1978:410). They may have numbered from 100–300 people (Levy 1978:410). Each had a headman, a patriarch of the patriline, who acted as chief for that *nená* (Gifford 1926:389). Chiefs were responsible for settling disputes, counseling, making decisions regarding resources—specifically when the acorn harvest should begin—as well as the timing of ceremonies, and acted as host during ceremonies, but only as such regarded their *nená* (Aginsky 1943; Levy 1978:410). This position was

hereditary, passed down to the chief's son, or daughter if there were no sons (Aginsky 1943:431–432; Levy 1978:410). Usually the chief and his immediate family would reside at the main settlement of his *nená*, regarded as the capital of the tribelet (Gifford 1926:389; Levy 1978:410).

The tribelets were land-owning entities, claiming the tracts of land that surrounded their village and hamlets (Gifford 1926:389–391). All the members of a *nená* had access to this land to hunt, gather, and forage (Gifford 1926:390–391). This territory was jealously guarded, but the land beyond was accessible to any of the *nená*, and was not owned (Gifford 1926:391). Gifford (1926:390–391) suggests this idea of land ownership may be partly due to the entirety of a *nená* leaving for part of the year and moving to upslope locations to hunt and gather, while the rest of the year the *nená* was occupied. This characterizes precontact Me-Wuk as semi-sedentary hunter-gatherers who practiced seasonal transhumance following the ripening of resources.

The main *nená* settlements were located near a river, spring, or stream below the snowline, as were the hamlets (Gifford 1926:390–391; Levy 1978:399). Along the deeply-incised river canyons or further upslope near or at the snowline, settlements were only located along ridgelines near a spring or stream (Barrett and Gifford 1933:135). Above the snowline, in the seasonally-restricted habitat within Me-Wuk communal territory, were numerous temporary camps (Gifford 1926:391). This speaks to the nature of settlement structure, as many points on the landscape were inhabited year after year, although seasonally, while other spots reflect logistical forays for hunting and gathering.

Levy (1978:Figure 2) attempts a reconstruction of the locations of some of these *nená* settlements, with 57 known for the Central Sierra Me-Wuk. His reconstruction shows this pattern well, as is depicted by Figure 3.4. In Levy's (1978) reconstructed map (Figure 3.4), much of the area around the lower reaches of the Tuolumne River remains void of known settlement

locations, with the exception of *Hochhochmeti* (number 25 on Levy's map), the one known *nena* in this area. *Hochhochmeti* was a *nena* settlement of the land-side moiety (*Tunuka*) (Gifford 1944:377). Although Levy's (1978) placement of *Hochhochmeti* is farther to the east, or upstream, than where Kroeber (1925:Figure 37) places it, it is possible the entire area between the two placements was settled by this *nena*. It is unclear if *Hochhochmeti* was flooded following the construction of either the old Don Pedro Dam or the New Don Pedro Reservoir, or whether Moratto (1971a) was aware of its existence during archaeological reconnaissance where he documented numerous village sites. Gifford (1926:391) notes some of the settlement locations remain unknown due to abandonment of some in the lower foothills along the San Joaquin Valley following pressure from Spanish and Mexican explorers pre-dating the Goldrush. This unknown area includes many of the streams and creeks feeding the lower reaches of the Tuolumne River up and downstream of *Hochhochmeti*, an area which is central within my research due to the sites excavated during Moratto's (1971a) archaeological survey of the area.

Various structures were present within the capitals and hamlets of the tribelets. The tribelet capitals each had an assembly house, considered the property of the residing chief, where all important ceremonies and social events were held (Levy 1978:410). The assembly house was a round, 12–15 meter-diameter, semisubterreanean (~1.5m deep) structure with four central posts, eight supporting posts, and a conical log roof that extended to the edge of the excavated pit at ground level (Barrett and Gifford 1933:200). Other structures included a conical, earth-covered sweat house (2–5 m diameter), a brush assembly house—either rectangular or round—that served as a meeting place during the summer mourning ceremonies, and at probably all locations was a small, conical brush, tule, or bark structure used by women as a menstrual hut (Barrett and Gifford 1933:198–206; Levy 1978:408–409). Domiciles varied by location and

elevation, but most were conical and made of tule in the lower foothills (below ~460 m, or 1,500 ft), while conical bark-slab houses were more common in elevations above this threshold (Barrett and Gifford 1933:198). In some instances, semisubterranean houses similar to the assembly house were constructed, but these were restricted to wealthier or important individual families—their construction was not dependent on elevation (Barrett and Gifford 1933:198). Other structures associated with all settlements include above-ground acorn granaries (at least one per family) and conical brush or bark-slab grinding houses built over bedrock mortars—for use in inclement weather and as shade (Barrett and Gifford 1933:207–208).

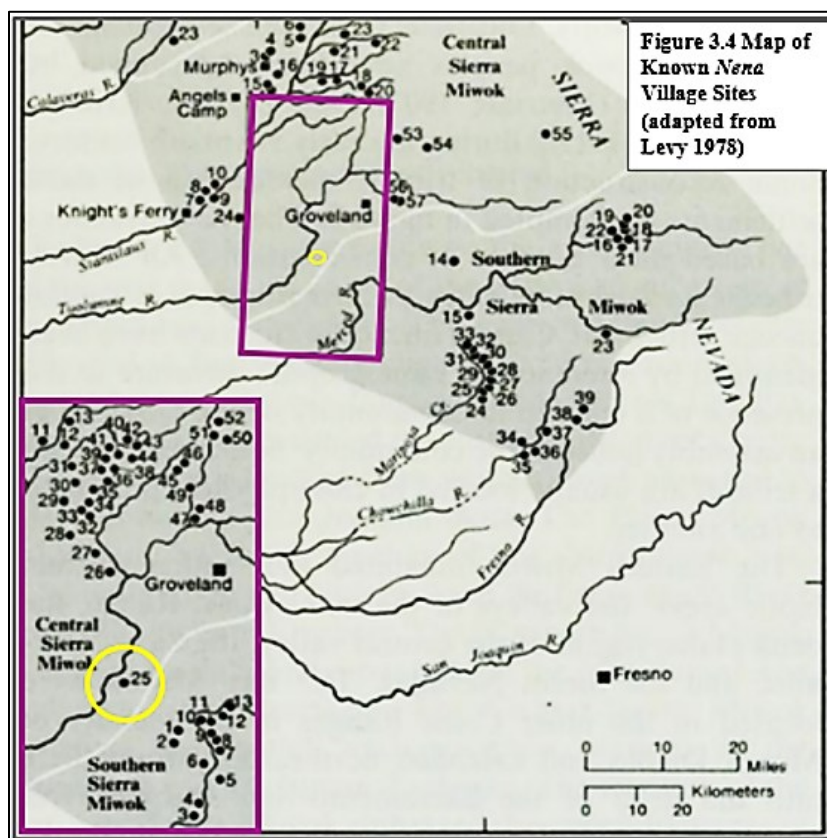


Figure 3.4 Map of Known Nena Village Sites
 Map adapted from Levy (1978). The purple inset box is an enlargement depicting the area within the purple rectangle. Circled in yellow is #25 on Levy's map, as it represents one of the only known nena sites in this part of the Tuolumne River. This site would have been close to CA-TUO-300 based on the river path.

3.1.3 Subsistence and the Seasonal Round

The Me-Wuk had a varied diet, subsisting on stored foods that had been dried, including some meats, as well as numerous fresh and seasonal resources. Among the vegetal foods, all were picked seasonally, with many seeds, nuts, bulbs, roots, tubers, and some fruits, greens and mushrooms being stored for winter. Most of these plant products (with the exception of acorns) were stored in baskets within a family's dwelling (Barrett and Gifford 1933:138–164).

Hunting, trapping and fishing were year-round activities (Barrett and Gifford 1933:128–135, 139, 178–189). Animals eaten included deer, elk, antelope, jack rabbit, cottontail, beaver, mountain lion, bobcat, fox, gray squirrel, ground squirrel, wood rat, goose, duck, quail, mourning dove, pigeon, jays, northern flicker, woodpecker, mud hen, turtle, fish of many species (but especially salmon, trout, whitefish, and lamprey eels), and river mussel (Aginsky 1943:397–398; Barrett and Gifford 1933:136–139, 178–189, 192; Levy 1978:403–404). Although the ethnographies do not always agree, it appears that only some of the Central Sierra Me-Wuk ate black bear, grizzly bear, lizards, rattlesnake, gopher snake, and water snakes (Aginsky 1943:397–398; Barrett and Gifford 1933:137–138, 180–182). Insects also served as food, especially grasshoppers, yellowjacket larvae, angleworms, Pandora moth chrysalids, and hairy caterpillar cocoons (Aginsky 1943:397–398; Barrett and Gifford 1933:190–191). Some animals and insects were more abundant or easier to catch in certain seasons: salmon, deer, and quail were easiest in spring; rabbit, hare, and grasshoppers were easier in early summer; (Barrett and Gifford 1933:181–182, 183–184, 187–188, 190).

Meat, from large mammals—especially deer—as well as from whitefish, trout, salmon, and quail was dried after all the fat had been removed and stored for winter, as were grasshoppers (Aginsky 1943:401, 454; Barrett and Gifford 1933:139). Bone marrow was also

extracted, and deer vertebrae were pulverized, boiled and eaten (Aginsky 1943:401, 454).

Additionally, mammal (mainly deer) and birds bones were used for a variety of tools, flutes, and game pieces (Barrett and Gifford 1933: 214, 217, 257-268). The making of bone implements, as well as marrow extraction likely accounts for the highly fragmentary nature of most archaeological faunal remains within the region.

Meat from large mammals such as deer, elk or the occasional antelope or bear, was more widely shared than the vegetal foods among members of a *nena* (Barrett and Gifford 1933:142–163, 180–182). Individually-hunted large mammals, such as deer, were partitioned amongst the friends, older individuals of a *nena*, and relatives and neighbors of the hunter, who only had the sirloin reserved for him (Barrett and Gifford 1933:180–182). However, this was a reciprocal relationship, as these people would also give the hunter meat after they had made a kill or would bring him acorn mush (Barrett and Gifford 1933:180–182). If mammals were hunted or trapped communally, the kill was divided among the hunters, and women would prepare acorns and other foods to accompany it (Barrett and Gifford 1933:180–182). However, small game (unless hunted communally) were the property of whoever killed the animal (Aginsky 1943:399). When large amounts of quail were procured, the meat was divided among the whole village (Aginsky 1943:396, 451). Frequently, when people cooked meat, they would take some to the assembly house to give to others (Barrett and Gifford 1933:200).

During the fall, winter, and spring, the *nena* villages and hamlets served as permanent residential bases (Barrett 1908:336; Barrett and Gifford 1933:129, 149–150; Kroeber 1925:442–443). During these seasons, hunting and gathering excursions from the *nena* settlements would return with food and supplies to be used immediately or stored for winter use (Barrett and Gifford 1933). These spots on the landscape were reoccupied year after year—attested to by the

investment in infrastructure described during the ethnographic era (e.g., semisubterranean and earth-covered structures, large bedrock mortars with many holes) and deep midden deposits unearthed later during archaeological exploration (Barrett and Gifford 1933:198–208; Moratto 1984:311–314).

The division of labor was gendered, with women responsible for the majority of plant gathering and food storage activities, and men's activities focused on hunting, fishing, and trapping (Aginsky 1943; Barrett and Gifford 1933). However, some hunting activities, such as rabbit and grasshopper drives, were village affairs and women would participate. The products of women's labor were usually family-centric and were not a shared good (Barrett and Gifford 1933:139–141, 151–163). While hunting was a year-round activity, gathering was mainly restricted to spring, summer, and fall. Very little gathering happened during winter, most of which was for mushrooms, toyon berries, or cordage-making materials (Barrett and Gifford 1933:137, 246). During winter, the tobacco fields were burned to aid new growth for the following year's crop (Aginsky 1943:425).

Winter

The base of the winter diet mainly consisted of stored foods—acorns, pine nuts (gray and sugar pine), various seeds, and dried greens and berries—as well as mushrooms and fresh, locally hunted meat (Barrett and Gifford 1933:136–137, 149–158, 163, 178; Levy 1978:402, 404). Toyon, or Christmas berries (*Heteromeles arbutifolia*) are the only fruit ripe in winter, and required boiling then baking prior to eating due to the presence of tannins and cyanogenic glycosides (Barrett and Gifford 1933:162; McMurray 1990). Although picked during winter, they were not a major food source (Barrett and Gifford 1933:162). More meat was eaten during the winter than in any other season, and the mammals were said to be fat during this season and nice

to eat, especially the gray squirrel (Barrett and Gifford 1933:137). For those living in the mountains, wintertime rabbit hunting entailed the use of snowshoes to track rabbits through deep snow (Barrett and Gifford 1933:182). Deer meat, however, was the most highly prized regardless of location or season (Barrett and Gifford 1933:136–137, 178).

Mushroom collecting in winter, as well as throughout the rest of the year, entailed a deep knowledge of the landscape as well as how the fungi react to certain weather conditions (Anderson and Lake 2013:34). Many fungi have a narrow set of conditions in which they will sprout, especially in winter when conditions are less predictable (Anderson and Lake 2013:52). Although we have descriptions of mushrooms through Barrett and Gifford (1933:163–164) and widespread agreement through Aginsky's (1943:401) work that many mushrooms were gathered, eaten or stored for winter, only the Sierra puffball (*Calvatia sculpta*) is specifically identified. However, further work on Me-Wuk mycophagy by Anderson and Lake (2013) has helped to clarify some possibilities. Edible winter mushrooms may have included oyster mushrooms (*Pleurotus ostreatus*), saddle fungus (*Helvella vespertina*), witch's butter (*Dacrymyces palmatus*), chanterelles (*Cantharellus californicus*), rosy gomphidius (*Gomphidius subroseus*), and deer mushrooms (*Pluteus cervinus*) (Anderson and Lake 2013; Barrett and Gifford 1933:163–164; Storer et al. 2004:37–41; Wood and Stevens 2020, 2021a, 2024a, 2024b).

Spring

In spring, numerous plant species were gathered in the snow-free areas of the lower elevations within the foothills and mountains. This area was the home of many *nena*, and short logistical forays away from the *nena* for a few days to gather took place (Barrett and Gifford 1933:155). Spring was a time for fresh greens, more mushrooms, green-coned gray pine, but especially bulbs, corms, and tubers; it was also the main season for salmon and a good season for

quail and deer because of their migration patterns (Barrett and Gifford 1933:136–137, 149–160, 163, 178–180, 183–189). Spring was also the time when “wild” tobacco (*Nicotiana quadrivalis* and *N. attenuata*) seeds were spread (Aginsky 1943:425; Barrett and Gifford 1933:193–194; Nee 2012a, 2012b). While tobacco was eaten for medicinal purposes, it was smoked socially, and was a culturally-important plant that was tended like no other within Me-Wuk culture, with fields purposefully managed to aid in its production (Aginsky 1943:425; Barrett and Gifford 1933:136, 140, 193–194).

Clover (*Trifolium* sp.) could be gathered beginning in early spring, followed by mushrooms in April and May (Barrett and Gifford 1933:136–137, 140) when Oyster mushrooms and chanterelles would have still been available (Storer et al. 2004; Wood and Stevens 2024a). When clover was to be stored for winter, it was first steamed, while white mushrooms were shredded then dried (Barrett and Gifford 1933:137, 140, 163). White coral mushrooms (*Ramaria rasilispora* scatesiana), white coccora (*Amanita calyptrata*), giant lentinus (*Neolentinus ponderosus*), and fire-following morels (*Morchella sextelata* and *M. eximia*) come into season in spring in low-mid elevations of the Sierra Nevada and are edible (Anderson and Lake 2013; Storer et al. 2004:37–41; Wood and Stevens 2019, 2021b, 2021c). Many greens, such as the leaves of white goosefoot (*Chenopodium album*), alumroot (*Heuchera micrantha* Dougl.), broad-leaved and rose lupine (*Lupinus spp.*) became available starting in spring and would be steamed, dried, and stored for later use (Barrett and Gifford 1933:158–160). Other greens, such as larkspur and columbine leaves, were gathered when young and boiled, but were not stored (Barrett and Gifford 1933:158). The leaves and stalks of miner’s lettuce (*Montia perfoliata*), tibinacua (*Eriogonum nudum* Dougl.), and young shoots of gray mule’s ears (*Wyethia helenioides*) were

eaten raw, as in a salad (Barrett and Gifford 1933:158–160). Wild onions (*Allium* sp.) were first available in spring, and eaten raw or steamed (McCarthy nd:112).

Harvest, white, and golden brodiaea (*Brodiaea spp.*) bulbs were dug by men and women in early May just as the shoots appeared above ground (Barrett and Gifford 1933:155). The timing of the dig was decided by the chief, and the occasion marked a four day excursion and picnic, with the bulbs being cooked in an earth oven and eaten on the fourth day (Barrett and Gifford 1933:155). Some of the bulbs were dried and stored for winter after baking (Barrett and Gifford 1933:141). Earlier sprouting bulbs, such as the white Mariposa lily (*Calochortus venustus*), were dug in April, but they were not stored, instead being baked and eaten within a few days of harvesting (Barrett and Gifford 1933:155). Blue camas bulbs were also dug, baked and eaten in spring (McCarthy nd:106). When the acorn supply had been diminished, around June, bulbs of *Eulophus bolanderi* would serve as substitute, gathered at the behest of the chief—they were eaten raw, and mashed, as well as dried and stored for winter (Barrett and Gifford 1933:157–158).

Green cones of gray pine were gathered in spring, but had to be twisted off by hand, which required men to climb for them (Barrett and Gifford 1933:149–150). The green cones were smashed with a cobble until the covering split, which was then peeled off and the nuts, which had a soft shell at this stage of development, could be eaten. The man who climbed the tree would divide the nuts amongst those in the party (Barrett and Gifford 1933:150). The pithy center of the cone was roasted in hot ashes and then eaten as a sweet (Barrett and Gifford 1933:149–150).

Springtime fishing focused on spawning salmon, which typically happened in the late spring (Barrett and Gifford 1933:188–189). Ethnographically, salmon are touted as the most

important fish in the lower foothills, replaced by trout in the mountains (Barrett and Gifford 1933:136–137). Strong evidence for their consumption remains to be found archaeologically and is one topic explored in my research. Salmon were said to spawn on the Stanislaus River as far up as Baker's Bridge, where there was a waterfall, while in the Tuolumne they were found as far up as La Grange (Barrett and Gifford 1933:188–189). The mountain-dwelling Me-Wuk made trips to the foothills to fish for salmon during the spawn (Barrett and Gifford 1933:139). Temporary fish camps were established, and salmon were taken with basketry fish traps, nets, three-pronged harpoon and toggling fish spears, sometimes by firelight at night (Aginsky 1943:398, 400; Barrett and Gifford 1933:187–189). The roe was also harvested, and either dried and stored for winter or boiled and eaten (Barrett and Gifford 1933:189). Salmon was cooked in a variety of ways, including smoking (for storage), air-drying for four to five days (for storage), broiled on hot coals, and it was the only fish to be baked in an earth oven (Aginsky 1943:401, 454; Barrett and Gifford 1933:138, 139). However, unlike many other Native California groups, the Me-Wuk did not observe a First Salmon Rite ceremony (Aginsky 1943:398).

Both mountain and valley quail were taken year-round; however, during spring they were more easily caught during their migration upslope after overwintering in the lower foothills and mountains (Aginsky 1943:451; Barrett and Gifford 1933:139, 183–184). A long quail fence, two to three feet high, was erected, usually on the west-facing crest near a stream, and snares were set in the openings of the fence (Aginsky 1943:451; Barrett and Gifford 1933:183–184). In fall, they migrated downslope and were taken in this same fashion. Two such fences, said to be 800 m long, were known to exist ethnographically, both near the modern town of Tuolumne: the first was on a steep ridge northeast of Indian Spring stream: the other, on a hill northeast of Tuolumne (Barrett and Gifford 1933:184). Up to 50 quail a day could be caught in these fences during

spring, a quantity sufficient to supply a family the entire summer (Barrett and Gifford 1933:139, 184). Quail was made into soup, roasted, or dried and stored (Aginsky 1943:451). To aid in the drying and preparation for storage, quail were plucked and their breasts split open (Barrett and Gifford 1933:139).

Summer

As the snow melted in late spring or early summer, the *nenas* became depopulated as groups fissioned (Barrett and Gifford 1933:129, 132–133; Kroeber 1925:443). Small family groups either traveled upslope to the mountains to gather seeds and fruits, and to hunt, or those from the lowest foothills may have traveled into the valley following the same pursuits (Barrett and Gifford 1933:129, 134, 137, 255). At temporary camps during the summer months, conical shelters of pole and thatch (or tule) were constructed—these were temporary shelters (Barrett and Gifford 1933:198). The use of the Upper Montane Forest included logistical forays to hunt and for trade with groups from the east or north (Barrett and Gifford 1933:192). Salt, obsidian, and rabbit-skin blankets were the trade commodities sought during summer, mainly through trade with the Mono (Barrett and Gifford 1933:192, 220, 255).

Similar to quail in spring, early summertime was prime for rabbit, hare, and grasshopper drives (Barrett and Gifford 1933:180–182, 190–191). Rabbits and hares would be driven into long (275–365 m) nets set in a straight line, in a V-shape, or around the base of a hill; they were taken usually by an entire village, then clubbed by men as the animals became entangled (Barrett and Gifford 1933:180–182). Grasshoppers were taken in systematic drives, typically in June (Aginsky 1943:452; Barrett and Gifford 1933:190). Groups of several families, numbering up to entire villages, would assemble in a grassy area where grasshoppers were numerous and would dig 1-m deep, 30 cm-wide holes in which to drive the insects by means of swinging branches and

bunches of grass. The pits were surrounded by piles of grass, which was ignited after the grasshoppers were corralled within (Barrett and Gifford 1933:190). Wings singed, the grasshoppers could not escape—they were then steamed, and eaten, and some were dried and stored for winter (Barrett and Gifford 1933:139, 190). Sometimes, instead of fire, the pits were filled with water and the grasshoppers were scooped out (Aginsky 1943:452). Alternatively, without any pits being created, sometimes the entire field was set ablaze and the grasshoppers were collected afterwards (Aginsky 1943:452). Occasionally baskets were used, instead of pits, and the basket was placed in water to drown the grasshoppers (Aginsky 1943:452).

Among the larger mammals, deer that had migrated into the mountains to fawn were hunted by mountain dwelling groups, while groups in the foothills hunted tule elk, resident deer, or antelope in Yokuts territory (Barrett and Gifford 1933:178–182; Woolfenden 1988). For the groups in the lower foothills, the hunting of resident deer, or elk and antelope in the Central Valley was not necessarily restricted to summer.

As groups moved higher into the mountains, many of the greens, some seeds, and mushrooms (e.g. fire-following morels) accessed in the lower elevations were ripening or sprouting in the mid to high elevations, extending their availability. Some new mushrooms were also gathered at this time, mainly the Sierra puffball, but possibly also king boletes (*Boletus edulis*) and honey mushrooms (*Armillaria mellea*, *A. solidipes*, and *A. ponderosa*) (Anderson and Lake 2013; Barrett and Gifford 1933:163–134; Storer et al. 2004:37–41; Wood and Stevens 2021d, 2021e, 2022). Seed gathering began in late spring and continued through summer (Barrett and Gifford 1933:151–154). When done in the areas below the snowline (Upper Sonoran and parts of the Lower Montane Forest—the regions where seeds ripened first), many were gathered from logistical forays from the *nena*, and some would be stored for winter (Barrett and Gifford

1933:151–154). For example, in the late spring, near the end of May, seeds of red maids (*Calandrinia menziesii*) were gathered from lower elevation sites (Barrett and Gifford 1933:151–152). The entire plant was uprooted and spread out on cleared hard ground or a granite outcrop to dry. Seeds were separated from the plant by shaking or beating the dried plant, and once separated, were dried and stored in a basket (Barrett and Gifford 1933:151–152).

Tobacco leaves were gathered when green, starting in May, and possibly lasting until October when the last flowers go to seed (Aginsky 1943:425; Barrett and Gifford 1933:193–194; Nee 2012a, 2012b). Tobacco seeds were also gathered when ripe, and saved for the next spring’s spreading (Aginsky 1943:425; Barrett and Gifford 1933:193–194). In June, the seeds of paintbrush or prairie-fire (*Castilleja* spp.), clarkia or godetiae (*Clarkia* spp.), and California buttercup (*Ranunculus californicus*) were harvested with seed beaters, dried and stored for winter (Barrett and Gifford 1933:151–154); godetia seeds, in particular, were a highly prized food (Barrett and Gifford 1933:136–137). In some cases, such as the many varieties of godetia or clarkia, the entire plant was uprooted, sometimes the stems were broken off, then left to dry, with seed collection proceeding similar to that for red maids (Barrett and Gifford 1933:151–154). Just as the Sierra blazing star (*Mentzelia crocea*) stops flowering in June, its seeds were collected and eaten as a mash, like pinole (Barrett and Gifford 1933:151–154; Brokaw et al. 2023).

Seed collecting continued in the forests, meadows, and chaparral throughout the summer, focusing on those species already mentioned, as well as on later-seeding plants such as hazelnut (*Corylus rostrata* var. *californica*), balsam root (*Balsamorhiza sagittata*), and tarweed (*Madia elegans*) (Barrett and Gifford 1933:151–154; Fryer 2007a). Of these, tarweed seeds were preferred, and were stored in numbers that could last a year (Barrett and Gifford 1933:153–154; McCarthy nd:92). In the higher elevations, the seeds of valley tassels or attenuate Indian

paintbrush (*Castilleja attenuatus*) were gathered using a seed beater—these may not have been stored (Barrett and Gifford 1933:154; Wetherwax et al. 2012). Seeds from many species of brome grasses (*Bromus* spp.) were gathered throughout summer (Barrett and Gifford 1933:151–154; Saarela and Peterson 2019a, 2019b, 2019c). It should be noted that Barrett and Gifford (1933:151–154) only list brome (*Bromus rigidus*) seeds as being collected; however, ripgut is an invasive species native to Eurasia (Saarela and Peterson 2019d), but the use of brome grasses predates European colonization (Wohlgemuth 1996:Table 5). There are numerous species of *Bromus* native to the Sierra Nevada, such as *B. ciliatus*, *B. richardsonii*, and *B. sitchensis* var. *carinatus* (Saarela and Peterson 2019e, 2019a, 2019c, 2019b), and it is likely that ripgut was misidentified as the sole species of brome used.

Fruits were also gathered during summer. Some, such as sourberry (or sumac) (*Rhus aromatica*), Sierra plum (*Prunus subcordata*), gooseberry (*Ribes roezlii*), wood strawberry (*Fragaria vesca* and *F. virginiana*), thimbleberry (*Rubus parviflorus*), and blackberries (*Rubus vitifolius*) were eaten fresh (Barrett and Gifford 1933:162; McCarthy nd:36, 56, 50, 90, 94). Others, such as blue elderberry (*Sambucus nigra caerulea*) and Sierra currant (*Ribes nevadense*) were consumed both when fresh and were dried and stored for winter (Barrett and Gifford 1933:162; McCarthy nd:30, 32). From late summer into fall, wild grape (*Vitis californica*), chokecherry (*Prunus virginiana*), and bitter cherry (*Prunus emarginata*) ripened, and were eaten fresh as well as dried and stored for winter (Barrett and Gifford 1933:162; McCarthy nd:26, 28, 38).

Of special note are manzanita and madrone berries. The berries of Mariposa manzanita or white sticky-leaf manzanita (*Arctostaphylos viscida*), Parry's manzanita (*A. parryana*), and Pacific madrone (*Arbutus menziesii*) were used to make an unfermented cider (Barrett and

Gifford 1933:161; McCarthy nd:46–47). Madron berries are the least favored for the drink, as they are dry and not very flavorful (McCarthy nd:12). The berries were gathered from summer through fall and could be used fresh or dried and stored for winter (McCarthy nd:46–47). They were also chewed for flavor but not swallowed (Barrett and Gifford 1933:161). When making the cider, the berries were sometimes briefly boiled, the berry meat pounded into a meal, and then hot water was poured over to percolate through it, much like coffee or tea today. The liquid was caught in a basket and decanted to remove any remaining small particles, after which the cider was ready. It could be stored from two to four days (Barrett and Gifford 1933:161). Manzanita cider remains a popular traditional drink within Me-Wuk culture today (McCarthy nd:46).

Late Summer

Typically, *nena* groups would return to the foothills beginning in late summer through early fall for the annual burn and to collect various important nut and seed crops from the Upper Sonoran Zone and Lower Montane Forest (Anderson 1996:418; Anderson and Rosenthal 2015:17–19; Barrett and Gifford 1933:140–141). Anderson (1996) suggests, based on interviews with ethnographic informants, the timing of the burn coincided with the beginning of the rains, and varied from burning individual plants (and bunch grasses) to whole areas as a way to replenish soil nutrients, remove dead growth, and promote new growth of culturally-favored plants the following spring. Fire was also useful for hunting deer communally, as hills surrounding meadows would be set ablaze to drive deer into range where they were shot with bow and arrows by waiting hunters (Barrett and Gifford 1933:179–180).

The first nuts to be gathered were sugar pine, as groups descended from the mountains (Barrett and Gifford 1933:149–150; Habeck 1992; Kinloch and Scheuner 1990). Sugar pines range from 600 to nearly 2,300 m (2,000–7,500 ft) within the Sierra Nevada (Kinloch and

Scheuner 1990:370). It takes two years for sugar pine cones to mature, and they drop from the branch tips a year after opening (Habeck 1992; Kinloch and Scheuner 1990:372–373). Cones begin shedding nuts as early as August in the lower elevations of their range, and in October in upper elevations (Habeck 1992; Kinloch and Scheuner 1990:372). The seeds are ripe when the cone turns a light-brown color (Habeck 1992; Kinloch and Scheuner 1990:373). Because cones were collected prior to nut-dropping but after the cones had turned brown (Barrett and Gifford 1933:149–150), the collection proceeded mainly in the upper elevations as people moved downslope towards their *nena*. The cones were shaken off branches by men who climbed the trees, piled upside down, then covered by pine needles. This was lit to burn the pitch from the cones (Barrett and Gifford 1933:149–150). The cones were then split with a rock and pressed to remove the nuts. Then they were winnowed by women, and divided amongst the party by the man who climbed the tree (Barrett and Gifford 1933:149–150). The nuts, which are soft shelled, were sometimes eaten while still warm, others were stored for winter, while still others were mashed into a paste and eaten, shell and all (Barrett and Gifford 1933:149–150; McCarthy nd:24).

Late summer and into fall entailed some of the last gathering of small seeds. Skunkweed (*Navarretia squarrosa*) only grows in elevations less than 1000 m (Johnson 2013), and its seeds were gathered in August with seed beaters and stored (Barrett and Gifford 1933:151–154). Seeds from Fitch’s spikeweed (*Centromadia fitchii*)—resident within the lower elevations (Baldwin 2012)—were gathered and cooked as a porridge (Barrett and Gifford 1933:151–154). Although gumweed (*Madia gracilis*) grows throughout the foothills and mountains (up to 2,500 m) (Baldwin 2022), its seeds, the most favored of the tarweed seeds, were harvested with a seed beater from lower elevations in August, winnowed and stored for winter (Barrett and Gifford

1933:151–154). Primrose (*Boisduvalia densiflora* and *B. stricta*) seeds were gathered in fall, parched, pulverized and eaten dry, while unparched seeds were stored for winter (Barrett and Gifford 1933:151–154).

As the last seeds and all fall nuts were harvested, some mushrooms were also available for picking. Short-stemmed russula (*Russula brevipes*), coccora (*Amanita calypttrata*), and chicken of the woods (*Laetiporus gilbertsonii*) become available starting in late summer into fall, and typically sprout on hardwoods, on the ground under pine needles, or under madrones and oaks (Storer et al. 2004:36, 37, 39; Wood and Stevens 2021f, 2021g). In late fall, as the acorns were being harvested, oyster mushrooms, honey mushrooms, deer mushrooms, rosy gomphids, king boletes, chanterelles, and saddle fungus were either going out of season, or just becoming available as the weather cooled and moistened (Storer et al. 2004:36–41). Some of these likely would have been picked as they were available and within the same gathering patches as the acorns and pine nuts.

Fall

Nut collection ramped up as the *nenas* were repopulated. By September and lasting until October, gray pine cones mature, with seed dispersal beginning in October—seeds and cones were collected from the ground, or trees were climbed for cones like in spring, with the man who climbed the tree dividing the nuts amongst his party members (Barrett and Gifford 1933:149–150; Farris 1982; Powers 1990). Similar to sugar pine nut collection and processing (described above), cones were placed in fire to remove the pitch, then split with a stone and torn apart to remove the hard-shelled nuts which were stored for winter (Barrett and Gifford 1933:149–150). Gray pine nuts were an important and favorite food (McCarthy nd:22). California bay (*Umbellularia californica*) nuts begin to drop in November (Stein 1990) and were collected and

roasted in ashes for consumption (Barrett and Gifford 1933:162; McCarthy nd:4). California nutmeg (*Torreya californica*) is an understory associate of California bay, and the nuts begin to drop beginning in September (Howard 1992a). These nuts were leached then roasted in ashes and eaten (McCarthy nd:16). Buckeye nuts became available by the time gray pine nuts had been harvested, and were typically collected after they fell from the tree (Barrett and Gifford 1933:148). Buckeye was not a favorite food, as it required extended leaching beyond that for acorns, but the nuts could be eaten if the acorn crop failed, and could be stored up to a year, until the next acorn harvest (Barrett and Gifford 1933:148; McCarthy nd:6). Raw buckeye nuts were also used to stupefy fish without actually poisoning them (Barrett and Gifford 1933:148–149; McCarthy nd:6).

Migrating deer were taken in fall (and to a lesser extent, spring) by means of a long brush fence, similar to quail (Barrett and Gifford 1933:178–182). The fence was usually V-shaped and followed the lay of the land. At the most advantageous point, given the landscape, an opening was left usually near the base of the V (Barrett and Gifford 1933:178–182). An oak branch with desert mistletoe (*Phoradendron californicum*) hung from it was placed at the opening to capture the deer's attention long enough so that a concealed hunter was able to get a good heart shot. The hunter was usually concealed in a pit-type blind, covered with brush (Barrett and Gifford 1933:178–182). Another version of this type of V-drive used a small corral at the V, in which were three to four openings. At each opening were snares attached to trees or heavy logs. Near the entrance to the corral were hunters, again concealed in brush-covered pit-type blinds (Barrett and Gifford 1933:178–182). The hunters would wait for a deer to approach, and would then block their exit, forcing the deer to run for one of the openings, where they were caught by the snare and clubbed or shot (Barrett and Gifford 1933:178–182). Fall migrating deer were usually

more abundant than the spring, as deer were quicker to move downslope to escape the threat of snow (Woolfenden 1988).

Late fall into early winter was for acorn harvesting (Barrett and Gifford 1933:142–147). They were the staple crop for the winter, spring, and any time spent at the *nená*. Among the oaks, the acorns from black oak and canyon live oak were preferred, followed by valley oak, scrub oak, huckleberry oak, interior live oak, and blue oak (Barrett and Gifford 1933:142–143; McCarthy nd:18). Although blue oak was abundant in the foothills, its acorns were last in the order of preference as the soup made from them was watery and the bread would fall apart (Barrett and Gifford 1933:142–143).

The first acorns were collected when the chief decided they were ready, a part of the First Acorn Right—a *nená*-wide celebration (Aginsky 1943:432). They were harvested and pounded by everyone (Aginsky 1943:452). After cracking, they were dried for four days while the men hunted, and at the end everyone had a big time celebration that included eating the hunted meat and acorn mush (Aginsky 1943:398, 452). After the First Acorn Right, the acorns were gathered by family groups, being harvested in numerous ways including knocked from trees with various poles, shaken off, picked from the ground after they fell, pried from woodpecker caches, and sometimes a limb was cut to gather the acorns before they were ripe (Aginsky 1943:400, 453; Barrett and Gifford 1933:142–147; McCarthy nd:22). The nuts were brought to the *nená* to dry and be stored (Aginsky 1943:453).

Large (2.5 m tall, 1 m wide) above-ground acorn granaries were constructed by each family to house their year's crop (Aginsky 1943:453; Barrett and Gifford 1933:207). Sometimes, smaller granaries were constructed if the crop warranted it (Barrett and Gifford 1933:207). Acorns were dumped into the granary before the roof was put on (Aginsky 1943:454–455).

Granaries were water-tight to prevent spoilage (Aginsky 1943:402, 454–455; Barrett and Gifford 1933:207). Up to several tons of acorns could be stored this way and could last a family for several years (McCarthy nd:128).

Stored acorns had many uses. Taken from the granary as needed, acorns typically were pounded into flour in bedrock mortars, the flour was sifted, leached of tannins over several hours, and could then be cooked into soup, mush, biscuits, or bread (Aginsky 1943:400, 453; Barrett and Gifford 1933:142–147). When people cooked acorns, they frequently would take some to the assembly house to distribute to others (Barrett and Gifford 1933:200). Different species of acorns were traded among the valley and foothill groups, while acorns were traded to the Mono for salt and other items (Aginsky 1943:400, 453; Barrett and Gifford 1933:142–147, 192). Acorns also served as bait for catching woodrats, pigeons, jays, red-shafted flickers, and ducks.

3.1.4 The Me-Wuk During the Early Historic Era

As the Spanish missions depleted the Native populations in the coastal regions, they turned their attention to the interior of California seeking new converts (Levy 1978:400). Many of the valley-dwelling groups were sought, which, over time raised hostilities between the Indigenous peoples and their would-be captors (Levy 1978:400). Trade between the valley and foothill/mountain dwellers was interrupted, and foreign diseases swept through the foothill and mountain regions reducing population numbers (Hull 2012; Levy 1978:400). These events led some survivors to take solace higher in the mountain refugia such as Yosemite Valley (Hull 2009:53–114, 220–300, 2012:122–127, 134–135). The people throughout the foothills and mountains were affected by the colonial-induced influx of traders, miners, trappers, and settlers during 1840s to 1850s following the discovery of gold and the subsequent annexation of

California by the U.S. government, further reducing their numbers and entailing numerous new adaptations, such as wage-earning, and diminishing reliance on hunted and gathered goods due to the reduced access to what was once a large territory (Hull 2009:1–114, 2012:122–125; Levy 1978:400–401).

Following annexation, numerous unratified treaties were signed between the U.S. federal government and Indigenous groups throughout the Sierra Nevada during the early 1900s (Hull 2012:124–125; Levy 1978:401). By and large, this practice resulted in the removal of Indigenous people from their traditional lands, as well as reassignment to smaller territories referred to as *rancherias* (Levy 1978:400–401). While some in foothills *rancherias* worked as wage-laborers for the new settlers, others sought employment with mining companies, while still others moved away as they found employment elsewhere (Levy 1978:400–401). By the early 1900s and into the 1930s, it was the elderly—some over 100-years old—who persevered at the *rancherias* and supplied information to ethnographers as they ventured into the Sierra Nevada (Aginsky 1943:393–394; Barrett 1908; Barrett and Gifford 1933:127; Gifford 1944, 1916, 1917a, 1926).

3.2 History of Archaeological Research

Interest in western-Sierra Nevada ancient history developed out of a desire to protect and salvage what could be learned before it was destroyed. Unlike other areas of California, archaeological research began alongside the first ethnographers. Although initial interest in Sierra Nevada ancient history was short-lived, it set the stage for future developments in archaeological practice within the region.

3.2.1 Cave Archaeology

The earliest accounts of archaeology in the west central Sierra Nevada come from newspaper articles and occasional papers written about the discovery of human remains and artifacts purportedly found within caves and gold-bearing gravels thought to be Pliocene in age (Becker 1891; Blake 1899; Holmes 1901; Nelson et al. 1910; Wallace 1951). A majority of these finds occurred as immigrants to California blanketed the hills and creeks, streams, and rivers looking to strike it rich in their search for gold (Becker 1891; Holmes 1901; Nelson et al. 1910; Wallace 1951). As California archaeology was in its nascency, few of the cave discoveries were professionally excavated, although by the early 1900s some famous anthropologists had begun to investigate the antiquity claims for some of these discoveries (e.g. Holmes 1901; Nelson et al. 1910). Overall, the claims for great antiquity of humans in the region remained contentious, despite the efforts of William Henry Holmes and Nels Nelson who provided ample logic to refute the claims (Holmes 1901; Nelson et al. 1910). Sierra Nevada archaeology progressed slowly in these early years (Moratto 1984: 293–294).

By the early 1930s–40s, many cave sites had been looted or disturbed; however, professional archaeologists initiated more scientific investigations in some of these caves (Gonsalves 1955; Heizer 1952; Moratto 1984; Wallace 1951). A brief excavation in Moaning Cavern (also known as Solomon’s Hole, Cave of the Sepulcher, Moaning Cave, and CA-CAL-13) by Wallace and Lathrap in 1950 revealed a number of disassociated human remains, purple olive (*Callianax* [*Olivella*] *biplicate*) shell beads dating from the Middle Period through the Late Period, abalone shell ornaments, barbed triangular obsidian points, charred wood, and the remains of coyote, elk, rabbit, and gopher (Wallace 1951). Important to the time, Wallace (1951:

38) noted that the “archaeology of the Sierra Nevada foothills is unknown, making it impossible to fit the Moaning Cave materials into any local cultural sequence.”

Excavations at Winslow Cave (CA-CAL-99) revealed materials noted by Gonsalves (1955) as being comparable to Moaning Cave in artifact types. Disassociated human remains were mineralized, but not to the extent of those from Moaning Cavern. Aside from the human remains, shell pendants, beads, and projectile points—mostly of obsidian—were recovered (Gonsalves 1955). He tentatively assigned the collection to the Middle Horizon with some Early Horizon holdovers; however, he suggested that even though those finds were comparable to the Moaning Cave artifacts, the reconstructed period of use as a mortuary cavern might be unreliable, due again to the paucity of comparable data from the Sierra Nevada (Gonsalves 1955).

To the north, in Eldorado County, Wallace and Lathrap (1952), discuss artifacts and human remains recovered from Hawver Cave (CA-ELD-16), first discovered in the early 1900s, and later used as a lime quarry. One piece of bone from the recovered remains returned a radiocarbon date of 4052 ± 160 BP, but could not be directly associated with the artifacts recovered due to the long period of time the cave had been collecting washed in materials from the surface (Wallace and Lathrap 1952). With no other means to date the other associated artifacts, Wallace and Lathrap (1952) compared the projectile point forms to others from better known contexts, and suggested those from Hawver Cave were most similar to point forms from Early Horizon sites in the Sacramento Valley and older Gypsum points from the Great Basin. In a similar fashion, Heizer (1952: 2), in his coverage of cave sites throughout California, noted that the cultural materials from Moaning Cave and Winslow Cave were both similar to Middle Horizon artifact types of the lower Sacramento Valley. Thus began a long tradition of attempting

to correlate Sierran cultural finds with items encountered elsewhere, mostly projectile points similar to Great Basin and Central Valley types, and cross-dating these finds with bead types traded from the coast.

Archaeological exploration of caves located throughout the foothill belt has been sporadic since. In 1973, Heizer and Hester (1973) published a report on the findings from Bamert Cave, in Amador County. Although the cave had been excavated multiple times, beginning in 1950 and lasting through subsequent investigations through the 1960s, their report summarized the collections from the original set of excavations from 1950–51 (Heizer and Hester 1973). Later work in the foothill belt, where most caves are located, saw the discovery of other caves during archaeological reconnaissance prior to and during the building of new dams and reservoirs. For example, Johnson (1966) identified numerous caves and investigated a few during his work at the Comanche Reservoir prior to its filling. As well, along the catchment area of New Melones Reservoir, a total of 87 caves were investigated, with some producing artifacts indicating calcite quarrying, and others showing use as temporary shelters or mortuary caves (McEachern and Grady 1978). Little academic work was published on the archaeological findings from these caves, as most were undertaken as salvage projects, and thus information is stored within the gray literature of CRM reports. However, Moratto (1984: 304-308) provides a cogent discussion on some of these caves and their place within Sierra Nevada cultural history.

3.2.2 The True Beginnings of Sierra Nevada Archaeology

Aside from cave archaeology, much of the cultural history research in the Sierra Nevada began to be investigated in the late 1940s with the Smithsonian Institution's River Basin Surveys (Moratto 1984:294; Moratto and Riddell 2016). Progress was slow at first, as the River Basin Surveys focused only on areas to be impacted by the construction of new dams following the

passage of The Flood Control Act of 1944 (Moratto and Riddell 2016). The River Basin Surveys typically involved two-man teams spending a few days at a site surveying, then moving on to the next spot assigned to them (Moratto and Riddell 2016). Francis Riddell, who worked on several River Basin Surveys, notes that these were not systematic transect surveys, but rather where teams would target locations they thought sites ought to be (Moratto & Riddell 2016: 55-56). Some of the areas surveyed include Pine Flat (Drucker 1949; Fenenga 1947), Sly Park (Drucker 1948a), Folsom (Drucker 1948b; Fenenga 1950), Mariposa (Osborne 1948), and New Melones (Fredrickson 1949). Although the River Basin Surveys were mostly cursory investigations to scout out the locales of proposed new reservoirs and dams, they are important because they brought professional archaeologists into the Sierra Nevada (Moratto 1984: 294), a region that had received little archaeological attention to that point.

Concurrent with the River Basin Surveys was the establishment of the University of California Archaeological Survey (UCAS), created in 1948 and headquartered at University of California Anthropology Museum at Berkeley (Heizer 1949; Moratto 1984; Moratto and Riddell 2016). Part of the impetus for the formation of UCAS was growing concern over the post-WWII boom in development and construction of dams, highways, and roads (Fagette 1998:22–23). UCAS members were responsible for many of the initial River Basin Surveys, and later, more thorough investigations into the cultural history of the Sierra Nevada (Moratto and Riddell 2016). Robert Heizer (1949) of UC Berkeley noted that UCAS mandate was to work jointly with UC Los Angeles, the Los Angeles County Museum, UC Santa Barbara, the Santa Barbara Museum of Natural History, the Southwest Museum, the San Diego Museum of Man, Sacramento College (now California State University Sacramento—CSUS), and the Archaeological Survey Association of Southern California. It is mainly from the cooperation

between these universities and museums, as well as the National Park Service's Interagency Archeological Services (IAS) and California State Parks, that investigation of the Sierra Nevada's cultural history began in earnest (Foster 2014; Moratto and Riddell 2016; West 2000).

Some of this early work resulted in the first culture history chronologies for the region. For example, under the directives of UCAS, work by Heizer, Albert Elsasser, and Thomas Bolt culminated in the first chronology for the Tahoe region of the Sierra Nevada (Heizer and Elsasser 1953), while to the south, survey and excavation by Gordon Grosscup (1954) and James Bennyhoff (1956) established the first culture chronology for Yosemite National Park. Important to the understanding of cultural history within the Sierra Nevada was the noted differences between the Tahoe chronology and that of Yosemite. For example, people inhabiting the Yosemite area showed a preference for obsidian regardless of time period (Bennyhoff 1956), while Tahoe inhabitants showed a heavier reliance on basalt with more use of obsidian during later periods (Heizer and Elsasser 1953).

During the 1960s and early 1970s, collaboration continued among numerous universities, colleges, and local, state, and federal agencies following the development and implementation of new Federal laws aimed at inventorying, collecting and preserving cultural and historic resources (Foster, 2014; Moratto, 1984: 311-312, 321; West, 2000). These new laws—the Reservoir Salvage Act of 1960, and the National Historic Preservation Act of 1964—ultimately came to be the first steps towards the creation of Cultural Resource Management (CRM) archaeology as a profession, which ever since, has had the strongest influence over archaeology conducted in the Sierra Nevada. During this era, work undertaken within Yosemite National Park was directed by the National Park Service (NPS) (Hull and Moratto 1999). A collaboration between NPS and California State College, Stanislaus resulted in a huge survey project that not only relocated sites

originally identified by Bennyhoff, but also recorded over 560 new sites, including rockshelters, quarries, cemeteries, lithic scatters, middens, bedrock milling stations, and pictographs (Napton 1978; Napton et al. 1974; Napton and Greathouse 1976).

Meanwhile, many CRM projects outside Yosemite dating to this time were staffed and run by archaeologists from numerous universities, as well as students looking to gain experience in the field. Although this era of archaeology in the lower elevations of the Sierra Nevada was largely focused on salvaging what could be learned from sites before they were obliterated by construction activities usually involving the construction and expansion of reservoirs, some resulted in academic project summaries (e.g. Moratto 1971), while others became the subject of MA theses and PhD dissertations (e.g., Johnson 1966; Moratto 1972), while still others generated a succession of CRM reports that traced the progression of a single project over a decade (e.g., New Melones). Johnson's (1966) work at the construction site of Comanche Reservoir entailed the excavation of at least six sites, a few of which revealed a developed midden deposit, and one of which was a cave with rock art. Moratto's (1972) dissertation work at Buchanan Reservoir entailed archaeological testing at more than 27 sites, from which he was able to produce a three phase chronology for the Chowchilla River region (Moratto 1984: 316).

However, as this era of archaeology was during the formation and enacting of these new laws, interpretations of the laws varied, and funding for the federally mandated archaeological portion was not always available, and varied according to whose interpretation and which district or government branch was involved. While the federal government funded ten stages of archaeological investigation for the New Melones Reservoir project that lasted from 1968 to 1982 (Moratto 2002; Moratto et al. 1988), other state-proposed improvement projects were not so lucky.

Case in point, of note and direct relevance to this dissertation is Moratto's (1971) publication on the Tuolumne River sites impacted by the creation of the New Don Pedro Reservoir. During the fall of 1970 and winter of 1970–1971, survey and excavations in the New Don Pedro Water Project area, located 22 miles south of Sonora, were conducted by students and staff from San Francisco State College (now SFSU), Columbia Junior College, and Merced Junior College and overseen by State Archaeologist Francis Riddell (Moratto 1971a:1, 39).

Even though the construction of the new dam began in 1967, funding for the archaeology portion of the project was not available until 1970 (Moratto 1971: 2). Funding was provided by a joint effort between the Turlock and Modesto Irrigation Districts and the City and County of San Francisco and administered by the National Park Service and the Frederik Burke Foundation for Education of San Francisco State College (Moratto 1971:ii).

Although the teams documented 41 sites, nearly all of them had already been damaged in some way (Moratto 1971: 1, 39). For example, at CA-TUO-314, bulldozers had scraped the ground clear, unearthing, scattering, and in some cases pulverizing human burials prior to any archaeological work being performed (Slaymaker 1971:129). Despite the damage, seven sites, including CA-TUO-314, were still excavated in an attempt to salvage what could be learned of the cultural history of the Tuolumne River area within the foothill region before reservoir inundation. Funding for analysis was limited (Moratto 1971a). At the time, only a handful of radiocarbon dates were obtained, which was insufficient to place them within a broader cultural sequence. The Tuolumne River sites are rarely considered or discussed in later publications, as their analysis was incomplete, and further archaeological investigation was preempted by the filling of the New Don Pedro Reservoir.

Three of these sites (CA-TUO-279, -300, -314) are addressed in greater detail within this dissertation research and fill a gap in our understanding of the cultural history of the region. I discuss these sites and their new dates in more detail at the end of this chapter. Three additional sites associated with New Don Pedro Reservoir preliminary construction activities, which only saw survey and surface collection, are also addressed at the end of this chapter and within this research.

Although the Don Pedro case is extreme, this situation was not unusual. Much early CRM work was conducted in poorly known regions of California. If funding was not sorted out prior to the construction project beginning, archaeological investigations commenced after construction began, and in the worst scenarios, after it was nearly complete (Foster 2014: 6). During this era of new laws, state construction activities took precedence over archaeological investigations, or, in other words, archaeological investigations could not delay, by law, construction activities overseen or conducted by the state (Foster 2014:5–6). This issue has since been addressed by the Archaeological and Historic Preservation Act of 1974 and the Archaeological Resources Protection Act of 1979. These newer laws are responsible for bringing about CRM archaeology in the Sierra Nevada as we know it today, where archaeological survey, inventory, testing, and mitigation all precede construction activities on State and Federally managed lands, and construction activities now require monitoring should unknown cultural resources be unearthed during construction. This change is significant, as only 36% of the entire region is privately owned, and the remainder is split amongst various State and National or Federally managed lands (Sierra Nevada Ecosystem Project 1996:15).

Since the full implementation of CRM laws, further archaeological investigations throughout the west central Sierra Nevada resulted in large swaths of the Stanislaus National

Forest being inventoried (Bouey 1991a, 1991b, 1991c; Chartkoff and Chartkoff 1981; Goldberg and Moratto 1983; Jackson et al. 1994; Moratto 1976, 1981; Van Bueren et al. 1989), as well as large portions of the Stanislaus River at both ends (Hanson 1993; Moratto 1976, 2002; Moratto et al. 1988; Peak and Crew 1990; Peak and Neuenschwander 1991), parts of the Mokelumne River (Wirth Environmental Associates 1985), Yosemite (Baumler and Carpenter 1982; Ervin 1984; Hull 1988, 1989; Hull and Moratto 1999; Hull and Mundy 1988; Moratto et al. 1999; Riley 1987), as well as Sonora (Caputo 2005; Francis and Stewart 1992; Meyer 2008; Rosenthal 2008a, 2011d; Stewart 2001; Waugh and Rondeau 1990) and Groveland (Andolina and Rosenthal 2009; Mikkelsen et al. 2012). The wealth of data produced from these projects continues to inspire numerous questions and hypotheses about settlement, subsistence, cultural responses to climate change, the evolution of technology, among other topics, within ancient cultural systems.

3.2.3 Settlement and Subsistence Studies

Archaeologists working within the west-central Sierra Nevada have opined that the evolution of precontact subsistence and the corresponding changes in land use are poorly understood (Hull and Moratto 1999; Jackson et al. 1994; Moratto 2002; Moratto et al. 1988; Rosenthal et al. 2011a:117). Part of this stemmed from the lack of a cohesive chronology for the region, and, as such, an incomplete picture of the cultural history (Rosenthal 2008a). As well, most have focused on areas to the north and south of the project area, as these regions are better studied. Many have focused on Yosemite and Southern and Central Sierra Me-Wuk and Mono (Bennyhoff 1956; Hull 1988, 2009; Montague 2010; Rubinstein 2020); the southern Sierra and Mono and Southern Me-Wuk lifeways (Morgan 2008, 2009a, 2006; Rubinstein 2020); and the

Northern Me-Wuk together with Nisenan/Maidu and Washo within the northern portion of the range (Elsasser 1960; Hunt 2004; Leftwich 2010; Tullo 2023).

Despite this limitation, archaeologists within the region have produced a wealth of information that can be used to explain patterns in site locations versus environmental features. Some of these studies have focused on vegetation in relation to surface manifestations of lithic scatters and bedrock mortars (Bennyhoff 1956; Hull and Mundy 1988; Moratto 1981). In a similar vein, some examined floral communities in relation to lithic scatters and middens (Elsasser 1960), while still others focused on predicting site types and locations in relation to deer migration routes (Woolfenden 1988), geologic setting (Jackson 1988), vegetation, landform, and/or water availability (Pilgram 1982). Lastly, there are studies that focused on explaining site locations and site function vis á vis some combination of any of the above (Chartkoff 1990; Hunt 2004; Jackson et al. 1994; Jackson 1991; Leftwich 2010).

While appreciable work has been devoted to trying to piece together what factors appear to be the main drivers of settlement decisions, the main consensus is that throughout the cultural history of the west-central Sierra Nevada, the majority of site locations are most closely associated with nearly level terrain, in proximity to a water source, and located within productive foraging patches—*sensu* Binford (1980; Leftwich 2010).

Studies that incorporate bedrock mortars have gone a step further but are necessarily limited to the most recent Holocene interval (e.g., Leftwich 2010; Rubinstein 2020; Stevens et al. 2019), although there are exceptions (e.g., Montague 2010). From these studies, sites interpreted as winter settlements tend to be in lower elevations while sites in higher elevations—above some expectation of a snowline—represent mid-year occupation (e.g., Hunt 2004). A long-standing pattern of landscape use has emerged because sites that have been re-occupied over millennia

also tend to have bedrock mortars. These sites frequently have deep midden deposits if they are in the lower elevations, or lithic scatters in the higher elevations; both have bedrock mortars. The assumption, which is difficult to test, is that the bedrock mortars are not as old as the long *durée* of site use.

Few paleo-subsistence studies have been undertaken within the region. The earliest of these only considered acorns and why they dominated Me-Wuk diets. For example, Mayer (1976) concluded that acorns were a primary factor in determining cultural development—mainly that of the *nena*, as they were nearly inexhaustible, have a high nutritional content, and were easily gathered and stored which reduced competition amongst related family groups during periods of population growth. Although Mayer (1976) brought up interesting correlations between the adoption of balanophagy and the function of the *nena*, his ideas are only applicable to the most recent cultural periods.

Later subsistence studies have instead focused on paleobotanical remains as indicators of the importance of plant foods, and how their relative frequencies changed through time (Wohlgemuth 2005). Some are able to provide a diachronic perspective on the season of Sierran biotic zone use (Rosenthal et al. 2011a), while others compare the patterns of the Sierra Nevada to those across California (Reddy 2016). From these studies we learn that most subsistence research has focused on the food production, rather than on food consumption, which, because of the differential pathways paleobotanical materials enter the archaeological record, may not offer a true reflection of actual diets (Reddy 2016: 234-236). Important in this consideration is that some plant remains, such as small seeds, do not have utilitarian uses like acorn nutshell as fuel for fire.

These studies do help define a sampling universe, i.e., they help to further define what resources *may* have been used, suggest intensity of use, and set the stage for questions regarding the actual diet. For studies using stable isotopes to analyze human diets, these contribute to expectations regarding the resource base, such as which food items to sample to test isotopic differences among different plant types (e.g., tree, shrub, or annual) within the sampling environment—something that is not common practice among many paleodietary studies globally. I further address this issue in Chapter 4.

While faunal studies provide much the same function as the paleobotanical studies for isotopic dietary analyses, they tend to be fewer within the Sierra except in gray literature tallies. Faunal remains are highly fragmentary, something that is noted by numerous archaeologists working in the Sierra Nevada (Baumler and Carpenter 1982:235, 246; Moratto et al. 1988:70; Whelan 2016:50, 69, 83, 95, 111, 120). As well, western Sierra Nevada soils are typically characterized as slightly acidic (Moratto et al. 1988:70; Rosenthal 2008a:74), which degrades the inorganic matrices of bone and leads to demineralization over time. When highly fragmented bones with greater exposed surface areas are buried in slightly acidic soils, they will experience increased demineralization.

The few faunal analyses that do exist, such as Baumler and Carpenter (1982:233–248), McGuire et al. (2011), Rosenthal et al. (2011b), and Rosenthal et al. (2011a), all agree that deer constitute the greatest source of meat throughout the entire culture-history of the region. As well, while numerous other species are present, with the exception of elk and pronghorn (very few specimens), all are much smaller animals. In other words, while a broad array of taxa were consumed, these smaller bodied species contributed less to the meat portion of the diet than did

deer (Rosenthal et al. 2011a:145–146). This has further implications for paleodietary studies in the Sierra Nevada, which I cover in Chapters 5 and 6.

Because the main thrust of this research revolves around a diachronic interpretation of diet as an evaluation of change in dietary patterns, and how this change reflects the broader culture-environment system, below I mainly focus on those studies that evaluate archaeological patterns of subsistence and settlement decisions at a region-wide level through time for the west-central Sierra Nevada, which represents my sampling universe. The most relevant studies to my project area are those of Whelan (2016; Whelan et al. 2013), Wohlgemuth (2005), and Rosenthal and others (Rosenthal 2008a, 2011a)—which directly cover the region of study. These studies take a region-wide perspective, on which I build in my subsequent chapters. Below I cover some of the macro-scale analyses framed by these studies, while the finer details of their analyses are covered throughout the summary of the chronology for the Indigenous people of the west-central Sierra Nevada.

Regional Macro-scale Analyses

Wohlgemuth (2005) tested the predictions of intensification models at CA-AMA-56, an Upper Sonoran Zone site with evidence of use during the Medieval Climate Anomaly (MCA). The MCA was a period of increased temperatures and two near-century long drought periods in California which were estimated to have occurred between 892 to 1112 CE and 1209 to 1350 CE (Stine 1994). Since AMA-56 had evidence of occupation dating to the MCA, Wohlgemuth hypothesized he would see signs of intensification in the paleobotanical and faunal components similar to that which he (Wohlgemuth 1996) had noticed in Central Valley and East Bay sites. However the AMA-56 data did not conform to the predictions of intensification models, and

instead indicated declines in diversity and abundance of aquatic animals, fish, and small seeds through time (Wohlgemuth 2005:309). He suggested that a reduction in the seasons of occupation could account for some of the data but then considered the wider settlement trends from along the Mokelumne and Stanislaus Rivers, which also show low visibility of occupations dating to this period, something previously mentioned by Moratto (1968, 1981; Moratto et al. 1978, 1988) for the Stanislaus River watershed and areas further south.

Further, Wohlgemuth (2005) considered that MCA droughts affected streamflow in many of the waterways within the Sierra Nevada. Importantly, he notes that Meko et al. (2001) did not find evidence for low flows in the Sacramento, Yuba, Feather, and American River drainages that corresponded to the timing of the MCA, which implies a negation to Wohlgemuth's (2005) hypothesis that stream flows were reduced. Because the MCA dates have been refined to between 1050–940 cal BP and 770–675 cal BP (Graham and Hughes 2007; Lyon et al. 2025), Meko et al. (2001:1035-1036) do suggest reduced flows dating to the MCA, with region-wide data indicating that even areas above 40° N latitude were affected by the MCA droughts at times. These data are important, as Wohlgemuth (2005) may have been correct in his assertion that the paucity of MCA-era components in the lower elevations of the Sierra Nevada were likely due to drying of the low elevation creeks and streams which had been reoccupied and used for longer seasonal durations prior to this time.

As part of CRM work undertaken for the East Sonora Bypass Project, Rosenthal (2008) and colleagues (2011) assessed the settlement structure of the west-central Sierra Indigenous communities as it relates to resource distributions across time and space using a model of central place foraging and patch choice as discussed by Orians and Pearson (1979) and Stephens and Krebs (1986) respectively. In their model, they assume that Indigenous people employed the

most efficient combination of residential and logistical mobility to realize the greatest overall energetic returns (Rosenthal et al. 2011a:118). They also consider the differences between men's and women's foraging goals, and suggest that when spatial conflicts occurred, men should choose to harvest large animals logistically, as they provide a much higher overall return and can withstand higher overall transport costs, as compared to plant resources on which women focus. Mainly, the model suggests that most settlement locations should have been chosen to represent women's foraging goals, as predicted by Zeanah (2004), to account for the lower-overall resource rankings but higher reliability of plants.

Their goal was not to predict site locations, but to test archaeological behaviors against some predicted model outcomes (Rosenthal et al. 2011a). This model is the first (and only) of its kind to be applied across such a large portion of the west-central slope, and is unparalleled in the number of sites, the distributions of sites across all elevations, and the time-depth considered. This model helps to form the basis of our current understanding of archaeological patterns of settlement and mobility across this region.

To create model predictions from resource structures, the biogeography of the west slope between the Mokelumne and Tuolumne Rivers was considered, and economically-important plant resource distributions for each biotic zone were defined and compared (Rosenthal et al. 2011a). Results showed that the Upper Sonoran Zone and Lower Montane Forest have the highest seasonal diversity of economically important plant foods, while the Upper Montane and Sub-alpine Forests had the lowest and were grouped together (Rosenthal et al. 2011a:120–122).

The productivity of these resource patches was then compared after all important plant foods were ranked according to their energetic return rates, and their seasonality profiles had been considered (Rosenthal et al. 2011a:122–125). The predicted pattern of plant food

productivity from this model suggests greens should have been taken in the foothills during late winter to early spring, and in the Lower Montane Forest during early spring; roots and bulbs should have been gathered in the Lower Montane Forest between mid-spring through early summer; small seeds should have been taken in the Lower through Upper Montane Forests during late summer and early fall; fruits should have been accessed from chaparral or Montane forests in summer, and nuts should have been collected from the Upper Sonoran Zone during late fall and early winter (Rosenthal et al. 2011a:125–126).

This process was repeated for economically important faunal resources. Those predictions suggest the Upper Montane Forest and above are the best habitats for hunting economically desired species in spring through autumn, while snow-free areas of the Lower Montane Forest and Upper Sonoran Zone were the best in fall through winter to take advantage of migrant deer aggregations below the snowline—until the snows melt at the higher elevations and the animals disperse—(Rosenthal et al. 2011a:126–128).

The last consideration was winter snow as a limiting factor of settlement locations, with predictions for winter settlements below the snowline to mitigate cold, maintain continued access to foraging patches in snow-free areas, and to take advantage of winter deer aggregations (Rosenthal et al. 2011a:128–131).

These predictions were tested using three main types of archaeological evidence: toolstone distributions; artifact and faunal assemblage compositions; and seasonality profiles of paleobotanical assemblages (Rosenthal et al. 2011a:131). The assemblages are from among 55 single period site components between the Mokelumne and Tuolumne River drainages ranging in elevation between 186–2493 m (610–8,180 ft), and spanning the last 7,500 years (Rosenthal et al. 2011a:131).

For their first analysis, comparisons of toolstone distributions used un-weighted averages for each temporal period and biotic zone (Rosenthal et al. 2011a:132). Functional assemblages were compared for the same parameters, using assemblage diversity calculated as a log-log regression comparing the total number of artifacts to the total number of classes in each site component (Rosenthal et al. 2011a:139). A chi-squared statistic was run on artifact classes to analyze differences in assemblage content, but only for data sets that were of a contemporaneous age—i.e., some biotic zones had restricted temporal expressions, which meant comparisons were limited to periods that overlapped in areal extent (Rosenthal et al. 2011a:141). Faunal assemblages from 38 components within the foothills and Montane forests were analyzed for any differences among time periods, biotic zones, or targeted resources (Rosenthal et al. 2011a:145–146). A total of 169 flotation samples were analyzed for seasonal differences among biotic zones and time periods using ubiquity measures—i.e., the number of samples containing a particular taxon as a proportion of all samples containing dietary remains (Rosenthal et al. 2011a:146, 149). The results of these analyses are discussed in my overview of the culture history of the region, in Section 3.3 below. One thing that stands out from these analyses is that the authors (Rosenthal 2011c; Rosenthal et al. 2011a) could not rule out the possibility that the MCA droughts did in fact forcibly change the residential settlement pattern.

Building on the evidence presented by Rosenthal (2008a, 2011a), Whelan et al. (2013) examined the reasons why acorns became the preferred item for storage during the last thousand years. A number of paleobotanical assemblages were examined from the Rosenthal (2011a) dataset in addition many sites external to the Rosenthal (2011a) dataset. Importantly, the same ubiquity measures were used, and the results were much the same: acorns became favored for storage around the same time we begin to see evidence for sedentary occupation of winter village

sites in the Upper Sonoran Zone (Whelan et al. 2013). An argument against a reduction in the prominence of gray pine during the MCA is presented, and the authors suggest that acorns (oak) and gray pine nuts (gray pine) would have been encountered at the same rate as preceding periods, and state that it was likely these resources just moved upslope. Because of this, the authors suggest why acorns became favored over gray pine nuts during the last thousand years, given their post-encounter return rates are similar: women, who are in charge of most food storage tasks, faced trade-offs between foraging efficiency and childcare. Using the opportunity costs model, acorns are argued to have been preferred for storage in the situation of reduced residential mobility because the up-front processing costs are low compared to gray pine nuts, and the effort of processing them (unlike gray pine nuts) can be delayed until a time of year when childcare tasks and foraging are not in competition, i.e., winter (Whelan et al. 2013).

Whelan (2016:293) expands on the argument of Whelan et al. (2013) and suggests one way to test the hypothesis from the opportunity costs model is to examine the age of weaning to see if an earlier age of weaning happens concurrently with the switch to acorns as preferred storage items. An earlier age of weaning has been observed for more residentially stable groups elsewhere in California (Greenwald 2017), as higher inter-birth-intervals are expected when the constraints on mobility and lactation are relaxed. This remains as a direction for future research.

Drought, and its effects on the resource base and on the people inhabiting the west-central Sierra Nevada, remains an open topic. Despite years of archaeological research and numerous publications (e.g., Moratto et al. 1988; Moratto et al. 1978; Rosenthal 2011a; Rosenthal 2008a; Whelan 2016) hinting at change during the MCA, no one has been able to fully address the issue. This is mostly due to the apparent paucity of sites within the region that date to this period. My intention within this dissertation research focuses on what diet tells us about society and building

a baseline for expected isotopic dietary values, and, given the fortuitous results of radiocarbon dates on human remains, I am equipped to address some of the questions that surround culture during the MCA.

3.2.4 Chronology Building

Beyond the inventorying of sites by state and federal land managers, and site protections from CRM, over the last seventy years a great deal of work has been devoted to understanding the tempo of events within Sierran cultural history, and hence chronology building. Most, if not all of the existing chronologies are the results of numerous CRM studies done throughout the area from Lake Tahoe south to Buchanan Reservoir at the west end of the Chowchilla River. Some of these previous investigations resulted in separate chronologies for specific areas within the region, for example, New Melones (Moratto et al. 1988; Moratto 2002), the Stanislaus Forest (Jackson et al. 1994), Buchanan Reservoir (King 1976; Moratto 1972; Peak 1976), and the Mokelumne River (Cleland 1988; Wirth Environmental Associates 1985). Other projects have resulted in additions to, or overhauls of, existing chronologies, such as those for Lake Tahoe (Elsasser 1960; Elsasser and Gortner 1992; Elston 1982, 1986; Elston et al. 1977; Hutchins and Simons 2000; Waechter and Bloomer 2009) and Yosemite Valley (Hull and Moratto 1999; Moratto et al. 1999; Rosenthal 2012).

Most of these chronologies are extremely area specific and tend to mask broader cultural changes within the west-central Sierra Nevada. Additionally, most rely on the comparison of artifact forms first defined within the Great Basin and Central Valley, rather than quantitative measures of artifact forms from within the Sierra Nevada—in other words, many repeat previous interpretations and rely on the dating of point types found elsewhere to determine what the Sierran projectile points actually are and when they date to, sometimes without any diagnostic

measurements being taken. Others (e.g., Jackson et al. 1994; Rosenthal 2011b) point out this fallacy, and note that crossdating artifact forms is not enough for building meaningful chronologies.

Within the last thirty years, two regional chronologies have been proposed. These reach beyond one specific project area and attempt to broadly understand changing material culture for a larger portion of the west-central Sierra Nevada.

The first, *Framework for Archaeological Research and Management for North Central Sierra Nevada*, commonly referred to as the FARM chronology, was developed by researchers focused on the Stanislaus National Forest, but attempts to incorporate the entire north-central Sierra Nevada under one chronological framework (Jackson et al. 1994). The FARM chronology broadly follows ideas set forth from Fredrickson (1973) and Chartkoff and Chartkoff (1984) for a chronological framework. It divides the last 11,000+ years of human use of the western Sierra Nevada into six periods, mostly based on large cultural trends from throughout California. Overall, it is extremely broad and could be applied to the whole of California. While this is not necessarily a problem for uniting the whole California cultural sequence, it lacks any real meaningful detail specific to the west-central Sierra Nevada, which seems to have its own cultural development in the broad scheme.

The second regional chronology, proposed by Rosenthal (2011b) and colleagues differs from earlier chronologies as it does not rely on artifact styles and cross dating of projectile points, but rather re-analyzed multiple points from across the region, pairing the new analysis with obsidian hydration, radiocarbon dates, and stratigraphy to come up with a sequence applicable to the entire west central Sierra Nevada, rather than small portions. The Rosenthal (2011b) chronology also avoids using period names that have already been applied in other

Sierran chronologies to avoid confusion. My overview of the cultural history of the region draws heavily on Rosenthal (2008a, 2011b, 2012).

3.3 Pre-contact History of the West-central Sierra Nevada over the Last 11,500 Years

Human use of the west-central Sierra Nevada spans more than 11,500 years and encompasses the most fleeting use to that of well-established villages and hamlets. The Sierra Nevada, like many inland locations throughout California, over time saw highly mobile groups slowly reduce residential mobility to the point of territoriality and semisedentism, intensify food production, invent and adopt new technologies, and establish organized trade, which entailed the use of a shell bead currency among other items. However, the timing of these changes within the Sierra Nevada is unique within California, as this rugged landscape created multiple subsistence-related opportunities, but also entailed restrictions on seasonal movements given the upslope patchwork distribution of resources and a fluctuating snowline. My outline of this cultural history focuses on temporal changes in diet—evidenced here from technology and food remains, settlement patterns and mobility. However, I also refer to environmental changes (see Chapter 2: Environmental History) as reference points in this overview for easy reference and to provoke thought. Figure 3.5 summarizes the cultural period divisions discussed below in sections 3.3.1 – 3.3.5 alongside the available climate (and/or) environmental information.

Figure 3.5

Chapter 3 Comparative Timeline:
Archaeological Periods and Correlated Environmental Change

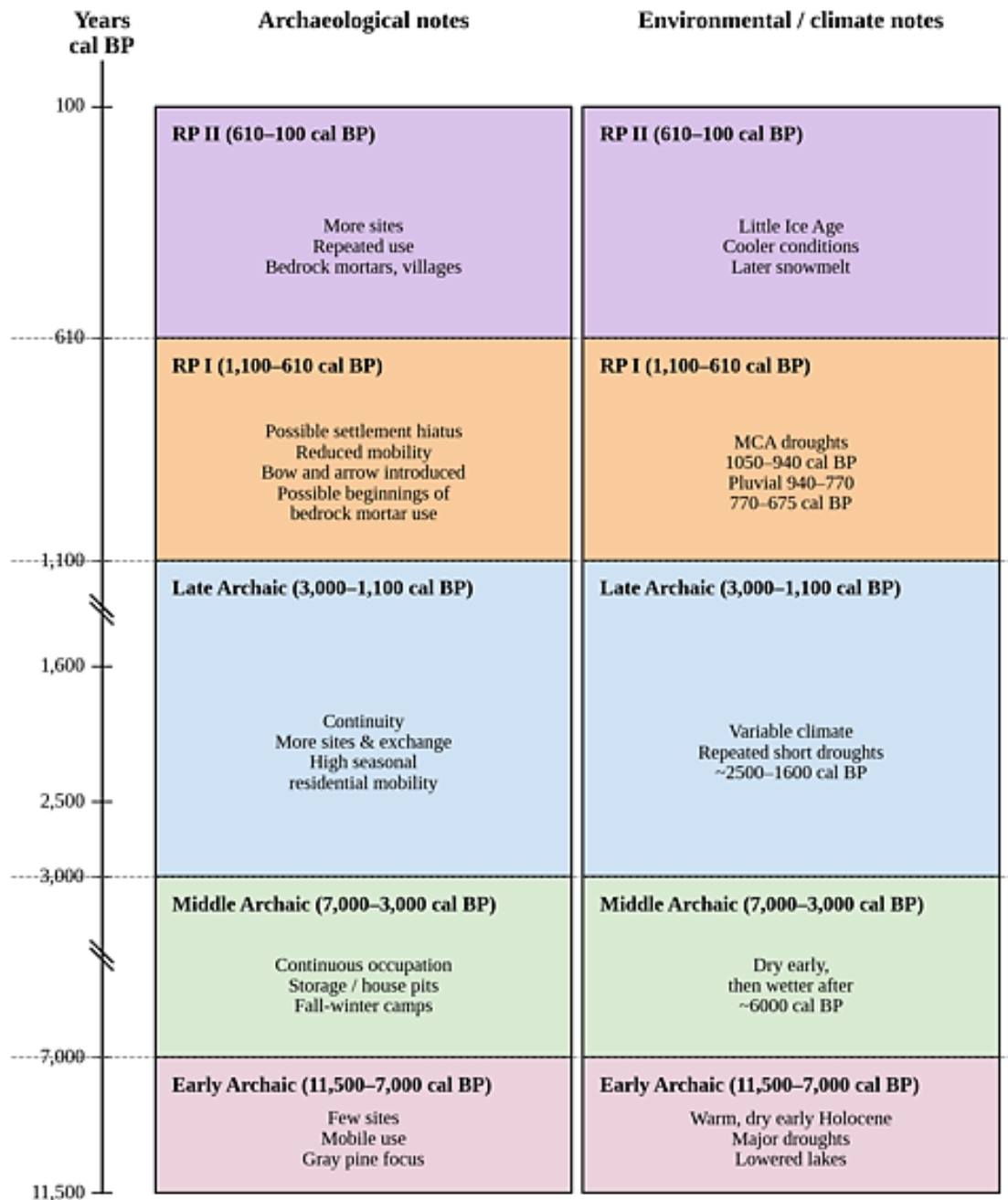


Figure 3.5 Chapter 3 Comparative Timeline

Summarized from Chapter 3, sections 3.3.1–3.3.5 only. Older spans are vertically compressed to fit the page; breaks mark omitted scale. Timeline diagram layout and formatting were created with assistance from ChatGPT (OpenAI).

3.3.1 Early Archaic Period (11,500–7000 cal BP; 9,550–5,050 BCE)

The Early Archaic, as defined by Rosenthal's (2011b) chronology, takes place within the early Holocene. Paleoclimatic information characterizes it as a warm, dry period with lowered lake levels and major droughts, punctuated by short intervals of reprieve and wetter conditions (Anderson 1990; Davis and Moratto 1988; Lindström 1990; Mensing et al. 2004; Osleger et al. 2009). The long dry period resulted in lowered lake levels in Tahoe (Lindström 1990; Osleger et al. 2009) and Swamp Lake, Yosemite (Street et al. 2012: 102) sometime between 7,500 and 6,000 cal BP, around the end of the Early Archaic.

During this period, the ecotones of the Sierra Nevada began moving upslope to reach their modern altitudinal limits, however, forest structure was not the same as today (Anderson 1987, 1990; Smith and Anderson 1992). Across the western slope of the Sierra Nevada, paleoecological data indicate lower montane forests were becoming established in mid-slope elevations (~1,500 m, or ~5,000 ft), while Upper Montane, Sub-Alpine and Alpine forests—previously compressed between 2,000–3,350 m—began to disperse upslope (Anderson 1987; Anderson 1990; Brunelle and Anderson 2003; Smith and Anderson 1992). As such, these forest types were more elevationally constrained and condensed within a narrow band beginning with the onset of the Holocene.

At mid-elevations, oaks expanded relative to pine and fir, while montane chaparral became common in the High Sierra, with sub-alpine conifers confined to the most mesic habitats (Brunelle and Anderson 2003; Davis et al. 1985; Mensing 2015; Smith and Anderson 1992). Records from Tulare Lake suggest lower elevations within the valley transitioned from pine-juniper woodland to oak woodland and chaparral (Davis 1999). The floral composition of the foothill region is not known except from archaeologically documented remains of gray pine

(nutshell), oak (acorn nutshell), California bay (nutshell), wild cucumber (nutshell), blue grass seeds (*Poaceae* sp.), and clarkia seeds (Rosenthal et al. 2011a:Table 60). All of these are from plants scattered throughout the foothill region today, with the remains indicating they were present there in the past as well. Researchers have noted high fire frequency during this period, consistent with the interpretation of prevailing dry conditions (Brunelle and Anderson 2003; Smith and Anderson 1992). Overall, the early Holocene period is characterized by substantial environmental changes, which need to be considered when interpreting the Early Archaic archaeological record.

The Early Archaic archaeological record is represented by only a handful of sites. Currently, there are three known within the modern Upper Sonoran Zone of the foothills, all near 300 m (1,000 ft.) elevation: Skyrocket (CA-CAL-629/630) (La Jeunesse and Pryor 1996), Clark's Flat (CA-CAL-342) (Peak and Crew 1990), and Taylor's Bar (CA-CAL-1180/H) (Milliken et al. 1997; Rosenthal 2011a:169). All three sites are located on low angle ridges, originally thought to be non-depositional landforms, with Early Archaic deposits found as much as three meters deep (La Jeunesse and Pryor 1996; Moratto et al. 2017; Peak and Crew 1990; Rosenthal 2011d). What we know of the early period at high elevations is limited to a few lithic scatters within Yosemite (Montague 2010) and Gabbott Meadow (CA- ALP-109, -149, -192) (Peak and Neuenschwander 1991). In addition, a few isolated Clovis-like points have been found, often understood as representing some of the earliest evidence of human use of the Sierra Nevada (Moratto et al. 2017, 2018).

The Early Archaic is dominated by two local projectile point forms, Wide-stemmed and Large-stemmed darts as (re)defined by Rosenthal (2011d). Measurement of the Stanislaus Broad Stem, originally found at Clarks Flat, resulted in a reclassification of this type to Large-stemmed

Dart (Rosenthal 2011b:21). The Wide-stem and Large-stem darts are identified on the basis of measurable basal morphologies, rather than previously used qualitative descriptions (Rosenthal 2011b). Wide-stemmed darts from west-central Sierra Nevada contexts can be distinguished by proximal shoulder angles (PSAs, measured on the largest angle) less than or equal to 110° and neck widths measuring 18 mm or more (Rosenthal 2011b:Table 8). Large-stemmed darts, the next most common of early point forms, have PSAs ranging from $\leq 110^\circ$ to $\geq 85^\circ$ and neck widths between $<18\text{mm}$ to $\geq 13.5\text{ mm}$ (Rosenthal 2011b:21). Rosenthal (2011b) also determined low frequencies (i.e. less than three per site) of other dart forms present within contexts dating to this period, mainly Concave Base, Basally-thinned Concave Base, Corner-notched, Contracting-stem, and Small-stemmed. Of these five, only Basally-thinned Concave Base is restricted to use during this period (Rosenthal 2011d:57). The other four reach peak use during later periods, suggesting these earlier low frequencies are an inception point. Bodie Hills obsidian hydration readings characteristic for this period (usable only for sites below 1,220 m ($\sim 4,000$ ft), or below the snowline) range between 8.6 to 6.9 microns (Rosenthal 2011d:48). Notably, the use of local greenstone and crypto-crystalline silicates (CCS) is widespread throughout the foothill region at this time, compared to the use of obsidian, which is more common later in time (Rosenthal et al. 2011b:88–89; Rosenthal et al. 2011a:134–136).

At Taylor's Bar, this period is represented by Wide-stemmed Dart points made from a silica-rich greenstone and occasionally from Bodie Hills obsidian, and a single date of $9,610 \pm 120$ ^{14}C BP, suggesting possible early use of this locality (Milliken et al. 1997; Rosenthal and Meyer 2011:11–12). At Clark's Flat, levels C and D produced Wide-stemmed and Large-stemmed Darts, and fourteen radiocarbon dates spanning from 7,180 to 13,665 cal BP (Peak and Crew 1990; Rosenthal 2011b, 2011d:47). The deepest strata at Skyrocket contained Wide-

stemmed and Large-stemmed darts, and seven radiocarbon dates that range between 10,200 and 7,765 cal BP support the site's antiquity (La Jeunesse and Pryor 1996; Rosenthal 2011b, 2011d:47).

People using the west-central Sierra Nevada were residentially mobile, moving seasonally to harvest resources (Rosenthal et al. 2011a). Overall, it is suspected that hunting activities targeted mainly deer and other large mammals throughout this period, regardless of location (Rosenthal et al. 2011a:146). Perhaps most interesting is that sites between 1,000 m to 1,800 m (~3,300–5,900 ft) on the west slope dating to this period are absent; however, the high elevations continued to be used for hunting—indicated by a few thick hydration rims from high-elevation lithic scatters and radiocarbon dates (Montague 2010:113–114; Peak and Neuenschwander 1991; Rosenthal 2011d:42–47). Some have suggested the use of the High Sierra was the domain of Great Basin groups rather than west-side foragers (McGuire et al. 2011; Montague 2010; Rosenthal 2012; Whelan 2016). Due to the sparse archaeological record, the west slope does not seem to have been permanently occupied until later, beginning in the Middle Archaic (Rosenthal et al. 2011b; Rosenthal et al. 2011a).

Handstones and millingstones are well-represented in the Early Archaic at Skyrocket, suggesting a seasonal focus on nut processing (Rosenthal et al. 2011a:157). Both Skyrocket and Taylor's Bar show gray pine nuts were of major dietary importance, supplemented to a lesser degree by acorns, California bay nuts, clarkia seeds, and blue grass seeds (Rosenthal et al. 2011a:Table 60). Seasonal availability of these resources differ: clarkia ripen in late spring through early summer, blue grass seeds are available in summer, and gray pine, acorn, and bay nuts are available in fall, (Rosenthal et al. 2011b:Table 39). Plant resource seasonality could

mean small groups accessed the foothill upland regions sporadically from lower elevation locations (i.e., Central Valley) from late spring through fall.

There are, however, several differences between Central Valley and foothill paleobotanical assemblages, which suggest these biotic zones were used differently and brings into focus a few interesting questions. Acorn makes up only 12.4% of nutshell assemblages in these foothill contexts, as compared to 73.7% within Central Valley assemblages dating to the same period (Rosenthal and Wohlgemuth 2011:184–185), suggesting different dietary adaptations between the two regions. Although it would seem the Sierras were not permanently occupied at this time, there is clear differentiation in autumn dietary resources between the Central Valley and Foothill inhabitants by the end of this period, specifically in nut crops, with gray pine taking precedence over acorn in the foothill locations (Rosenthal and Wohlgemuth 2011). This difference represents a problem that has yet to be fully articulated or resolved: if the Sierras, mainly the foothills, were not permanently occupied by at least some groups, why are fall dietary adaptations so different between foothill and valley sites during this early period? Also, if we assume these are small free-ranging groups at low population densities, why would people venture into the foothills and expend energy walking upslope when valley resources are thought to be more diverse and abundant? Given the available environmental information, the Central Valley and its margins would still be more productive habitats than the lower-ranked Sierran foothills. Clearly, if people are using the foothills and depending on acorns in the Central Valley this early, it suggests some degree of population-resource imbalance within the Central Valley. These questions are, unfortunately, outside the scope of the current research.

3.3.2 Middle Archaic Period (7,000–3,000 cal BP; 5050 to 1050 BCE)

The Middle Archaic is when we see the first permanent occupation within the region as the number of sites and diversity of site types increase (Rosenthal 2011d:49; Rosenthal et al. 2011b:82). At least eighteen sites have been documented containing assemblages of this period (Rosenthal 2008a, 2011a). Some of these sites had previously served as type sites for entire cultural periods within the New Melones chronology, for example Texas Charley (CA-CAL-286) and Redbud (CA-CAL-347) (Moratto 2002; Moratto et al. 1988; Rosenthal 2011b:35–36). Middle Archaic artifact collections are characterized by a higher number of expedient flake tools and a lower presence of core tools, drills, battered stone, and other modified stone and bone tools compared to other time periods (Rosenthal et al. 2011b:96).

Sites range from single to multi-component, and span in elevation from around 183 m (600 ft) near the Stanislaus River to upwards of ~1830 m (6,000 ft) in the Yosemite region (Bouey 1991a; La Jeunesse and Pryor 1996; Montague 2010; Moratto et al. 1984, 1988, 1999; Peak and Crew 1990; Rosenthal 2008a, 2012; Rosenthal et al. 2011a; Wheeler et al. 1991). Evidence for permanent settlement comes not solely from the number of and diversity in site types, but also from remains of buried midden deposits, house pits (semi-subterranean houses) and storage pits from the Edgemont site (CA-TUO-4559), which date between 6,510–4,520 cal BP (Meyer 2008; Rosenthal 2008a, 2011a). Substantial evidence for settlement appears around 6,000 cal BP (Rosenthal 2008a:71).

The people who first made continual use of this region would have experienced the same climatic conditions from the early Holocene—warm, dry, and drought-riddled (Anderson 1990; Davis and Moratto 1988; Lindström 1990; Mensing et al. 2004; Osleger et al. 2009). It was not until ~6,000 years ago that conditions improved and precipitation began to increase across the

entire western Sierra Nevada (Lindström 1990; Mensing et al. 2004). Between 4,200 and 4,100 years ago there is evidence for particularly strong Atmospheric Rivers (ARs) and cooler temperatures (Benson et al. 2002; LaMarche 1973; Lyon et al. 2020; Osleger et al. 2009; Street et al. 2012), which would have affected decisions on where to place winter habitation sites. These conditions prevailed until the Late Holocene after 3,000 cal BP, when climatic conditions again became more variable across the western slope.

Paleoecological research indicates that as climate conditions improved through the Middle Holocene, the lower elevation forests grew more dense, while mid elevations between 1525 m and 2440 m (~5,000 to 8,000 ft) experienced an increase in pine with stable low numbers of oak and fir, and sub-alpine conifers colonized high elevation lake margins (Anderson 1990; Brunelle and Anderson 2003; Davis et al. 1985; Smith and Anderson 1992). In other words, the west-central Sierra Nevada initially became permanently occupied during a period when climate conditions were poor, and environmental conditions were unstable. The improving climatic and environmental conditions throughout the Middle Holocene into the first part of the Late Holocene were not the initial draw for the region to be permanently settled, but instead likely served as incentive for people to stay.

Storage of gathered foods became a fundamental strategy for permanent occupation, and evidence for seasonal transhumance within the foothills into the middle elevations is more widespread than in the Early Archaic (Rosenthal et al. 2011b; Rosenthal et al. 2011a). Large storage pits, found at the Edgemont Site (CA-TUO-4559) were repeatedly used and maintained during this period (Meyer 2008:212–252; Rosenthal et al. 2011b:82, 112, 115; Rosenthal et al. 2011a:120, 157). These pits were mostly oval in shape, seem to have been more than a meter

long, and some more than a meter deep (Meyer 2008:212–252). A few found in association with house pits indicates they served as internal storage (Meyer 2008:212–252).

Fall nut-processing camps are evident throughout the foothills, but are absent from higher elevations (Rosenthal et al. 2011a:157). While the Edgemont Site within the Upper Sonoran Zone shows clear evidence for repeated occupation and use during winter (Meyer 2008:212–252), contemporary sites situated between 1,675 and 2,750 m (5,500 and 9,000 ft; i.e. Lower Montane Forest to Upper Montane Forest) within Yosemite regularly consist of projectile points and faunal remains (Rosenthal 2012), suggesting use primarily in the spring and summer. Artifact assemblage diversity is greater within sites situated in Upper Sonoran contexts as compared to those within the Lower and Upper Montane Forests, further suggesting that the mid-elevation sites were warm-season encampments (Rosenthal et al. 2011a:139–141).

The use of Large-stem and Wide-stem darts wanes at the beginning of this period, accounting for the major period division between the Early and Middle Archaic, while Corner-notched, Contracting-stem, Small-stemmed, and Side-notched darts become the dominant point forms for the Middle Archaic (Rosenthal 2011d:47–49, 51, 57). The use of local toolstone, mainly cryptocrystalline silicates (CCS), dominates, although the use of Bodie Hills obsidian is also common (Rosenthal et al. 2011a:132–136). Bodie Hills obsidian hydration values for this period range between 6.8–4.8 microns (Rosenthal 2008a:38, 2011d:48).

The most common dart points are again distinguished based on basal metric attributes. Corner-notched darts are distinguished by PSAs greater than 110° and less than or equal to 140°; Contracting-stem darts are defined by neck widths less than 18.0 mm and PSAs less than 85°; those with PSAs greater than 140° are considered Side-notched darts; Small-stemmed darts have neck widths less than 13.5 mm and PSAs between 85–110° (Rosenthal 2011b:21). Of these

types, the notched darts (Corner-notched and Side-notched) are the most numerous within this region, as compared to the American-Feather River watershed (Stemmed Darts dominate), the Chowchilla River watershed (Concave-base Darts dominate), as well as Central Valley Early and Middle Period contexts (Stemmed, and Concave-base Darts dominate) (Rosenthal 2011b:35). This difference suggests the Mokelumne-Tuolumne River watershed has a distinct projectile point chronology that has been largely obscured by the borrowing of point classifications external to the region and a distinct lack of quantitative assessment of internally defined types (Rosenthal 2011b:35–36).

Hunting of artiodactyls remained important, evidenced by the prominence of medium-large mammal remains, all presumably deer (Rosenthal et al. 2011b:110–111; Rosenthal et al. 2011a:145–146). The dietary use of small mammals is also evident, with jackrabbit, cottontail, squirrel, and rodent remains (some burned) found within a few sites' components indicating their capture and consumption (Rosenthal et al. 2011b:106–109, 115; Rosenthal et al. 2011a:126–130, 145–148, 157). Birds seem to have been rarely consumed (Rosenthal et al. 2011a:Table 59), although given the morphology of bird bone (thinner cortical walls than mammal of similar size, hollow medullary cavities, etc.), acidic soils of the Sierra Nevada (prone to degrade mineral structure of bone) and this early time frame, a dearth of bird bone could be expected due to natural attrition.

The Middle Archaic plant-based diet shows interesting patterns in the seasonal use of different biotic zones, as attested to by artifact assemblage diversity and paleobotanical remains among sites. Foothill sites within the Upper Sonoran Zone regularly show that fall nut crops were of primary importance, dominated by gray pine, with acorns, California bay, and buckeye as lesser contributors (Rosenthal et al. 2011a:146–155). Low relative and absolute frequencies of

berries and small seeds suggest these lower elevation sites were infrequently occupied during warmer seasons (Rosenthal 2008a:101; Rosenthal et al. 2011a:Table 60). Sites within the Lower Montane and Upper Montane Forests most often contain the remains of berries (manzanita and blackberry pits/seeds) and grass seeds, indicating use of these biotic zones occurred mainly after the snows melted, which restricts use to the spring and summer (Rosenthal 2011c:232; Rosenthal et al. 2011a:151). As well, fewer battered stones and cobbles—associated with the processing of pine nuts—have been found in the mid-to-upper elevation contexts as compared with low elevation, suggesting infrequent use during fall (Rosenthal et al. 2011a:157).

In sum, the Middle Archaic is associated with the emergence of continuous occupation of the west slope, with most fall-winter camps located below the snowline in the Upper Sonoran Zone, and spring-summer task camps within the mid-elevations (Rosenthal 2011a). Large mammals, presumable deer, remain the primary target of hunting pursuits, although a wider range of small-bodied taxa are also present within the diet (Rosenthal et al. 2011a). Among the charred plant remains encountered, gray pine—and to a lesser extent acorn—dominate foothill assemblages, while small seeds and berry pits are more common in the mid-upper elevations (Rosenthal et al. 2011a:157–158). The Middle Archaic is also when we begin to see clear evidence for regional differentiation in projectile-point types, suggesting a much more internal interaction sphere than has previously been interpreted (e.g., Moratto 1984, 2002; Moratto et al. 1988, 1999) (Rosenthal 2011b). This pattern of land use and subsistence continued into the Late Archaic (Rosenthal 2011a).

3.3.3 Late Archaic Period (3000–1,100 cal BP; 1050 BCE to 850 CE)

The Late Archaic period can be characterized by the term “cultural continuity”—meaning it is in most ways similar to the Middle Archaic (Rosenthal 2011c:236; Whelan 2016:35).

Because it appears similar to the Middle Archaic, the boundary between the two was defined by Rosenthal (2008a:39, 2011d:48) so that it “roughly split the difference between the beginning of the Newberry Period (3,375 cal BP) (Bettinger and Taylor 1974) in the southwestern Great Basin and the end of the Early Period in the Central Valley (2,500 cal BP) (Groza 2002),” and because it placed the converted mean hydration value—in accordance with radiocarbon dates—of the Knoll locus of TUO-4559 (Edgemont) in the Middle Archaic. The first of these reasons is crucial to understanding the increase in obsidian from east-side quarries (Rosenthal 2011d:48). It is only during the Late Archaic in the Upper Sonoran Zone that obsidian was the dominant debitage material, even outnumbering CCS flakes (Rosenthal et al. 2011a:134). Shift suggests the establishment of a formalized regional trade network (Rosenthal et al. 2011a; Whelan 2016:197–251), but there is no substantial differences in time marker artifacts (i.e., dart points and shell beads) that would warrant a clear separation (Rosenthal 2008a:39).

The Late Archaic Period, largely a continuation of Middle Archaic patterns, does have a few subtle differences. These mainly revolve around occupation intensity, and to a lesser extent, dietary remains and food-related technologies. In regards to occupation intensity, sites dating to this period are more numerous than those of the Middle Archaic (Moratto et al. 1988:559; Rosenthal et al. 2011b:84). In the Sonora area, occupation components occur at a frequency of one deposit for every 180 years, as compared to the encounter rate for Middle Archaic sites of one for every 665 years (Rosenthal et al. 2011b:84). Similar to Middle Archaic contexts, about 50% of Late Archaic sites tend to be buried with no surface expression—an indication that Middle and Early Archaic sites are more rare (Rosenthal et al. 2011b:83). Single component sites are also more common throughout the entire west-central region, and have been used to compare the interregional exchange of obsidian (King et al. 2011:197–200).

Related to occupation intensity are possible differences in settlement patterns among Sonora-area sites and those within the New Melones Project boundaries. For example, sites from the Late Archaic in the Sonora region show protracted occupations—a wide range of artifacts, are present within multiple sites, even some that resemble specific task sites, but it seems as though habitation was for a much shorter duration, or in some cases, repeated but infrequent use (Rosenthal et al. 2011b:112). No house or storage pits have been found that date to this period in the Sonora project area (Rosenthal et al. 2011b:100). However, records from New Melones suggest the presence of some buried house pits situated at a few multicomponent sites, which Moratto and others (1988:511–514) placed within this time frame (their Sierra Phase). Although the chronological placement of these New Melones sites has been questioned (see Rosenthal et al. 2011a:157), other sites within the New Melones project area show a similar pattern to that of Sonora sites.

Dietary differences evidenced by subsistence-related technologies in addition to paleobotanical and faunal remains are even more subtle. Notched darts, and darts in general, continue to dominate point assemblages and are found in higher frequencies within lower elevation assemblages (Rosenthal et al. 2011a:139–145). Mortars and pestles are still outnumbered by handstones and millingstones, but the encounter rate is lower for both (Rosenthal et al. 2011b:85, 94–95). A slight increase in small seed use, particularly late-spring ripening seeds, relative to acorns and pine nuts is apparent, and a mild uptick in the proportion of small animals in the diet was recorded for the Sonora area (Rosenthal et al. 2011b:103, 106). More broadly, this pattern in faunal assemblages is evident across the region, where large-mammal remains tend to always dominate (Rosenthal et al. 2011a:145–146).

The seasonality profile for paleobotanical remains continues Middle Archaic patterns, where upper elevation contexts show a strong summer signature, and fall nut crops dominate lower elevation sites, with gray pine and to a lesser extent, acorn, as the main plant components (Rosenthal et al. 2011a:151). Clear use of montane forests above ~1,220 m (4,000 ft) is present, but as with the Middle Archaic, use of this biotic zone was habitually focused on summer gathering as evidenced by the high relative frequency of handstones and millingstones, and the paucity of battered cobbles associated with nut processing (Rosenthal et al. 2011a:145). Overall, the settlement pattern throughout the Late Archaic indicates a wider range of activities took place at sites within the Upper Sonoran Zone and Lower Montane Forest as compared to sites in the Upper Montane Forest (Rosenthal et al. 2011a:141). There is clear evidence for the continuity of a seasonally based foraging adaptation, or seasonal round.

Although mid- to high-elevation sites within Yosemite show habitation during this period, particularly in high elevation meadow valleys near mountain passes (e.g., Dana Meadows; CA-TUO-2833 and -2834), these may be more related to east-side groups making their way onto the western slope (King et al. 2011:212–214; McGuire et al. 2011:178; Montague 2010:106–108; Whelan 2016:36). This period corresponds to the peak in obsidian production at east side quarries, which King et al. (2011) and McGuire et al. (2011) argue is related to the increase in big game hunting, particularly of big horn sheep at high elevations, and what may have been the height of a stable Great Basin residence pattern.

Whelan (2016:35–36) suggested the occupation of the Dana Meadows sites (CA-TUO-2833, -2834) may also be related to groups taking advantage of improved foraging conditions related to the droughts documented through the works of Stine (1994) and Graham and Hughes (2007). While Whelan (2016) could be correct, Graham and Hughes (2007) and Stine (1994) did

not look at records of droughts that predated 2000 cal BP, while some of the structural features at CA-TUO-2834 returned dates between 2430 and 1900 cal BP, and a hearth feature at CA-TUO-2833 returned dates between 1300–1060 and 1990–1610 cal BP (Montague 2010:106–108), predating the MCA and indicating possible extended use of these two high-elevation sites. Whelan’s (2016) suggestion is an interesting notion because archaeologists researching the west slope rarely consider the possibility of droughts not associated with the MCA.

Muti-proxy paleoclimatic records for early Late Holocene indicate cooler conditions and above average precipitation continued until sometime around 2,500 years ago (Anderson 1990; Brunelle and Anderson 2003; Davis 1999; Davis et al. 1985; Davis and Moratto 1988; Smith and Anderson 1992). Across the west-central Sierra Nevada, this is represented by Lower Keystone Colluvium and Alluvium deposits first identified by Meyer (2011:79; Rosenthal 2008a:57–64). Between 2350 and 1850 cal B.P, winter temperatures peaked and Atmospheric River (AR) activity had increased across west-slope locations (Benson et al. 2002; Kleppe et al. 2011; Knight et al. 2024; LaMarche 1973; Lloyd and Graumlich 1997; Lyon et al. 2020, 2025; Scuderi 1993; Street et al. 2012). Lyon et al. (2025) identify the period from 3100 to 1800 cal BP as the Late Holocene Dry Period in the Great Basin similar to the period identified by Mensing (Mensing et al. 2023), but the records for the wester Sierra Nevada are sparser. However, multiple periods of short-term droughts were recorded by Giant Sequoia tree rings in the southern Sierra Nevada between 2,050 and 1,800 years ago, with many periods of multiple-year droughts occurring between 1,800 and 1,500 years ago (Hughes and Brown 1992).

As discussed in Chapter 2, warm winter temperatures and increased AR activity tend to reduce snowpack totals, although they also lead to wintertime flooding in low-elevation valley locations. Also, lower snowpack totals make the seasonal drought period begin earlier and

increase in intensity, especially in lower elevation contexts or those which experience rain-shadow effects (i.e., east-slope locations). This in turn affects plant phenology, where they bloom earlier, seed (and fruit) earlier, and may undergo much loss of the year's seed if a strong storm disrupts the reproduction cycle by wind or water removing blooms. For annuals, the pattern above is much the same, although they may not be severely affected by strong storms after blooming, they do tend to desiccate sooner during the yearly cycle during drought years. This period has been characterized as having multiple droughts (Benson et al. 2002; Cook et al. 2004; Hughes and Brown 1992; Kleppe et al. 2011; Lindström 1990; Lyon et al. 2025; Mensing et al. 2023). By 1,600 years ago winter temperatures had stabilized, which remained the trend until the MCA (Benson et al. 2002; Brunelle and Anderson 2003:Figure 4; Kleppe et al. 2011; Knight et al. 2024; LaMarche 1973; Osleger et al. 2009; Scuderi 1993). This variable climate is a major marker of the Late Holocene across the Sierra Nevada.

Overall, the record indicates a long period of variable precipitation and temperature that led to numerous short-term droughts (i.e., ranging from 10–40 years; see Lyon et al. 2025) between 2,500 and 1,600 years ago. These droughts are only now coming to light, as many researchers have recorded their occurrence, but none have discussed them in California. Mensing et al. (2023) indicate the period from 2000-1800 cal BP was a more significant and of greater intensity drought than either of the MCA droughts in the Great Basin.

It is possible that the long period of “adaptive continuity” that characterizes the Late Archaic of the western Sierra Nevada is related to the overall continuation of climate and environmental trends from the late Middle Holocene into the early Late Holocene around 2,500 years ago, as this would have no effect on resource structure. However, the subtle differences in the archaeological record between the Middle and Late Archaic may alternatively indicate

greater variability in seasonal water sources and in resource productivity—especially for annuals and fruiting perennials—due to the fluctuating climate between ~2,500 and 1,600 years ago. Although these environmental aspects are difficult to reconstruct and few archaeological comparisons to environmental fluctuations have yet been undertaken for the west slope of the Sierra Nevada, these are areas of future research that should be conducted.

Climate-environment variability might also explain some of the differences in the locations of sites showing evidence for longer-term repeated occupation within the foothills and lower elevations. For example, New Melones sites are much closer to the Stanislaus River and its proximal tributaries which are reliable water sources (Moratto et al. 1988), while the Sonora area sites are located along perennial streams and creeks between the Stanislaus and Tuolumne Rivers and hence are much further from reliable water sources (Rosenthal 2008a:5). The Sonora area creeks and streams may have been less reliable water sources during the 2500–1600 cal BP period, incentivizing seasonally mobile groups to habitually settle closer to major waterways during fall and into winter.

While it is expected the Sonora area creeks and streams would flow during winter, even during a drought, fall is a different story given the evidence for expanded seasonal droughts and droughts spanning multiple years. Reliable water was likely a primary factor in determining fall and winter camp locations, which would increase occupation density and intensity along major waterways, and at the same time, increase differentiation among sites as either habitation or task specific as logistical mobility should be expected to have increased.

Even though differences exist in interpretations over the degree to which Late Archaic people were residually stable or mobile (the Sierra Phase vs Late Archaic), there are more

continuities and similarities between Middle and Late Archaic than there are between Late Archaic and what is termed the “Recent Prehistoric I” (Rosenthal et al. 2011b:115–116).

3.3.4 Recent Prehistoric I Period (1100– 610 cal BP; 850–1340 CE)

The Recent Prehistoric I period (RPI) is the least well-understood of the west-central Sierra Nevada chronology owing to a dearth of reliably-dated, single-component sites (Davis and Moratto 1988; Hull et al. 2016; Hull 2007; Moratto 2002; Moratto et al. 1988, 1999; Rosenthal 2008a, 2011a, 2012; Whelan 2016; Whelan et al. 2013). Rosenthal (2008a:38–39) defined the period breaks based on radiometric dates for the end of the Late Archaic (lower boundary) from a regional survey of points and dates, and the known introduction of Desert Side-notched points in the Great Basin at 610 cal BP (upper boundary).

Sites dating to RP I exist, but the deposits are most frequently mixed with components dating to other periods (Rosenthal 2008a:73–74, 2012). Most of the mixed deposits are surface scatters (Meyer 2011:76–77), and those few that are buried are within Upper Keystone Alluvium (floodplain) or Lower Keystone Colluvium (foot slope) deposits (Meyer 2011:75; Rosenthal 2008a:Figures 4, 14). These deposits *seem* to exemplify some of the sites described at New Melones by Moratto et al. (1988). The paucity of RP I sites cannot be explained by a preservation bias in the archaeological record. Although the period only spans 500 years, the overwhelming number of dates from the Late Archaic and RP II suggest the absence of RP I sites is not because of preservation bias (Rosenthal et al. 2011b:84). Despite fewer radiocarbon dates than the Middle and Late Archaic—only three RP I dates on cultural remains exist in the Sonora region (Meyer 2011:Table 31)—this period may be one of the most interesting archaeologically simply because there is so much evidence for change.

There are indications of an interruption to settlement patterns, although the cause is unclear. The lack of RP I sites within lower elevations suggests comparatively less use was made of the region, which has prompted some to suggest the region was depopulated during this period (Hull 2005, 1989; Hull and Moratto 1999; Moratto 1984, 2002; Moratto et al. 1978, 1988; Wohlgemuth 2005). However, there seem to be differences in use among different biotic zones, suggesting a resident population, but mainly indicating a reduction in use of the Upper Sonoran Zone and an increase in use of the Lower Montane Forest for winter base camps.

In the Yosemite region, work within the park indicates winter base camps dated to RP I seem to be more common between 1,220–1,675 m (4,000–5,500 ft)—the elevational zone that was previously frequented during summer (Rosenthal 2012). To the north, along the Mokelumne River elevations between 1,000–1,220 m (3,300–4,000 ft) show an increase in the number of sites, similar to the Yosemite pattern (Cleland 1988:217–218). Further to the south in the Bass Lake vicinity (circa 1,040 m or 3,400 ft), this pattern of land use is also evident, and was argued by Goldberg and Skinner (1990) to represent the greater appeal of mid-elevation montane resources and water availability relative to foothill or valley settings during this period, which by 1994, Stine (1994) had defined as the MCA.

In the Upper Sonoran Zone, sites within the New Melones project area, the New Don Pedro project area (see Moratto 1971; also this dissertation), and the Sonora project area do show use during RP I, although the evidence is highly varied. At Sonora, there is little evidence for sustained use, even in the mixed assemblages (Rosenthal 2008b:5). The evidence of use consists of three radiocarbon dates on dietary nut remains, and only one of those is from a feature context (CA-TUO-2643) (Rosenthal 2008a:73). In the Tuolumne River region, there are a number of burials from three of the Don Pedro sites which date within this period and are addressed within

this dissertation. A common misconception about the Don Pedro sites is that many were abandoned during this period and never reoccupied (Moratto 1971a; Whelan 2016:161). In this case, radiocarbon dates really *do* represent people (e.g., Coddling et al. 2024) because they are on human bone collagen. Thus, this dissertation substantially increases the number of dates for this period for future analysts.

Among the New Melones sites, there are at least four which have radiocarbon dates during RP I, suggesting additional use of the Upper Sonoran Zone (see Moratto et al. 1988:Table 5.1). For example, the upper-midden at Texas Charley (CA-CAL-286) has radiocarbon dates from 1100–100 cal BP, and the lowest portion of the upper midden was associated with Rosegate points and the lowest stratigraphic occurrence of Desert-series points (Moratto et al. 1988:221, 229). Although Moratto et al. (1988: 221-229) suggest this is a mixed deposit, the use of this site during RP I is not surprising given its extremely long occupation history and proximity to reliable water. Also within the New Melones project area, CA-TUO-444/449, and TUO-657 have a few radiocarbon dates falling within RP I and the following period (Moratto et al. 1988:Table 5.1). Of these, CA-TUO-444/449 has additional elements such as house pits and burials with purple olive beads, which offer further indication of its use during RP I and later (see Groza 2002). This site was interpreted as a habitation locale dating from as early as the Middle Archaic into the historic period (Moratto et al. 1988:299–313); however, only the presence of side-notched and concave-base dart points suggest a possible earlier occupation. CA-TUO-657 is a small, but deep, stratified midden next to the Stanislaus River, with evidence for occupation beginning before 770 cal BP (uncalibrated is 850 ± 80 BP) (Moratto et al. 1988:137–142). The site was rich with groundstone and milling implements but had no associated bedrock mortars (Moratto et al. 1988:137–142), which are a hallmark of the subsequent period. As is true for

most of the New Melones sites, updated chronological revision and review needs to happen on whatever remains of these collections. They still have significant potential to help tease out cultural patterns for this time period.

Beyond the possible difference in winter settlement locations, there is evidence for decreased mobility, a trend that began earlier, and becomes apparent in the Late Archaic, but one which is fully manifest in the Recent Prehistoric periods with the establishment of semisedentary residential bases (Whelan 2016:197–251). This interpretation is based on a regional survey of the use of obsidian sources (including the Don Pedro sites), as well as testing of theoretical models about toolstone reduction and transport decisions (Whelan 2016:197–251). Whelan's (2016) research into the topic supports previous research (e.g., King et al. 2011), which suggests a collapse of regional obsidian exchange networks during RP I. However, the question of why this change occurred looms large. Explanations for this settlement interruption range from the effects of technological innovations, population replacement, population pressure, and drought (MCA), or combinations thereof.

RP I encompasses the MCA. The MCA was two episodes of near century-long droughts linked to an increased period of warming (Anderson and Carpenter 1991; Brunelle and Anderson 2003; Büntgen et al. 2011; Cook et al. 2004; Graham and Hughes 2007; Graumlich 1993; Kirby et al. 2012; Kleppe et al. 2011; Knight et al. 2024; LaMarche 1973; Lindström 1990; Lloyd and Graumlich 1997; Lyon et al. 2020; Meko et al. 2001; Scuderi 1993; Stine 1994). The first drought is estimated to have occurred between 1050–940 cal BP and was more severe, while the period from 770–675 cal BP encompasses a less-severe, second drought (Graham and Hughes 2007; Lyon et al. 2025). The droughts were separated by a pluvial interval with increased precipitation (Lyon et al. 2025). The environmental effects of the MCA in the Sierra Nevada are

most well-known from now-dead tree stumps at the bottom of modern lakes, such as Tenaya and Mono, which grew during drought periods when the lakes were some 17–19 meters below modern levels (Graham and Hughes 2007; Kleppe et al. 2011; Lindström 1990; Stine 1994). However, more recent evidence provides a clear picture of reduced precipitation across the eastern, and by extension, western, slope of the mountains below 40°N (Lyon et al. 2025), indicating that many of the perennial waterways on the west slope would not have been sustained during periods of extreme drought. These data align with current research on modern hydrologic systems across the western slope, which indicate even just a few dry years can cause perennial waterways to cease flowing (Belmecheri et al. 2016; Dettinger et al. 1998, 2011, 2018; Godsey et al. 2014; Shulgina et al. 2023; Tague and Peng 2013).

Changes in mobility, settlement strategy, food storage preferences, and technology are suggested to have taken place during RP I, given the well-established pattern of cultural florescence evident in the next archaeological period, the RP II (Davis and Moratto 1988; Hunt 2004; Leftwich 2010; Moratto et al. 1988; Morgan 2009b; Rosenthal 2011a, 2012; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005). However, because of the limited number of RP I components, most researchers rely on theoretical arguments to make assertions, or lump RP I with RP II into a general Recent Prehistoric period.

The bow and arrow and bedrock mortar came into use during RP I, and each is reflective of changes to behavior and hence societal changes (Bettinger 1991, 2015; Davis and Moratto 1988; Moratto et al. 1988; Rosenthal 2008a; Stevens et al. 2019; Ugan et al. 2003). For example, the creation of bedrock mortars represents a substantial investment in time and energy in a non-portable technology, and one that suggests reduced residential mobility as they tether people to fixed spots on the landscape (Stevens 2002; Ugan et al. 2003). In other words, rational people

will not expend unnecessary energy in the creation of a permanent feature unless they plan to return and use that feature over many repeated trips. As the processing of plant foods is largely women's work, bedrock mortars represent women's labor (Willoughby 1950). In lower elevations where water is a more a limiting resource during warmer seasons we should expect populations to congregate where water was reliable, whereas in higher elevations occupation should be more dispersed, as higher elevations regardless of drought have more reliable water resources as, even in low water years, these areas still receive some snow which would melt. Because bedrock mortars reflect the foraging efficiency of women, they should be more dispersed above the 1,220 m (4,000 ft) level, while in lower elevations the oldest sites should be clustered around reliable water sources. This hypothesis will need testing *vis a vis* radiocarbon dating of midden deposits, obsidian hydration of associated projectile points, or by testing newer dating methods for exposure ages of granite surfaces—for example, Terrestrial Cosmogenic Nuclide dating and reflectance spectroscopy; see Gallach et al. (2021).

Bedrock mortar sites also have implications for territoriality, as the creation of such permanent features should signal that the spot is occupied, or “claimed,” which has been argued recently for territorial behavior across the Sierra Nevada (see Stevens et al. 2019). Bedrock mortars can be found at every elevation throughout the west-central Sierra Nevada; however, they are difficult to date directly, and typically rely on association of near-by artifacts (Leftwich 2010:145, 158–168; Stevens et al. 2019). However, newer dating methods for the exposure ages of granitic rocks are being developed, such as the Terrestrial Cosmogenic Nuclide (TCN) dating and reflectance spectroscopy mentioned above and employed by Gallach et al. (2021). This newer direct dating technique may offer some insight into the timeframes of when mortar holes were created on exposed granitic bedrock outcrops.

If we consider the greater restrictions placed on people who rely on the natural abundances of water and resources during drought, some spots on the landscape should be favored over others. This hypothesis suggests the oldest bedrock mortars should be located near the largest reliable water sources within the most productive resource patches. In other words, not in canyons, but near level terrain, along major rivers and nearby tributaries, and within productive oak and gray pine groves. It is perhaps rather informative that the locations of some of the largest settlements throughout the entire precontact sequence are located at such spots and reflect repeated occupation over multiple millennia.

Bow-and-arrow technology has been argued to have allowed for privatization of resources (Bettinger 2015), which may be linked to archaeological evidence for smaller, scattered settlements as people relied less on cooperative hunting (Stevens et al. 2019). Arrow points, mainly Corner-notched and Contracting Stem varieties, and arrow-shaft straighteners — although less frequently encountered—are the most prominent evidence for bow and arrow technology for RPI (Rosenthal 2008b:16, 22, 86). Of note are “Rosegate” and “Gunther” points so frequently identified in older archaeological literature, which in the point scheme of Rosenthal (2008a, 2011a) for the west-central Sierra Nevada are classified as Corner-notched and Contracting stem, respectively.

The adoption of new technologies, such as bedrock mortars and the bow and arrow could explain some of the changes evident, however, they do not explain the lack of single-component sites. If the bow and arrow allowed for groups to become smaller as they were less reliant on shared resources such as meat, then we should expect habitation sites that are smaller in size (Bettinger 2015). However, seeing as most settlement locations are based on the opportunity costs of women’s foraging decisions (Whelan et al. 2013; Zeanah 2004), a change in technology

mainly associated with men's foraging pursuits only explains a reduction in group size, not in settlement location.

Because of the lack of single-component sites, dietary information for this period is also minimal. Flotation samples indicate the presence of gray pine and acorn, as well as small seeds in the diet, as some of these dietary remains were from short-use features that were radiocarbon dated within RP I (Rosenthal 2008b:Table 3; Rosenthal et al. 2011a; Wohlgemuth 2005). Yet, capturing this period through flotation has been notoriously difficult. Faunal remains indicate large mammals (likely deer) were the primary focus of hunting efforts, while medium and small mammals account for a much smaller proportion of remains (Rosenthal et al. 2011a:Table 59). Two sites, CA-AMA-34 (in the Montane Forest) and AMA-110 (Upper Sonoran Zone) account for the majority of faunal assemblages with RP I contexts (Rosenthal et al. 2011a:Table 59). Dietary remains suggest continued use of the same basic resources, although relative proportions of different animals in comparison to other periods are lacking.

The timing of the droughts and the ambiguity of the archaeological record during the MCA has led many archaeologists who have worked in the region to question the nature of cultural differences observed before and after this period (e.g., Moratto 2002; Moratto et al. 1978; Rosenthal 2011c; Wohlgemuth 2005). Overall, there is clear evidence for a disruption in settlement or a change in land use, and the potential causes and consequences require further consideration (Rosenthal 2008a:74). Rosenthal (2011c:235) suggests that, as based on their multiple quantitative and theory-driven analyses of the west-central Sierra Nevada archaeological record, they found no obvious socioeconomic motivation that would explain the disjunction between the Late Archaic and Recent Prehistoric I and RP II assemblages.

This dissertation aims to add to our understanding of RP I through a dietary analysis based on carbon (^{13}C), nitrogen (^{15}N), and sulfur (^{34}S) stable isotopes in human remains, paired with direct radiocarbon dates on those individuals (Chapter 6). I also discuss the possibility of local versus non-local residents, and what this might mean in terms of population movements within the Sierra Nevada (Chapter 6). To lay the foundations for this analysis, in Chapter 4 I examine the carbon stable isotope ratios of Sierran paleobotanical remains, how these should vary with climate perturbations, and I relate these to the broader understanding of what we should expect for Sierran diets through time. Then, in Chapter 5, I examine faunal isotope values and what they suggest about past environmental conditions and human diets. My final chapter (Chapter 7) summarizes this research.

3.3.5 Recent Prehistoric II Period (610–100 cal BP; 1340–1850 CE)

The Recent Prehistoric II (RP II) is perhaps the best-known archaeological period across the west-central Sierra Nevada. RP II sites are found in Upper Keystone Alluvium and Colluvium, mainly as surface deposits (Rosenthal 2008a:67–69), aiding their visibility in the archaeological record. The period break between RP I and RP II was defined by Rosenthal (2008a:38–39) based on a large number of radiocarbon dates and the known introduction of Desert Side-notched points in the Great Basin at 610 cal BP. The second period break at 100 cal BP, or 1850 CE signifies historic-era contact with Euro-American settlers.

In contrast to RP I, RP II sites are numerous, evincing repeated occupation and use throughout the Upper Sonoran Zone and Lower Montane Forest (Rosenthal et al. 2011a). Sites dating to RP II are situated in the Upper Montane Forest and Sub-alpine and Alpine Zones, however, these do not seem to be associated with people who were permanently occupying the west slope (Rosenthal et al. 2011a:155–158). RP II sites appear to have been more intensively

used than sites dating to the Archaic (Rosenthal 2008a:74). Repeated use of particular locations, marked by the presence of bedrock mortars and associated midden deposits, denotes a clear difference between RP II and Archaic sites (Rosenthal 2008a).

A clear investment in bedrock mortars is manifest at all sites exhibiting evidence for repeated habitation. Yet, these RP II deposits seem to be spatially restricted compared to Archaic deposits, suggesting a feedback loop between bedrock mortars, site locations, and repeated use (Rosenthal 2008a:74–75). Multiple site types (e.g., villages, hamlets, seasonal camps) are associated with bedrock mortars, as bedrock mortars and the number of mortar holes and working surfaces have long been used to define site types (e.g., Bennyhoff 1956). Perhaps because of the use of bedrock mortars, portable ground stone is rare in RP II assemblages; however, there is evidence for the increased use of portable mortar and pestles as compared to Archaic assemblages (Rosenthal 2008a:87). Bedrock mortars exist in all of the biotic zones, but not all are associated with residential sites. Some of the bedrock mortar sites in the Lower Montane Forest likely represent productive bulb, seed, and berry patches that saw frequent seasonal reoccupation by small family groups. Those at the uppermost elevations might be associated with the seasonal camps of family groups from the east-side of the range (King et al. 2011; McGuire et al. 2011; Montague 2010).

Artifact assemblages from RP II sites are more diverse than those from earlier periods. Sites located below the snowline are smaller than Archaic sites, but have well-developed midden deposits, numerous residential and mortuary features (e.g., house pits and graves), and a wide array of tool classes (e.g., awls, drills, scraper planes, steatite vessels, and beads) which suggest longer periods of seasonal occupation and repeated use (Rosenthal 2011a; Whelan 2016). For example, tools used to make other tools—such as bone awls and drills—and non-utilitarian

objects like bone whistles and beads are found in greater quantities, which Rosenthal (2008a:93) suggests speaks to increased residential use of most RP II sites.

Given the Little Ice Age (LIA) and advance of the Matthes cirque glaciers (650–50 cal BP; Clark and Gillespie 1997; Phillips et al. 2009), understanding changes in the snowline might be important when surveying land use patterns during the RP II period. Spring snow at lower elevations on the west slope would keep west-slope people from reaching high elevation sites until after most of the snow had melted—a statement expressed by McGuire et al. (2011:162) regarding west-slope peoples' access to bighorn sheep at high elevations, but echoed here regarding restrictions to seasonal mobility. For cirque glaciers to grow, or advance, snowfall must accumulate and the temperature must remain cool enough so that more snow remains than melts (Bierman and Montgomery 2013). Because glaciers were advancing during the LIA, it implies a later snowmelt for west-slope residents given the requisite cooler temperatures, which may have restricted west-side residents' seasonal upslope movements until later in the year. Later snowmelt would affect the amount of time spent in the Lower Montane Forest above the snowline, effectively shortening it by delayed upslope movement. As well, it likely shifted the timing of spring and summer blooms and fruiting to slightly later in the year (Millar and Woolfenden 1999). In lower elevations below the lowered snowline, this may have actually stretched the season of ripening and fruiting, as the added water and cooler temperatures extending longer into the year may have favored prolonged or slower growth for some plants (Millar and Woolfenden 1999). Archaeologically, this might explain some of the evidence for extended seasons of occupation below the snowline during RP II.

When RP II site locations are compared across biotic zones, most residential sites are in the Upper Sonoran Zone (Rosenthal et al. 2011a:145). As well, assemblages from this zone also

indicate greater settlement differentiation than in the Lower Montane Forest due to the presence of special-use localities and the aforementioned longer-term residential sites (Rosenthal et al. 2011a:145). While Upper Sonoran Zone sites indicate a wide range of activities took place, those in the Lower Montane forest typically lack evidence for fall and winter occupation (e.g., battered cobbles associated with gray pine processing)—the same basic pattern of biotic-zone exploitation witnessed during the Archaic (Rosenthal et al. 2011a:145–151).

Paleobotanical evidence indicates that sites below the snowline were mainly occupied from fall through spring, because of the presence of fall nuts and late-spring small seeds (Rosenthal et al. 2011a:149). These sites are dominated by acorn-nut debris, and to a lesser extent gray pine (Whelan et al. 2013). Thin-shelled pine (likely sugar pine) also appears in the record for the first time during this era (Rosenthal et al. 2011b:106; Whelan 2016:262). RP II is the first period throughout the precontact sequence in which acorn supplants gray pine nut through ubiquity measures, indicating an increased reliance on this resource as either a food item or an increase in the utilitarian use of acorn nutshell as kindling or bedding (Reddy 2016; Whelan et al. 2013; Wohlgemuth 2005). However, RP I is usually not included in these analyses due to the lack of verifiable single occupation components. This pattern of plant exploitation and preference for acorn is similar to the ethnographic pattern, where acorns were preferred for storage. A major dependence on acorns was noted by Barrett and Gifford (1933) and continues to spark debates as to the reasons why and when this switch in preferred stored resources occurred. I undertake a diachronic analysis of diet in order to elucidate when during the Recent Prehistoric this shift may have occurred (Chapter 6:).

At the same time, sites situated above the snowline show an increase in the number of small-seed taxa and an increased use of berries—this pattern is paralleled by increases of these

remains in Upper Sonoran Zone contexts as well (Rosenthal et al. 2011a:155; Whelan 2016:272). This evidence suggests a shift in the seasons when Upper Sonoran Zone sites were occupied, and that these resources were transported to residential sites and stored for later consumption—a pattern also similar to the ethnographic era (Whelan 2016:272). Despite a larger variety of small seeds included in the diet, their relative abundance does not seem to increase, ruling out explanations regarding an expansion in diet breadth based on paleobotanical remains (Whelan 2016:272).

Faunal remains from this period differ little from Archaic period contexts. A stable pattern of animal exploitation showing neither resource depression nor expansion in diet breadth is evident, even when Upper Sonoran Zone sites are compared to those of the Lower Montane Forest or across time periods (Rosenthal et al. 2011a:146). Large mammals, presumably mostly deer, dominate over medium and small mammals as well as birds (Rosenthal et al. 2011a:Figure 42). Because preservation is better in this recent context, we might expect to see a wider variety of animals within the diet. However, it seems the same taxa are present throughout the entire precontact sequence: large numbers of deer, and small numbers of fish, reptiles, amphibians, birds, rodents, cottontails, jack rabbits, canids, pronghorn, and elk (Rosenthal et al. 2011a:Table 59). This pattern has been interpreted by Rosenthal et al. (2011a:146) to mean men's hunting returns were stable regardless of season or habitat, and they appear to be stable through time.

Desert Side-notched points (DSNs) come into widespread use during RP II. While other arrow types, such as Cottonwood Triangular, Corner-notched or Contracting Stem may also be found, their numbers pale in comparison to DSNs (Rosenthal 2008a:44–45). While these point types can be found throughout this region and into the Great Basin, the materials they are made from vary. In the Lower Montane Forest and Upper Sonoran Zone, CCS is the dominant

toolstone type, accounting for between 52–59%, respectively, of all toolstone within these assemblages (Rosenthal et al. 2011a:131–137). Obsidian accounts for 22–30%, while other knappable stone accounts for just 18–19% within these two zones (Rosenthal et al. 2011a:134–137). In the Upper Montane Forest and higher elevations, obsidian dominates toolstone assemblages, and CCS only accounts for ~4% of these assemblages, which suggests west-side resident populations were not frequently accessing these higher elevations during RP II, because, if they were, we would expect a larger amount of their local CCS toolstone to be transported with them upslope (Rosenthal et al. 2011a:137).

The use of fire as a landscape management tool becomes apparent in RP II. A decline in pine and expansion of oak pollen coupled with an increase in charcoal deposits in the Yosemite region during the LIA is offered as evidence of this practice by Anderson and Carpenter (1991). Klimaszewski-Patterson et al. (2023) found a similar pattern in their analysis of pollen, suggesting the forest structure was much more open and heterogeneous because of traditional fires, going back at least a thousand years or more. Although the antiquity of this practice is yet unknown, mounting evidence suggests that it has greater antiquity than just the LIA or the MCA. Anderson and Smith (1997) were unable to excuse Native American fires as a possible cause for a decreased fire severity beginning around 4,500 years ago; frequent low-level burning of the landscape reduces fire severity. Similarly, Hull and Moratto (1999) suggest this practice may have started sometime after 9,000 years ago, while Anderson and Rosenthal (2015) suggest this practice is critically embedded in Indigenous Sierra culture, as it relates to more than producing food, but to producing landscapes that enable materials for vital technologies, such as baskets, bows, arrows, and cordage to be grown under controlled conditions. Low-level burning is also

briefly recorded by Barrett and Gifford (1933), although it was not a subject of interest to ethnographers of the era.

In sum, the RP II archaeological pattern is in many ways similar to the ethnographic pattern of the Central Sierra Me-Wuk. Sites show evidence for repeated long-term occupation below the snowline. Numerous residential features, such as house pits, hearths, semisubterranean structures, and bedrock mortars are encountered at RP II winter habitation sites, with dimensions similar to those in ethnographies. Paleobotanical remains and assemblage diversity measures indicate a strong seasonal-round pattern, with fall, winter and possibly part of spring spent in the Upper Sonoran Zone, and summers spent at family-centric base camps in the Lower Montane Forest. A greater reliance on acorns is also evident, much like the ethnographic pattern. The use of a number of small-seed taxa is also noted, with most species identified in early ethnographies. Deer *seems* to have been the most highly sought animal as noted by ethnographers, and while a number of other animal taxa were on the menu, none come close to the quantity of deer in archaeological assemblages. Bedrock mortars appear as multifunction tools, and their presence likely attests to concepts of territoriality. And last, the ancestors of the Tuolumne Me-Wuk managed their landscape through fire.

3.4 Reconsidering the Chronological Placement of the Don Pedro Sites

The New Don Pedro Reservoir sites, summarized by Moratto (1971a), have long been overlooked by archaeologists working within the Sierra Nevada region. While the nature of the 1971 report is highly speculative and incomplete, it does suggest a majority of the Native American sites within the impound area of the dam had long periods of occupation, which have

not been previously included in chronological studies (cf. Whelan 2016). These sites matter to the overall picture of the central Sierran lifeways and change over time.

I draw attention to these sites and reconsider how they fit into Sierran lifeways. Three sites stand out because of the human remains recovered. Unlike the New Melones sites, human remains from the Don Pedro sites allow for an unprecedented understanding of ancient lifeways within the region. The Tuolumne Me-Wuk requested scientific analyses on these ancestral remains after they had been repatriated but prior to their reburial. I have been privileged to work with these remains prior to their new inhumation. Below I detail individually the excavation context and original interpretations of these sites (CA-TUO-279, -300, -314). For each, I consider the direct radiocarbon dates on the human remains, and how this new data changes their interpretation. I also include three other sites here, as they were part of initial surveys and surface collections prior to excavations at Don Pedro; these surface collections included human remains.

3.4.1 Excavations at the New Don Pedro Reservoir

While funding for archaeological excavation and reconnaissance for the New Don Pedro Reservoir was delayed until 1970, after construction activities had commenced in 1967, an unknown number of sites had already been impacted by the flooding of the La Grange Reservoir in the 1890s and of the Old Don Pedro Reservoir in 1923 (Moratto 1971a:1–2). Initial archaeological survey of the area of impact noted the presence of human remains at a few sites within the project boundaries (CA Dept. of Parks and Recreation 1996; Riddell 1970a, 1970b). Further survey and reconnaissance by volunteers from a number of colleges and universities constitute the majority of findings prior to the flooding of the New Don Pedro Reservoir (Moratto 1971a:39–44).

From a historical perspective, sites located within the project boundaries of the New Don Pedro Reservoir were surveyed and excavated in a rush to beat the clock of impending flooding. Little consideration was given to the archaeological importance of any sites located within the project boundaries by the project foremen or the overarching utilities districts, mainly because inclusion of Native American viewpoints and archaeology took a back seat to progress. As a result of continued negligence by the government and policy, numerous sites important to the cultural history of the region had already been lost. While this interpretation has been shared by Moratto (1971a: 1-2), the full impact of this kind of oversight was not fully realized until more recently, when Sierran archaeologists considered the paucity of sites dating to the MCA.

Much like arguments centered around the peopling of the Americas, where the earliest coastal sites are hypothesized to have been destroyed by sea-level rise (Fladmark 1979), the ancient history of the Sierra Nevada is incomplete due to the rise of reservoir waters along major rivers, which were never fully investigated, and sometimes not at all, prior to flooding. We cannot know the price we have paid for progress, as we are only now grappling with an incomplete picture of the past. While it is probable that many important sites were flooded prior to any archaeological reconnaissance, we are left with those remaining sites that were more distant from the major rivers, which were dammed early in California's written history. As such, these relict sites along tributaries need re-evaluation, as so few have been placed within the context of updated chronologies and more precise dating techniques.

3.4.2 CA-TUO-279

CA-TUO-279 was a large midden site containing both precontact and historic-era components (Henn 1971:45; Moratto 1971a:41). At the time of excavation, it had been partly destroyed by bulldozing (Moratto 1971a:41). Located on a small peninsula jutting into the waters

impounded by the Old Don Pedro Reservoir, it is the only site excavated that was directly along the Tuolumne River. Prior to the impounding of the Tuolumne River by the Old Don Pedro Dam and the La Grange Dam, the site would have been uphill and less than 200 m from the free-flowing river (Henn 1971: Map IV-A-I). Records by Henn (1971) do not indicate the presence of bedrock mortars, and nothing is known about what remains were already underwater. Also, among the New Don Pedro sites it is the only one on Moratto's (1971a:40) Map III not associated with other sites in close proximity.

Situated at approximately 200 m (~650 ft) in elevation, the site was within the low rolling hills of the Upper Sonoran Zone. Excavations were carried out during November 1970 through January 1971 (Henn 1971; Moratto 1971a), as flooding of the New Don Pedro Reservoir had already begun months prior (Barnes 2010:11). For example, the top of Old Don Pedro Dam, downstream of the site, was completely covered on April 12, 1970, by the newly impounded waters (Barnes 2010:11).

Excavations sought to answer questions about the season of site use (informed by the tool types encountered), its relationship to trade with the Mono (informed by the presence/absence and abundance of possible exotic goods), and the inhabitants' reliance on local toolstone. Henn (1971) used the ethnography of Barrett and Gifford (1933) to guide questions and interpretations regarding the site, as it was not expected to have any great antiquity (small size, no bedrock outcrops). A 5% sample of the site was selected, totaling nine 2x2 m units excavated in 20 cm arbitrary levels by shovel, or by trowel when features were encountered (Henn 1971). Sterile soil was reached between 20–80 cm below surface (cmbs). Midden deposits were passed through ¼ inch screens, and artifacts were documented in-situ (Henn 1971).

Unit 96 had the only radiocarbon date for the site, 295 ± 90 years (uncalibrated) (Henn 1971). The date was on charcoal recovered from 55 cmbs; however, since three burials were encountered within this unit at 60–80 cmbs, it is unlikely the charcoal was in its original position. Of the three burials encountered, two were excavated, representing possibly four individuals. In total, nine people are represented by the human remains recovered from four excavation units at this site. These remains were assessed multiple times by NAGPRA personnel at San Francisco State University, the most recent in 2014 as the remains were being repatriated to the Tuolumne Me-Wuk (San Francisco State University 2014a).

A variety of artifacts were recovered from the site. Most notable are a handstone, a millingstone, a variety of simple flake tools, hammerstones, chert cores, drills, dart points (obsidian and chert), arrow points (obsidian), steatite objects and vessel fragments, a bird bone whistle, “gambling bones,” and purple olive shell beads (Henn 1971). Chert debitage outweighed obsidian debitage by a factor of 13.2 to 1 (Henn 1971). Obsidian sourcing by Whelan (2016: Table 4.8) indicates Bodie Hills as the primary source, accounting for 76% of the obsidian debitage, although small amounts of seven other obsidian sources are present within the collection. Faunal remains included mule deer bones, a canid tooth, a horse tooth, and freshwater pearl mussel (*Margaritifera margaritifera*). The historic component of the site was read as intrusive. The site was interpreted by Henn (1971:55, 57) as a spring or summer camp, with all artifacts said to “be in agreement” with the one radiocarbon date—indicating the site was not very old.

Given new direct radiocarbon dates on these ancestral remains, this site was occupied beginning no later than 1545 cal BP, during the Late Archaic, based on two samples from Unit 96, possibly from a single highly fragmented individual. Table 3-1 summarizes the burial

remains, radiocarbon dates, as well as any provenience information provided by Henn (1971) and San Francisco State University (2014a). The site's eleven dart points also signal a Late Archaic component (Whelan 2016: 167). The site saw occupation through RP I during the MCA: three ancestors date to this period. All were adults of unknown sex, represented by highly fragmentary remains. Finally, TUO-279 was also occupied during RP II: four ancestors date to this period. One of these RP II burials, referred to as Burial 2, individual 1 (B2 i1), comes from unit 96, at a depth of 67 cmbs, only a few centimeters below the charcoal fragment and post-dates the charcoal indicating stratigraphic mixing of this deposit. This individual was the only near-complete skeleton removed from these deposits, and Henn's (1971) notes indicate this individual was buried in a tightly flexed position and oriented to the northwest.

Overall, TUO-279 shows a long history of occupation and use, spanning from the Late Archaic to the RP II, and afterwards into the historic era. That it has evidence of occupation during the MCA and RP I is important, as the human remains dating to this period offer some of the only insights on diet and settlement for the whole of the region. The wide array of artifact types, from the beads, steatite fragments, awls, handstone and milling-stone, cores, and possible gambling bones, as well as the points and debitage—when considered with the burials and their dates, suggest that TUO-279 was likely a small habitation site that saw increasing use throughout the last 1,500 years. There may have been other sites nearby in the past, but a catastrophic flood in 1862 may have washed them away as it did the town of Jacksonville (Dietz 1971:10). As well, in the early 1900s, the construction of the Yosemite Short Line and Hetch-Hetchy Railway nearby likely contributed to the demise of associated sites (Dietz 1971:6, MAP I-B).

Table 3-1 Ancestral Remains from CA-TUO-279

Sample ID	Age	Sex	Context	¹⁴ C BP	±	95% cal BP	Median	Period
TUO-279 B4	Adult	Ind.	U 96; 60-80 cmbs	1730	25	1715-1585	1650	LA
TUO-279 B2 i 2	Adult	Ind.	U 96; 60-80 cmbs	1760	25	1700-1545	1615	LA
TUO-279 B1	Adult	Ind.	U 96; 60-80 cmbs	1050	20	1045-920	945	RP I
TUO-279 Unk1	Adult	Ind.	U 96; 60-80 cmbs	975	20	925-795	855	RP I
TUO-279 Unk4 i 1	Adult	Ind.	U X; 20-70 cmbs	714	19	680-575	670	RP I
TUO-279 Unk4 i 2	Adolescent	Ind.	U X; 20-70 cmbs	476	23	535-500	515	RP II
TUO-279 Unk2	Adult	Ind.	U 87; 40-60 cmbs	315	23	455-305	390	RP II
TUO-279 Unk3	Adult	Ind.	U 137; 20-40 cmbs	205	25	300-0	180	RP II
TUO-279 B2 i 1	Adult	Male	U 96; 67 cmbs	170	30	290-0	175	RP II

Note: table is organized by calibrated radiocarbon dates and includes the Sample ID, estimated ontogenetic age, estimated sex, burial context, uncalibrated radiocarbon date, error, as well as the full 95% confidence calibrated date range, calibrated median date, and the archaeological period for each individual. “B” is Burial when following directly after Site ID. “Unk” is unknown. “i” is short for Individual. “Ind.” means indeterminate and indicates sex could not be determined. “U” means unit. “cmbs” means centimeters below surface. “LA” = Late Archaic; “RP I” = Recent Prehistoric I; “RP II” = Recent Prehistoric II.

3.4.3 CA-TUO-300: The Roger Creek Site

Excavated by Moratto and a large crew during the fall of 1970 through winter 1971, CA-TUO-300—the Roger Creek site—is the largest and least disturbed site from the Don Pedro excavations (Moratto 1971b:78, 80, 1971a:1). A large bulldozer cut, outside of visually-estimated site boundaries, was the only apparent disturbance (Moratto 1971a:Map IV-D-1). The site was located in a small valley along the north bank of Roger Creek, about 4 km to the southeast of the Tuolumne River (prior to flooding via dams). Roger Creek drains the valley, has

a number of drainages that feed into it, but it is unknown if it was a perennial stream in the past as it is today. The site sat at 238 m (780 ft) elevation and was surrounded by Upper Sonoran Zone flora and fauna (Moratto 1971b:78).

TUO-300 is the southeasternmost site within a cluster of sites (CA-TUO-298, -297, -296, -301, and -302) along Roger Creek, with the most distant site, TUO-301, less than 3 km away (Moratto 1971a:Map III). Of these sites, TUO-296 had 29 bedrock mortars, TUO-302 had two, and TUO-301 had 18. There was no noticeable bedrock mortar or outcrop associated with TUO-300 at the time of excavation (Moratto 1971b:80); however, it is possible inhabitants used the ones at TUO-296 because of its proximity.

The site was chosen for excavation for a number of reasons. First, because it was one of the few that was mostly undamaged, it held potential for informing on native lifeways “some distance” from the river (Moratto 1971b:80). Second, a large house pit, visible on the surface, was to be cleared, and it was thought to hold information on construction techniques and materials. Third, it was possible that the site could help to test a hypothesis regarding the diachronic shift of settlement patterns away from rivers as populations increased (Moratto 1971b:80).

Excavation techniques were the same as at TUO-279, except the grid was alphanumeric. A total of 19 2x2 m units were excavated, as was one 1x1 m unit (Moratto 1971b:81). Unit depths ranged from 80–200 cmbs, and all midden was screened through ¼ inch mesh. A total of 107 cubic meters were excavated from the site, with an estimated 20–30% of each unit’s total volume consisting of fist-size or larger clastic rocks (Moratto 1971b:80–81).

A wide variety of implements for making other tools were unearthed, as were many items of personal adornment, projectile points, millingstones and handstones, portable mortars, pestles,

an atlatl weight, and a fish spear element (Moratto 1971b:81–88). Faunal remains were poorly preserved and highly fragmentary, and most were identified as mammal bone (Moratto 1971b:109). One bird bone was identified among the faunal remains, but no fish bones were recovered (Moratto 1971b:109).

Of the debitage, chert and metachert were the most frequently encountered chipping waste, averaging 326 gm per level in the midden (Moratto 1971b:109). Basalt flake waste was the next in abundance, averaging 34.3 gm per level, while the obsidian averaged 4.1 gm per level (Moratto 1971b:109). Small quantities of quartzite, jasper, and chalcedony debitage were also recovered, but were not specifically tallied. By weight, non-obsidian debitage was about 100 times more abundant than obsidian debitage (Moratto 1971b:109). Of the obsidian debitage recovered, work by Whelan (2016: Table 4.8) indicates the majority is from the Bodie Hills source, with a 34% contribution from Casa Diablo and seven additional sources making up the remainder (between 1-5% each of the total sampled assemblage).

The site's house pit indicated it was likely a large semisubterranean winter house. A piece of burned support post returned an uncalibrated date of 1035 ±90 BP (Moratto 1971b:92, 111); calibrated with Calib 8.2, this gives a median date of 941 cal BP and range of 735–1125 cal BP at 95% confidence). A total of nine excavation units explored the house pit, which measured 9x8m, with the interior depression ranging between 25–40 cm deep (Moratto 1971b:92). The house pit had at least two superimposed floors, encountered at depths of 60 and 70 cmbs in units N6 and M6. All nine units excavated within the house pit had evidence of a compact earthen floor between 20 and 70 cmbs (Moratto 1971b:92).

Moratto (1971b: 94-95) tentatively set the initial settlement of TUO-300 at 1400 cal BP (Late Archaic in Rosenthal's scheme) given the depth of the deposit and associated projectile

points below the radiocarbon-dated strata. Use of the site was thought to terminate somewhere around 500 cal BP (RP II). Moratto (1971b:95) states that the evidence for diachronic change at TUO-300 indicates gradual innovations, but mostly that the site's use is characterized by continuity. He was unable to test the hypothesis regarding the order of settlement away from the river, as there were no large sites excavated along the river with which to compare.

Eight burials consisting of multiple individuals were excavated from under the floors of the structure. Half of the burials were beneath cairns and most were in a flexed position (Moratto 1971b:106). A number of other human remains were encountered, mostly in the form of disarticulated bones scattered amongst the other units not associated with the house pit (Moratto 1971b:106–107).

These remains have been assessed multiple times by NAGPRA personnel at San Francisco State University, the most recent in 2014 as the remains were being repatriated to the Tuolumne Me-Wuk (San Francisco State University 2014b). According to their assessments, the human remains from TUO-300 include at least 39 people. Of the 39 people, I include those that were radiocarbon dated ($n=25$) within this study. This information is organized in Table 3-2 below.

Of these 25 individuals in Table 3-2, only one dates to the terminal Middle Archaic, which likely signals the first repeated use of CA-TUO-300. As for the other 24 people, eight date to the Late Archaic, nine date to RP I, and seven date to RP II. On average, one person was buried here every 240 years. However, there are minor gaps between the radiocarbon dates during the Late Archaic, which possibly indicates short gaps in occupation of TUO-300. In particular, a notable gap of 1,900 years during the Late Archaic suggests a long period where the site was not, or only sporadically, used for human interment. Alternatively, this may be reflect

lower population density and a more residentially-mobile settlement system, as suggested by Rosenthal et al. (2011a) for the Late Archaic. However, by RP I, it is clear that the site was consistently occupied by a small, but stable population, with, on average, one person buried here every 62 years. This same trend continued into RP II, with the last burial dating to the protohistoric era, a time of major cultural changes. If I account for the end date of the last known burial, this shortens the RP II time frame by ~50 years, and suggests a larger population burying their dead here once every 58 years. This last 200 to 150 years of RP II was a time when European-introduced diseases ravaged Central Valley populations, and refugees from the Missions were taking sanctuary within the foothills of this area, but direct contact by the foothill and mountain people with Europeans had not yet happened.

Table 3-2 Ancestral Remains from CA-TUO-300

Sample ID	Age	Sex	Context	¹⁴ C BP	±	95% cal BP	Median	Period
TUO-300 Unk7A	adult	ind.	site ID only	2947	26	3180-3000	3110	MA
TUO-300 B3	adult	male	UM-6; 90 cmbs	2840	25	3005-2865	2945	LA
TUO-300 B8	young adult	female	UQ-7; 140 cmbs	2560	25	2750-2520	2725	LA
TUO-300 B9B	adult	ind.	UR-10 & Q-10; 90 cmbs	2200	25	2310-2125	2235	LA
TUO-300 Unk2 i.1	adult	ind	UN-6; 40-60 cmbs	2210	33	2330-2125	2230	LA
TUO-300 B5	adult	ind.	UR-13; 179 cmbs	1870	20	1825-1720	1775	LA
TUO-300 B6	infant	ind.	UO-4; 75 cmbs	1760	25	1715-1585	1650	LA
TUO-300 Unk4	adult	male	US-7; 96 cmbs	1198	25	1240-1060	1115	LA
TUO-300 Unk8	ind.	ind.	UM-2; 80-100 cmbs	1199	20	1175-1065	1115	LA
TUO-300 Unk16B	adult	male	faunal remains bag	1042	21	970-920	945	RP I
TUO-300 Unk6	adult	ind.	UP-4; 0-53 cmbs	1000	24	955-800	920	RP I
TUO-300 B1	adult	female	UM-6; 70 cmbs	885	35	910-725	780	RP I
TUO-300 B11B	subadult	male	UN-5; 60-80 cmbs	860	30	895-690	760	RP I
TUO-300 Unk9	adult	female	UN-3; 55 cmbs	840	21	785-690	735	RP I
TUO-300 B10A1	young adult	female	UO-4; 105 cmbs	810	30	770-675	710	RP I
TUO-300 Unk18	adult	ind.	UP-5; 80-100 cmbs	753	22	725-665	680	RP I

Sample ID	Age	Sex	Context	¹⁴ C BP	±	95% cal BP	Median	Period
TUO-300 Unk13-rib	ind.	ind.	UR-5; 100-120 cmbs	687	25	675-565	655	RP I
TUO-300 Unk11	adult	male	UP-5; 0-20 cmbs	614	19	650-555	605	RP I
TUO-300 B11A	child	ind.	UN-5; 96 cmbs	631	28	655-555	600	RP II
TUO-300 Unk1	child	ind.	UN-7; 60-100 cmbs	635	22	660-555	595	RP II
TUO-300 Unk20	ind.	ind.	UP-5; 60-80 cmbs	554	22	625-525	550	RP II
TUO-300 Unk7B	child	ind.	UM-6; 105 cmbs	543	19	625-525	545	RP II
TUO-300 B9A	old adult	female	UR-10 & Q-10; 90 cmbs	310	20	445-305	390	RP II
TUO-300 Unk5	adult	female	UN-5; 100 cmbs	280	30	445-155	375	RP II
TUO-300 Unk16C	adult	ind.	faunal remains bag	151	21	280-5	145	RP II

Note: table is organized by median calibrated radiocarbon dates, and includes the Sample ID, estimated ontogenetic age, estimated sex, burial context, uncalibrated radiocarbon date, the 95% confidence interval for calibrated dates in cal BP, median calibrated dates (cal BP), and the archaeological period associated with each individual based from those dates. “B” is Burial when following directly after site ID. “Unk” is unknown. “i” is short for Individual. “Ind.” Means indeterminate and indicates sex could not be determined. “U” means unit. “cmbs” means centimeters below surface. “MA” = Middle Archaic; “LA” = Late Archaic; “RP I” = Recent Prehistoric I; “RP II” = Recent Prehistoric II.

Of interest to many archaeologists, Burial 9a from TUO-300, is the main contributor for arguments centered around violence and warfare within the Central Sierra Nevada (Schwitalla 2013; Schwitalla et al. 2014). This burial was found to have a chert Desert Side-notched point embedded in her spine, which showed signs of healing. She was an aged individual, who had other spinal conditions suggesting poor health (Brennan 1971; San Francisco State University 2014b). She returned a mid-RP II date (352–447 cal BP) and cannot be associated with the MCA droughts.

Because of the number of burials, and the time frames to which they date, I suggest that TUO-300 was a small hamlet, which was established during the Late Archaic, and was a part of a larger settlement tract that stretched from the Tuolumne River down Roger Creek. Because of its association with other precontact sites in close proximity (those mentioned above), this

settlement tract *may* have represented a *nena*. It is clear from the close associations of some of these other proximate sites with bedrock mortars and other house pits that they too were used during the Recent Prehistoric period. That TUO-300 has a deep history of use cannot be argued. Based on these new radiocarbon dates, it saw increased use from the Middle Archaic to the Late Archaic as people continually returned to this site and buried their dead, likely during winter and spring given the stability of the seasonal round documented by Rosenthal et al. (2011a). It saw sustained use during RP I and the MCA, indicating that the Tuolumne River was not dry during fall at the end of the seasonal drought despite MCA conditions, and that Roger Creek was likely surrounded by a well-established series of small settlements of the ancestors of the Tuolumne Me-Wuk, possibly representing an ethnographic *nena*. The “sustained use” of TUO-300 continued into RP II as climate conditions ameliorated during Little Ice Age, and people continued to live at the site and bury their dead.

3.4.4 CA-TUO-314: The Moccasin Site

The Moccasin Site, CA-TUO-314, was a heavily damaged large midden site excavated during January and February of 1971 (Slaymaker 1971:129). Only sparse patches of the original ground surface were left after heavy earthmoving equipment had scraped the ground and uprooted tree stumps. Slaymaker (1971: 129) notes that hundreds of ancestral remains were scattered across the surface of the site prior to vandals and looters stacking the remains in a pile measuring three feet high, four feet wide and six feet long. It is unknown how many individuals this desecration represented. No remains were collected from this pile.

Efforts were, however, made to excavate *in-situ* burials (including cremations) as they were encountered in excavation units. In addition, other remains were collected from the surface of units prior to excavation on both the eastern and western peripheries of the site (Slaymaker

1971:129–132). The context, burial position, and orientation were recorded for seven partially disturbed burials. Individuals were buried in a flexed position, varying from tightly to loosely flexed (Slaymaker 1971:132–133). At least three individuals were interred under a cairn (Slaymaker's Burial 4; San Francisco State University 2014c), and the remains of several cairns scattered about the site are noted by Slaymaker (1971:129, 133). However, he does not describe the excavation methods they employed, how the site was laid out for excavation, nor how units were chosen for sampling.

The site was situated on the south bank of Moccasin Creek, about 1.6 km from its confluence with the Tuolumne River (Slaymaker 1971:130). Much like TUO-300, TUO-314 was associated with at least four other precontact sites: TUO-318, TUO-307, TUO-313, and TUO-308. It was the middle site within this tract along Moccasin Creek. Judging by Moratto's (1971a) Map III, TUO-314 was about 800 m from the two most distant sites, TUO-318 and TUO-308. TUO-318, situated on the Tuolumne River, had a bedrock mortar with 43 mortar holes. TUO-307 was a rock shelter with four associated mortar holes and cupule petroglyphs. TUO-313 was a small precontact "campsite," and TUO-308 was another midden site with seven associated mortar holes (Moratto 1971a:Table III–1).

At the time of excavation, TUO-314 had been home to the Golden Chain campground (San Francisco State University 2014c). Local residents said prior to the work performed by the earthmoving equipment, a low mound, about two meters high was present at the site (Slaymaker 1971:129–131). Slaymaker (1971:129–131) confirmed this by examining the depths of looter holes and suggested the mound may have approached three meters in some spots. Numerous ash lenses, an intact cairn, a rock feature, and a disturbed house floor with post-hole impressions were visible prior to excavation. One still-intact bedrock mortar with seventeen mortar holes was

located 183 meters northwest of the site, and residents suggested another large outcrop with hundreds of mortar holes had been destroyed about 800 meters to the southwest of the site (Slaymaker 1971:132)—close to TUO-308. Excavations at TUO-314 were preemptively shut down by political activism (Slaymaker 1971:129).

Faunal remains recovered from the site were scant but includes large mammals, small mammals, a few bird and rodent remains, and a single *Canis* bone (Slaymaker 1971:134). According to the level-bag data, large mammal bones were the most frequently encountered faunal remains, followed distantly by birds, rodents, unidentified small mammals, and small amounts of freshwater shell. Paleobotanicals were recovered in only trace amounts.

Few artifacts were recovered, possibly because excavations were cut short, or more likely because of the extensive prior looting damage the site had sustained. Shell beads were recovered with burials from under the cairn (Slaymaker 1971:134–136). Associated with Unit C and the cairn unit were awl fragments, a bone bead or ear spool, a bone needle, a concave-base side-notched knife or point, small numbers of flaked tools, and small amounts of debitage. Chert dominates the tools and debitage in the upper levels (surface to 40 cmbs), while obsidian dominated the lower levels from 40–60 cmbs (Slaymaker 1971:134). Whelan (2016:Table 4.8) indicates that Bodie Hills obsidian is the major source for the obsidian debitage. No other artifacts are discussed in Slaymaker (1971); however, a larger number of artifacts were identified by NAGPRA personnel at San Francisco State University (2014) as Associated Funerary Objects and have been returned to the tribe.

Beyond Slaymaker's (1971) written impression of the site, no formal analyses were undertaken. Moratto (1971a:143), in his conclusion regarding the Don Pedro sites suggested that, of all the deposits tested within the project area, TUO-314 was probably the largest, deepest and

oldest, and that it constituted a village, which he estimated saw occupation beginning around 500 CE or earlier, and lasted until late precontact times. Based on the newly radiocarbon-dated individuals in this study, the occupation of TUO-314 began on the earlier side of his estimate. In total, the remains excavated and surface collected from TUO-314 constituted at least twenty individuals (San Francisco State University 2014c). Of these twenty, I sampled 15 that were identifiable, and radiocarbon dated 11 (Table 3-3).

The resulting dates show that TUO-314 saw occupation during the Late Archaic, as Moratto had suggested. Four adult individuals recovered from the northeast power-cut date to this period. Because of the state of the site during excavation, no behavioral inference can be made about the thousand-year gap in occupation dates between the LA and RP I, and it likely represents a sampling bias with the recovered burials. However, the site was used during RP I, much like both TUO-279 and TUO-300. Half of the dated burials fall within this time frame. The differing contexts of these burials suggest that the MCA population was large, considering so little of the site was sampled and RP I accounts for half of the radiocarbon dates. The site saw use during RP II as well. Based on the new radiocarbon dates, and the larger context of the Sierran chronology, I suggest TUO-314 was settled during the Late Archaic and used throughout the last 2,500 years as a fall and winter village. It was probably a part of a *mena* that stretched from the Tuolumne River down Moccasin Creek, given the other sites in close proximity that also had bedrock mortars.

Table 3-3 Ancestral Remains from CA-TUO-314

Sample ID	Age	Sex	Context	¹⁴ C BP	±	95% cal BP	Median	Period
TUO-314 B2B	adult	ind.	North-east power-cut	2440	25	2700-2360	2480	LA
TUO-314 B2A	adult	male	North-east power-cut	2210	30	2325-2125	2230	LA
TUO-314 Unk7A	adult	male	North-east power-cut	2075	25	2115-1945	2035	LA

Sample ID	Age	Sex	Context	¹⁴ C BP	±	95% cal BP	Median	Period
TUO-314 Unk6A	adult	ind.	North-east power-cut	2068	22	2110-1945	2030	LA
TUO-314 Unk5A	subadult	ind.	unknown	1059	23	1050-925	950	RP I
TUO-314 B4B	adult	ind.	U-C; 45-60 cmbs	895	20	900-730	785	RP I
TUO-314 Unk2Bi1	adult	ind.	Western surface scatter	862	21	895-695	760	RP I
TUO-314 Unk8A	adult	male	Eastern surface scatter	848	32	795-680	745	RP I
TUO-314 Unk2A	child	ind.	Western surface scatter	770	26	725-670	695	RP I
TUO-314 B4A	young adult	ind.	U-C; 45-60 cmbs	760	35	730-660	690	RP I
TUO-314 Unk8B	adult	ind.	Eastern surface scatter	234	19	310-0	285	RP II

Note: table is organized by median calibrated radiocarbon dates, and includes the Sample ID, estimated ontogenetic age, estimated sex, burial context, uncalibrated radiocarbon date, the 95% confidence interval for calibrated dates in cal BP, median calibrated dates (cal BP), and the archaeological period associated with each individual based from those dates. “B” is Burial when following directly after site ID. “Unk” is unknown. “i” is short for Individual. “Ind.” means indeterminate and indicates sex could not be determined. “U” means unit. “cmbs” means centimeters below surface. “MA” = Middle Archaic; “LA” = Late Archaic; “RP I” = Recent Prehistoric I; “RP II” = Recent Prehistoric II.

3.4.5 Other Don Pedro Burials

Prior to Moratto’s (1971a) involvement with the New Don Pedro Reservoir sites, Francis A. “Fritz” Riddell, the first State Archaeologist, oversaw the initial surveys, and even participated in some himself (Moratto 1971a:ii; Riddell 1970a, 1970b). Three sites (TUO-s331, -342, and -s497) surveyed by Riddell yielded isolated surface finds of human remains (CA Dept. of Parks and Recreation 1996; Riddell 1970a, 1970b). These sites were not chosen for excavation by Moratto’s team. Two had human remains that produced enough collagen for radiocarbon dating (Table 3-4).

CA-TUO-S331 was formerly known as CA-TUO-301 (Riddell 1970b). Riddell (1970b) noted the site as a small village with fourteen visible mortar holes within a partially-buried bedrock outcrop. It had been badly damaged by a bulldozer cut, but Riddell felt that the site still

held significant archaeological information (Riddell 1970b). The site was located along Roger Creek one mile northwest of the Blanchard Fire Station at an elevation around 222 m. It was within 3 km of TUO-300 along the same drainage. This site is likely permanently inundated today and, given the timeline of Moratto's (1971a) excavations, was probably already submerged when a crew was gathered for excavation. Among the artifacts collected were core tools, six simple flake tools, four CCS flakes, a bird bone, five mammal bone fragments, and a quartz crystal. Riddell (1970) collected a fragment of a human occipital bone that lacked any identifiable features from which to estimate sex, although the visible suture showed evidence of closure, suggesting an age of at least young adult (between 19 and 35 years old). This individual produced an RP I era radiocarbon date.

The second site is *probably* recorded as TUO-S497, along Lucas Gulch. The site at the time may have been labelled as TUO-487 (CA Dept. of Parks and Recreation 1996). The original report as detailed and filed by Riddell had gone missing by 1996, according to the paperwork received with the human remains from this survey collection (CA Dept. of Parks and Recreation 1996). This site was probably about three kilometers northwest from TUO-S331, along Lucas Gulch, which fed into Roger Creek at its northern terminus. There were 56 artifacts collected from this site, including a blade, a knife, a chopper, a scraper-plane, a scraper, a CCS core, one simple flake tool, 40 pieces of debitage, one handstone, one pestle, a glass trade bead, one shell fragment, some nails and a fork (CA Dept. of Parks and Recreation 1996). Among these items were two small human parietal-bone fragments. These pieces did not refit but looked to be in the same condition. The larger piece contained a section of either the coronal or sagittal suture margin that indicated sutural closure, suggesting this cranial fragment belonged to an adult. No features were present from which to estimate sex. This person returned an RP I date.

Table 3-4 Ancestral Remains from Other Don Pedro Sites

Sample ID	Age	Sex	Context	¹⁴ C BP	±	95% cal BP	Median	Period
TUO-S331 38-8a	adult (young)	ind.	surface	960	30	925-790	850	RP I
TUO-S497 15-9a	adult	ind.	surface	900	30	910-730	800	RP I

Note: table shows the radiocarbon dates, context, and estimated age and sex of the two individuals recovered during surface survey. “Ind.” means indeterminate and indicates sex could not be determined. “RP I” = Recent Prehistoric I.

3.4.6 Summary of Don Pedro Burial Dates

Out of 47 radiocarbon-dated individuals from the Don Pedro project area, the majority (40%) date to RP I, which is surprising. If the whole of the west-central Sierra Nevada were depopulated during the MCA, it seems the Tuolumne River and its tributaries within the foothills and lower elevations were not. The evidence from Don Pedro is based on direct dating of a sample of human remains, which provides direct evidence of population size, and settlement trends through time. This area could have been a refugium, or perhaps the archaeological sample is telling us the water was sustained and reliable within a foraging radius of the river (*sensu* Morgan 2008) even during prolonged drought. Reliable water would have allowed for fall settlement within this area, similar to the pattern of the Late Archaic and RP II.

Given the number of RP I dates produced by this sample, it is interesting that so little RP I information exists elsewhere in the west-central Sierra Nevada. One of several factors might explain this incongruence. First, it is possible that deposits from RP I are hidden within temporally-mixed deposits and are not easily identifiable and separated from other materials. The data generated by this dissertation strongly supports this hypothesis. Given this result, it will be necessary in future archaeological work to conduct more extensive dating to gain insight into human cultural change and evaluate behaviors from the RP I. Likewise, further updates to

chronologies with other important collections, such as those from New Melones, seem warranted. Unfortunately, many sites are not extensively dated and merely regarded as RP I /RP II, and as such, are not included within broader regional analyses. This greatly limits our understanding of regional antiquity.

Second, it is possible RP I sites are mostly located in alternative locations on the landscape that have not yet been investigated by archaeologists. More systematic survey across the landscape—not just areas associated with major river corridors—would help test this hypothesis.

Third, given the development of the region's rivers as reservoirs early on in the state's history, it is possible that RP I sites were differentially lost without documentation or investigation. Unfortunately, there is little opportunity to evaluate this hypothesis further, unless reservoirs are drained.

If radiocarbon dates can be used as a proxy for population size, then actual radiocarbon dates on people should hold special weight when we consider the region's culture-historical sequence. This is discussed further in Chapter 6. At minimum it suggests that Late Archaic populations around the Don Pedro area were larger, and likely denser than during the Middle Archaic. As well, the 40% representing the RP I likely suggests further population expansion, or alternatively that the population of the region was condensed around reliable water sources.

As for RP II, ~30% represent this period, which is surprising given our current understanding of how densely populated the region is thought to have been at this time. However, if we consider that environmental conditions had ameliorated, then we should expect whatever restrictions the MCA imposed on humans living here was relaxed and could account for the increased numbers of sites across the region. This pattern may explain to some degree the

smaller percentage of RPII dates at Don Pedro. For example, if the population had aggregated along perennial waterways during the MCA, with water acting as a limiting factor for settlement (i.e., water-patch number was reduced), then more dates should be expected near these waterways, and much fewer should be expected any distance longer than a day's walk from a known water source. Water is not a resource that is easily transported (i.e., carried). If water was no longer as much of a limiting factor during the LIA and RP II, because the water "patches" had increased in number, then we should expect settlements and camps even along the intermittent streams, as they too should have water during fall given the cooler temperatures and later season of snowmelt associated with glacial periods.

In sum, I have demonstrated that the Don Pedro sites are unique among the sites throughout the west-central Sierra Nevada. The archaeological patterns here are not as clear as at Sonora, but the excavations from the early 1970s pale in comparison to what can be accomplished today. The ancestral remains from these sites provide more than dates by which to inform us of their history. The dates, however, serve as a starting point through which these sites can, at minimum, be given future consideration in regional analyses. These dates also allow for diachronic trends in human subsistence to be discerned, which should further inform our understanding of patterns of food consumption, rather than of food production.

3.5 Chapter Summary

I began with an overview of sources, detailing briefly the history of ethnographic and linguistic research in the Sierra Nevada. I then covered the ethnography of the Central Sierra Me-Wuk, focusing on settlement and sociopolitical structure. Moving on, I discussed Indigenous seasonal rounds, and the seasons in which resources were accessed throughout the west slope.

Next, I detailed the archaeological history of research in the Sierra Nevada, noting that it did not begin in earnest until the passage of the Flood Control Act of 1944. I then chronicled the development of CRM archaeology on the west slope and argued that a deep understanding of this history was needed to fully appreciate the findings from the Don Pedro burials. I next moved on to a discussion of previous settlement and subsistence studies across parts of the west slope, paying particular attention to analyses undertaken as a part of the East Sonora Bypass Project, as this study was one of the first to take a region-wide perspective. Following that, I briefly discussed the close ties between CRM studies and chronology-building, and then I explain why I focus on the most recent chronology developed from the Sonora Bypass. Next, I gave an overview of the culture-history of the region, which included a discussion of different climate trends (summarized in Figure 3.5), as well as an overview of sites and cultural developments evidenced by increasing numbers of archaeological analyses.

Lastly, I discussed the chronological placement of burials from Don Pedro, giving overviews of the sites from which the burials included in this dissertation study were recovered. Here I offer an updated chronology for each site and discuss how these new dates challenge our understanding of cultural trends across the study region. I ended with a discussion of the Don Pedro sites as a whole, and how they fit into the puzzle of overall Sierra Nevada cultural history.

Chapter 4: C₃ Plants, Paleobotanicals, and Carbon Isotopes

This chapter begins with a brief review of carbon circulation across Earth and a short discussion of the different photosynthetic pathways employed by different classes of plants. It then explores more deeply what factors contribute to variation in $^{13}\text{C}/^{12}\text{C}$ of C₃ plants and suggest that the use of a global average of $\delta^{13}\text{C}$ of C₃ plants to understand $\delta^{13}\text{C}$ in C₃ consumer tissues is inadvisable. It then lays out expectations of $\delta^{13}\text{C}$ for different sample types based from previous ecological research.

The goal of this chapter is to investigate intra- and inter-species variation in $\delta^{13}\text{C}$ of C₃ paleobotanical remains to extrapolate differential responses to broad paleo-environmental changes and how this relates to the $\delta^{13}\text{C}$ expected in human and animal remains from the same local region and time frame. To achieve this, I test a model of precipitation linked to $\delta^{13}\text{C}$, developed by Kohn (2010), using $\delta^{13}\text{C}$ measured in the tree rings of a black oak from one of the archaeological sites and paleobotanical remains. I show how different water-management strategies in plants affect their isotopic values, and how this translates up the food chain by linear manipulations of results and modeling.

I create an isotopic baseline from C₃ plants important to hunter-gatherer diets within a Mediterranean biome that accounts for differences among plant morphological types, diachronic climatic variability, elevation, and fluxes in $^{13}\text{C}/^{12}\text{C}$ in atmospheric CO₂ across the Holocene. The results indicate the pine nutshell in this study are from conifers that have an isohydric water-management strategy, as compared to oaks, evergreen shrubs, and perennial and annual bunch grasses from within the same context. Pine nuts tend to have stronger isotopic effects within human diets, as they are high protein, but conifers tend to follow a conservative water-management strategy which increases ^{13}C in plant parts. This has implications for stable isotope

analysis of diets of humans and animals where dietary contributions from conifers or other isohydric plants may be involved. Last, I use the baseline to model the range expected for archaeological herbivore collagen $\delta^{13}\text{C}$ given differences in the consumption of dietary resources from angiosperms versus gymnosperms. This modelling is then used to parse the diets of the animals represented by the faunal remains in the following chapter.

4.1 Carbon in C_3 Plants

For carbon, ^{13}C makes up only 1.07% of all stable carbon circulating on Earth, while the light version, ^{12}C , comprises 98.93% (Hoefs 2009). Atmospheric CO_2 is the main source of carbon for all terrestrial plants and is in isotopic equilibrium with oceanic carbon values (Schwarcz and Schoeninger 1991). In natural waters, such as rivers and marine environments, carbon contributions come from dissolved inorganic carbon, atmospheric CO_2 , and CO_2 from decomposing organic matter (Schwarcz and Schoeninger 1991). For marine environments, ^{13}C values are higher as the oceans are huge carbon sinks (Schwarcz and Schoeninger 1991).

Oceanic and atmospheric carbon are transferred into the biological system through photosynthesis (Schwarcz and Schoeninger 1991). The photosynthetic activity of phytoplankton is the main determinate of carbon values for organisms living within marine ecosystems, while in terrestrial ecosystems the photosynthetic pathways plants use to fix CO_2 from the atmosphere determine carbon values of living organisms (Fry 2006; Schwarcz and Schoeninger 1991).

Plants can be broadly classified by which pathway they use— C_3 , C_4 , or crassulacean acid metabolism (CAM)—because each pathway is unique in how the resultant fractionation discriminates against the incorporation of $^{13}\text{CO}_2$ (Farquhar et al. 1989). Plants that use the C_3 pathway, such as trees, shrubs, and most grasses typically have lower $\delta^{13}\text{C}$ values that average

near -28‰ in a global sense, whereas those that use the C₄ pathway, such as corn and dryland grasses, have higher $\delta^{13}\text{C}$ values averaging around -13‰ (Fry 2006). CAM plants, such as agave and yucca, have an intermediate average between C₃ and C₄ plants (DeNiro 1987; Farquhar et al. 1982; Fry 2006; Koch 2007). The variability observed for the range of $\delta^{13}\text{C}$ exhibited by C₃ plants through multiple collection and testing methods suggests caution when interpreting the $\delta^{13}\text{C}$ of consumer tissues (Heaton 1999). In general, the interaction between environmental conditions—such as water-stress and increased temperatures—and plant morphological and hydrological characteristics affect discrimination and contribute to the variation in $\delta^{13}\text{C}$ values seen in plants, especially in the C₃ group (Farquhar et al. 1989; Leavitt and Long 1988).

4.1.1 Why Do Local C₃ Plants Matter?

Plants have been an important component of human diets for much, or perhaps all our evolutionary history. Globally, C₃ plants make up the majority (~90%) of plant biomass, while C₄ plants account for about 18% of global bioproductivity but are limited to about 3% of global biomass, and CAM plants account for even less (Cerling et al. 1998; Kellogg 2013; Kohn 2010a; Taub 2010). How these plants differentially contributed to past human diets is an active area of research. Most studies focus on either the paleobotanicals as an indicator of which plants were culturally important, while others take an isotopic approach and focus on the consumption patterns evident from the $^{13}\text{C}/^{12}\text{C}$ in human and faunal remains.

Owing to better preservation of plant remains in more recent time periods, the analysis of plant contributions to human diets are frequently based on identification of macrobotanical remains, pollen, starch grains, and phytoliths, or some combination thereof. However, the archaeological residues of plants are mostly a reflection of the products of labor and preservation, and not necessarily direct evidence of consumption patterns (Reddy 2016).

Although paleobotanicals can inform on items within the diet, and, in some instances can give researchers an idea of the importance of some plants to human diets, especially in the case of seeds and some nuts, others inform on cultural uses, such as for house construction, bedding, fuel for hearths, and medicines (Reddy 2016; Wohlgemuth 2010).

Conversely, the most direct evidence of consumption patterns is stable isotope analysis of human remains, but in most instances this line of inquiry is limited in that it can only distinguish where diets fall on a continuum of C_3 versus C_4 /marine. The most powerful stable isotope analyses of human diets are those that use human, archaeobotanical, and faunal remains from the same contexts to discern past human diets and make informed interpretations (Makarewicz and Sealy 2015). However, this approach has not been standard in application owing to several reasons, not the least of which is the lack of sampling for paleobotanicals through soil sampling and flotation, as well as the differential preservation of plant remains as compared to bones and teeth from different environmental contexts and time frames.

Unfortunately, without sampling paleobotanicals, those using stable isotope analysis of human remains are left to make assumptions about the plants consumed by the humans they are studying. Chief among these assumptions is the use of the global average for C_3 plants based on measurements of modern plants. In this regard, use of a global average masks the differential responses of plant morpho-types to climatic fluctuations and unlinks diet from the surrounding biotic community and climate. When we consider hunter-gatherer diets—constituting the majority of our evolutionary history—this is an important consideration given that only local foods were generally consumed. The global average, depending on which paper is cited (Cerling et al. 1997; Dawson et al. 2002; Kohn 2010a), has mainly been focused on measurements of isotopic values in leaves.

However, leaves are not the only plant parts that contribute to consumer diets. Other plant parts, such as seeds, nuts, fruits (which contribute to human and animals diets), and woods (mostly animals consumers) are frequently enriched in ^{13}C compared to leaves (Carlson and Kingston 2014; Han et al. 2024; Leavitt and Long 1982). As well, not all plants react in the same way to climatic fluctuations, from millennial to seasonal time scales (Fardusi et al. 2016; Heaton 1999; Tieszen 1991). The use of a global average also masks differences among climate types, for example Mediterranean, tropical, continental, boreal, etc., which has an effect on the types of plants represented as well as their water management strategies.

4.1.2 What Contributes to Variability in $^{13}\text{C}/^{12}\text{C}$ of C_3 Plants?

A growing body of literature indicates that C_3 plants exhibit a large degree of variation in $^{13}\text{C}/^{12}\text{C}$ across time and space, even at the local level (Carlson and Kingston 2014; Fardusi et al. 2016; Heaton 1999; Philippsen et al. 2019; Tieszen 1991). For example, in a recent study by Philippsen et al. (2019) that covers 5,000 years for a 300-hectare area in Denmark, the variation observed in the wood and charcoal samples between different C_3 species was between 2-3‰ for $\delta^{13}\text{C}$. They caution that these differences can lead to uncertainty for paleodietary studies which rely on average estimates (Philippsen et al., 2019).

Location plays a big part in the variation witnessed in C_3 plants. Broader interpretations of regional variability are linked to climate, such as the differences found across Europe by Van Klinken et al. (2000). In a global survey of C_3 plants, Kohn (2010) indicated a monotonic increase in $\delta^{13}\text{C}$ with decreasing Mean Annual Precipitation (MAP). Kohn's (2010) study corrected for elevation above sea level (m), latitude (absolute decimal degrees from equator) and $\delta^{13}\text{C}$ in atmospheric CO_2 , indicating that these are important drivers of variation in plant $^{13}\text{C}/^{12}\text{C}$

in localized ecosystems. According to Körner et al. (1991), carbon isotope discrimination can change between 0.8 and 2.7‰, depending on species group, per km change in elevation.

Heaton (1999) illustrates how some of the variability in C₃ plants arises and presents a review of processes that contribute to it from plant to ecosystem level. At the geographic level for a location of interest, the environmental factors that contribute to some of the variation seen among C₃ plants are slope, aspect, elevation, soil type, climate (temperature, humidity, precipitation, growing degree days), as well as canopy cover density (Heaton 1999; Tieszen 1991). For example, a recent study suggests that soil parent material impacts soil moisture content at different levels, which by affecting rooting depth, leads to differences in the hydrologic function of plants (Maxwell et al. 2018). The authors observed that 12% of the variability in the efficiency of plants' water use across and within species is attributed to differences in soil parent material (Maxwell et al. 2018).

However, these environmental factors only cover part of the reasons behind the variability in ¹³C/¹²C of different C₃ species. Many studies show that some of the observed variation in δ¹³C among and within C₃ species at the habitat level can be attributed to access to light. Even within a single tree, leaves at the top of the tree have less negative δ¹³C values than those near the ground (Ehleringer and Cerling 1995; Farquhar et al. 1982; Garten and Taylor 1992). This is often attributed to two different mechanisms associated with photosynthesis—access to light, which is reduced as shade increases, and the use of respired CO₂ near the ground level (Garten and Taylor 1992). Kohn (2010) suggests this is why some of the most negative δ¹³C values (below -31‰) are associated with tropical forests—a reflection of the interaction of canopy effects and low light (high shade).

The morphotypes and life forms of plants determine their access to water, photosynthetic capacity, light sensitivity, and regulate their interactions with the environment (Heaton 1999; Tieszen 1991). As an example, a meta-analysis by Fardusi et al. (2016) examined studies across a broad swath of woody species (i.e., trees and shrubs) and suggests that plant life form, such as conifer vs shrub, but not broadleaved trees, show consistent positive intraspecific correlations for the relationship between growth and $\delta^{13}\text{C}$, especially as it relates to biomass. This relationship increases from Mediterranean environments (water-limited) to temperate and boreal environments (energy-limited) (Fardusi et al. 2016). It indicates a strong linkage of plant productivity to $\delta^{13}\text{C}$ at the level of the life form, or morphotype, in correlation with different environments. The correlation between plant biomass/growth and $\delta^{13}\text{C}$ was strongest for conifers regardless of environmental type, suggesting that life form within conifers is highly constrained, while for broad-leaved woody plants, the relationship was more variable (Fardusi et al. 2016). That broad-leaf trees show varying degrees of correlation might be explained through differences among plants in their water-use strategies, which are likely linked to leaf area index, number of vacuoles, and root to shoot length, among others. These relationships among plant morphological types are important when considering what plants entered into human and animal diets and contributed to the carbon pool assimilated among different archaeological tissues of interest.

Also well-studied are plant responses to available soil moisture, high temperature, and drought (Adams and Kolb 2004; Araus et al. 2003; Bachofen et al. 2018; Bréda et al. 2006; Galmés et al. 2007; Linares and Camarero 2012; Martín-Gómez et al. 2017; Morison and Gifford 1983; Rouspard et al. 1996; Shestakova et al. 2017; Tardieu and Simonneau 1998; Xu et al. 2018; Zhang and Nobel 1996). Across C_3 taxa, from grasses (e.g., Araus et al. 2003; Morison and Gifford 1983) to trees (e.g., Adams and Kolb 2004; Bachofen et al. 2018; Bréda et al. 2006;

Linares and Camarero 2012; Martín-Gómez et al. 2017; Roupsard et al. 1996; Shestakova et al. 2017) and shrubs (e.g., Galmés et al. 2007), the most obvious trend is that ^{13}C becomes enriched in droughted plants as discrimination against ^{13}C is reduced when plants guard against water loss through the leaves by regulating stomatal opening (Tardieu and Simonneau 1998; Xu et al. 2018; Zhang and Nobel 1996). After the stomata close, the carbon present within the system continues to be used and incorporated into plant tissues, without new carbon being “inhaled” through the stomata. This is akin to a plant holding its breath, and can lead to carbon starvation and system failure in cases of extreme or prolonged moisture stress; however, this threshold differs among plant types (Fardusi et al. 2016; Tardieu and Simonneau 1998; Xu et al. 2018; Zhang and Nobel 1996). These studies help explain why there is a large variation in $\delta^{13}\text{C}$ at the species level. For any given environment, the average $\delta^{13}\text{C}$ of a plant will vary according to environmental conditions during the period of the plant’s tissue formation (Dawson et al. 2002).

The atmosphere also plays a role in this variation. As atmospheric levels of CO_2 have fluctuated over geologic timescales, so too has $^{13}\text{C}/^{12}\text{C}$ in CO_2 (Ahn et al. 2012; Belmecheri and Laverigne 2020; Cerling et al. 1997; Drake 2012; Ehleringer and Cerling 1995; Elsig et al. 2009; Etheridge et al. 1996; Indermühle et al. 1999). Atmospheric fluctuations prior to the Industrial Revolution were mainly influenced by natural processes such as volcanism, fires, and, on longer geologic timescales, plate tectonics and the creation and destruction of ecosystems. Diachronic variation in $\delta^{13}\text{CO}_2$ can be estimated from ice core data for the archaeological period of interest. It is advisable to include this information if paleobotanical remains are used to understand environmental fluctuations or create isotopic baselines for animal or human consumers.

For modern time periods, and depending on location, a huge increase in atmospheric ^{12}C (and a dilution of the atmospheric ^{13}C) associated with the Industrial Revolution and the burning

of fossil fuels is observed (Etheridge et al. 1996; Indermöhle et al. 1999; Keeling 1979; Suess 1953, 1955). This increase during the modern era is referred to as the Suess effect (Keeling 1979; Suess 1955) and makes impossible direct comparisons of $\delta^{13}\text{C}$ between modern plants and archaeological materials predating ~1750 CE without estimating changes to atmospheric $^{13}\text{C}/^{12}\text{C}$ available to modern plants and correcting $\delta^{13}\text{C}$ on one end or the other.

The relationship of measured $^{13}\text{C}/^{12}\text{C}$ values of charred C_3 plant remains from local level samples can be expressed mathematically to infer plant reactions to climate perturbations, such as drought (Drake 2013, 2014, 2012; Farquhar et al. 1982, 1989). The inferences are based on well understood reactions of plants when they close their stomata to reduce transpiration (i.e., water loss from evapotranspiration at the cellular level within leaves) and possible hydraulic failure (i.e., reduced water flow due to cavitation [air bubbles] in the xylem), and are deduced from measures of water use efficiency (WUE) (Bates and Hall 1981; Farquhar et al. 1982, 1989; Leavitt and Long 1982; Morison and Gifford 1983; Saliendra and Meinzer 1989; Wong et al. 1979). Water use efficiency, when calculated from the measured $\delta^{13}\text{C}$ of paleobotanicals or of collected modern leaves or wood, is referred to as intrinsic water use efficiency, or iWUE. When iWUE is high, stomatal conductance is low or the photosynthetic rate has increased (or both) over the averaged time period of tissue formation (i.e., the period of time associated with the formation of the sampled plant part—leaf, stem, wood, nutshell, seed, etc.) (Farquhar et al. 1982, 1989; McCarroll et al. 2009). However, in order for the photosynthetic rate (A) to have increased, an increase in CO_2 is implied (Farquhar et al. 1989; Taub 2010). Many morphological, phenological, and physiological attributes among plants increase iWUE, however many of the attributes that increase iWUE may also impose limitations on carbon gain and compromise performance in competitive situations (DeLucia and Schlesinger 1991).

Water use efficiency of plants is an important factor to consider. The point at which any given plant closes its stomata to protect against increasing transpirational water loss varies according to its water-use strategy, which can be classified along a continuum from isohydric to anisohydric (Klein 2014; Klein et al. 2013; McDowell et al. 2008, 2010; Roman et al. 2015; Tardieu and Simonneau 1998; Wang et al. 2021; Yi et al. 2019). Isohydric plants tend to maintain relatively constant mid-day leaf water potential regardless of soil moisture variability, whereas anisohydric plants maintain higher stomatal conductance and CO₂ assimilation under optimal, and mild to moderate drought conditions (McDowell et al. 2010; Sade et al. 2012; Yi et al. 2019). The indication of which strategy a particular plant follows has been modeled many different ways, from mechanistic to environmental interactions with genetic expressions (Kurowska 2020; McDowell et al. 2008; Sade et al. 2012; Tardieu and Simonneau 1998; Wang et al. 2021; Yi et al. 2019). In both cases, and anywhere along the continuum is an implied variation in the amount of ¹³C that may be incorporated into plant tissues, as the metabolic processes involved in photosynthesis may be further regulated by multiple factors related to the iso/anisohydric continuum.

This is possibly a species-level phenomena, as Sade et al. (2012) have suggested from their work with tomatoes. In their study, anisohydric behavior was only expressed in an isohydric strain of tomatoes after manipulation of *SITIP2;2*—a gene that regulates expression of a tonoplast intrinsic aquaporin protein which helps regulate water transport from the cytoplasm to the vacuole (Sade et al. 2012). While the expression of the protein was upregulated during drought treatments, it enabled continued water transport across cells which allowed the plants to grow and fruit despite the drought treatment (Sade et al. 2012). They suggest anisohydric plants may be more productive than isohydric plants during episodic drought stress, as they are not

limited by issues of carbon starvation as is prone to happen when stomatal regulation is tightly fixed as happens in isohydric plants (Sade et al. 2012). The gene *SlTIP2;2* is present only within tomatoes, but other plants have different TIP genes—ranging in number from 6–35 (Kurowska 2020). Much research has been devoted to understanding TIP genes in crop plants (e.g., sunflower, wheat, barley, corn/maize, rice, radish, tobacco, etc.) as improving drought resistance and yield are of concern, but much less has been devoted to understanding non-domestic species (Kurowska 2020), for example, those that may have been important to human paleodiets prior to agriculture.

While this line of research is ongoing, and the genetics underlying the iso/anisohydric behavioral continuum are not known for a variety of species, both modes of research (mechanistic and genetic) suggest that anisohydricity may be a dominant factor in determining how ecosystem productivity responds to environmental stress such as short episodic and intense drought (Konings and Gentine 2017; Novick et al. 2019; Roman et al. 2015; Yi et al. 2019). For example, increased fine root density in progressively deeper soils may give anisohydric species an advantage over more conservative isohydric species as the increased root density helps to continue water uptake to offset further transpirational water loss in leaves during drought and allows primary growth to continue. This has been observed by Walthert et al. (2024) for Downey oak and European beech as compared to Scots pine and Norway spruce. Complementary to this is the observation that anisohydric species can maintain constant photosynthetic capacity so long as hydraulic conductance is not negatively affected (Roman et al. 2015). This relationship between anisohydric behavior and drought survival has been used to explain the shift observed in pinyon-juniper woodlands during twenty-four months of drought, as the juniper (*Juniperus monosperma*) has been classified as anisohydric, while pinyon (*Pinus edulis*) is isohydric in

relation to the juniper (Shaw et al. 2005). In short, junipers experienced lower mortality rates and had greater productivity compared to the pinyon (Shaw et al. 2005).

When we consider the parts of plants that are consumed, those unknown $\delta^{13}\text{C}$ values are also going to differ from measurements taken from leaves. Early work on the differences between $\delta^{13}\text{C}$ of leaves and wood showed that woods are isotopically heavier than leaves, typically by 3–4‰ (Leavitt and Long 1982). In a tropical setting, research on $\delta^{13}\text{C}$ of the fruits, seeds, pith, sprouting leaves, and mature leaves of the most common preferred foods of chimpanzee were analyzed, and results indicated variation around 7‰ from mean values among the different C_3 food types and as much as 14‰ among all C_3 samples (Carlson and Kingston 2014). More relevant to this dissertation is the work by Han et al. (2024) on the difference in $\delta^{13}\text{C}$ of leaves and acorn nut parts of two broadleaf evergreen oaks. They found pericarps and nutmeats to be isotopically enriched, ranging between 1-2‰, compared to the current year leaves (Han et al. 2024). If we consider the variation among C_3 plants, we should also consider some of the variation in $\delta^{13}\text{C}$ among parts of the plants, as some, such as seeds (grains) and nuts, are some of the most important dietary items within hunter-gather diets and early agriculturalists.

Because there are so many factors contributing to variation in $^{13}\text{C}/^{12}\text{C}$ of C_3 plants, the use of a global average of $\delta^{13}\text{C}$ can lead to erroneous interpretations of forager and animal diets. Hence, it is important to sample paleobotanical remains from the local scale. Few of the wild taxa important to past human and animal diets have been analyzed, and their corollaries may indicate variations that are unexpected from average modern values. The use of stable isotope analysis of local paleobotanicals can inform on past environmental conditions and add another line of evidence for what baseline values should be for a given environment.

Figure 4.1 summarizes the conceptual sources of variation in measured $^{13}\text{C}/^{12}\text{C}$, expressed as $\delta^{13}\text{C}$, among C_3 plants discussed in chapter sections 4.1.1 and 4.1.2. Panel A shows how plant part (e.g., stem versus leaf) and life form (e.g., grass versus angiosperm tree) vary within a local environment in relation to the respective equivalents. Panel B indicates the expectations given environmental circumstances.

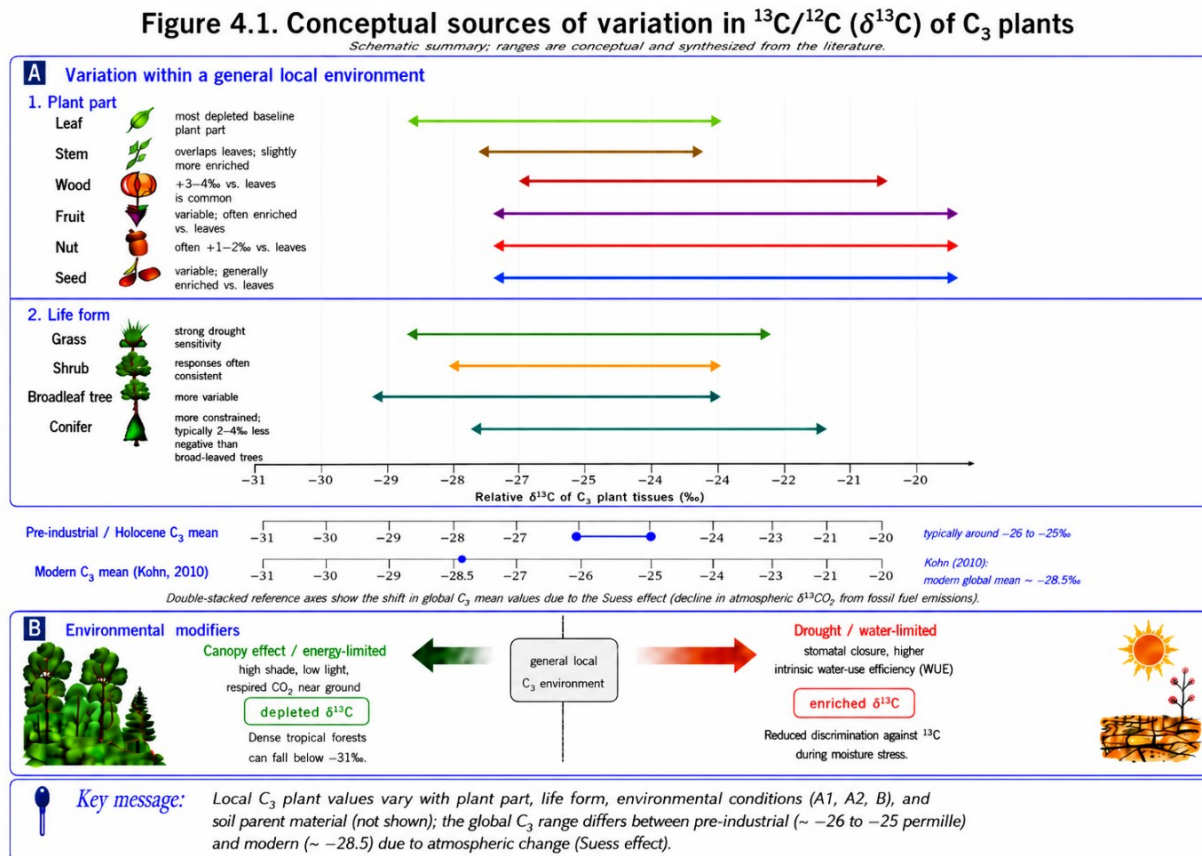


Figure 4.1 Conceptual Sources of Variation in $^{13}\text{C}/^{12}\text{C}$ ($\delta^{13}\text{C}$) of C_3 Plants
 Figure summarizes in visual form the factors that can affect $\delta^{13}\text{C}$ of C_3 plants, as discussed in sections 4.1.1 and 4.1.2. The key message is local C_3 plant values vary with plant part, life form (morphotype), environmental conditions, and soil parent material (not shown). Of note is the global C_3 range differs between preindustrial times and modern due to the Suess effect. Figure was created with the help of Chat GPT (Open AI).

Specifically, Figure 4.1 Panel A shows variation within a general local environment on a horizontal $\delta^{13}\text{C}$ scale from approximately -31– -20‰. In Panel A1, plant parts vary in their expected $\delta^{13}\text{C}$ ranges, leaves are shown as a baseline plant part, stems overlap leaves but are

slightly more enriched, wood is commonly enriched by about 3-4‰ relative to leaves, and fruits, nuts, and seeds are generally more variable and often more enriched than leaves. In Panel A2, plant life forms also vary: grasses and broad-leaf trees show broad ranges, shrubs show a slightly narrower range, and conifers are shown as more constrained and generally less negative than broad-leaved trees. Below Panel A, two stacked reference axes compare C₃ plant values through time. The pre-industrial/Holocene C₃ range of $\delta^{13}\text{C}$ is estimated to fall between -26‰ and -25‰, while the modern C₃ mean, following Kohn 2010, is shown near -28.5‰. This shift reflects atmospheric change associated with the Suess effect. Panel B shows environmental modifiers. Canopy effect, or energy-limited settings shift plant $\delta^{13}\text{C}$ values more negative while drought, or water-limited environments, shift values towards less negative. The key message is that local C₃ plant values vary with plant part, life form, environmental conditions, and soil parent material (not shown), so a single global average can obscure important local variation.

4.1.3 Study Goals

This study aims to illustrate the value of analyzing $\delta^{13}\text{C}$ in paleobotanical remains to establish baseline variation between different species and how this affects interpretation of stable isotope values in human and animal remains. This study aims to illustrate the value of analyzing $\delta^{13}\text{C}$ in paleobotanical remains to establish baseline variation between different species and how this affects interpretation of stable isotope values in human and animal remains. I analyzed the charred remains of pine nutshell, acorn nutshell, manzanita berry seeds, and grass seeds from a mountainous Mediterranean environment. These represent a range of common C₃ plant contributors to hunter-gatherer and animal diets within the study region, the Sierra Nevada of California. This study is relevant to other regions where past human and animal populations consumed pine nuts and acorns, as few studies beyond California analyze the isotopic

composition of these items, nor considered how their $\delta^{13}\text{C}$ values contributed to human dietary values.

Beyond the study region, concrete evidence for the consumption of pine nuts and/or acorns by hunter-gatherers can be traced to multiple places and time periods, for example, during the Upper Paleolithic (~23,000 cal BP) on the Sea of Galilee (Ohalo II) (Kislev et al. 1992; Nadel and Werker 1999; Weiss et al. 2011), 15,000 cal BP in Morocco (Humphrey et al. 2014), and at 10,000 cal BP in Tunisia (Morales et al. 2015). In more modern contexts, pine nuts were imported to Britain during the Roman period, and consumed in major towns (Van der Veen et al. 2008). However, acorns and pine nuts should not be treated the same through the lens of isotopic analyses. It is this I aim to bring to light. I investigate variability among the grass taxa and evergreen shrubs as well, as they are rarely reported for California, yet they contributed heavily to the diets of the humans and animals under consideration within this dissertation.

I also use $\delta^{13}\text{C}$ from tree rings of a black oak from one of the study sites to test model predictions for extrapolating precipitation from C_3 plant and consumer tissues. The model, developed by Kohn (2010), can be arranged mathematically to predict $\delta^{13}\text{C}$ values from precipitation, elevation (m) above sea level (masl), and latitude. I use this model and its variants to estimate expectations for the paleobotanical remains and C_3 consumer $\delta^{13}\text{C}$ values across a range of precipitation conditions expected across growing seasons for the study region. The model is ideal for estimating how drought conditions affect plant carbon metabolism, and in turn, how drought affects carbon values of consumer tissues, mainly collagen and apatite. I use the tree ring $\delta^{13}\text{C}$ to test and compare modelled estimates to known precipitation from 1897 to 2017. I then show how the combination of atmospheric carbon, precipitation, and intrinsic water use efficiency inter-relate and modulate $^{13}\text{C}/^{12}\text{C}$ values within C_3 plants. This is important because I

am able to show how prolonged drought would shift the isotopic baseline of the study region and what this means for $\delta^{13}\text{C}$ measured in animal and human bones and teeth.

4.2 Materials, Plant Characteristics, and Expectations

The study region encompasses the foothills and lower elevations within the west-central Sierra Nevada Mountains of California outlined in Figure 4.2 (map). The elevation transect of interest, between 150-1500m above sea level (asl), encompasses the most productive biotic communities for the region—the Upper Sonoran Zone and Lower Montane Forest (Rosenthal 2011a; Wohlgemuth 2010). In terms of plant food resources, this elevation transect is among the highest ranked for the entire state (Wohlgemuth 2010). Food resources of interest include the nuts of oak (acorns), gray pine, sugar pine, grass seeds (perennial and annual), and berries from evergreen shrubs such as manzanita. Also present within past human diets in the region were roots and tubers for which we have scant archaeological data, and as such they are not considered within this paleobotanical analysis.

Of prime importance are the nuts, which have been a staple in human and animal diets for thousands of years (Hunt 2004; Mayer 1976; Morgan 2009a; Rosenthal 2011a; Whelan 2016; Wohlgemuth 2010). Indeed, pine nuts and acorns represent the two most abundant paleobotanical remains in archaeological sites (Rosenthal 2011a; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2010). Berry pits and grass seeds make up a lesser total proportion of archaeobotanical assemblages (Rosenthal et al. 2011a; Whelan 2016; Wohlgemuth 2004). While proportion within assemblages is unlikely to be a faithful correlate to the true fraction within human diet, assemblage proportion still offers important insight into actual foods consumed and

the relative proportion to other food items within assemblages. This is useful for interpreting which foods may have been more frequently consumed.

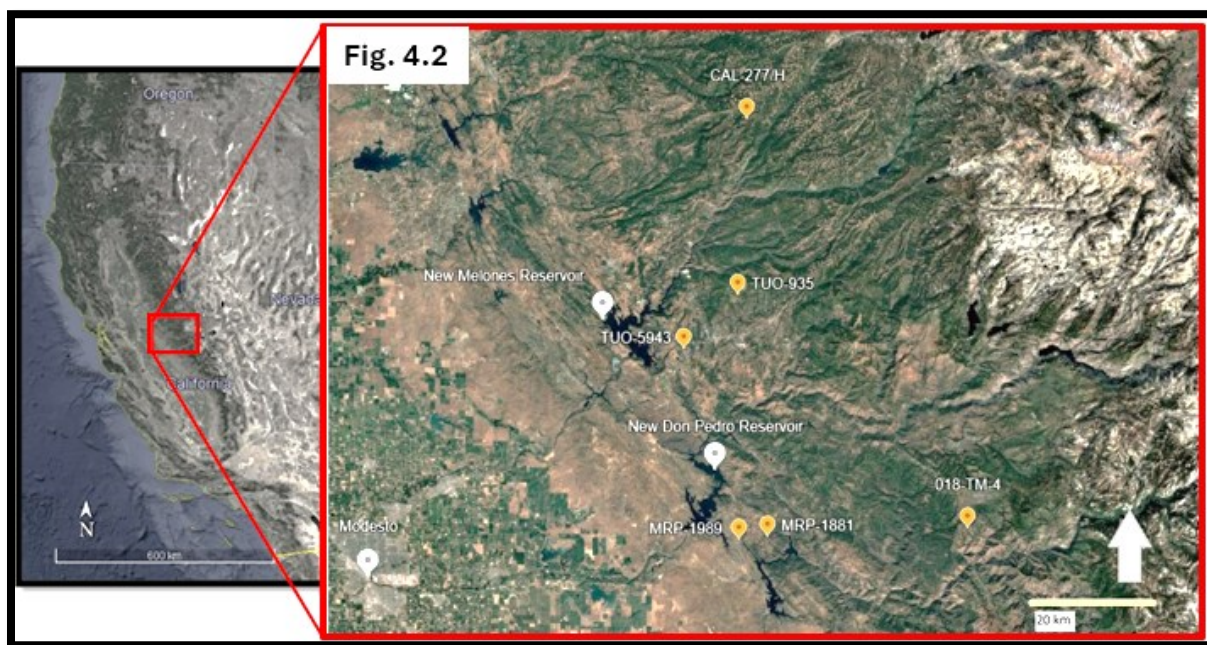


Figure 4.2 Map of Study Region

Map shows the general location of the six sites from which paleobotanical samples were obtained in relation to: each other, the city of Modesto, the two local reservoirs—New Melones and New Don Pedro—and the broader relationship to where in California this region is located. Map inset scale is set to 20km, while CA state map scale is set to 600km; white arrow indicates North.

Sixty-five paleobotanical samples were analyzed for stable carbon isotopes. All charred plant samples are from C_3 plants of archaeological origin. The acorn shell, pine nutshell, and manzanita seed-remains were recovered from 2 mm-grade flotation samples, while grass seeds were recovered from smaller 0.7- and 0.5-mm grade flotation samples. Samples derive from six previously excavated sites (see Figure 4.2, above) within 80 km from one another. The sample and site information are organized in Table 4-1, arranged by site. The sites have been radiocarbon dated, with the earliest evincing occupation around 7000 cal BP. This information, alongside latitude in decimal degrees north (DDN), and elevation in meters above sea level (masl), are also

included in Table 4-1 to give context to estimation of possible environmental effects on $\delta^{13}\text{C}$ in the charred plant remains.

Table 4-1 Paleobotanical Sample Information

Site	Occupational Range	Elevation (masl)	Lat. (DDN)	Taxon	Common Name	# samples
CA-CAL-277/H	7000-180 cal BP	1463	38.27	<i>Quercus</i> spp.	acorn	4
CA-CAL-277/H	7000-180 cal BP	1463	38.27	<i>Pinus lambertiana</i>	sugar pine	4
CA-TUO-935	4700-650 cal BP	832	38.03	<i>Quercus</i> spp.	acorn	15
CA-TUO-935	4700-650 cal BP	832	38.03	<i>Pinus sabiniana</i>	gray pine	15
CA-TUO-935	4700-650 cal BP	832	38.03	<i>Arctostaphylos</i> spp.	manzanita	12
CA-TUO-935	4700-650 cal BP	832	38.03	<i>Vulpia</i> spp	fescue grass	2
CA-TUO-935	4700-650 cal BP	832	38.03	<i>Bromus</i> spp.	brome grass	2
CA-TUO-935	4700-650 cal BP	832	38.03	<i>Poa</i> spp.	meadow grass	2
CA-TUO-5943	3000-2800 cal BP	430	37.95	<i>Quercus</i> spp.	acorn	1
CA-TUO-5943	3000-2800 cal BP	430	37.95	<i>Pinus sabiniana</i>	gray pine	1
CA-MRP-1881	7000-1100 cal BP	348	37.70	<i>Quercus</i> spp.	acorn	1
CA-MRP-1881	7000-1100 cal BP	348	37.70	<i>Pinus sabiniana</i>	gray pine	1
CA-MRP-1989	7000-3000; 610-100 cal BP	260	37.69	<i>Quercus</i> spp.	acorn	1
CA-MRP-1989	7000-3000; 610-100 cal BP	260	37.69	<i>Pinus sabiniana</i>	gray pine	1
CA-018-TM-4	1100-100 cal BP	885	37.64	<i>Quercus</i> spp.	acorn	1
CA-018-TM-4	1100-100 cal BP	885	37.64	<i>Pinus sabiniana</i>	gray pine	1
CA-018-TM-4	1100-100 cal BP	885	37.64	<i>Pinus lambertiana</i>	sugar pine	1

Note: Table shows the taxon, common name, and number of samples for each of the sites from which paleobotanical samples were obtained. Table is organized by site, and pertinent site information, such as occupational range (cal BP), elevation (masl), and latitude (DDN) are also given. “masl” is meters above sea level; “Lat” is latitude; “DDN” is decimal degrees north; “# samples” refers to the number of samples. Paleobotanical identification was made to species when possible; all others were identified to genus.

Carbonized plant samples were identified by Eric Wohlgemuth using a reference collection maintained at Far Western Anthropological Research Group in Davis, California. The samples were classified to genus, or species when possible. As can be seen in Table 4-1, most samples represent charred nutshell from acorn and pine, while fewer are of charred manzanita

berry pits and native grass seeds. Acorn nutshell was only identifiable to genus, but based on species growing in the region today, samples possibly belong to *Quercus douglasii* (blue oak), *Q. wislizeni* (interior live oak), *Q. kelloggii* (black oak), *Q. chrysolepis* (canyon live oak), or *Q. lobata* (valley oak) (Thorne et al. 2008). The determination of the pine nutshell was more straightforward, as *Pinus sabiniana* (gray pine) and *P. lambertiana* (sugar pine) nutshell fragments are distinguishable from each other based on thickness, where *P. lambertiana* has a thinner shell. Between these two species, this relationship in thickness holds for both the nutshell hull as well as the scales: *P. sabiniana* scales typically measure 12.3 ± 1.1 mm, hulls average 1.59 ± 0.3 mm ; *P. lambertiana* scales average 4.5 ± 0.5 mm, while hulls average 0.36 ± 0.04 mm (Johnson et al. 2003). *Arctostaphylos spp.* berry pits are distinct from other paleobotanicals and easily identified by their globular spherical shape. Although species attribution was not possible, the most likely candidates are *A. manzanita*, *A. mewukka*, *A. patula*, and/or *A. viscida* (Abrahamson 2014; Fryer 2015; Hauser 2007; Merriam 1918). The native grass seeds could not be identified beyond genus (*Poa*, *Festuca* and *Bromus*). The native *Poa* and *Bromus* species are perennial bunch grasses, while the few native species of *Festuca*—once called *Vulpia*—are annual herbs. Each of these taxa are known dietary constituents for the indigenous Me-Wuk groups who inhabit the region and have been a part of the Indigenous communities' diets for millennia (Barrett & Gifford 1933; Rosenthal et al. 2011b; Whelan 2016; Wohlgemuth 2010).

While the wood from the tree rings was not a dietary item, tree rings have long been used to infer paleoclimate information (e.g., LaMarche 1973). Integral to this study, the tree rings are used to infer precipitation over the period 1768-2017 as a test case to see if isotopic results from paleobotanicals and bone collagen can be used to likewise infer precipitation. Tree rings were sampled from a black oak at CA-TUO-935 that was cut down in spring of 2020 by PG&E as part

of fire prevention efforts. A cookie, or a full cross section of the tree trunk, was obtained for isotopic analyses, shown in Figure 4.3. The tree cookie measured 91 cm across at the diameter, excluding bark, and averaged 9.2 cm thick.



Figure 4.3 Tree Cookie

Picture shows the full cross-section of the tree trunk from which rings were sampled. Image is meant as a visual aid regarding size of the tree and what constitutes a “tree cookie”. Meter stick is included for scale.

4.2.1 The Plants and Their Characteristics

Each of the plants which likely contributed to the identified paleobotanical samples are discussed below. When possible, a general description is provided if the genus is fairly standard or if there are commonalities among the endemic wild taxa. However, some taxa are quite variable, and different species are discussed as they may be present within those samples that

cannot be identified beyond genus, such as the oaks and the manzanitas. Because of the tree ring samples, I pay extra attention to discussing black oak.

Oaks present within the foothills and mountains of the Sierra Nevada today can be characterized as highly variable. In general, their leaves are variable, but each has characteristics (e.g., smaller leaf size, increased leaf thickness, increased stomatal density, or decreased stomatal size, etc.) that allows them to tolerate moisture stress and drought episodes (Dickson and Tomlinson 1996). Many oak species are also commonly tap- or deep-rooted (multiple deep roots and no taproot) which enables them to obtain most of their water from the water table or deep groundwater sources so that they do not depend on uncertain rains or surface water (Dickson and Tomlinson 1996).

Valley oaks (*Q. lobata*) persist into the lowest elevations of the foothills but are limited in number. When in the presence of other oaks in the foothills and mountains, they can be found in more mesic habitats and along seeps and springs (Howard 1992b). They are deciduous, with large expanding crowns, multiple deep roots and many large lateral root expansions (Howard 1992b). They are classified as being flood and drought tolerant (Howard 1992b). Their rooting adaptations allow them to deal with periodic floods, as is common in the valley, as well as high evapotranspiration during the summer. Knops and Koenig (1994) suggest that they are drought avoiders due to their rooting habits and high daytime stomatal conductivity, suggesting low WUE. Valley oak are not adapted to deal with snow because of their very broad and extensive branching, so their numbers are limited above 1,700 meters in the driest portions of their range (south, in the Tehachapi Mountains) (Howard 1992b), which means their distribution in the Sierra is limited to below the snowline. They produce an acorn crop annually (Howard 1992b), which made them a reliable species.

Quercus douglasii, or blue oak, are the most drought tolerant of all the deciduous oaks in California (Fryer 2007b). They are characterized by a deep taproot if soils permit, otherwise being characterized as having large lateral root systems that are more mass than what is represented aboveground in the body of the tree (Fryer 2007b). Because of their root adaptations, they are flood intolerant (Fryer 2007b). One particular trait is that they have low xylem water potential during the day, and quick drought recovery because of their expansive lateral roots (Knops and Koenig 1994). These oaks produce an acorn crop every year, which disperse from late summer into late fall; the insect-damaged acorns are shed first (Fryer 2007b).

Quercus kelloggii, the black oak, provided the favored acorn of the Me-Wuk (Barrett and Gifford 1933). They are winter deciduous, meaning they drop their leaves and are dormant during November and December (no wood or leaf growth), and have the highest elevational range of any of the western oaks, capable of surviving at high temperatures in the summer in low elevations (>80 m) and low temperatures during winter at high elevations—up to 2,400 m (Fryer 2007c). These oaks tend to develop one to several taproots or multiple large, laterally-spreading roots—some of which protrude above the ground (Fryer 2007c). Because of their low xylem water potential during the day and good overnight recovery, Knops and Koenig (1994) suggest they have high drought tolerance. Black oaks are a hardwood species which are ring porous, meaning that earlywood is clearly visibly differentiated from latewood by larger pores, which makes differentiating one ring to the next easier. Earlywood growth begins after the winter dormancy period, prior to bud burst, while latewood growth begins after the leaves have unfurled (Hill et al. 1995; Loader et al. 2003; Szczepanek et al. 2006). Black oak are a masting species, but this is limited to within stands of these oaks, and is not synchronous across their entire range in the Sierra (Fryer 2007c). They produce acorns every two years (it takes two years for a crop to

ripen), and, averaged over the range, will produce a good crop every two to three years given the mast habits (Fryer 2007c). Acorns begin to drop from late August to early November (Fryer 2007c).

Quercus wislizeni, interior live oak, is an evergreen oak whose leaves are retained for two years (Fryer 2012). It grows from 300-1,900 m, but is not well adapted to snow (Fryer 2012). It has sclerophyllous (i.e., hard, thick, and leathery) leaves as they are adapted to minimize water-loss, which protect it from desiccation during the summer, as does its deep rooting system (Fryer 2012). In a comparison of sclerophyllous species globally, California's interior live oak was found to have the deepest rooting depths of all oaks and when compared to most other species (Canadell et al. 1996). It is dominant in the chaparral communities of the Sierra, and is a common associate of gray pine (*Pinus sabiniana*) in the foothills (Fryer 2012). Of California's oaks, it is classified as the most drought tolerant (Barbour et al. 2007; Dodd and Kashani 2003). Interior live oak produces an acorn crop every two years, and a good crop every five to seven years (Fryer 2012).

Quercus chrysolepis, the canyon live oak, is the most widely distributed oak in California (Tollefson 2008). It is a spreading, perennial, sclerophyllous evergreen (Tollefson 2008). Its root system is highly adaptable; in deep or loose soils, it develops a pronounced taproot, in shallow soils it tends to have shallow spreading roots (Tollefson 2008). Knops and Koenig (1994) describe canyon live oaks as "drought evaders" that limit their growth during the dry season, instead shifting most growth to winter. Because of this, the species likely would be classified as having low WUE; however, this may be more of a function of leaf and root morphology than a heritable trait as it is highly adaptable. It is a prolific acorn producer at irregular intervals

(Tollefson 2008), and of the ones considered here is the greatest producer of acorns; but, many are not viable owing to insect damage. It masts every two to six years (Tollefson 2008).

The pines in general have less root mass than the mass of the tree above the ground (about 1/10) (Farjon 2021). However, while most pines develop a deep taproot, rooting is flexible and in shallow soils or substrates the roots will grow laterally (Farjon 2021). The pines also are well adapted to nutrient-deficient soils on which pines typically grow, as well as for environments with short growing seasons and long periods of drought due to their sclerophyllous, needle-shaped leaves (Knight et al. 1994). Forty-one species of pine are native to the United States, and as a general rule, seeds from sources in dry regions are large and produce slower-growing and more deeply-rooted seedlings than seeds from sources in moist regions (Krugman and Jenkinson 1974). Pines also tend to have a symbiotic relationship with mycelium, which enlarges the absorbing area which supplies the tree its nutrients and water—this allows pines to grow and colonize nutrient-poor soils (Farjon 2021).

Pinus sabiniana, or gray pine, grows on exposed, dry, rocky slopes at elevations from 30-1,800 m (Howard 1992c). Gray pine is a common associate of blue oak woodlands and chaparral within the foothills and lower elevations (Howard 1992c). Four climatic conditions characterize most of its natural range: hot, dry summers; absence of summer fog; precipitation, mostly as rain; and generally mild winters (Powers 1990). Its ability to withstand summer drought, and to photosynthesize during mild periods of winter and spring give it a strong competitive advantage over many other species in the California foothills (Powers 1990). It is a drought-tolerant, native evergreen conifer that produces a good seed crop at two to three year intervals (Howard 1992c; Powers 1990). However, it takes two years for a cone to mature, and cones tend to stay on trees

after seed dispersal due to the absence of an abscission layer where the cone attaches to the tree (Powers 1990).

Pinus lambertiana, sugar pine, is found on a variety of sites from moist, steep, north- and east-facing slopes, to more mesic, south-facing slopes (Habeck 1992). A low drought tolerance may be the determining factor as to where they are found (Habeck 1992). Sugar pine is a deep-rooted species with a single taproot that is not susceptible to windthrow (Habeck 1992), however lateral root development is not as flexible as gray pine. It can be found at elevations from 610 to 2,285 meters (Habeck 1992). Cone production starts later and is less prolific in sugar pine than in its associates (Kinloch and Scheuner 1990). Pine cones (and nuts) take two years to form and reach maturity (Habeck 1992).

The manzanitas (*Arctostaphylos* spp.) are all evergreen shrubs, however, leaf morphology, branching and stem morphology, rooting depth and the presence of a lignotuber (a heavy globular shaped organ capable of resprouting) are variable both within and across species (Abrahamson 2014; Fryer 2015; Hauser 2007; Parker et al. 2023). All of the species of interest here have sclerophyllous leaves, produced drupes that contain between five to six nutlets per drupe, and are fire followers (i.e., their seeds require fire to reproduce).

Common manzanita (*A. manzanita*) is the most widespread throughout the state and generally occurs in xeric conditions on rocky slopes, canyons, and barren ridges (Abrahamson 2014). It is an erect, evergreen shrub with thick leaves that may also grow as a single-stemmed tree (Abrahamson 2014). Its roots are often poorly developed, shallow, and vulnerable to heat; yet despite this it is often associated with blue oak woodlands, chaparral, and is found in coniferous forests as an understory associate (Abrahamson 2014). Its fruits begin development in early summer and mature from late summer to fall (Abrahamson 2014).

Arctostaphylos viscida, sticky whiteleaf manzanita, is another of the sclerophyllous shrub species occurring in chaparral, oak woodland, and low-elevation mixed-conifer communities of the Sierra Nevada (Fryer 2015). It occurs from 30 to 2,200 meters elevation and can range from three to thirteen feet tall with an erect form and spreading branches (Fryer 2015). It has laterally spreading, shallow roots which usually penetrate less than 8 inches (20 cm) below ground (Fryer 2015). Plant growth above ground will cease with the onset of summer drought. In this species, the leaves are held vertically which helps to reduce heat load and transpiration (Fryer 2015). Its fruits develop about 2 months after flowering, setting from late spring to early summer and ripening from early summer to early fall (Fryer 2015).

Greenleaf manzanita, *A. patula*, is the most common manzanita in the Great Basin and much of the Sierra Nevada (Hauser 2007). It is an erect shrub with stout branches that grows from 3 to 7 feet (1-2 m) tall, with an ultimate lateral branch spread up to ten feet (~3 m) (Hauser 2007). It can be found at elevations up to 2,130 m (Hauser 2007). Spreading or drooping leaves (never vertical) are 0.8 to 2 inches (2-6 cm) long, 0.6 to 2 inches (1.5-4 cm) broad, and produced on twisted, crooked, or gnarled stems (Hauser 2007). Unlike its populations elsewhere, greenleaf manzanita in the Sierra Nevada has a lignotuber which can resprout following fire disturbance. Its roots grow deep into the ground (up to seven ft/2.1 m), enabling it to extract water from moisture-depleted soils (Hauser 2007). It tends to have high drought tolerance and high nitrogen use efficiency, but low WUE due to its high xylem potential during the day (DeLucia and Schlesinger 1991; Hauser 2007). This suggests it has an anisohydric water-use strategy. Its fruits ripen from late summer to early fall (Hauser 2007).

The most variable species, *A. mewukka*, or Indian manzanita, is endemic to the Sierra Nevada (Parker et al. 2023). It is an evergreen erect shrub, growing from one to three meters

high (Parker et al. 2023). There is high variation in its stem form (hairy to non-hairy), and in the presence (or not) of a lignotuber (Parker et al. 2023). Its root system is unknown. It flowers from March through April, with fruits ripening through summer (Parker et al. 2023).

The perennial bunchgrasses (*Poa* and *Bromus* sp.) are mostly typified as cool season grasses that have wider distributions beyond California in North America, although some species are (or were) endemic (Howard 1997; Wennerberg 2004). The annual grasses from the genus *Festuca* (formerly *Vulpia*) tend to co-occur alongside these perennial bunchgrasses, but are shorter, and not as wide in their clumps (Rayburn 2015).

The genus *Poa* is extremely uniform and species determination is difficult, even in live specimens (Howard 1997). All are graminoid, and common in scrub oak, mountain brush, ponderosa pine and mountain chaparral scrub communities (Howard 1997). Species have deep fibrous root systems, and their reproduction is typically by seed (Howard 1997). They tend to tolerate open, dry conditions better than most herbaceous species. Species from this genus flower from May to August in California (Howard 1997).

The Bromes in California have short lifespans of three to five years (Wennerberg 2004). Their roots are fibrous, grow quickly, and become deep and widespread. They are associates in open woodlands and forests, and tend to be dominant in oak woodlands, but have low shade tolerance (Wennerberg 2004). Seeds mature in May and June at low elevations, and by late August at elevations up to 4,000 m (Wennerberg 2004).

There are four co-occurring species of *Festuca* in California, which are identified by patterns of fine hairs on the spikelets (Rayburn 2015). As these hairs are burned off during charring, this makes species identification of *Festuca* nearly impossible in paleobotanical remains. *Festuca* species are cool season annual grasses (Rayburn 2015). They are dominant in

low valleys and the foothills up to 1,500 m, especially on disturbed dry, thin, compact, or serpentine soils. Their root structure is deep and fibrous, which has made it a favorite for erosion prevention in modern contexts (Rayburn 2015). Seeds mature between April and June at elevations below 1,500 m (Smith and Aiken 2012).

4.2.2 Expectations

In general, because all samples in this study are from a variety of C₃ plants, I expect a variation in $\delta^{13}\text{C}$ and iWUE among the different taxa. However, I also expect some degree of overlap within and among the taxa as they shared the same general environment and hence were subject to a range of climatic variables during the growth and formation of the sampled tissues. Because they are from a region with a Mediterranean climate, characterized by high variation in annual precipitation, hot dry summers, and mild winters, I expect most samples to express less negative $\delta^{13}\text{C}$ than the global average $\delta^{13}\text{C}$ of C₃ plants which ranges between -27 -28.5‰ (Cerling et al. 1997; Kohn 2010a). I also expect the angiosperms (all of the plants within this study except the pines) to exhibit a depletion in $\delta^{13}\text{C}$ relative to the gymnosperms (the pines in this study), as this relationship is well established when environmental conditions are held constant (Diefendorf et al. 2015).

For the pines, I expect the pine nutshell to exhibit the least negative $\delta^{13}\text{C}$ values as pines from dry environments typically have the highest $\delta^{13}\text{C}$ of C₃ plants from the same environment (Bachofen et al. 2018; DeLucia and Schlesinger 1991; Gea-Izquierdo et al. 2021; Grinsted et al. 1979; Guehl et al. 1995; Kohn 2010a; Leavitt and Long 1988; Lev-Yadun and Sederoff 2000; Martín-Gómez et al. 2017). As well, recent research on gray pine from Sierra Nevada, the first research of its kind on this species, has further characterized gray pine as particularly sensitive to climate, as compared to co-occurring blue oak and ponderosa pine (Ho et al. 2024). Sugar pine,

with its preference for more mesic habitats and moist environments (Habeck 1992), may have more negative $\delta^{13}\text{C}$ than the gray pine, on average, but the actual difference may be negligible. In a global survey, evergreen gymnosperms, such as pines, tend to have greater leaf-level water use efficiency compared to other woody plant morphotypes, which causes their discrimination against ^{13}C to be lower (Diefendorf et al. 2010).

For the oaks, which range from evergreen to deciduous within the study area, I expect a large range of values among the acorn nutshell, owing to the differences in rooting habits and drought tolerance or avoidance. The tree rings sampled from the black oak should retain a climate signal, as oaks are some of the most common trees to be used for climate reconstructions (Meko et al. 2011). Because the nutshell was and cannot be identified to species with current methods, the most parsimonious expectation is, in general, the acorn nutshell $\delta^{13}\text{C}$ values should be more negative (or more depleted in ^{13}C) than the pine nutshell except in instances when pine was well watered and oaks experienced drought stress. There has been a large amount of research on oaks and coexisting pines (and on angiosperms versus conifers) (Guehl et al. 1995; Ho et al. 2024; Meinzer et al. 2014; Pausas et al. 2004; Poyatos et al. 2008; Roman et al. 2015), which suggest this should hold true for oak and pine-derived samples within this study.

The manzanita berry pits, from the broadleaved and evergreen shrub category, are expected to overlap the $\delta^{13}\text{C}$ of the oak samples, mainly because they are broad-leafed and woody, and what little research has been done on them suggests they exhibit low WUE (e.g., DeLucia and Schlesinger 1991). However, because rooting habits vary (shallow versus deep) among the possible species present within the samples, it is likely the berry pits will exhibit a similar range of values to the acorns. Evergreen leaves suggest an adaptation towards drought resilience as they help protect against water loss (Basu et al. 2016), which when considered with

reported low WUE for the deepest rooting species, *A. patula*, could also serve as an indicator that the evapotranspiration threshold at which they close their stomata is higher than the variable oaks and pines. This allows comparatively prolonged diffusion of CO₂ into the leaves throughout the day, which means continued discrimination against ¹³C compared to other taxa whose thresholds might be lower. This causes δ¹³C to be less (more negative) within these samples compared to the acorns or pine nutshell.

For the *Poa* seeds (two seeds made one sample), previous research indicates the species *Poa secunda* is impervious to changes in temperatures, elevations and soil moisture from within its natural range, as the δ¹³C measured from shoots showed only minimal and non-significant increase as these parameters varied (Link et al. 2003). The authors suggest that because *Poa secunda* has a large geographic distribution, it is likely that their treatments of varied elevation, climate and associated soil moisture were not as extreme as those that would be experienced by the species at the current limits of its range (Link et al. 2003). This suggests that, because *Poa secunda* could be represented by our *Poa* sample, it may not show much difference than the values (between -27 and -28) reported by Link et al. (2003), as the Sierra are not near the extent of its range. In a different study (Henderson et al. 2004), natural *Poa* varieties in Alberta, Canada were also found to have δ¹³C values around the global average for terrestrial C₃ vegetation—indicating that under cool and continental conditions the genus largely conforms to expectations of balanced evapotranspiration and stomatal control. These studies suggest that the sample from this study may represent the closest value to the global average, but because they are in a Mediterranean environment I still expect them to be slightly less negative than the global average.

The *Bromus* seed $\delta^{13}\text{C}$ values are likely to be comparable to the *Poa* value given that they are both perennial bunchgrasses that begin maturing in the early spring, have seeds that ripen near the same time, are from the same environment, and have similar rooting patterns. Yet, work by Beerling and Woodward (1995) indicated *Bromus* spp. may tend towards higher iWUE than *Poa* spp., which means they have lower discrimination against ^{13}C . This suggests the $\delta^{13}\text{C}$ may be less negative than that of *Poa*.

The *Festuca (Vulpia)* sample, as cool season annual grass, will likely have $^{13}\text{C}/^{12}\text{C}$ comparable to the perennial grasses as they grow and reproduce during the same seasons. Work by Waller and Lewis (1979) indicates there is some variation in $^{13}\text{C}/^{12}\text{C}$ among the C_3 grasses from the Tribe *Poaceae*, to which *Festuca* belongs. However, I expect that all of the grasses in this study will be similar to each other, and at the higher end of discrimination against ^{13}C simply because they grow when soil moisture deficits are annually low due to winter- and spring-dominant precipitation patterns. However, because none of the samples were directly radiocarbon dated, it is possible that they could have experienced extreme drought or pluvial conditions in the particular year of their growth and fruiting, which would affect their carbon assimilation, and thus their $\delta^{13}\text{C}$.

4.3 Methods: Tree Rings and Paleobotanicals

The tree ring samples and paleobotanicals represent related but dissimilar sample types for chemical processing and submission. As well, each of these sample types has different applications to this project—while tree rings are used for testing and calibrating precipitation estimates, paleobotanicals are used to create isotopic baselines and set baseline expectations for paleoprecipitation estimates. As such, each of these are treated separately, below.

4.3.1 Methods- Tree Ring Sampling and Calibrating Precipitation Estimation

Sampling the black oak tree cookie involved a long series of steps to prepare the wood. First, wood was sanded mechanically with a Ryobi hand-held belt sander, using increasingly fine grit sanding belts, up to 120-grit. Next, one half of the tree cookie was divided into four radial transects and sanded by hand with 150–180 grit sandpaper to make the thinnest rings distinguishable. Last, rings were counted four times from the center to the outermost ring to estimate the true age of the tree at different spots along radial transects of the tree cookie. This yielded an average count of 262 years, with the first ring estimated to date to 1757 CE.

From the 262 rings, 25 were sampled under my supervision by Harry Cao, a University of California- Davis undergraduate intern as part of his Senior Honor's Thesis project in 2022-2023. We chose to sample a radial transect where the rings were visually widest and one that would align with an area of the sapwood that was undamaged by insect activity. The goal was to sample every tenth ring, with ring 11 from the center sampled first. However, the samples are not exactly ten years apart because some rings pinch out (i.e., disappear), some rings split from another ring (because it pinched out elsewhere along the cookie), and some rings were so narrow that sampling was impossible and were skipped.

The goal was to sample the latewood within each selected ring, as it represents the photosynthetic product of that year's growth period, which takes place from spring through late summer/early fall (Hill et al. 1995; Loader et al. 2003; Szczepanek et al. 2006). The latewood was easily distinguished from the earlywood as a dense dark band of smaller compact cells, whereas the earlywood shows larger cells, is not as compact, and is lighter in color. However, owing to the extreme narrowness (less than 1 mm) of some of the rings, earlywood was included in some of the more recent samples (where growth rings are narrower). Earlywood represents the

first growth of the ring after the winter dormancy period before the new buds unfurl, but includes some photosynthetic product from the previous year which is mainly converted to starch and remobilized aiding in new ring growth and bud burst (Hill et al. 1995; Pilcher 1995; Szczepanek et al. 2006). In terms of isotopic effects, the earlywood signal is more similar to the previous years' latewood. However, it is not an exact match because stored starch (sucrose) (which tends to be isotopically enriched) is remobilized and used in part to form the earlywood (Helle and Schleser 2004), and because precipitation and climate conditions after the winter dormancy period still contribute to the ring growth before the leaves have budded (Pilcher 1995; Szczepanek et al. 2006).

The sampled wood was removed from selected rings using a handheld razorblade and a magnifying glass, and placed into a pre-labelled glass vial. After sampling, the rings were assigned a calendric date (or range of dates for samples that contained multiple years' worth of wood), the wood parts that were sampled were noted, and the ring-width measurements (i.e., thickness) were estimated by hand. The sampled rings and corresponding years are detailed in Table 4-2. As well, Table 4-2 indicates an estimate of the ring width for each sampled ring and which parts of the corresponding year's rings were sampled (earlywood, latewood, or both).

Table 4-2 indicates that four of our samples entail juvenile effects as they represent the first fifty years of growth of the tree, while the rest of samples are from the mature period onward. In Table 4-2, fourteen samples fall within the historic period (after 1895) for which there are precipitation data for the region, and it is mainly these that are the focus of the tree ring study and precipitation.

Table 4-2 Black Oak Tree Ring Samples

Sample #	Ring #	Av. Ring Width (mm)	Calendar Year (CE)	Ring Part	Notes
1	11	>4	1768	latewood	all latewood, Mar.-Oct.
2	25	>1-<2	1782	latewood	all latewood, Mar.-Oct.
3	35	<1	1792	latewood	all latewood, Mar.-Oct.
3	36	<1	1793	both	whole ring; used as centroid
3	37	<1	1794	earlywood	clips into earlywood, but not all
4	43	<1	1800	both	some earlywood, all latewood
4	44	<1	1801	both	whole ring; used as centroid
4	45	<1	1802	earlywood	most earlywood
5	62	<1	1819	both	narrow ring
5	63	<1	1820	both	narrow ring; used as centroid
5	64	<1	1821	both	narrow ring
6	70	>1-<2	1827	both	sampled across rings
6	71	>1-<2	1828	both	sampled across rings; centroid
6	72	>1-<2	1829	earlywood	sampled across rings
7	82	>1-<2	1839	both	whole ring; used as centroid
7	83	>1-<2	1840	earlywood	clips into earlywood, but not all
8	92	>2-<3	1849	latewood	all latewood, Mar.-Oct.
9	102	<1	1859	both	whole ring; used as centroid in graph
9	103	<1	1860	earlywood	clips into earlywood, but not all
10	118	<1	1875	both	whole ring; used as centroid
10	119	<1	1876	earlywood	clips into earlywood, but not all
11	130	>1-<2	1887	both	whole ring; used as centroid
12	140	>2-<3	1897	latewood	nearly all latewood; Apr.-Oct.
13	150	>4	1907	latewood	nearly all latewood; Apr.-Oct.
14	160	>3-<4	1917	latewood	all latewood, Mar.-Oct.
15	170	>2-<3	1927	latewood	all latewood, Mar.-Oct.
16	180	>2-<3	1937	latewood	all latewood, Mar.-Oct.
17	190	>1-<2	1947	latewood	all latewood, Mar.-Oct.
18	208	>1-<2	1965	latewood	all latewood, Mar.-Oct.
18	209	>1-<2	1966	both	whole ring; used as centroid
18	210	>1-<2	1967	earlywood	all earlywood
19	217	<1	1974	latewood	all latewood, Mar.-Oct.; centroid
19	218	<1	1975	earlywood	all earlywood
20	226	<1	1983	latewood	all latewood, Mar.-Oct.
20	227	<1	1984	both	whole ring; used as centroid
20	228	<1	1985	both	whole ring
21	238	<1	1995	both	whole ring; used as centroid
21	239	<1	1996	earlywood	all earlywood
22	242	<1	1999	latewood	all latewood, Mar.-Oct.; centroid
22	243	<1	2000	earlywood	all earlywood

Sample #	Ring #	Av. Ring Width (mm)	Calendar Year (CE)	Ring Part	Notes
23	250	<1	2007	latewood	all latewood, Mar.-Oct.
24	255	<1	2012	latewood	all latewood, Mar.-Oct.; centroid
24	256	<1	2013	earlywood	all earlywood
25	260	<1	2017	latewood	all latewood, Mar.-Oct.

Note: table details the sampling of the targeting rings. Table includes sample number (#), ring number (#), average (av.) ring width in mm, correlating calendar year (CE), ring part (earlywood, latewood, or both), and pertinent notes used to make decisions on the period of precipitation represented by each sample. Note that some samples contain multiple rings. In these cases, the ring represented by the greatest amount of sample material was used as the centroid in further analyses.

Figure 4.4a-d provides a scale to the ring width variation that was encountered while sampling as indicated in Table 4-2 and discussed above, and below. Some of the labelling and counting of rings is visible in Figure 4.4 a-d, but note that pen and pencil marks were applied after the samples had been taken. Figure 4.4a shows the radial transect that was sampled, while Fig. 4.4b-d enlarge certain sample areas. Insect damage to the sapwood is visible in Fig.4.4a-b, as are some of the narrowest rings encountered within this radial transect. Figure 4.4c shows a twenty-year section of samples, from 1927 to 1947, that were taken in less than ten cm of the radial transect, as well as an example of a narrow but well-defined ring at 1927 (far right, pink lines). Figure 4.4d shows a wide ring at 1907 where only some of the latewood was sampled, which meant adjusting the correlated historic period of precipitation.

The inclusion of earlywood in some samples represented a problem for easy interpretation of precipitation. Because sampling varied for many of the rings—for example, some samples contained the latewood of the previous year plus an entire ring for the target year, as seen in Table 4-2, and as shown in Figure 4.4b—I considered which months of precipitation would be reflected by the different ring sections. Based on growing patterns of black oak, the latewood should represent the majority of the year up to the winter dormancy period and excluding the period prior to bud burst which I set at March, while earlywood should represent

the short period following winter dormancy and up to bud burst, plus some contribution from starch formed during the previous year's latewood growth (McCarroll et al. 2017). Based on my understanding of tree ring growth, latewood represents precipitation totals for the period of March through October, while earlywood possibly represents the average between the previous year's latewood precipitation period plus the current year's total precipitation for January and February. In other words, the earlywood precipitation period was calculated by adding precipitation totals for the previous year period of March through October to the total for the current year precipitation for January and February and dividing the total sum by two, as it represents two different climate periods that are amalgamated into one growth period.

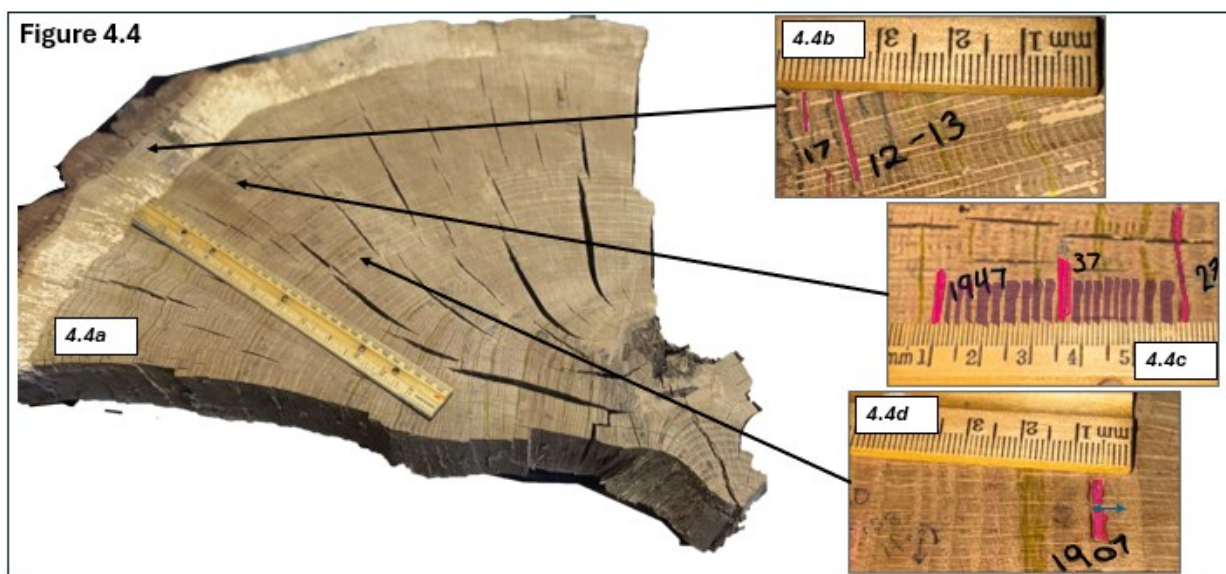


Figure 4.4 a-d Tree Ring Sample Examples

*Pictures show how the rings widths vary and include a selection of samples that capture some of the sampling procedure adjustments; a ruler showing mm was used for scale. **4.4a**: Picture is of the radial transect that was sampled. Breakage occurred after sampling, ruler for scale. **4.4b**: Picture shows the extreme narrowness of the most recent decades of rings, the location of sample 25 (2017, left) in relation to sample 24 (2012-2013, right) (drawn pink lines) and some of the bug damage present within the sapwood. **4.4c**: Picture shows samples 15-17 (1927, 1937, 1947; right to left) (drawn pink lines) in relation to each other, as these were the last samples that were exactly 10 years apart and were only of latewood, purple hatch marks show the rings in between the samples. **4.4d**: Sample 13 (1907) is shown as an example of only the latter portion of the latewood being sampled, which truncated the range of months used for precipitation comparison, blue arrow shows total width of the latewood for the 1907 sample year.*

Precipitation totals for each ring growth period were calculated separately for every year represented by the samples. For wide rings where the sample included only a section of latewood, such as that pictured in Figure 4.4c, estimated precipitation was truncated as indicated in Table 4-2, which entailed leaving out March. For samples that included both earlywood and latewood of a single growing year, the earlywood precipitation was calculated as mentioned above and added to the precipitation total for the March-October period that represents the latewood. When the previous year's latewood was included with the earlywood of the next year as a sample, these two totals were added together. When more than two years were included as a sample, I took the average of the totals for each year. In short, I tried to keep the method for calculating precipitation for the growth period represented by each sample as standard as possible.

Precipitation during November and December are not included because no tree-ring growth occurs during this period and there are no living leaves to photosynthesize and contribute to the carbon being assimilated by the black oak. Although, this is typically the period when roots may grow (Nilsson 2022). I expect that precipitation occurring during November and December likely serves in part to recharge groundwater, with some being utilized by the evergreen species present, and the rest likely contributes to runoff that may be captured downstream. This may account for some differences between predictions of precipitation based on observed $\Delta^{13}\text{C}$ in tree rings and actual precipitation totals in historic records, for the groupings of months.

4.3.2 Methods- Considerations, Processing, and Submission Techniques for Stable Isotope Analysis

To create an isotopic baseline that is applicable to our study region over the last 7,000 years, the paleobotanical samples are considered in taxa groups. Because of excavation and

flotation techniques, these represent random samples of foods but also represent a random sample of environmental effects on the parent plants over the period of tissue formation. Based on the expectations outlined above, and considering the large body of knowledge regarding environmental effects on C₃ plants, I expect a normal distribution of measured $\delta^{13}\text{C}$ values.

Over the 6,900-year period covered by the archaeological sites, the region experienced droughts, pluvials, glacial, and “normal” conditions. By working from sample $\delta^{13}\text{C}$ values and applying equations developed by Farquhar et al. (1982) and Farquhar et al. (1989) to calculate iWUE and $\Delta^{13}\text{C}$ (plant discrimination against the heavy isotopologue in relation to the lighter version minus variation in $^{13}\text{CO}_2$), I am able to better understand the environmental effects on the parent plants. This helps to characterize the range of variation expected among the different taxa, and helps identify those that might have higher iWUE due to isohydric behaviors or those that experienced drought. Isohydric behavior of plants and drought will affect consumer isotope values.

All charred plant remains in this study were well preserved, and likely carbonized below 350 °C owing to their intact external morphologies (Fraser et al. 2013; Stroud et al. 2023). Processing the paleobotanical samples followed a modified acid-only procedure as covered by Vaiglova et al. (2014) and began with samples being placed into individual 20mL scintillation vials and sonicated in 0.5M HCl solution for five minutes to remove inorganic impurities and any loose detritus introduced by local sediments. Samples were then sonicated in dH₂O for five minutes. Next, they were soaked in a 0.5M HCl solution for two hours at room temperature to complete the dissolution of any remaining inorganic materials. They were then rinsed with dH₂O to pH neutral and left to dry. After drying, they were frozen and lyophilized to remove any remaining moisture.

Tree ring samples were not chemically processed, and instead were submitted as whole wood samples for isotopic measurements. For charred paleobotanicals, approximately 0.3–1 mg of each sample was placed into a tin capsule and submitted to the Stable Isotope Facility at the University of California, Davis (UCD SIF) for isotopic measurements. Whole wood sample weights ranged between 1.1–2.8 mg, and each sample was placed into a tin capsule for submission to UCD SIF. Charred plant and whole wood $\delta^{13}\text{C}$ were measured by continuous-flow mass spectrometry through a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK). During each analytical run, samples were interspersed with replicates of different laboratory standards, including Bovine Liver, Nylon 5, Glutamic Acid, Peach Leaves, and Enriched Alanine. These laboratory standards were calibrated against NIST Standard Reference Materials (IAEA-600, USGS-40, USGS-41, USGS-42, USGS-43, USGS-61, USGS-64, and USGS-65). The long-term standard deviation for the University of California-Davis Stable Isotope Facility is 0.2 ‰ for $\delta^{13}\text{C}$. Paleobotanical sample repeats (two submitted items per sample, pine and manzanita from CA-TUO-935 only) experienced less variability than the long-term standard deviation of UCD SIF $\delta^{13}\text{C}$ analyses, indicating the samples were homogenous despite different sections of the samples being submitted. I use the more conservative UCD SIF standard deviation to estimate the error range within and across taxa.

All carbon stable isotope data is expressed in permille notation (δ) in comparison to the international reference standard for carbon, Vienna PeeDee Belemnite (VPDB). The relationship of $^{13}\text{C}/^{12}\text{C}$ of our samples and the international standards can be expressed by Equation (1) as:

$$\delta = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000 \quad 1.$$

where R is the ratio of the heavier isotope to its lighter version, both in the sample and in the reference standard.

Experimental studies show that carbonization at temperatures between 100–475 °C does not affect the $\delta^{13}\text{C}$ of paleobotanical remains (Hall et al. 2008; Vaiglova et al. 2014). However, other studies have shown the isotopic signal decreases with increasing temperatures (Czimeczik et al. 2002; Stroud et al. 2023). There is also an observed positive correlation between the decrease in $\delta^{13}\text{C}$ and an increase in %C, so, some recommend a correction derived from %C (Audiard et al. 2018; Ferrio et al. 2006). However, a “%C” below 70 indicates the $\delta^{13}\text{C}$ is not significantly affected (corrections range from 0.1 to 0.3 ‰, falling largely within instrumental error) (Audiard et al. 2018, 2019; Ferrio et al. 2006; Stroud et al. 2023; Vaiglova et al. 2014), and we use this as a cut off for our samples as a check on data integrity. No correction was added because the seeds and nutshell represented by the samples have not been investigated for effects of charring, and applying a correction that falls within instrumental error is pointless and could introduce more noise into the dataset.

4.3.3 Methods- Estimating the Environmental Effects on Sampled Paleobotanicals

For the paleobotanical remains, values for fractionation during photosynthesis—also termed carbon isotope discrimination and annotated as $\Delta^{13}\text{C}$ —were estimated to aid in the comparison to modern plant samples of the same type when possible, as future reference for other analysts, and to remove the variance introduced by $\delta^{13}\text{CO}_2$ at the time of tissue formation. A comparison to modern samples allows more detailed information about the link between environmental conditions affecting plant ^{13}C discrimination and aids in understanding inherent variation among C_3 plants. Many studies often include only the $\delta^{13}\text{C}$ values which can limit easy comparison among modern studies or those that may report on paleobotanical data with clear

environmental contexts. Here I incorporate both values ($\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$), following Ferrio et al. (2005). The intention is to allow comparison among both modern and paleobotanical samples, where no correction is needed for atmospheric variability in $\delta^{13}\text{CO}_2$ (Keeling 1979; Suess 1955). This effectively removes changes in $\delta^{13}\text{CO}_2$ associated with different time periods as well as the Suess effect. This was also necessary because I aim to show the usefulness of analyzing archaeobotanical samples and estimating how environmental effects affected our plant carbon isotope values, and what this means regarding paleoenvironment in terms of what the plants were experiencing, but also how this reflects on a diachronic analysis of human and faunal stable isotope values. However, please note that as more records of $\delta^{13}\text{CO}_2$ are added, the estimates, particularly for post-1800 industrialization, change, which is one major reason to include the raw $\delta^{13}\text{C}$ plant values so that future researchers may use the data with new and better atmospheric calibrations.

The $\Delta^{13}\text{C}$ values for the paleobotanical and wood samples were estimated based on two major premises and one common assumption. First, because the amount of atmospheric CO_2 fluctuates (Cerling et al. 1997; Ehleringer and Cerling 1995; Etheridge et al. 1996; Indermöhle et al. 1999), the availability of ^{13}C for plant tissue synthesis during plant respiration also fluctuates (Ehleringer and Cerling 1995; Farquhar et al. 1989). Therefore, $\delta^{13}\text{C}$ values of plants are the result of source carbon isotopic composition (atmosphere) and carbon isotope discrimination, whereas $\Delta^{13}\text{C}$ is the result of the biological processes of the plant (Farquhar et al. 1989:507). Second, $\Delta^{13}\text{C}$ is comparable across time periods irrespective of atmospheric fluctuations and allows for investigation of environmental factors that affect plant carbon isotope fractionation.

Last, because paleobotanical samples are the seed/nutshell remnants, mainly consisting of cellulose, these plant parts are non-photosynthetic, and instead are heterotrophic and represent an

average of discrimination against ^{13}C across the period of tissue formation. These heterotrophic tissues typically exhibit slightly higher $^{13}\text{C}/^{12}\text{C}$ than photosynthetic tissues (leaves) and are more comparable to tree rings or stems which form over longer periods of time (Badeck et al. 2005; Carlson and Kingston 2014; Cernusak et al. 2009; Farquhar et al. 1982, 1989; Gessler et al. 2014; Leavitt and Long 1988; Schwarcz and Schoeninger 1991). Tree rings and stems, as well as seeds and nuts, are the average of the products of photosynthesis and discrimination and reactions to the environment during the period of tissue formation (Hoch et al. 2013). These slightly less negative values are still distinguishable from C_4 plants (Bender 1971). Cellulose, whether from nutshell or wood, shows clear correlations with climatic records, so there is no reason to suspect that the shift in $\delta^{13}\text{C}$ between photosynthetic tissues and heterotrophic tissues is not systematic (Badea et al. 2021; Drake 2013; Hall et al. 2008; Leavitt and Long 1988; Tieszen 1991). In short, I assume the samples represent the average products of discrimination and routing of energy, similar to that of wood and, given that well-defined relationship, expect that the different time frames (i.e., periods of tissue formation) associated with seed, nut, or fruit production is comparable to wood and stems of the same basic taxa experiencing similar environmental constraints.

For oaks and pines, nuts form over a period of 1-3 years (Lev-Yadun and Sederoff 2000; Olson and Boyce 1971). Because of this prolonged period of tissue formation, the isotopic values of nut tissues will represent an average of the environmental conditions no shorter than one year and no longer than three. For species such as manzanita, berry production and ripening happens annually in the summer to fall, while the flowers are produced as early as winter (Abrahamson 2014). This means that for manzanita berry pits, the period of formation would be between 3-6 months, if seeds begin to form after the flower is pollinated. For grasses, the isotope values

represent a short window of time (weeks to a month) that is constrained by the emergence of the plant itself as well as the development and fertilization of the female reproductive organ.

The calculation for $\Delta^{13}\text{C}$ for C_3 plants, as developed by Farquhar et al. (1982) and Farquhar et al. (1989), is represented by Equation 2 as:

$$\Delta^{13}\text{C} = a + (b - a) c_i/c_a = (\delta^{13}\text{C}_a - \delta^{13}\text{C}_p)/(1 + \delta^{13}\text{C}_p/1000) \quad 2.$$

where a is the fractionation of CO_2 in air due to diffusion through the stomata (4.4‰; Craig, 1953), b is the net fractionation caused by carboxylation and discrimination by RuBisCO (27 ± 2 ‰; Ubierna & Farquhar, 2014), c_i/c_a is the ratio of the intercellular partial pressure (c_i) in leaves to ambient partial pressure (c_a) of CO_2 . According to Farquhar et al. (1989), $\delta^{13}\text{C}_a$ is the ratio of $^{13}\text{C}/^{12}\text{C}$ in air in relation to the VPDB standard, $\delta^{13}\text{C}_p$ is the ratio of $^{13}\text{C}/^{12}\text{C}$ of the plant sample in relation to the VPDB standard, and $\Delta^{13}\text{C}$ is the result of the plant's photosynthetic processes and represents the plant's discrimination against ^{13}C .

It should be noted that c_a and $\delta^{13}\text{C}_a$ can be found in the literature as ambient CO_2 concentration (in parts per million; c_a) and the ^{13}C in CO_2 ($\delta^{13}\text{C}_a$, or $\delta^{13}\text{CO}_2$) for thousands of years by referencing ice core data. Based on ice core data indicating minimal atmospheric fluctuations in $\delta^{13}\text{CO}_2$, on the order of ± 0.3 ‰ over the last 7000–100 years cal BP (Bauska et al. 2015; Belmecheri and Lavergne 2020; Drake 2013; Eggleston et al. 2016; Francey et al. 1999), I took the average $\delta^{13}\text{CO}_2$ ($\delta^{13}\text{C}_a$) for the occupation period (7000–100 cal BP; -6.4‰) and applied it to the paleobotanical samples. This atmospheric stability is illustrated in Figure 4.5a-b. However, as more paleo-records are added, the datasets could change in the future. Using the most up-to-date $\delta^{13}\text{CO}_2$ for the archaeological period of interest is important, as it does have an effect on $\Delta^{13}\text{C}$ values and any later calculations regarding c_i/c_a , iWUE, or precipitation estimates.

I calculated c_i/c_a , the inter partial cellular pressure (c_i) of the samples in relation to the ambient partial pressure (c_a), as follows:

$$c_i/c_a = (\Delta^{13}C_p - a)/(b - a) \quad 3.$$

In theory, when c_i (defined above) is small, $\Delta^{13}C_p$ will tend to be small as well, moving towards the value of a (4.4‰), which suggests stomatal conductance is small in relation to the capacity for CO₂ fixation (Farquhar et al. 1989). The opposite is true when stomatal conductance is large, c_i approaches c_a and Δ values move towards b (+27 ‰) (Farquhar et al. 1982, 1989; Ubierna and Farquhar 2014). This is significant for C₃ plants because, when stomatal conductance goes down, the expected outcome is a decrease in discrimination of ¹³C. This decreased discrimination against ¹³C results in less negative $\delta^{13}C$ of plant tissues. The c_i/c_a value represents an overarching measure of the many factors that influence both water loss and CO₂ uptake in plants (Ehleringer and Cerling 1995). Thus, $\Delta^{13}C$ is reflective of the plant's response to environmental conditions at the time of tissue formation, where c_i/c_a is a measure of those factors that modulate water loss and assimilation of carbon.

The iWUE of a plant is a measure of water loss per unit carbon gained (McCarroll et al. 2009; Saurer et al. 2004), including respiratory losses at the plant level. It is typically measured in micromoles of CO₂ per mole of water ($\mu\text{mol CO}_2 \text{ mol}^{-1}$). An increase in assimilation rate and/or a decrease in stomatal conductance can produce an increase in iWUE (McCarroll et al. 2009). I used the average c_a (280.5 ppmv) from ice core data sets (Ahn et al. 2012; Köhler et al. 2017; Macfarling Meure et al. 2006; Schmitt et al. 2012) for the 6,900 year period to enable an estimation of iWUE of the undated paleobotanicals under study. For the modern tree ring samples, I used the $\delta^{13}C_{CO_2}$ and CO₂ recommended by Belmecheri and Laverigne (2020:Supplementary Information) for the years of interest. The iWUE for each sample was

estimated using the following equation (4) according to Ehleringer and Cerling (1995) and McCarroll et al. (2009):

$$iWUE = (c_a - c_i)/1.6v \quad 4.$$

where 1.6v is the pressure difference between the water vapor in intercellular spaces and the atmosphere, and is assumed to be constant (Farquhar et al. 1989).

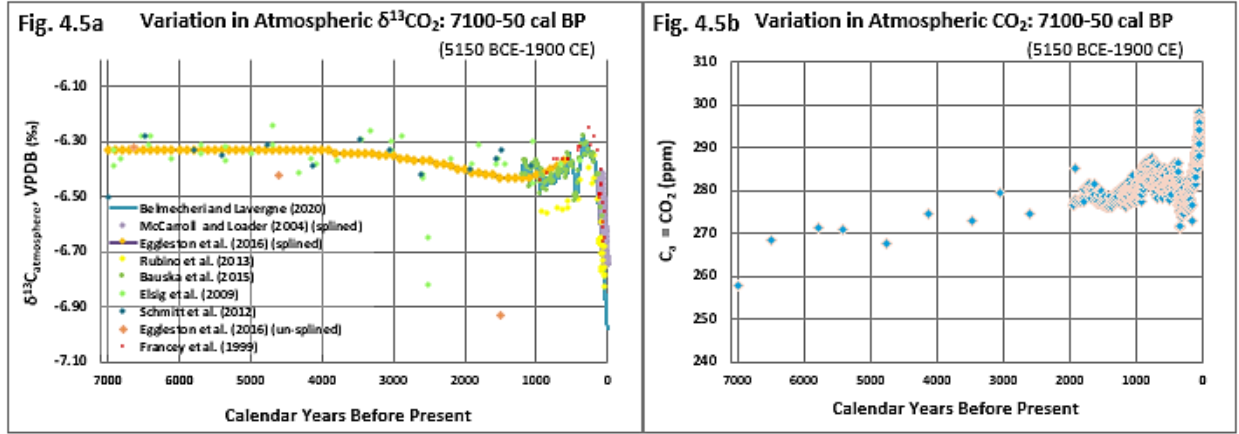


Figure 4.5a-b Variation in Atmospheric Carbon
Graphs show variation in atmospheric $\delta^{13}\text{C}$ (a; left) and CO_2 (b; right) over the last 7,000 years. **4.4a:** Graphical representation of atmospheric $\delta^{13}\text{C}$ from the period 7100–50 cal BP (5150 BCE–1900 CE) obtained from ice core data. Sources are listed in the text and within 4.4a graph legend. **4.4b:** Variation in CO_2 over the same time period showing relative stability prior to the Late Holocene. Points for c_a are from Belmecheri and Laverne (2020:supplementary Information).

4.3.4 Methods- Precipitation in Relation to Consumer and Plant $\Delta^{13}\text{C}$

I use Kohn's (2010) Equation (Eq.) 1 and Eq. 2 (here, Eq. 5 and Eq. 6), to predict expected outcomes of plant $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$ based on a modelled range of precipitation for the region. Equation 5 is written as:

$$\begin{aligned} \delta^{13}\text{C} (\text{‰}, \text{VPDB}) = & -10.29 + (1.90 * 10^{-4} * \text{Elevation (m. asl)}) \\ & - (5.61 * \log_{10}(\text{MAP} + 300, \text{mm/yr})) \\ & - (0.0124 * \text{Abs (latitude, } ^\circ)) \end{aligned} \quad 5.$$

where MAP is Mean Annual Precipitation, here substituted by average precipitation in mm over the period of tissue formation. Equation 5 is useful for predicting plant $\delta^{13}\text{C}$ over a range of

precipitation values, as it accounts for elevation and latitude effects on plant ^{13}C discrimination. However, Kohn (2010) suggests that the model is designed to account for modern plant $\delta^{13}\text{C}$, where $\delta^{13}\text{CO}_2$ is held at -8‰. When modelling predictions over a range of precipitation, this is not an issue. However, when working backwards from known $\delta^{13}\text{C}$ of paleobotanicals, or collagen or apatite values, the suggested equation is Eq. 6, which is written as:

$$\begin{aligned}\Delta^{13}\text{C} (\text{‰}, \text{VPDB}) = & 2.01 - (1.98 * 10^{-4} * \text{elevation (m, asl)}) \\ & + (5.88 * \log_{10}(\text{MAP} + 300, \text{mm/yr})) \\ & + (0.0129 * \text{Abs (latitude, °)})\end{aligned}\tag{6}$$

and solving for MAP after all offsets (diet-apatite, diet-collagen, or plant leaf-plant part) have been applied. For working with paleobotanical, or paleo- apatite or collagen values of $\delta^{13}\text{C}$, the $\delta^{13}\text{CO}_2$ needs to be estimated from the ice core datasets.

These equations (Eq. 5 and Eq. 6) are based on modern global observations of C_3 leaf values and MAP, plus elevation and latitude effects (Kohn 2010). However, seeds, nuts, and fruits typically do not have the same $\delta^{13}\text{C}$ values as leaves or wood, and some offsets are required for interpolation. When used with wood from an angiosperm, such as the oak wood, no offset was applied. However, some researchers suggest that to bring gymnosperm values closer to angiosperm values, an offset of about -2‰ is needed to make gymnosperm data comparable to that of the angiosperms experiencing the same conditions (Diefendorf et al. 2010; Hare and Lavergne 2021). However, this offset may not work in all instances or across all taxa within the gymnosperm clade. Some differences do exist among gymnosperms, such as those discussed by Shaw et al. (2005), where the juniper was found to be anisohydric compared to pinyon pine. This suggests that in nearly all comparable instances, pinyon pine exhibits lower $\Delta^{13}\text{C}$, which would

mean a greater offset would be needed to make its values comparable to the angiosperms under the same conditions.

Kohn's (2010) formulas also assume modern $\delta^{13}\text{CO}_2$ (aka $\delta^{13}C_a$), set to -8‰ when compiling data for creation of the models. According to Kohn's (2010a) regressions, elevation and latitude alone have only minor effects on plant $\delta^{13}\text{C}$, but MAP is a major predictor of discrimination values, and on its own explains about 59% of the global variation among C_3 plants across morphotypes. When all three variables are taken together, Kohn's (2010) formulas explain ~96% of the global variation among C_3 plants. The formulas are *possibly* useful for estimating MAP from $\delta^{13}\text{C}$ or $\Delta^{13}\text{C}$ of large sets of C_3 plants and paleobotanicals, or from smaller sets of herbivore apatite and collagen (after adjustments for diet offsets and $\delta^{13}C_a$), as the herbivore $\delta^{13}\text{C}$ values time-average plant $\delta^{13}\text{C}$ similar to the way in which climate models calculate MAP (usually over a decadal or longer period), to within ± 100 mm for low-precipitation regions (i.e., those with annual rainfall averaging less than 2,000 mm/year—like the western slope of the Sierra Nevada) (Kohn 2010). Likewise, it can be used to predict C_3 plant $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$ when MAP is modeled, and hence is useful for estimating consumer diet values after known diet-consumer tissue offsets are applied.

4.4 Results and Discussion

4.4.1 Tree rings, Precipitation, and Testing Kohn's (2010) Formulas

To test Kohn's regressions and develop preliminary expectations, I first calculated what the expected $\delta^{13}\text{C}$ should have been at CA-TUO-935 for the period 1960-2019 using Eq. 5 and historic precipitation from Oregon State University's PRISM database, which interpolates data from local weather stations at a resolution of 4 km to target location (PRISM Group 2023). This

period was chosen because Mean Annual Precipitation (MAP) is typically calculated based on 30-year increments. Thus, 60 years should properly characterize the historical precipitation variation (maximums, minimums, and average) experienced by the oak.

This is represented by Figure 4.6. Figure 4.6 does not account for variance in $\delta^{13}\text{CO}_2$, nor is it specific to tree growth patterns, but instead relies on total annual precipitation (purple line) and total Water Year precipitation (Oct. through Sept.) (blue line) to estimate extreme minimum values for plant $\delta^{13}\text{C}$. Water Year precipitation is the measurement used by the United States Geological Survey to estimate hydrological fluxes within ecosystems, used by water managers throughout California's Mediterranean climate. Figure 4.6 shows a 3.5‰ fluctuation between the wettest year (1983) and the driest year (2013) for the annual record, as noted on the graph. This suggests the most negative $\delta^{13}\text{C}$ values from the tree rings should fall within this range as it captures more precipitation than what is expected within the tree rings based on ring growth patterns. Because of the logarithmic scale of precipitation, a one-permil difference from the mean at TUO-935 equates to about 463mm, whereas the difference is less at lower values. The predicted average $\delta^{13}\text{C}$ for CA-TUO-935 over this period under both precipitation calculations is $-28.2\text{‰} \pm 0.7$, which is 0.3‰ below Kohn's (2010) estimate of the global average (-28.5‰). Overall, this implies that CA-TUO-935 is not far from the global average of MAP if the global average of $\delta^{13}\text{C}$ is -28.5‰ . However, these modelled minimums are estimates and do not consider the period of the growing season, high evaporation during summer due to California's Mediterranean climate, nor the soil water deficits it causes which make plant $\delta^{13}\text{C}$ less negative if the plant continues to grow during summer.

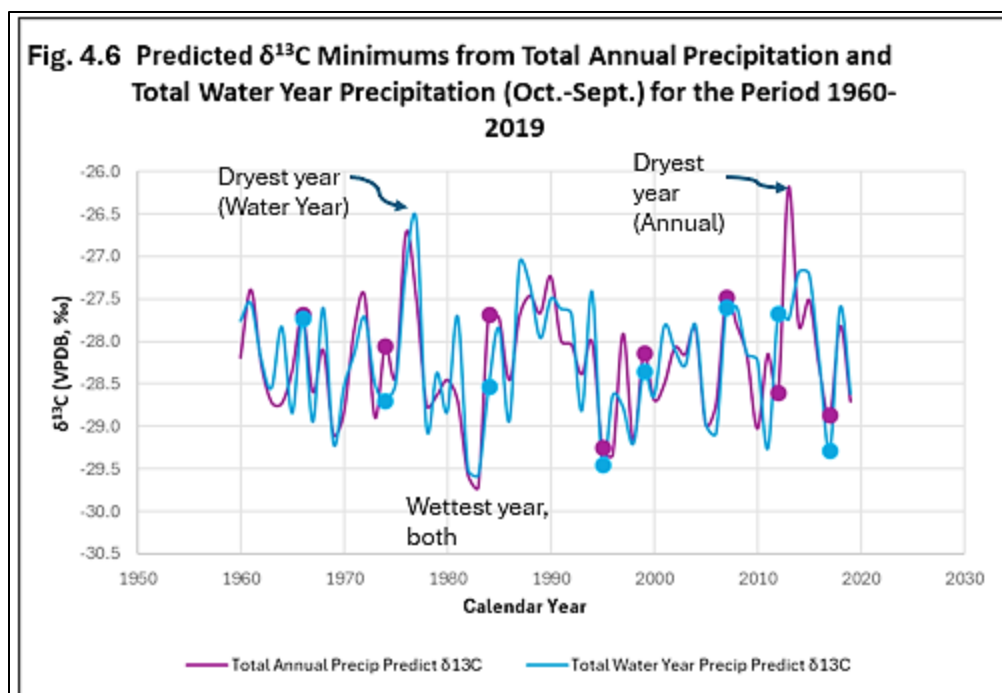


Figure 4.6 Predicted $\delta^{13}\text{C}$ Minimums from Total Annual Precipitation and Total Water Year Precipitation (Oct.–Sept.) for the Period 1960–2019
Graph shows the predicted minimum $\delta^{13}\text{C}$ for plants and the oak growing at CA-TUO-935 during the period 1960 to 2019. The $\delta^{13}\text{C}$ predictions were modelled from total precipitation for each year on an annual January–December basis (purple line) and from a Water Year basis (October–September; blue line) using monthly precipitation data downloaded from PRISM Group (2023) and applying Kohn’s (2010: Eq. 1; here listed as Eq. 5). The enlarged points on the lines represent modelled data representing the tree ring sample years. The driest and wettest years are indicted by text on the graph.

To investigate the possibility of reconstructing precipitation from paleobotanicals or herbivore $\Delta^{13}\text{C}$, I tested Eq. 6 (Kohn 2010: Eq. 2) using the tree ring isotope data shown in Table 4-3, and represented by Figure 4.7a-b. Table 4-3 shows the tree ring $\delta^{13}\text{C}$, $\Delta^{13}\text{C}$, iWUE, atmospheric $\delta^{13}\text{CO}_2$ and CO_2 —estimated from the ice core data sets in Belmecheri and Lavergne (2020: Supplementary Information), predicted precipitation from the tree rings (from Eq. 6), and the precipitation estimated for CA-TUO-935 from the data downloaded from PRISM Group (2023) and NCEI (2025) in relation to the tree ring years and tree ring sampling. The average tree ring $\delta^{13}\text{C}$ was $-26.0 \pm 1.03\text{‰}$, while for $\Delta^{13}\text{C}$ the average was $19.5 \pm 0.9\text{‰}$. Taken together, the average precipitation predicted over the lifespan of the tree is 622 mm. The average iWUE

was $65.3 \pm 11.6 \mu\text{mol mol}^{-1}$. This low average for iWUE indicates an anisohydric water management strategy of this oak.

Table 4-3 Tree Ring Results

Sample Number	Ring Year	Ring $\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{CO}_2$ (‰)	CO_2 (ppm)	Ring $\Delta^{13}\text{C}$ (‰)	Ring iWUE ($\mu\text{mol mol}^{-1}$)	Ring Predict Precip (Eq. 6) (mm)	PRISM Recorded Precip. (mm)	NCEI Recorded Precip. (mm)
1	1768	-26.58	-6.36	277.91	20.77	48	1064	n/a	n/a
2	1782	-25.33	-6.41	278.80	19.41	58	503	n/a	n/a
3	1793*	-25.66	-6.44	279.77	19.73	56	608	n/a	n/a
4	1801*	-26.29	-6.46	280.55	20.36	51	864	n/a	n/a
5	1820*	-26.00	-6.52	282.44	20.00	55	711	n/a	n/a
6	1828*	-25.91	-6.54	283.24	19.88	56	664	n/a	n/a
7	1839*	-25.72	-6.58	284.41	19.64	58	578	n/a	n/a
8	1849	-26.99	-6.61	285.97	20.95	48	1166	n/a	n/a
9	1859*	-25.10	-6.63	286.62	18.94	64	367	n/a	n/a
10	1875*	-25.68	-6.68	288.61	19.50	60	529	n/a	n/a
11	1887	-25.80	-6.71	291.97	19.59	60	561	n/a	n/a
12	1897	-24.10	-6.72	295.34	17.81	75	128	142	187
13	1907	-24.58	-6.80	298.58	18.23	72	205	170	204
14	1917	-24.58	-6.87	302.07	18.15	74	190	203	178
15	1927	-25.84	-6.86	305.52	19.49	63	526	442	434
16	1937	-25.63	-6.93	309.78	19.19	67	436	411	321
17	1947	-25.86	-6.98	310.94	19.38	65	493	447	362
18	1966*	-25.73	-7.25	320.27	18.97	71	374	318	276
19	1974*	-26.40	-7.40	329.88	19.51	68	534	562	459
20	1984*	-27.11	-7.70	343.75	19.96	67	692	694	672
21	1995*	-28.11	-7.92	359.75	20.77	62	1066	1105	967
22	1999*	-26.62	-8.06	367.41	19.07	81	402	433	370

Sample Number	Ring Year	Ring $\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{CO}_2$ (‰)	CO_2 (ppm)	Ring $\Delta^{13}\text{C}$ (‰)	Ring iWUE ($\mu\text{mol mol}^{-1}$)	Ring Predict Precip (Eq. 6) (mm)	PRISM Recorded Precip. (mm)	NCEI Recorded Precip. (mm)
23	2007	-25.69	-8.26	382.80	17.89	96	143	180	191
24	2012*	-26.83	-8.36	392.77	18.98	87	376	386	268
25	2017	-28.72	-8.51	405.13	20.81	69	1085	1117	1224

Note: Table shows the Sample Number, Ring Year, uncorrected $\delta^{13}\text{C}$ results from the tree ring samples, the atmospheric $\delta^{13}\text{CO}_2$, atmospheric CO_2 , $\Delta^{13}\text{C}$ of each ring sample, iWUE of each ring sample, predicted precipitation from Eq. 6 for each ring sample, and two recorded precipitation records (PRISM Group 2023; NCEI 2025) from which to compare. The table is organized by Ring Year, with the oldest year sampled listed first. The error range for the predicted precipitation is ± 100 mm. Years marked with an asterisk () represent years where more than one year's worth of tree ring growth was sampled, as indicated by Table 4-2, but the Year date provided (centroid) accounts for the majority of the wood product sampled. All tree ring samples were from the black oak from CA-TUO-935. Table is continued on next page. "Precip." means precipitation.*

For the period covered by Figure 4.7a-b, the average $\delta^{13}\text{C}$ is $-26.9 \pm 1.1\text{‰}$.

Comparatively, this average is 1.3‰ lower than what was predicted based on total precipitation estimates of what the average $\delta^{13}\text{C}$ *should* be (Figure 4.6). This suggests the tree ring samples do not reflect total precipitation for the year, and lends support to the notion that including which months each ring section represents is important. Again, the predicted precipitation record does not capture total annual precipitation, but instead reflects precipitation experienced by the oak only as the ring was growing. This reduces the average precipitation calculated for a given period, but is still informative for comparisons between or among periods on longer timescales. Accordingly, what the tree rings capture is a measure of growth period precipitation, which is useful for understanding periods that may have unusually low precipitation.

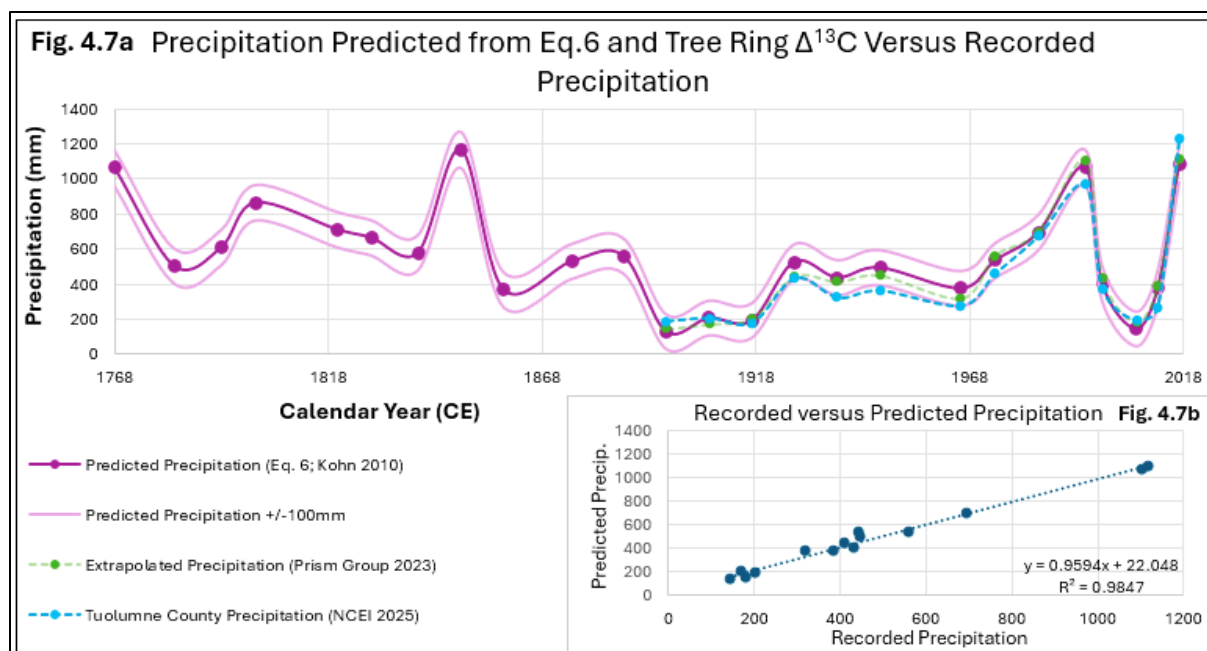


Figure 4.7a-b Precipitation Graphs

*Graphs show the precipitation (mm) predicted from the tree ring $\Delta^{13}\text{C}$ versus recorded precipitation. **a:** Graph shows the predicted precipitation (purple line and markers) from all tree ring $\Delta^{13}\text{C}$ results as compared to the recorded precipitation from NCEI (2025) for Tuolumne County (blue markers and dashed line), and the interpolated precipitation from PRISM Group (2023) (green markers and dashed line) for CA-TUO-935 from the period 1897-2017. Pink lines above and below the predicted precipitation are the error associated with Eq. 6. **b:** Inset graph shows the relationship and good agreement ($R^2 = 0.98$) between the recorded precipitation (PRISM Group 2023) and the predicted precipitation from the tree ring $\Delta^{13}\text{C}$ values for the historic to modern period; values for recorded precipitation (x) and predicted precipitation (y) were paired according to ring year, and this relationship is indicated by the linear trendline. Note: The predicted precipitation results (1768-2017) exceed the period of recorded precipitation (1897-2017). All precipitation measurements are in mm.*

In Figure 4.7a, actual precipitation (NCEI 2025; PRISM Group 2023) is shown against modeled precipitation based from the tree ring $\Delta^{13}\text{C}$ data over the entire period (1768 to 2017). Of note, the precipitation record for the region only stretches back to 1895, so the period of recorded precipitation is shorter than the modelled precipitation record. Importantly, Figure 4.7b illustrates the excellent agreement between predicted versus actual precipitation from the tree ring series ($R^2 = 0.98$). I obtained a Pearson's $r = 0.99$ between the predicted values and the PRISM Group (2023) data, and $r = 0.97$ between the predicted values and the NCEI (2025) data. However, because I was concerned with autocorrelation, which can frequently happen with time

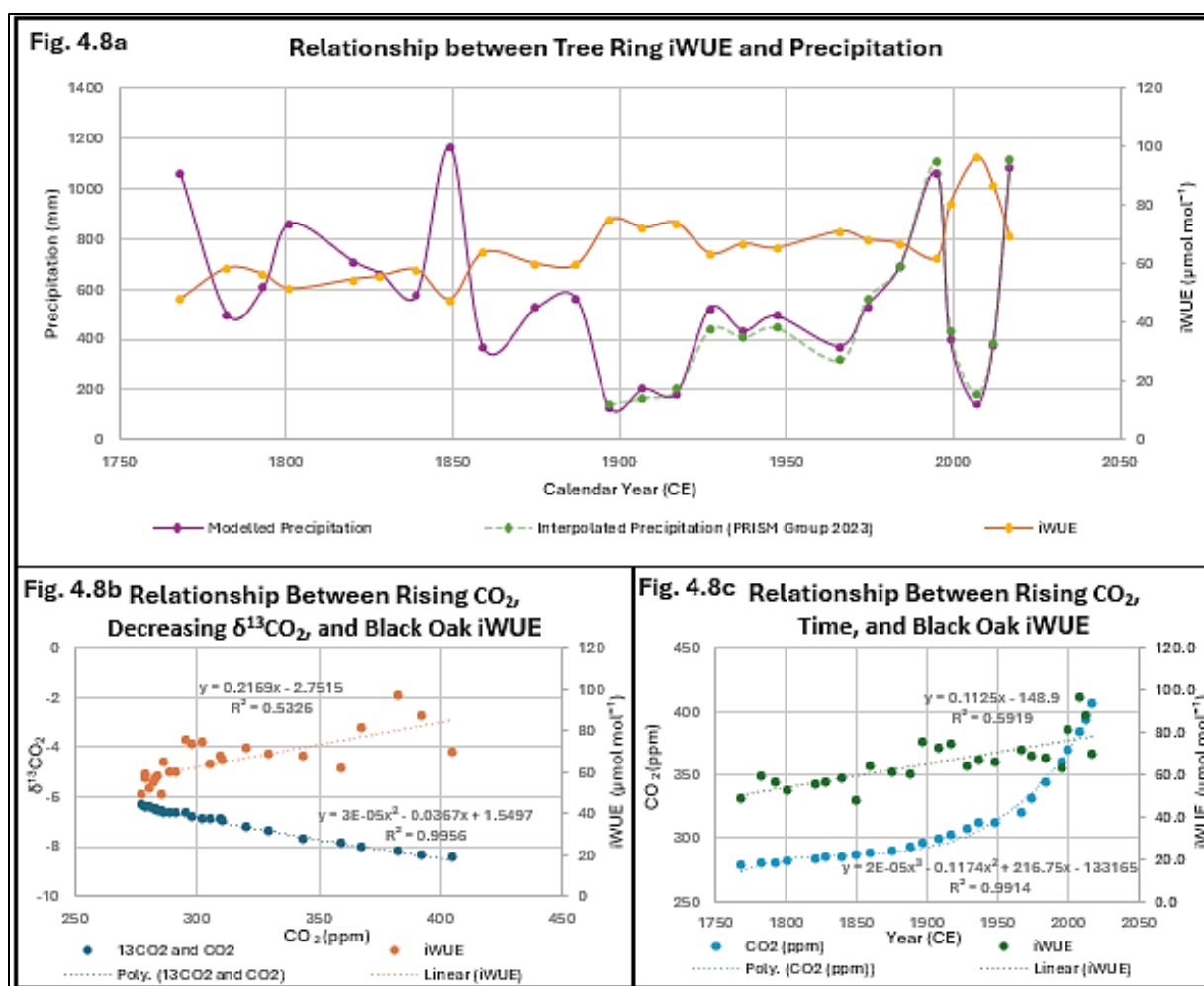
series, I next ran a Root Mean Square Error (RMSE) to examine how far from reality the predicted precipitation is, on average, which produced an error of 38.2 mm. Taking that into consideration, I then ran the Nash-Sutcliffe Efficiency Coefficient (NSE) (Nash and Sutcliffe 1970), which measures model performance and is frequently used in hydrology and paleoclimate studies (Cook and Kairiukstis 1990; Knutti and Sedláček 2013; Waseem et al. 2017). A measure of 0.5 to 1 would be considered good to excellent performance of a model. The NSE result was 0.98 relative to the interpolated precipitation (PRISM Group 2023), which strongly supports the idea that the transformation of the $\Delta^{13}\text{C}$ values to precipitation estimates for the growing period was highly successful. In short, the modelled precipitation explains 98% of the variance in observed values and performs extremely well, with residuals nearly negligible as compared to overall variability.

Most notable is Figure 4.7a-b shows proof of concept for using C_3 angiosperm paleobotanicals (and oak tree ring) $\Delta^{13}\text{C}$ to reconstruct precipitation when no historic records are available for the growth period of the plant. It also allows a much better understanding of how precipitation can drive plant $\Delta^{13}\text{C}$ values, which would be evident in consumer tissues of interest. This opens the possibility to using the regressions as Kohn (2010) intended—enabling us to estimate paleoprecipitation from the well preserved fossil remains of bones and teeth—something which I explore with the faunal bone collagen samples in Chapter 5: , and with human bone collagen samples in Chapter 6: .

Figures 4.8a-c examine the relationship between predicted precipitation, interpolated precipitation, $\delta^{13}\text{CO}_2$, CO_2 , and the resultant iWUE of the oak rings. Figure 4.8a indicates the oak's iWUE is inversely related to precipitation (both predicted and interpolated/recorded), as expected based on previous studies. Overall, when precipitation is high, iWUE is lower, and vice

versa. Also noticeable, iWUE seems to increase over time (Figure 4.8a, c), which is mostly a function of increasing atmospheric CO₂, as shown in Figure 4.8b. In this figure, the decreasing $\delta^{13}\text{CO}_2$ and increasing CO₂ (blue points) is shown in relation to the corresponding iWUE values (orange points) of the oak samples. This trend was also shown by Mathias and Thomas (2021), but on a global scale. In Figure 4.8b, the orange trendline shows the general pattern of increase, as some of the wiggle in iWUE is from precipitation. However, if the cluster at the left (Fig. 4.8b) is considered, it suggests that precipitation is not the only driver of $\Delta^{13}\text{C}$, as the trend of increase largely follows that of increasing CO₂. This is more clearly shown in Figure 4.8c, where the increase in CO₂ and iWUE are shown in relation to time. In this figure, iWUE shows a fractional increase in relation to the increase in CO₂.

There is no solid agreement on the long-term effects of increasing CO₂ on iWUE, and by default, *ci/ca*. Some argue that in the short term, plants will acclimate and adjust their physiology to optimize leaf gas exchange through stomatal control (Lammertsma et al. 2011), while at greater than decadal timescales, such as those examined here, others suggest plants evolve in response to changing CO₂ by adjusting stomatal size and density, and by regulating the rate of carbon fixation to maintain optimal set points (Beerling and Woodward 1995; Diefendorf et al. 2015; Ehleringer and Cerling 1995). As such, more researchers are turning to paleo-archives of fossil plant materials to gain a better understanding of plant reactions to increasing CO₂.



Figures 4.8a-c Relationship Among the Tree-ring iWUE, Precipitation, and Decreasing Atmospheric $\delta^{13}\text{CO}_2$ and Increasing Atmospheric CO_2 .

a: Graph shows the relationship between the iWUE of the oak rings (orange markers and lines) and the predicted precipitation from the tree rings (purple line and markers) and interpolated precipitation from PRISM Group (2023) (green markers and dashed line) for the period 1768-2017. **b:** Graph shows the relationship among increasing CO_2 and decreasing $\delta^{13}\text{CO}_2$ (blue markers/trendline), and tree-ring iWUE (orange markers/trendline); as CO_2 increases and $\delta^{13}\text{CO}_2$ decreases, iWUE increases but is still influenced by other environmental factors (e.g., precipitation). **c:** graph shows the relationship between rising CO_2 (blue markers/trendline) and iWUE (green markers/trendline) over time; trendlines indicate the general fractional increase of iWUE in relation to rising CO_2 through time. In Figure 4.8a-c, iWUE is shown on the secondary y axis.

4.4.2 Results and Discussion: Paleobotanicals

Summarized results of the $\delta^{13}\text{C}$ analyses and $\Delta^{13}\text{C}$ of the paleobotanicals from the six sites are shown in Table 4-4 and Figure 4.9. Individual results are detailed in Appendix A. For the calculation of $\Delta^{13}\text{C}$ values, I used the average $\delta^{13}\text{CO}_2$ from the 6,900 years of the occupation

record (7000–100 cal BP), which was -6.4‰. Table 4-4 is organized by plant clade, then taxa/group and details the range, mean, standard deviation for both $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$, and number of samples, for each row. In general, the paleobotanical samples from this study show that the average $\delta^{13}\text{C}$ for the region is less negative than the modern global average by 4.7‰. However, as cautioned earlier, the paleobotanical $\delta^{13}\text{C}$ results are not directly comparable to modern values, which is why $\Delta^{13}\text{C}$ values are provided. Using Kohn's (2010) average $\delta^{13}\text{C}$ for C_3 plants (-28.5‰) and $\delta^{13}\text{CO}_2$ set at -8‰, by doing the conversion, the modern average $\Delta^{13}\text{C}$ for C_3 plants is 21.1‰ which is 3.2‰ higher than the paleobotanical average presented here for the west-central Sierra Nevada. If the gymnosperms are left out of the average, and the remaining taxa compared to the global average, the difference is still 1.8‰ below the global average. This indicates that terrestrial-based consumer $\delta^{13}\text{C}$ values for this region should also be less negative, or lower in the case of $\Delta^{13}\text{C}$, compared to the global estimates for C_3 consumers, whether they are omnivorous humans, herbivores, or carnivores.

Table 4-4 Summary Results for Paleobotanical Samples

Plant Clade	Plant Taxon/Group	$\delta^{13}\text{C}$ (‰) Range (min-max)	$\delta^{13}\text{C}$ (‰) (mean $\pm$ SD)	$\Delta^{13}\text{C}$ (‰) Range (min-max)	$\Delta^{13}\text{C}$ (‰) (mean $\pm$ SD)	# of Samples
Gymnosperm	Gray Pine	-23.8 to -20.4	-21.8 $\pm$ 1.0	14.3 to 17.8	15.7 $\pm$ 1.0	21
Gymnosperm	Sugar Pine	-23.5 to -21.9	-22.7 $\pm$ 0.6	15.8 to 17.5	16.6 $\pm$ 0.7	5
Gymnosperm	All gymnosperm	-23.8 to -20.4	-21.9 $\pm$ 1.0	14.3 to 17.8	15.9 $\pm$ 1.0	26
Angiosperm	Oaks/Acorns	-27.6 to -22.4	-24.8 $\pm$ 1.4	16.3 to 21.8	18.9 $\pm$ 1.5	21
Angiosperm	Manzanita	-28.7 to -24.3	-25.9 $\pm$ 1.4	18.3 to 23.0	20.1 $\pm$ 1.5	11
Angiosperm	C_3 Grasses	-26.2 to -23.9	-25.4 $\pm$ 1.3	17.9 to 20.3	19.5 $\pm$ 1.4	3
Angiosperm	All angiosperm	-28.7 to -22.4	-25.2 $\pm$ 1.5	16.3 to 23.0	19.3 $\pm$ 1.5	35
Both (G and A)	All C_3 Taxa	-28.7 to -20.4	-23.8 $\pm$ 2.1	14.3 to 23.0	17.9 $\pm$ 2.2	61

Note: table is organized by plant clade (Gymnosperm or Angiosperm), then by plant taxon/group and shows the summary results (range, mean $\pm$ standard deviation) for both $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$, as well as the number of samples. Color-coding is used as decoration, but does highlight the indicated relationship among the data. “G” refers to Gymnosperms; “A” refers to Angiosperms. “SD” is standard deviation.

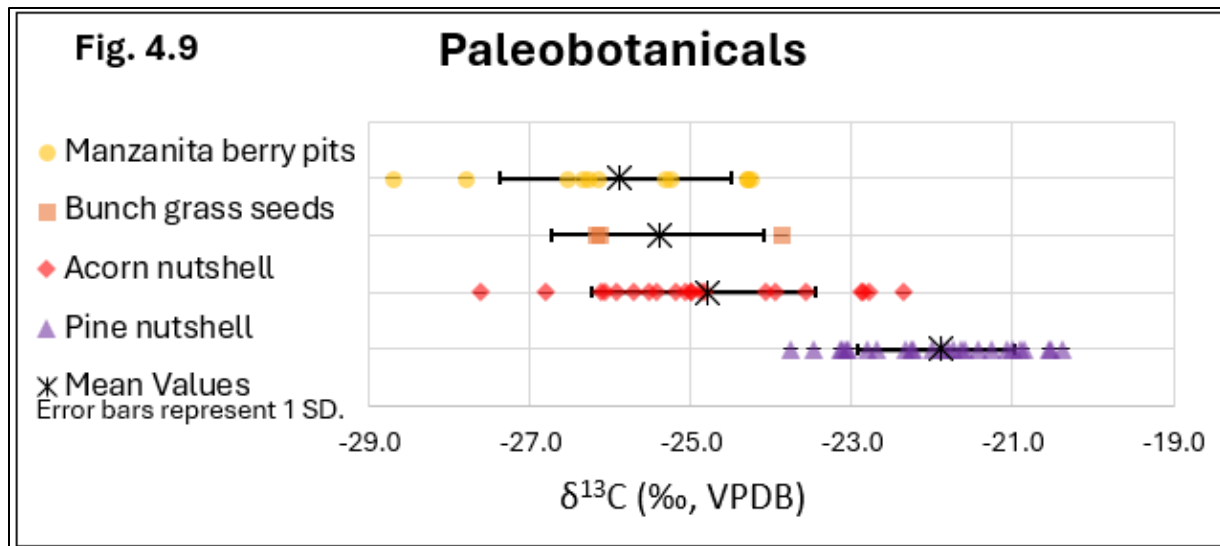


Figure 4.9 Paleobotanicals

Figure represents the data summarized in Table 4-4, but shows the individual results as points. The graph shows the uncorrected $\delta^{13}\text{C}$ results of the paleobotanical isotopic analyses where samples are organized by taxa. Here, samples are arranged by mean, with the taxa showing the most negative values at the top, while the least negative values are represented by the pines at the bottom. Mean values are marked by an asterisk, and black bars represent the error range of one standard deviation within each taxa group. Taxa are color-coded, but different marker shapes also help identify taxa within the graph, and the key matches the position of the taxa on the graph. Manzanita is shown in yellow circles (top), bunch grass seeds are orange squares (top of middle), acorn nutshell is indicated by red diamonds (bottom of middle), and the pines are represented by purple triangles at the bottom.

As is also visible in Table 4-4, the gymnosperms are consistently less negative than the angiosperms, and the range of variation across and within taxa is large. In Figure 4.9, clearly visible are the range of $\delta^{13}\text{C}$ values among the sample taxa, where the taxa are represented by different colors and symbols, taxa means are represented by asterisks, and black bars show one standard deviation for each taxon/group. Because the gray pine and sugar pine samples overlap, they are represented by a single color and symbol. Visible within the graph is how large the range of variation is among the acorn samples, which overlap at the bottom end of the range of the pine nutshell samples. A possible explanation for this is that the oaks exhibit greater flexibility in the point at which they close their stomata, which theoretically should lead to a larger range of $\delta^{13}\text{C}$, as compared to plant taxa with a more conservative water management

strategy, or less flexibility and tighter stomatal control, such as is possible with the two species of pines. The manzanita berry pits exhibit the lowest mean values in $\delta^{13}\text{C}$, meaning the highest mean values of $\Delta^{13}\text{C}$ as shown in Table 4-4 (above). Their range of variation is similar to that of the oaks, which may suggest a similar water management strategy.

Somewhat surprising is the range of variation in $\delta^{13}\text{C}$ of the grass taxa, with the *Bromus* as an outlier (-23.9‰) to the right of the graph (Figure 4.9). Since these grass taxa all grow during the same winter–spring season, environmental differences between growing years is a possible explanation for the large variance. However, as discussed in the expectations, Beerling and Woodward (1995) also found that their *Bromus* samples had less negative values when compared to other C_3 grasses, which may indicate that, in terms of the perennial bunchgrasses, *Poa* and *Bromus* have differing water management strategies and *Bromus* may be isohydric. However, as the sample size here is small, the most that can be said is among the samples here, there appears to be a difference (~2.3‰). That difference could be an artifact of a good precipitation year versus a poor one, animal damage to the *Bromus*, differences in charring temperatures and Maillard reactions, or something more inherent within the taxa. As for the $\delta^{13}\text{C}$ of *Festuca* (-26.2‰), it is most similar to the *Poa* sample (-26.1‰), and falls at the lower end of the range within the angiosperms.

The pine nutshell, as gymnosperm samples, largely conform to expectations. In Figure 4.9, they exhibit a great deal of overlap at their low end with the acorns, but their lowest value is comparable to the highest value among the acorns, and even among the black oak tree rings (Table 4-3). Comparatively, the pine nutshell mean $\delta^{13}\text{C}$ is 2.9‰ higher (less negative) than the acorn nutshell, 3.5‰ higher than the C_3 grasses, and 4‰ higher than the manzanita (Table 4-4; Figure 4.9). This suggests that any regular inclusion of pine nuts in the diets of indigenous

people, or animals, from this region would move consumer $\delta^{13}\text{C}$ values higher (less negative) than might be expected if dietary habits were unknown or if reliance on angiosperm plants was overestimated. Without knowing about this effect, researchers might question whether there were marine or C_4 plants contributions to the diet.

The boxplots in Figure 4.10 (below) detail the range of iWUE among the different taxa, where each taxa color is along a gradient representing high to low iWUE; as well, the legend entry order represents the same relationship from left to right. While rooting depth, leaf morphology, and taxa vary among samples here, the iWUE results indicate contrasting water management strategies mainly among the pines (gymnosperms) as compared to the other sampled taxa (angiosperms) (Figure 4.10). The pines exhibit consistently higher iWUE compared to the rest of the samples and despite site locations, as expected based on the literature review. This means these two gymnosperms, gray pine and sugar pine, fall within the isohydric range and regulate their stomatal aperture regardless of daytime soil moisture content, temperature, and humidity within this environment. Also in Figure 4.10, the acorn nutshell, representing the oaks, shows a comparable isotopic range to the evergreen manzanita berry pits, which may indicate that these two morphotypes (tree vs shrub) share a similar water-management strategy in regard to stomatal conductance, as suggested earlier. The oaks and manzanita are considered anisohydric relative to the gymnosperms which are isohydric. Last, the bunchgrass seeds also show a wide range of values, despite the small sample size ($n=3$), but are comparable in mean values to the other angiosperms as they fall in-between acorn and manzanita (Figure 4.10). Taken together, and considering these samples are spread amongst so many sites and are random samples that likely did not grow at the same time (calendar year), these results indicate that beyond environmental circumstances, plant phylogeny and, more likely genetic controls,

constrain the range of iWUE beyond simple morphological types, which translates to differences in $\Delta^{13}\text{C}$ among C_3 plants. These differences then contribute to baseline expectations for natural foodwebs, as is shown here.

Importantly, some of the acorn samples and some of the pine nutshell show indications of drought stress, due to the elevated iWUE (Figure 4.10). This has implications for environmental circumstances and human behavior. Humans are likely to only choose to harvest nuts from trees that are droughted if there is no other choice, as droughted trees reduce their productivity and produce fewer nuts, especially in consecutive years of drought (Sperling et al. 2023). Hence, some of these acorn and pine nutshell samples were harvested by humans during a period of drought that was not localized to the trees in question. These samples are few in number, and were only noticed from higher-than-average iWUE within the taxa comparisons. No other samples indicated signs of drought stress, except perhaps the single *Bromus* sample, but this taxon is possibly isohydric which would be indicated by elevated iWUE and hence $\Delta^{13}\text{C}$, as discussed below.

Figure 4.11, below, shows the range of $\Delta^{13}\text{C}$ and iWUE between the angiosperm and gymnosperm samples at premodern and modern levels of $\delta^{13}\text{CO}_2$ (-6.4‰, and -8‰, respectively) and CO_2 (280.5ppm, and 407ppm, respectively). There is some degree of overlap between the two plant clades, as expected due to varied environmental influences, plus physical and molecular constraints on photosynthetic rates, water uptake, and the possibly of shared genetic controls among C_3 plants. Figure 4.11 also indicates that the gymnosperm samples (square blue markers; both pine taxa) have higher iWUE than *most* of the angiosperm samples (circular green markers). Also pointed out by the arrows along the axes in Figure 4.11 are how water stress, atmospheric $\delta^{13}\text{C}$, daytime respiration, iso/anisohydric water management

strategies, and total atmospheric carbon dioxide (ppm) relate to measures of C_3 plant $\Delta^{13}C$ and $iWUE$. Increased total atmospheric carbon tends to shift $iWUE$ higher, as is visible within modern samples, and replicated here by the archaeological samples (circular turquoise, and square purple markers within Figure 4.11) manipulated to account for modern $\delta^{13}CO_2$ ($\delta^{13}C_a$) of -8‰, and total atmospheric carbon dioxide of 407 ppm (c_a). This manipulation has shifted the samples down and to the right. However, this shift can occur without affecting the plant's water management strategy or daytime respiration if water availability and photosynthetic rate do not change or are held constant (Farquhar et al. 1982, 1989). Figure 4.11 also illustrates why modern plant samples require a $\delta^{13}C$ correction of ~1.5–2‰ to be comparable to archaeological samples (i.e., the Suess effect).

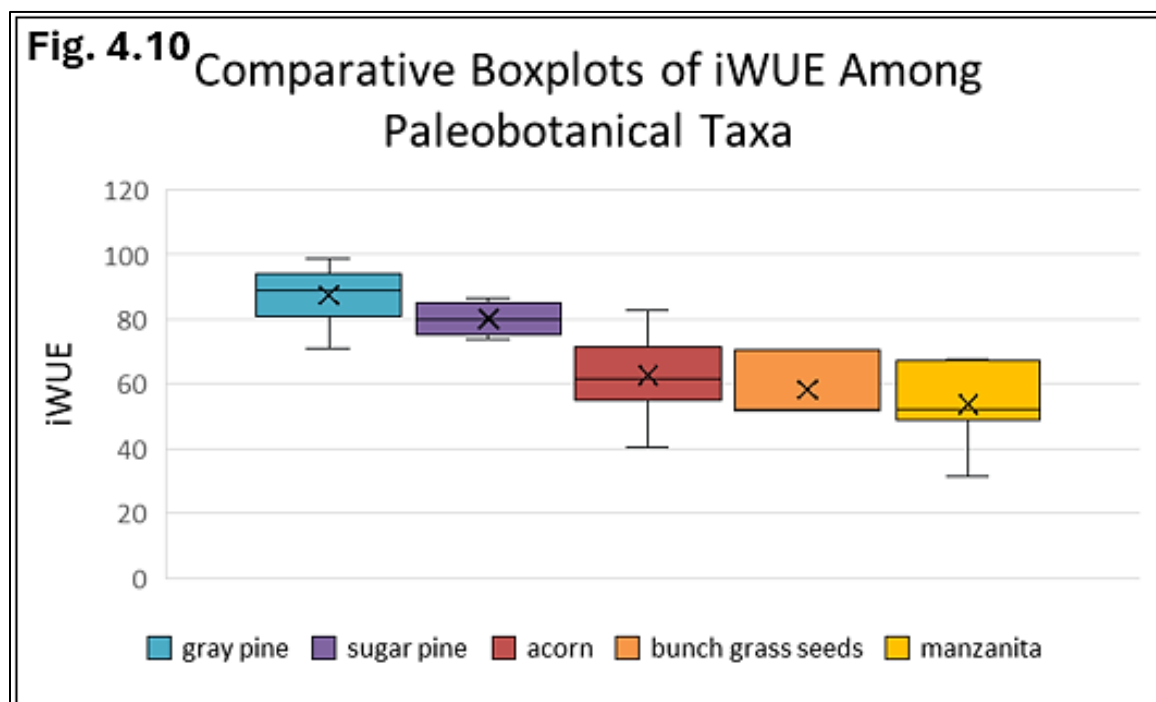


Figure 4.10 Comparative Boxplots of $iWUE$ Among Paleobotanical Taxa
 Graph shows that gray pine have the highest, while manzanita samples had the lowest. $iWUE$. Taxa colors represent a gradient from high (blue) to low (yellow) $iWUE$; scalar positioning is also used to show this relationship, where gray pine is at the top, and manzanita is at the bottom and has the lowest $iWUE$ among the paleobotanical samples. The position in the graph legend also represents the same relationship as the color coding and scalar positioning, where gray pine is on the left, and manzanita is on the right.

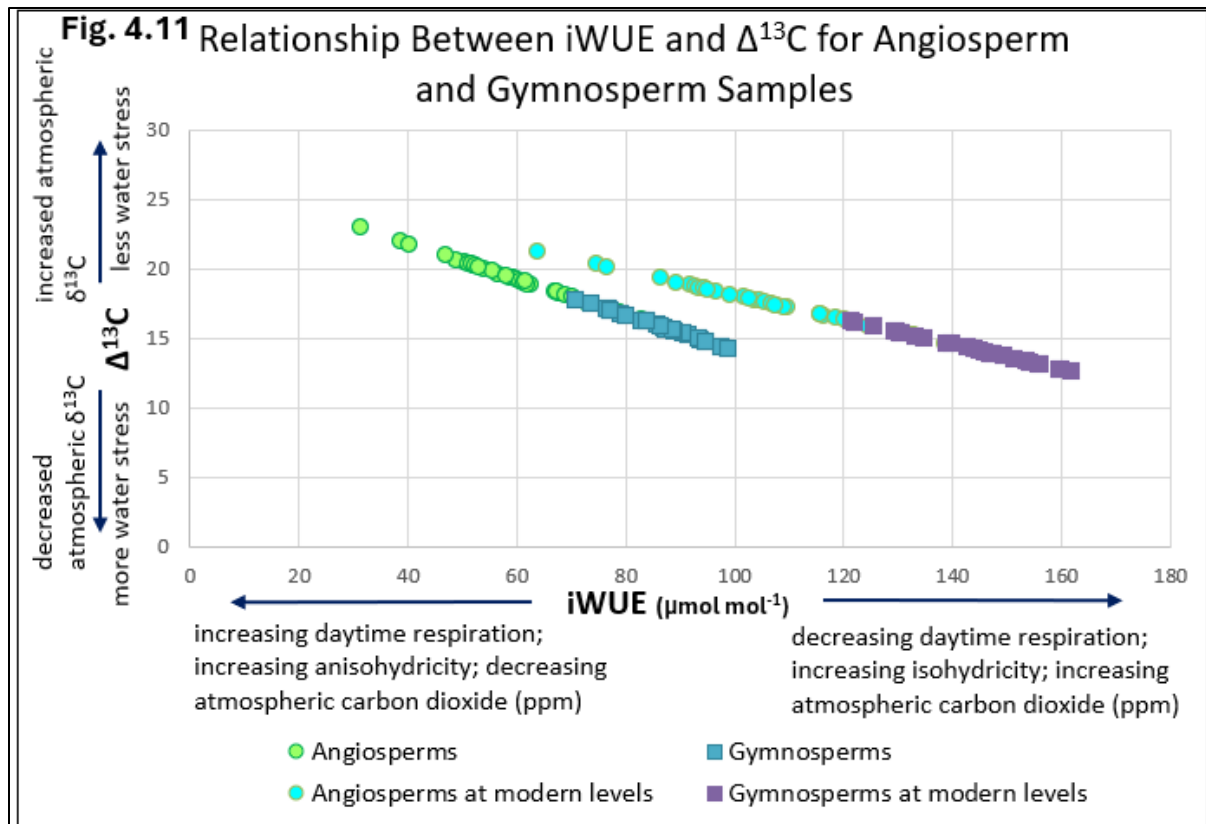


Figure 4.11 Relationship Between iWUE and $\Delta^{13}\text{C}$ for Angiosperm and Gymnosperm Samples
Figure shows the relationship between iWUE and $\Delta^{13}\text{C}$ among the angiosperm (green/turquoise circles) and gymnosperm (blue/purple squares) samples at premodern (green to blue; left) versus modern (turquoise to purple; right) levels of $\delta^{13}\text{CO}_2$ and CO_2 . Text next to each axis explains plant physiological responses and environmental parameters that shift iWUE and $\Delta^{13}\text{C}$.

Overall, the range of values, and the difference among averages between the two plant clades for $\Delta^{13}\text{C}$ and iWUE can be taken as an indication that beyond the physical leaf differences, and those in the seeds, these two clades have different water management strategies that will affect consumer values. In further analyses (within this chapter and the following chapters) I treat these two clades separately rather than lumping them into one single C_3 plant category for modelling consumer values. The two clades serve as the baselines.

4.4.3 Results and Discussion: Paleoprecipitation from Paleobotanicals

Returning to the idea of using paleobotanical samples to model pre-modern precipitation, the question arises what the scale of the model should be? If paleobotanical samples are not

directly dated, and samples come from mixed deposits, such as in this case, what can be said about the time frame? Inherent within this question are considerations of what the growing seasons and lengths are of the samples under consideration. Because of these questions, I chose to model the precipitation as an absolute average from all of the angiosperms from the all the study sites as a *gross* basic estimate of premodern average growing season precipitation for the period of occupation covered by the study sites (7,000-100 cal BP). I found that applying a $\delta^{13}\text{C}$ offset of -2‰ (as suggested in the literature review) was not enough to shift the pine values to be comparable to those of the angiosperms. Because the gymnosperms are clearly different from the angiosperms, they were excluded from the precipitation estimation. However, to make the gymnosperm paleobotanical samples more similar to the angiosperms, a $\delta^{13}\text{C}$ offset of -3.3‰ could be applied. This would make the means of angiosperms and gymnosperms equivalent.

The average presented here is an average estimate of paleo-precipitation. It is based from the mean $\Delta^{13}\text{C} \pm 1\text{SD}$ for all angiosperms, as this was the recommended procedure (Kohn 2010). This range was then applied to four locational points across the geographic landscape, representing the shape of a trapezoid that encompasses all of the archaeological sites, as shown in Figure 4.12. In this figure, the paleobotanical sites (orange markers) are encompassed within the polygon, and the two white markers (also encompassed within the polygon) represent New Melones Reservoir and New Don Pedro Reservoir. Latitude (decimal degrees north) and elevation (m asl) for the four corner points were estimated from Google Earth satellite and geospatial information and applied in Eq. 6. This information is represented in Table 4-5, along with the average estimated growing season precipitation for each of these locations, and an average estimate of precipitation and total area for the region encompassed by the polygon.

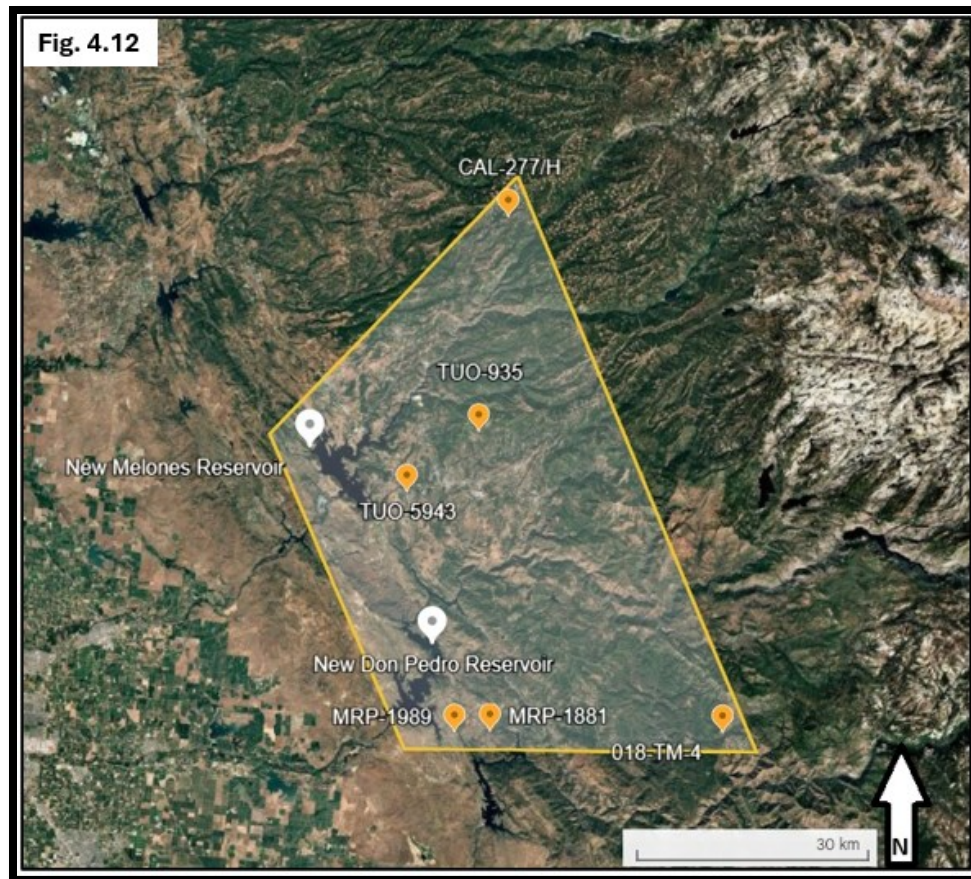


Figure 4.12 Polygon Map
 Map shows the polygon outlining the area used to estimate location and average growing season precipitation from the paleobotanical samples for the period 7000- 100 cal BP. The archaeological sites from which the paleobotanicals came are encompassed within the polygon and represented by orange markers. White markers represent two landmarks. Scale was set to 30 km.

Because human transport and culinary decisions shaped the final destination of these samples, I treat these samples as if they could have come from anywhere on this landscape. In the estimates presented in Table 4.5, precipitation increases from south to north to and with elevation. The average growing season precipitation for the period 7000–100 cal BP is estimated to be around 467 ± 100 mm for the area encompassed by the polygon. The error range is the same as that associated with the formula, rather than the standard deviation of the sample estimates. Because the samples include acorn nutshell, manzanita berry pits, and grass seeds—

plant parts that differ in sample size, formation time, and seasonality—they likely reflect precipitation from spring through early fall more strongly than winter precipitation.

Table 4-5 Predicted Average Growing Season Precipitation Across the West-Central Sierra Nevada (7000-100 cal BP)

Polygon Corner	Elevation (masl)	Latitude (DDN)	Predicted Precipitation (mm)
Northeast Corner	1399.6	38.330	501
Northwest Corner	449.8	38.011	445
Southwest Corner	303.3	37.665	438
Southeast Corner	1065.1	37.697	483
Total Polygon Area	2555.52 km²	Predicted Average Precipitation	467 ± 30 mm

Note: table details the corner points of the polygon shown in Figure 4.12, and gives the elevation of each point in meters above sea level, and latitude (shown as decimal degrees north). Each polygon corner has predicted precipitation associated with it, as based from the angiosperm paleobotanical remains and the locational data presented here. The last row of the table is a summary of the total area covered by the polygon, as well as the average predicted precipitation associated with the polygon. “masl” means meters above sea level; “DDN” means Decimal Degrees North; “mm” means millimeters.

Although precipitation can be estimated from single sites using a handful of paleobotanicals that are dated (Kohn 2010), in this sample set, none were dated directly and many sites only had representation of acorns and pine nutshell (the latter I excluded because of the difference in water-management strategies). Plus, because Indigenous people harvested these samples, the area of deposition was not necessarily directly connected to where the samples originated, as we can assume they were transported over some distance, even if that distance was small. Averaging the $\Delta^{13}\text{C}$ plant values together also serves to reduce stochasticity that may be introduced by differing seasonal growth patterns, and helps reduce noise created by these differences. Averaging in this manner does mask differences related to drought or pluvial periods, which may be of interest to future researchers who have well-dated materials. Estimating precipitation from among the same type of taxa is informative, and comparing taxa in this way could lead to deeper insights into seasonal variability within past climate regimes,

especially in the case where samples are associated with well constrained dates, or could indicate changing diet breadth, or the species humans targeted, during wet and/or dry periods.

The next question I sought to answer was how the estimated precipitation ($467 \pm 100\text{mm}$) compares to the historic average? The interpolated precipitation data (PRISM Group 2023) for the period 1895 to 2019 suggests that “growing season” precipitation (spring through early fall/ March through October) at CA-TUO-935 averaged about $419 \pm 185\text{mm}$. These two averages are close, within a single standard deviation of one another. Given the time frame covered by the paleobotanicals, and the fact that the historic precipitation data is centered on TUO-935, the average precipitation estimate represented by the paleobotanicals is plausible.

Globally, as Fardusi et al. (2016) suggest, plants in mediterranean environments are much more water-limited than they are energy limited (photosynthesis-limited by the amount of sunlight reaching the plant), hence precipitation is the main driver of C_3 plant $\Delta^{13}\text{C}$ within these environments. So, while the paleobotanicals within this study do not capture total annual precipitation estimates, there is reason to believe that growing season precipitation is the main driver of $\Delta^{13}\text{C}$ variation analyzed here. If total annual precipitation were modelled from plant $\Delta^{13}\text{C}$ from this environment, the targeted species would need to have a growth pattern that persists through winter, or one that is endemic to only winter and spring, and the wood or leaves instead of the nutshell or seeds would be better choices for analysis. In sum, growing season precipitation can be modelled from the $\Delta^{13}\text{C}$ of C_3 paleobotanicals when precipitation is expected to be the main driver of plant physiological processes. This latter implies that such a strategy works for Mediterranean, desert, plain, and steppe environments, but likely not densely forested or northern/southern boreal environments or dense jungles, where light is more of a limiting resource.

4.4.4 Results and Discussion: Creating an Isotopic Baseline

Using the paleobotanical samples, and focusing mainly on the two clades gymnosperm and angiosperm, I modelled $\delta^{13}\text{C}$ forward to create a baseline for estimating consumer diets. This will be used in the next two chapters to examine faunal and human diets in the study region.

The offset between collagen $\delta^{13}\text{C}$ and bulk diet $\delta^{13}\text{C}$ for mammalian herbivores has been estimated to be between +3-5‰ (Koch 2007). I used the average of +4‰ and applied this to the values represented by one to four standard deviations from the mean for each plant clade. Because I am modelling bone collagen values, the majority of the carbon (75%) is routed directly from dietary protein (Ambrose and Norr 1993; Fernandes et al. 2012, 2014; Froehle et al. 2010; Howland et al. 2003; Jim et al. 2004; Somerville et al. 2018; Tieszen and Fagre 1993), which the paleobotanical samples in this study would represent in the case of herbivores.

The results are shown in Table 4-6. Because the paleobotanicals are a sample set of all C_3 plants—which follow a normal distribution in $\delta^{13}\text{C}$ (Diefendorf et al. 2010; Kohn 2010b)—and herbivores are reliant on plants as their main energy source, collagen $\delta^{13}\text{C}$ should also follow a normal distribution. As such, I modelled all results under the assumption of a normal distribution. I calculated Z-scores and the corresponding probability density functions (PDFs) for each of the predicted values (Table 4-6, bottom). This table can be used as a reference for this region for pre-modern periods only. If this table were to be used for modern herbivore predictions, $\delta^{13}\text{CO}_2$ should be set at $\sim -8\text{‰}$, whereas in Table 4-4 it was set at -6.4‰ . Predicted $\Delta^{13}\text{C}$ could then be modelled forward while accounting for modern $\delta^{13}\text{CO}_2$.

Table 4-6 Modelled Estimates of Herbivore Collagen $\delta^{13}\text{C}$ from Paleobotanicals

Plant Clade/Diet	-4 SD	-3 SD	-2 SD	-1 SD	(0 SD)	+1 SD	+2 SD	+3 SD	+4 SD
Angiosperm (SD = $\pm 1.46\text{‰}$)	-31.04	-29.58	-28.12	-26.66	-25.2	-23.74	-22.28	-20.82	-19.36
Angiosperm diet offset = +4‰	-27.04	-25.58	-24.12	-22.66	-21.2	-19.74	-18.28	-16.82	-15.36
Gymnosperm (SD = $\pm 0.98\text{‰}$)	-25.82	-24.84	-23.86	-22.88	-21.9	-20.92	-19.94	-18.96	-17.98
Gymnosperm diet offset = +4‰	-21.82	-20.84	-19.86	-18.88	-17.9	-16.92	-15.94	-14.96	-13.98
Z-score	-4	-3	-2	-1	0	1	2	3	4
Angiosperm Diet Probability Density Function (PDF)	9.17E-05	0.003	0.037	0.166	0.273	0.166	0.037	0.003	9.17E-05
Gymnosperm Diet Probability Density Function (PDF)	1.37E-04	0.005	0.055	0.247	0.407	0.247	0.055	0.005	1.37E-04

Note: table shows the plant clade/diet (angiosperm or gymnosperm) along with associated standard deviations (SD) and diet offsets used from normal distributions of angiosperm and gymnosperm plant $\delta^{13}\text{C}$. Angiosperms and associated modelled values and statistical treatment are in green, while gymnosperm related information and values are in blue. Table above double border (top) shows the plant clade and plant values (average and standard deviations) and modelled herbivore collagen $\delta^{13}\text{C}$, while bottom table (below double border) shows associated Z-scores and probability densities for herbivore values under the assumptions of a normal curve for both diet curves. All stable isotope notations are in permille (‰), while pdf values are shown as normal numbers, except at -4 and 4 Z-score, which are shown in scientific notation.

The modelled herbivore $\delta^{13}\text{C}$ values are plotted against their associated probability densities in Figure 4.13 as they are shown in Table 4-6 (above). The standard deviations I used in Table 4-6 are rounded to the hundredth place, whereas in Table 4-4 they were typically rounded up to the nearest tenth. Precision beyond this point is spurious. However, these *slightly* different standard deviations (rounded to the nearest hundredth) made calculating the probability density for the area shared in common between the angiosperm and gymnosperm consumers (herbivores) more straightforward and accurate as it moved the angiosperm consumers closer to 0.0000098% probability in the right-hand tail at four standard deviations, making the calculation for the second intercept of the curves negligible. In Figure 4.13 (below), the angiosperm-consuming

herbivore area is represented in light green, the gymnosperm-consuming herbivore area is light blue, and the overlap between the two curves is purple. Means of the two curves are represented by dashed lines, the intersect point of the two curves is the purple solid line.

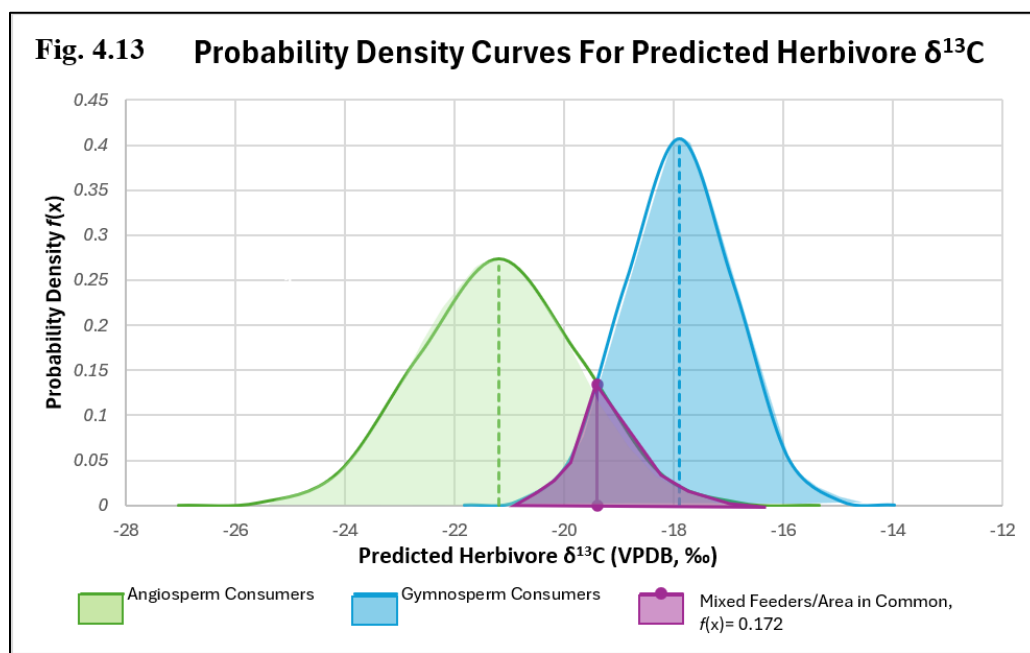


Figure 4.13 Probability Density Curves for Predicted Herbivore $\delta^{13}\text{C}$
Figure shows the two modelled ranges of herbivore collagen $\delta^{13}\text{C}$ based from the two plant clades, and the associated probability densities representing the likelihoods of values representing a diet based on angiosperms (green shaded area and curve), gymnosperms (blue shaded area and curve), or a mix of the two (area of overlap in purple). The means for the different curves are represented by dashed lines (green for angiosperm consumer average, blue for gymnosperm consumer average), while the intersection of the two curves is marked with a solid purple line and points.

In Table 4-6 and Figure 4.13, the modelled $\delta^{13}\text{C}$ for angiosperm-consuming herbivores ranges between -25.6 and -16.8‰ at three standard deviations (SD). For gymnosperm-consuming herbivores at three SDs, modelled $\delta^{13}\text{C}$ values are between -20.8 and almost -15‰. Herbivore $\delta^{13}\text{C}$ more negative than -19.86‰ are most likely to represent a predominantly angiosperm-based diet, while values above (less negative than) -18.28‰ are more likely to represent a much greater dietary contribution from gymnosperms.

Perhaps most interesting is the area of overlap (Figure 4.13; purple) of the angiosperm-gymnosperm consumers. The probability density represented by this area is 0.172—meaning they have about 17.2% of values in common—and the intersection is marked with a purple line at $\delta^{13}\text{C} = -19.4$. This purple shaded area is interpreted as the range of values expected of herbivores who: 1) rely on a mix of angiosperm and gymnosperm resources as food; 2) are consuming acorns as part of their diet (the acorns were the only angiosperms that overlapped the gymnosperm range, although the one *Bromus* sample was close); 3) *could* be consuming angiosperms that are experiencing prolonged drought during their lifetime, or specializing on those angiosperms which have an isohydric water-management strategy; and 4) could be eating well-watered or non-stressed gymnosperm resources only. The maximum probability for this range peaks at the intercept of $\delta^{13}\text{C} = -19.4\text{‰}$, $f(x) = 0.134$. This would suggest only a few herbivores should fall close to this point given the small total probability this area represents. This point also represents the greatest likelihood of equal dietary contributions from angiosperms and gymnosperms. Moving to the right of this point, the probability of diet being strictly angiosperm-based tapers, while the likelihood of regular gymnosperm contribution to the diet increases almost three-fold. For example, at +2 SD in the angiosperm area, the probability of an herbivore's collagen being close to $\delta^{13}\text{C} = -18.28\text{‰}$ and representing an angiosperm-based diet is about 4%, while for the same value in the gymnosperm predicted diet region, the probability is about 39%. Moving to the left of this point, the opposite is true and the likelihood that there is gymnosperm contribution to the diet decreases dramatically whereas the likelihood of greater angiosperm contribution to the diet increases.

There are some implications from the right-hand tail of the angiosperm density curve at +3 SD, and at +1 SD for the gymnosperms. First, while these least negative values are unlikely

to be produced by angiosperm consumption, they would be highly likely to represent herbivores relying strictly on gymnosperm resources, such as cones, nuts, pith, bark, wood, roots, or needles/leaves. However, these resources would have to be the bulk of these hypothetical animals' diets over a long period of time to account for values as high as these in herbivore collagen. Second, values this high in herbivore collagen *would never* be recognized as a product of gymnosperm consumption, and instead would certainly be interpreted as the consumption of C₄ plants along with some C₃ contribution if no paleobotanical data was recorded and known. Last, and something that remains a possibility, is that carnivore values could range this high even if they are consuming herbivores that ate nothing but angiosperms, with the caveat that this would have been a dire drought situation and the angiosperms were droughted for a long period of time, as in multiple years of low total precipitation. Again, though, even carnivore values this high are usually attributed to their prey consuming a C₃/C₄ mixed diet. It would be difficult to discern at this point if the diet was in fact mixed, or if gymnosperm consumption was the culprit. Paleobotanical isotopic data would be needed to differentiate between these possibilities.

The bulk of the modelled values here are fully plausible, given that similar results have been found for rats, mice and pigs in controlled feeding experiments (DeNiro and Epstein 1978; Froehle et al. 2010), for reindeer, bison, wolves, mammoth, cave lion, mountain sheep and bear from Pleistocene era-Siberia (Bocherens et al. 1996), and for bighorn sheep, deer and antelope from Utah (Ugan and Coltrain 2012). In the main, I expect the fauna from the west-central Sierra Nevada to largely conform to the predictions here, as they are based solely on paleobotanicals derived from the same area and represent the resource base of the terrestrial food web.

4.5 Conclusion and Summary

Large variability in the measured $\delta^{13}\text{C}$ of C_3 plants makes dietary inferences from $\delta^{13}\text{C}$ of collagen or apatite of C_3 consumers difficult, as there is no “one range fits all” solution. Instead, multiple micro-ranges exist, and they depend largely on the climate, location, and physiological process of plants. To overcome this obstacle, I used a combination of oak tree rings, precipitation records, and paleobotanicals to better understand the measured $\delta^{13}\text{C}$ of these sampled items in relation to the environment of the west-central Sierra Nevada. The end goal was to create an isotopic baseline from which I could model consumer values to better understand plant contributions to consumer diets, and from consumer values further test a connection to precipitation.

By first examining the link between precipitation and measured $\delta^{13}\text{C}$ from black oak tree rings from within the study area, and by using an equation (Kohn 2010: Eq.2), I was able to model growing season precipitation from the period 1768–2017 CE. This provided insight into the limitations of the equation, as it did not replicate total precipitation but instead captured growing season precipitation for the period of ring formation. However, this proved successful as well, as an estimate of precipitation that goes beyond the historic and modern recorded period is important to the understanding of paleoclimates and paleoecology. The tree ring analysis provides a proof of concept for using $\delta^{13}\text{C}$ from paleobotanicals to reconstruct paleo-precipitation, even if it is limited to the growing season. Estimates of paleo-precipitation for the growing seasons can inform on wet versus dry years when compared to historic and modern totals for growing seasons, and can help estimate when conditions were abnormal as we would define it, in the past. Others have developed similar methods to study paleo-precipitation going

back millions of years, albeit based from leaf wax biomarkers in depositional layers (Diefendorf et al. 2015).

The tree ring analyses also provided deeper insight into how modern changes to atmospheric $\delta^{13}\text{CO}_2$ and CO_2 have affected plant $\delta^{13}\text{C}$ during the modern era, as it is directly related to plant physiological processes and respiration, which showed greater stability prior to the industrial revolution. This was shown with the examination of the iWUE of the oak from before the industrial revolution and into the modern era. The iWUE of the oak was increasing as atmospheric CO_2 increased, indicating both a period of relative stability and clustering early (Figures 4.8b), then a linear trend of flux. This is similar to the findings of other researchers who have proposed that plants, mainly C_3 , work harder to maintain equilibrium between rising CO_2 and the internal partial pressure of the cells with their leaves, as in the c_i/c_a of leaves (Bowling et al. 2008; Feng 1998; Gray and Brady 2016; Guehl et al. 1994; Zhang et al. 2019). Over longer timescales than what was covered by the tree rings, others have hypothesized that plants maintain a set point in c_i/c_a that is adaptive, likely on timescales longer than just a generation (Diefendorf et al. 2015; Ehleringer and Cerling 1995).

The paleobotanical samples examined here served multiple purposes. First, they were analyzed in relation to each other, with the main indications of major differences in water management strategies and stomatal conductance between the two clades, while differences among the angiosperm taxa were negligible and overlapping. The angiosperm results, specifically in iWUE and $\Delta^{13}\text{C}$ also were comparable to the oak tree rings, and as such, suggest an environmental linkage to plant $\Delta^{13}\text{C}$. Importantly, all plants conformed largely to the outlined expectations despite not knowing exactly how old they were (i.e., within the last 7000 years), or their precise growing location (i.e., people could carry them from an area around each site).

These paleobotanical samples represent the largest archaeologically-derived set of samples to date in the Sierra Nevada to undergo any isotopic analyses. Results show that water, mainly growing season precipitation, plays a critical role in shaping C_3 plant $\Delta^{13}C$ within this environment. As such, average growing season precipitation was modelled from the angiosperm mean for the entire west-central Sierra Nevada region, and indicated that paleo-precipitation during the growing season was comparable to modern averages. By using the average $\Delta^{13}C$, I was able to estimate what the *normal* precipitation was, and then compare this to modern records. Alternative methods can be applied, however, as research questions vary. I found this method the most fruitful for what I was trying to achieve without having directly-dated materials. In the following chapter, I apply this foundational understanding between the linkage of precipitation and $\delta^{13}C$ measured in plants to estimate paleo-precipitation from dated archaeological faunal specimens, with the basic assumption that plant $\delta^{13}C$ is reflected in consumer (herbivore) tissues.

Last, and most important is that the paleobotanicals served as the basis from which herbivore collagen $\delta^{13}C$ values were modelled. The modelled results split angiosperm consumers from gymnosperm consumers, but also included an area of overlap. The probability distribution that was created is helpful for determining the diets of archaeologically derived herbivore samples based on $\delta^{13}C$, and will be applied to faunal samples in the next chapter. This baseline is also used as the foundation from which to understand human values, which is the main thrust of this dissertation.

Chapter 5: Light Stable Isotopic Analysis of Faunal Remains from the West-central Sierra Nevada

In this chapter, I examine what stable isotope analysis of faunal remains can tell us about Indigenous cultures, diets, and, more broadly, the environment? I explore the light stable isotope abundances of carbon (C), nitrogen (N), and sulfur (S) in a selection of faunal remains from several sites from the west-central Sierra Nevada in relation to modelled baseline values and expectations in order to predict and better explain the diets and geography of Indigenous peoples dwelling here over the last 4,000 years. Analyses will inform on, 1) the animal-based protein portion of human diets, mainly reflected by a relationship between N and trophic level, 2) the expected “local range” for S isotopes, and what this might tell us about human geography, 3) how faunal values compare to the isotopic baseline and predictions set forth within Chapter 4, and how plant C is transferred up the food chain, 4) how these values can be used to estimate and predict human diets, 5) how to derive precipitation estimates from radiocarbon-dated faunal remains, and 6) implications for paleoclimatic reconstructions.

To accomplish these goals, I first provide a brief overview of C, N, and S, and their use within paleodietary isotopic analysis studies. Next, I give an overview of the faunal record of the Sierra Nevada, and the utility of incorporating faunal remains within isotopic analyses of human diets. Following this, I discuss the sample selection and identification process, and outline the isotopic expectations based on animal feeding habits and home-range size. I then analyze the data and discuss the results to make predictions about human values, paleo-precipitation, and the local range for $\delta^{34}\text{S}$. The taxa incorporated in this study should represent human decisions based on opportunistic hunting, targeted hunting, and possibly trade.

Importantly, the faunal remains used within this analysis are a small sample of a much wider animal base Indigenous peoples relied on for meat. However, during sample processing it became abundantly clear that heat had affected some of the samples. This was not apparent during sample selection, but because these were dietary remains, it was anticipated to be an issue. As such, I also include a short discourse on stable light isotope abundances in heat-altered bone, as nearly two thirds of the samples were likely heat-affected.

5.1 Light Stable Isotopes (C, N, S), Animals, and the Environment

The saying, “you are what you consume, plus a few permil”, applies all vertebrate animals, including humans (Ambrose et al. 1997; Tykot 2004). This motto is especially true for carbon and nitrogen. Animals derive carbon from plants at the base of food webs. Their tissues reflect the average carbon of their diet plus a fractionation factor (ϵ) related to digestion, nutrient routing, and tissue synthesis (Ambrose 1990; DeNiro and Epstein 1978; DeNiro and Schoeninger 1983; Koch 2007; Krajcarz et al. 2025; Tykot 2004; Van der Merwe 1982). Metabolic processes within an animal’s body lead to isotopic discrimination during biochemical reactions and redistribution of molecules between metabolites, resulting in fractionation between diet and animal tissues (Krajcarz et al. 2025). The fractionation factor changes depending on the tissues analyzed, as nutrients are routed and incorporated differently in different tissues. For instance, the fractionation factor for carbon in bone or dentinal collagen, ϵ , is about +5.1‰ in measured $^{13}\text{C}/^{12}\text{C}$ of animals in controlled feeding experiments, as compared to dietary values when the diet is monoisotopic (all C_3 or all C_4), while for bone and enamel apatite, ϵ varies between +9 and +14‰. Variation is due to differences in digestive physiologies, mainly between methanogenic and non-methanogenic species, as well as differences in diets (Ambrose and

Krigbaum 2003; Ambrose and Norr 1993; Codron et al. 2018; Froehle et al. 2010; Howland et al. 2003; Jim et al. 2006; Jim et al. 2004; Lee-Thorp et al. 1989; O'Connell et al. 2001; O'Connell and Hedges 2017; Passey et al. 2005; Tieszen and Fagre 1993).

Many controlled feeding experiments on animals find that carbon in bone collagen *largely* represents macronutrient routing of the protein portion of the diet into protein tissues (Ambrose and Norr 1993; Chisholm et al. 1983; Froehle et al. 2010; Howland et al. 2003; Jim et al. 2006; Krueger and Sullivan 1984; Passey et al. 2005; Tieszen and Fagre 1993). For example, Tieszen and Fagre (1993) found that mice fed an entirely C₃ diet had collagen $\delta^{13}\text{C}$ that was 3.7‰ less negative than the bulk diet, but most closely resembled the $\delta^{13}\text{C}$ value of dietary protein (less than a fraction of a permil difference). Building on the work of Tieszen and Fagre (1993) and others cited above, Froehle et al. (2010) found that, in agreement with previous studies, roughly 65% of the carbon in collagen comes from intact amino acids routed from dietary protein, with relatively less carbon coming from other macronutrients. More recent work by Fernandes et al. (2012) largely confirmed the results of the Froehle et al. (2010) study, but provide an estimate of 75% of carbon coming from dietary protein, with the remainder coming from carbohydrates and lipids.

Complementary to these controlled experiments are studies on wild animals, whose tissues are harvested and isotopically analyzed after death. Results from these natural experiments reveal that there are differences between collagen $\delta^{13}\text{C}$ values and assumed trophic level in mammals (Codron et al. 2018; Lee-Thorp et al. 1989). However, these studies also suggest that variation exists among different species owing to different feeding habits, metabolisms, and variations within their environment. For example, differences are found between browsers and grazers, where part of the difference is related to higher protein content of

C₃ browse as compared to grasses targeted by grazers (Codron et al. 2018). After the first step of the trophic level, such as from plants to herbivores, there is little fractionation in $\delta^{13}\text{C}$ in successive steps, such as from herbivore to omnivore or carnivore, on the order of 0.8-1.3‰ (Krajcarz et al. 2016).

For animals inhabiting the Sierra Nevada, collagen $\delta^{13}\text{C}$ will reflect the protein garnered from plants, plus ϵ depending on whether they are herbivorous browsers or grazers, omnivores, or carnivores who consumed the meat of some other animal. The fractionation factor, ϵ , will likely vary to some extent within and among different species based on differences in feeding habits, digestive physiology, metabolic differences, and food quality. The faunal values can then be used to predict human values. Bone collagen of animals plus a trophic discrimination factor for the collagen of humans mimics ideas from ecology. In ecology, collagen to collagen comparisons are made for predator-prey pairs, typically for herbivore-carnivore relationships, (Bocherens and Drucker 2003; Krajcarz et al. 2016, 2025). However, this method is not complete without the use of nitrogen to distinguish trophic levels within this environment.

Similar to carbon, nitrogen is also traced back to plants at the base of the food web. However, the nitrogen cycle is more complicated than carbon, as nearly all nitrogen is present as unreactive N₂. For example, more than 99% of nitrogen on earth is atmospheric N₂ or dissolved N₂ in the ocean (Hoefs 2009; Schwarcz and Schoeninger 1991). ¹⁵N comprises 0.37% of N₂ in atmospheric air, while ¹⁴N accounts for the remainder (Craine et al. 2015; Hoefs 2009). In the biological nitrogen cycle, microorganisms are responsible for all major conversions of unreactive N₂ into usable N-compounds for plants (Hoefs 2009; Schwarcz and Schoeninger 1991). In aquatic systems, blue/green algae and bacteria produce nitrates and ammonia which are richer in ¹⁵N compared to dissolved N₂ (Hoefs 2009; Schwarcz and Schoeninger 1991). These higher

$^{15}\text{N}/^{14}\text{N}$ values are then passed on to phytoplankton which use the enriched dissolved nitrates as nutrients (Fry 2006; Schwarcz and Schoeninger 1991). In terrestrial systems, there are two ways nitrogen enters the biological system. This involves bacteria (or mycorrhizal fungi in the roots) producing nitrates and ammonia during the decomposition of dead organic matter; the activated nitrogen (in nitrates) can then be used by vascular plants and results in plant $\delta^{15}\text{N}$ values above that of atmospheric N_2 (Craine et al. 2015; Schoeninger and Moore 1992). The second involves bacterial nodules on terrestrial plant roots, where the bacteria exchange activated nitrogen for sugars or carbon from the plant—this results in plant tissue $\delta^{15}\text{N}$ values close to that of air (Craine et al. 2015; Schoeninger and Moore 1992).

Although the general expectation is lower $\delta^{15}\text{N}$ with increasing precipitation and decreasing temperature (Amundson et al. 2003), total available soil N has a strong influence on plant $\delta^{15}\text{N}$ (Brenner et al. 2001). However, globally, $\delta^{15}\text{N}$ values of plants are lower than soils, but the difference increases with decreasing temperature and only secondarily with increasing precipitation (Amundson et al. 2003). In recent work elucidating N fluxes in soils across an elevational gradient from the Upper Sonoran Zone to the Subalpine Zone in the Southern Sierra Nevada, the Upper Alpine and Lower Sonoran Zone were found to have the highest average soil $\delta^{15}\text{N}$ (within the light fraction), ranging between ~ 0.75 and 2% respectively, but the Upper Sonoran Zone had a much higher N concentration than the Alpine Zone where soils were shallow (Moreland et al. 2023). The Lower and Upper Montane Forests had much lower N concentrations within the light fraction, and average $\delta^{15}\text{N}$ varied between 0 and -2% , respectively (Moreland et al. 2023). These data suggest that $\delta^{15}\text{N}$ in animal tissues should follow much the same trend—higher in animals from the Alpine and Upper Sonoran Zones, lower in animals from the Lower and Upper Montane Forests.

Similarly, in a global survey of plant and soil $\delta^{15}\text{N}$, work within the Sierra Nevada indicated that plant foliar $\delta^{15}\text{N}$ values were the highest in the Upper Sonoran Zone (-1.9‰), lowest in the Lower and Upper Montane Forests (-4.5‰), and again higher in the Subalpine Zone (-2.4‰) (Amundson et al. 2003:31), which largely matches the trend seen in the soils. Because this pattern should be similar for N in the Central Sierra Nevada in the past, the expectation is that plant $\delta^{15}\text{N}$ values in the Lower Montane and Upper Montane Forests are the lowest as compared to the Upper Sonoran and Subalpine Zones. However, at the local level, individual plants can vary in $\delta^{15}\text{N}$ by up to 25‰ due to variation in the association between soil bacteria or mycorrhizal symbiosis, substrate, plant tissue, type of plant, season, as well as the form of the acquired N (Amundson et al. 2003; Craine et al. 2015). Additionally, some plants (legumes) fix nitrogen from atmospheric N_2 through a symbiotic relationship with bacterial nodules (rhizobia) living on their roots (mentioned above), which results in $\delta^{15}\text{N}$ values close to zero (Nutman 1976; Szpak et al. 2014). These plants (and phytoplankton) are of course then eaten, and N is transferred up the food chain, or they die and decompose where they return to the beginning of the cycle.

N in collagen is derived entirely from dietary protein. Because most sources of meat contain a higher density of protein than plants, $\delta^{15}\text{N}$ values in carnivores, and to a lesser extent, omnivores, are biased towards the former (DeNiro 1987; DeNiro and Epstein 1981; DeNiro and Schoeninger 1983). The trophic level effect is due to fractionation that takes place as nitrogen is metabolized within the body and as waste is removed through the excretion of urea, uric acid, amino acids, and/or ammonia, which lowers the quantity of ^{14}N as its bonds are more easily broken. This leaves higher proportions of ^{15}N within the body to be incorporated into tissues such as bone collagen, muscle, keratin, organs, and skin (DeNiro and Epstein 1981; Schwarcz

and Schoeninger 1991). There is a 3–6‰ enrichment of $\delta^{15}\text{N}$ for every trophic step in a food chain (DeNiro 1985, 1987; DeNiro and Epstein 1981; O’Connell et al. 2012; Schoeninger et al. 1983); this means that consumer tissues will be 3–6‰ higher in $\delta^{15}\text{N}$ than the foods consumed. Plants, at the base of the food chain, typically have $\delta^{15}\text{N}$ values between -4 and 9‰ (DeNiro 1987). In terrestrial environments, there are basically three trophic levels: 1) plants, 2) animals that consume plants, and 3) animals that consume plant-eating animals. In marine, and to a lesser extent, freshwater environments, food chains are much longer; phytoplankton are eaten by zooplankton (and some small fish), which are then eaten by small fish which are themselves eaten by medium fish, which are eaten by larger fish, and so on to the largest predators in the trophic chain. Hence, trophic variability is much greater as are the highest values obtainable for $\delta^{15}\text{N}$. In general, more meat means higher $\delta^{15}\text{N}$, whereas more plants mean lower $\delta^{15}\text{N}$ (DeNiro and Epstein 1981; DeNiro and Schoeninger 1983).

However, like carbon in plants, sources of enrichment exist, but mainly within non-plant organisms. $\delta^{15}\text{N}$ is enriched in nursing mammals as the offspring is, in effect, consuming parts of its mother (Eerkens et al. 2011; Fry 2006). Enrichment in $\delta^{15}\text{N}$ can also result from catabolism and water-stress in vertebrates (Hobson et al. 1993). Within plants, some enrichment in leaves is associated with differing climates. For example, a global study of over 11,000 non- N_2 fixing plants, shows that foliar $\delta^{15}\text{N}$ increased logarithmically with decreasing precipitation, and increased linearly with increasing mean annual temperature (Craine et al. 2009, 2015). This increase is associated with increased N availability in warm, dry ecosystems (Craine et al. 2009, 2015). If $\delta^{15}\text{N}$ is higher than expected in an environment, everything habituating and eating within that environment will also be enriched (Makarewicz and Sealy 2015). This fact is a major reason to incorporate faunal, especially herbivore, $\delta^{15}\text{N}$ analysis of local fauna into stable isotope

studies of human diets; as human diets vary, the base of the food chain, as discussed above, does as well.

For the faunal samples in this study, the broadest range of $\delta^{15}\text{N}$ values is expected among herbivores, particularly generalist and migratory herbivores. Although each species differs in preferred foods, habitat use, and seasonal movement patterns, generalist herbivores likely incorporated a wider range of plant resources across the year, including lower-quality forage during lean seasons. This broader dietary and habitat range should produce greater variation in herbivore $\delta^{15}\text{N}$ values than would be expected among more specialized feeders. Carnivores and omnivores should have higher average $\delta^{15}\text{N}$ values because their diets include animal protein derived from herbivore prey, but their observed ranges are difficult to evaluate because sample sizes are extremely small. Therefore, I rely primarily on herbivore $\delta^{15}\text{N}$ values to characterize the local plant nitrogen baseline and to establish expectations for interpreting the diets of pre-contact Indigenous people, who are the main focus of this study.

Much like C and N, S is also highly variable across different ecosystems. However, unlike C and N, there is very little fractionation in S as it is transferred up the food chain (Hobson 1999), which makes it valuable for detecting marine versus freshwater resources within diets, as well as acting as a geologic tracer capable of distinguishing between migrants and locals (Fernandez et al. 1999; Nehlich 2015; Tarrant and Richards 2024).

There are four isotopes of sulfur: ^{32}S , ^{33}S , ^{34}S , and ^{36}S (Fry 2006; Nehlich 2015). Of these, ^{32}S and ^{34}S are most frequently measured in ecological studies. Whereas ^{32}S accounts for about 95% of all sulfur on Earth, ^{34}S is less abundant (4.21%) and is measured in relation to ^{32}S . $\delta^{34}\text{S}$ represents the ratio of the two isotopes, relative to the Canyon Diablo Troilite standard (Fry 2006).

Sulfur is geologic in nature, but some ancient and modern marine bacteria and soil microbes both consume and expel sulphates and sulfides, causing fractionation within and across environments (Fry 2006). These sulfate and sulfide reducing bacteria and microbes are responsible for all major fractionations of global $\delta^{34}\text{S}$, with some on the order of 25‰, as compared to fractionations occurring within plants (~0–10‰) and larger animals (~1‰/trophic level) (Nehlich 2015). Inorganic environmental sulfur cycles through weathering, evaporation, precipitation, and tectonic movements, whereas atmospheric and biomass sulfur originates from oceanic and soil sulfur (Fry 2006; Nehlich 2015). In short, inorganic sulfur is incorporated at the local scale into biomass, whereas organic-bound sulfur is passed along food webs as amino acids within proteins (Nehlich 2015).

Sulfur enters local food chains through atmospheric deposition and microbial processes in bedrocks and soils. It is taken up by plants (or algae) and incorporated into amino acids, most importantly, which involves the synthesis of methionine in plants/algae (Nehlich 2015). Although work to understand how S is fractionated in plants is still poorly understood, in general research suggests that roots and stems are depleted relative to soil sulphates by about 2‰, while leaves and grains are enriched up to 2‰, representing a 4‰ difference between roots and leaves/fruiting bodies (Tarrant and Richards 2024; Tcherkez and Tea 2013). In terrestrial environments, and specifically in plants, there are several cascades involved in biosynthesis of serine and its transformation into cysteine, along with the incorporation of inorganic sulfur, where cysteine is the source for the synthesis of the essential amino acid methionine (Nehlich 2015). Out of the 20 common amino acids, cysteine and methionine are the only ones to contain sulfur (Nehlich 2015). Ergo, a first order consumer's body methionine should reflect the average value of $^{34}\text{S}/^{32}\text{S}$ of methionine in dietary protein garnered from plants. This is similar to collagen

$\delta^{13}\text{C}$ as representative of the average $^{13}\text{C}/^{12}\text{C}$ of dietary protein. However, this is slightly different within aquatic systems, although the basis is the same.

The ocean is a well-mixed sulfur pool, with $\delta^{34}\text{S}$ averaging around +20.3‰ globally, due to the constant cycling of water through all oceans (Nehlich 2015). As sea spray and fog can carry oceanic $\delta^{34}\text{S}$, areas near the coast typically have much higher $\delta^{34}\text{S}$ values. This gives $\delta^{34}\text{S}$ analysis some utility in identifying or tracing organisms living in coastal settings versus those living further inland (Fry 2006; Jaouen and Pons 2017; Richards et al. 2001, 2003).

Because freshwater environments differ in their range of sulfur values from marine settings, $^{34}\text{S}/^{32}\text{S}$ can also be used to discriminate between dietary inputs of fresh water versus marine, and anadromous fish (Richards et al. 2001). Only in estuarine environments with large inputs of freshwater would $\delta^{34}\text{S}$ be lower so close to the ocean (Nehlich 2015), such as should happen in the marshes of California's delta region, where saltwater mixes with freshwater. Further inland, such as in the Sierra Nevada, $\delta^{34}\text{S}$ should be much lower and more affected by terrestrial inputs and freshwater variation along different rivers. For example, most freshwater systems are highly variable in their $\delta^{34}\text{S}$; however, they typically range between 0 and +10‰ (Nehlich 2015). Rivers and lakes will vary in their $\delta^{34}\text{S}$ based upon terrestrial inputs (decomposing organic matter and microbial activity) and differing geologies which affect baseline geologic $\delta^{34}\text{S}$ upon which microbes act. Therefore, if animal values (including humans) were high, we might suspect the regular consumption of anadromous fish; however, $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ would also need to be high to support this hypothesis.

In the west-central Sierra Nevada, magnetite-series granites $\delta^{34}\text{S}$ values range from 1.6 to 4.0‰, particularly around the main Tuolumne body of granitic batholith (through which the Tuolumne River flows), while ilmenite series rocks range between -3.7 and -5.3‰, and are found

south and west of Tuolumne—closer to the flow path of the Merced River, near Coarsegold and Indian Flat (Ishihara and Sasaki 1989). More recent research across an elevation transect of the Sierra Nevada found differences in soil $\delta^{34}\text{S}$ from west to east and with depth (Yi-Balan 2013). For example, in the oak woodland, soil $\delta^{34}\text{S}$ at 10cm depth was 6.9‰, while at 50cm depth, it was 6.7‰, and at higher elevations in the mixed conifer forest (1,240 masl) soil $\delta^{34}\text{S}$ at 10 cm was 7.4‰, and at 50 cm depth it was 2.7‰ (Yi-Balan 2013:36). These differences are likely passed into plants according to rooting depth and then averaged among consumer tissues depending on different feeding habits, migration status, or home-range size among herbivores. Because there is variation in $\delta^{34}\text{S}$ from north to south and west to east, it is likely that animal $\delta^{34}\text{S}$ will trace vegetation and local water sources. This suggests that in the north, collagen $\delta^{34}\text{S}$ values could range between 1.6 to 7‰, while south of the Tuolumne River should be lower. Those within the foothill setting should have lower $\delta^{34}\text{S}$ compared to those living in higher elevations, or those that migrate. No sites were sampled from as far south as the Merced area in this study. If animals have $\delta^{34}\text{S}$ values lower than the average for the main portion of the region, it would support the hypothesis they were hunted from outside the main region. Overall, the bulk of the animal values, especially for the more localized fauna such as rabbits and gophers, should represent the terrestrial expectations for the range of the human population. In general, the average $\delta^{34}\text{S}$ for the fauna should be a good predictor for the average $\delta^{34}\text{S}$ of the humans.

All of this works because $\delta^{34}\text{S}$ in collagen measures proteinaceous dietary inputs; unfortunately, it requires a large sample of 8–10 mg of collagen for analyses, compared to the 0.8–1.2 mg required for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, which frequently reduces the number of samples available to archaeological researchers after other tests have been performed.

In short, when analyzed together, C, N, and S of the faunal remains provide a powerful tool for interpreting human values. Some of the faunal remains will inform on human hunting decisions, while all help to set expectations for where humans fall within the ecology of the Sierra Nevada of the past, and provide a better basis for a diachronic examination of diet, environment, and culture.

5.2 The Archaeology of Faunal Remains in the Sierra Nevada: a Brief Overview

Zooarchaeological studies within the Sierra Nevada region are limited. This is probably due to the fragmentary nature of faunal remains coupled with acidic Sierra Nevada soils—many faunal remains are so degraded and fragmentary that sometimes the most that can be said is large mammals contributed the most to Indigenous people's diets. The few faunal analyses that do exist, such as Baumler and Carpenter (1982:233–248), McGuire et al. (2011), Rosenthal et al. (2011b), and Rosenthal et al. (2011a), all agree that deer constitute the greatest source of meat throughout the entire cultural sequence. While numerous other species are present, with the exception of elk and pronghorn (very few identified specimens), these represent much smaller animals. In other words, while a broad array of taxa were consumed, smaller-bodied species contributed less to the meat portion of the diet than did deer (Baumler and Carpenter 1982:239; Rosenthal et al. 2011a:145–146). The ubiquity of deer in archaeological assemblages in this region shows no sign of resource depression, and does not seem to change through time (Rosenthal et al. 2011a; Whitaker 2009).

Faunal studies in the Sierra appear to show an increase in the variety and diversity of fauna represented in later contexts. For instance at Sonora, while deer is ubiquitous across all

time periods and outnumbers all small taxa, the diversity of small taxa, mainly lagomorphs and rodents from early periods such as the Middle and Late Archaic (7000-3000, 3000-1100 cal BP, respectively), appears to increase to include birds and western pond turtles in the Recent Prehistoric (1100-100 cal BP) (Rosenthal et al. 2011b). While at first this may seem to hint at a widening of diet breadth, these other small bodied taxa are also found in earlier time frames, but in less abundance (Rosenthal et al. 2011b). However, the apparent increase in diversity through time in this case is a function of sample size; i.e., more bone was collected from Recent Prehistoric II (RP II; 610-100 cal BP) contexts than from earlier periods, despite a higher volume of excavated soils from earlier contexts as compared to the entire Recent Prehistoric (Rosenthal et al. 2011b:109). When the non-riverine location of Sonora is compared more broadly with the regional context, the pattern does not change among time periods, nor habitat type (e.g., Montane Forest versus Foothill Woodland) (Rosenthal et al. 2011a:146). In fact, the authors note that there was a very stable pattern of animal exploitation throughout the entire sequence and across geographical locations that suggests neither resource depression nor any change to target specific taxa (Rosenthal et al. 2011a).

Given earlier analyses in the Central Valley of California showing significant resource depression later in time (e.g., Broughton 1994), this finding in the Sierra Nevada region is surprising. However, in recent work by Whitaker et al. (2019), the whole of central California was examined to check for alternative explanations to resource depression initially discussed by Broughton and others (1994; Broughton et al. 2010). Importantly, this has raised the question of whether territorial circumscription among the different cultural groups played a role in the disparity between the abundances of elk and antelope versus deer recovered. Their results support circumscription as a viable explanation for why deer are ubiquitous, while elk and

antelope are found in far fewer numbers throughout the 4,000-year sequence examined (Whitaker et al. 2019). This pattern also holds true for the Sierra Nevada; however, the region is poor habitat for elk and especially antelope. Still, elk and antelope are found in small numbers in Sierran assemblages, which suggests Sierran people had at least some access to these migratory herds on occasion. That access could have been in the form of trade, formation of cultural alliances with Central Valley groups, permission granted to hunt, a lack of territorial boundaries during some windows of time, or that animals occasionally wandered into the Sierra Nevada foothills or mountains. The faunal remains tested here include a single elk from CA-TUO-935, which could provide a small insight into this issue.

In recent work on elk remains from two sites, Emeryville (CA-ALA-309 in the San Francisco Bay Area) and King Brown (CA-SAC-29 in the Lower Sacramento Valley), Broughton (2023) found evidence to support a claim of resource depression at Emeryville, but less so at King Brown in the California Delta supporting the explanation proposed by Whitaker et al. (2019) for the latter site. An alternative explanation could be increased targeting of calves vs adults during the Late Period at the King Brown site, indicating some degree of resource depression. Millennia of human elk hunting in the Sacramento Valley marshlands region could have had a long-term cascade effect on the quantity of animals in sink populations in the San Francisco region, such as at Emeryville (Broughton et al. 2023). Similar to the findings at Emeryville, the possibility of depressed sink populations of elk ranging into the Sierra Nevada might explain the few occurrences of elk within the region's later Holocene archaeological record.

Most interesting about the lack of change in the Sierra Nevada faunal assemblages is it suggests human population pressure never reached a threshold at which it impacted the Sierran

fauna. Alternatively, the apparent lack of change could also indicate a greater reliance on plant resources, which offset a reliance on hunting. This may have been a long-standing pattern in the west central Sierra Nevada as evidenced from paleobotanical studies, which find a reliance on nut crops for the entire sequence, as well as the use of storage (Morgan 2008, 2009b, 2012; Rosenthal et al. 2011a:154–155; Whelan et al. 2013). So, rather than human populations remaining at low densities, it is possible that the population in this region did expand, but that animal resources were never taken in such great abundances that it affected animal populations, in part because of the long-standing use and storage of nut crops and plants. This is one hypothesis that I test in greater detail in the following chapter using diachronic stable isotope analysis of human remains.

The samples analyzed for this project were selected to represent a wide variety of taxa that became part of Indigenous diets. These isotopic analyses address three main issues. First, they help create a baseline for $\delta^{15}\text{N}$ expectations to study trophic positions of humans; second, they create the baseline $\delta^{34}\text{S}$ for the region to examine mobility and/or trade; and third, independently-dated faunal samples, as well as human samples in the next chapter, help build a paleo-precipitation model using the model from Kohn (2010: Equation 2). The robustness of this precipitation model will first be tested using data from Broughton et al. (2023: Supplementary Information), with the goal of comparing precipitation estimates for the west central Sierra Nevada to the western Central Valley over the last 1000 years. As the MCA has long been hypothesized to be a factor for the population and cultural history of the west central Sierra Nevada, precipitation estimates from radiocarbon-dated faunal remains might provide some of the best indications of precipitation variability for that period. Such variability, of course, has implications for ancient human foraging and settlement decisions.

5.3 Materials, Expectations, and Methods

5.3.1 Materials

Faunal samples were obtained with support from the federally-recognized Tuolumne Band of Me-Wuk Indians. They were taken from existing collections (i.e., no new excavations) from four sites situated at varied elevations within the west central Sierra Nevada. The sites largely represent the same sites as for the samples of human remains that will be discussed in the next chapter, here represented by: CA-TUO-300, -314, -395, and -935. Figure 5.1 provides a map showing site locations in relation to each other, and the region for which paleo-precipitation was estimated using the paleobotanical remains in the previous chapter, which is represented by the polygon. Samples and site information are detailed in Table 5-1 and correspond to the collection descriptions provided below.

In 2015, the New Don Pedro collection was repatriated to the Tuolumne Me-Wuk. After repatriation, the Tribe requested scientific analyses be undertaken prior to the reburial of the remains to learn more about their past. During sample selection of human remains, some faunal bone was identified and also sampled for isotopic analyses. For example, CA-TUO-300 had one gopher mandible associated with Burial 11, while a fragment of deer tibia, identified by Dr. Susan Talcott, was found in the bag for Unknown (Unk) Individual 15. Likewise, one questionable sample, Unknown Individual 7B, initially identified as a juvenile human from CA-TUO-314, was later positively identified as a fragment of a deer tibia by Talcott. This was the only faunal sample associated with this site collection. CA-TUO-279 had no faunal materials associated with the collection of human remains, and is not discussed further in this chapter. These sparse samples from the New Don Pedro collection represent a small portion of the faunal samples tested isotopically, but proved valuable in the overall research project.

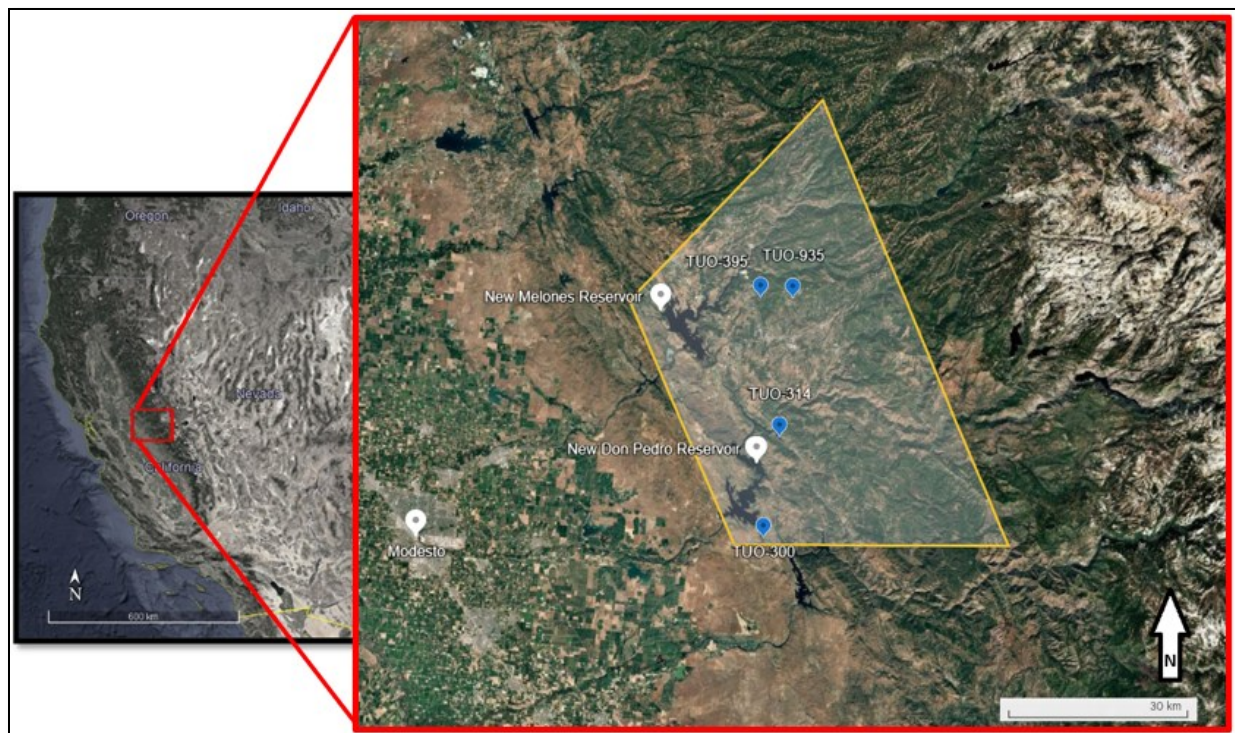


Figure 5.1 Faunal Sites Map

Map shows the Central Sierra Nevada region, outlined in red, in relation to surrounding geography. Sites from which faunal remains were sampled are noted by blue markers, while landmarks are noted by white markers. Yellow-shaded Polygon represents the area for which precipitation was modelled from paleobotanical carbon data (Chapter 4) Inset map scale is 30 km, while map of California (left) scale is 600 km. Map was constructed using Google Earth Pro 2025.

Table 5-1 Faunal Sample List

Site	Sample ID	Context	Latin Name	Common Name	Element Sampled	Viable Results?
CA-TUO-300	B11f	Unit N-5, 96 cm	<i>Thomomys</i> sp.	pocket gopher	mandible	yes
CA-TUO-300	Unk. 15f	Unit S-6, 140-160 cm	<i>Odocoileus</i> sp.	deer	tibia	yes
CA-TUO-314	Unk. 7Bf	N.E. Powercut	<i>Odocoileus</i> sp.	deer	tibia	yes
CA-TUO-395	283a	Housepit 1, Burial 1	<i>Odocoileus</i> sp.	deer	lumbar vertebra	no
CA-TUO-395	283b	Housepit 1, Burial 1	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-395	283c	Housepit 1, Burial 1	<i>Lepus</i> sp.	jackrabbit	humerus	no
CA-TUO-395	317e	Dancehouse cremation	<i>Lepus</i> sp.	jackrabbit	tibia	no
CA-TUO-395	325f	Housepit 2, Burial 2	<i>Odocoileus</i> sp.	deer	tibia	yes
CA-TUO-935	42a	North pothole, 0-50 cm	<i>Lepus</i> sp.	jackrabbit	astragalus	no

Site	Sample ID	Context	Latin Name	Common Name	Element Sampled	Viable Results?
CA-TUO-935	42b	North pothole, 0-50 cm	<i>Odocoileus</i> sp..	deer	metapodial	yes
CA-TUO-935	53a	South pothole, 0-50 cm	<i>Odocoileus</i> sp.	deer	distal vestigial phalanx	no
CA-TUO-935	53b	South pothole, 0-50 cm	<i>Sylvilagus</i> sp.	cottontail	astragalus	no
CA-TUO-935	53c	South pothole, 0-50 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	68a	SW pothole, 0-50 cm	<i>Odocoileus</i> sp.	deer	navicular	no
CA-TUO-935	68b	SW pothole, 0-50 cm	<i>Odocoileus</i> sp.	deer	tibia	no
CA-TUO-935	68c	SW pothole, 0-50 cm	<i>Thomomys</i> sp.	pocket gopher	crania	yes
CA-TUO-935	68d	SW pothole, 0-50 cm	<i>Thomomys</i> sp.	pocket gopher	mandible	yes
CA-TUO-935	90a	Trench 1, 0-45 cm	<i>Canis latrans</i> / <i>lupus familiaris</i>	coyote/do g	phalange	yes
CA-TUO-935	90b	Trench 1, 0-45 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	90c	Trench 1, 0-45 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	90d	Trench 1, 0-45 cm	<i>Callospermophilus lateralis</i>	golden mantled ground squirrel	mandible	yes
CA-TUO-935	104a	Trench 2, 0-45 cm	<i>Odocoileus</i> sp.	deer	humerus	yes
CA-TUO-935	104b	Trench 2, 0-45 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	104c	Trench 2, 0-45 cm	<i>Lepus</i> sp.	jackrabbit	femur	no
CA-TUO-935	119a	Trench 3, 0-45 cm	<i>Odocoileus</i> sp.	deer	1 st molar (adult)	yes
CA-TUO-935	119b	Trench 3, 0-45 cm	<i>Odocoileus</i> sp.	deer	metapodial	yes
CA-TUO-935	119c	Trench 3, 0-45 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	119d	Trench 3, 0-45 cm	<i>Lepus</i> sp.	jackrabbit	tibia	no
CA-TUO-935	126a	Trench 4, 0-30 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	126b	Trench 4, 0-30 cm	<i>Cervus canadensis</i>	elk	lunate	possibly
CA-TUO-935	131a	Trench 4a, 0-30 cm	<i>Odocoileus</i> sp.	deer	tibia	no
CA-TUO-935	131b	Trench 4a, 0-30 cm	<i>Lepus</i> sp.	jackrabbit	humerus	no
CA-TUO-935	143a	Trench 5, 0-40 cm	<i>Lepus</i> sp.	jackrabbit	scapula	yes
CA-TUO-935	143b	Trench 5, 0-40 cm	<i>Ursus americanus</i>	bear	canine	no
CA-TUO-935	143c	Trench 5, 0-40 cm	<i>Odocoileus</i> sp.	deer	vestigial metapodial	no
CA-TUO-935	143d	Trench 5, 0-40 cm	<i>Odocoileus</i> sp.	deer	tibia	no
CA-TUO-935	150a	Trench 6, 0-45 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	150b	Trench 6, 0-45 cm	<i>Sciurus griseus</i>	Western gray squirrel	pelvis	no
CA-TUO-935	180a	Trench 9, 0-40 cm	<i>Lepus</i> sp.	jackrabbit	humerus	no

Site	Sample ID	Context	Latin Name	Common Name	Element Sampled	Viable Results?
CA-TUO-935	180b	Trench 9, 0-40 cm	<i>Thomomys</i> sp.	pocket gopher	mandible	yes
CA-TUO-935	180c	Trench 9, 0-40 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	180d	Trench 9, 0-40 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	196a	SW Pothole/Trench 4	<i>Odocoileus</i> sp.	deer	rib	no
CA-TUO-935	196b	SW Pothole/Trench 4	<i>Taxidea taxus</i>	badger	pelvis	no
CA-TUO-935	196c	SW Pothole/Trench 4	<i>Neotoma</i> sp.	wood rat	mandible	no
CA-TUO-935	217a	CU 1, 0-10 cm	<i>Lepus</i> sp.	jackrabbit	ulna	no
CA-TUO-935	217b	CU 1, 0-10 cm	<i>Lepus</i> sp.	jackrabbit	femur	no
CA-TUO-935	217c	CU 1, 0-10 cm	<i>Odocoileus</i> sp.	deer	cervical vertebra	no
CA-TUO-935	217d	CU 1, 0-10 cm	unidentified mammalia	large mammal	tibia	no
CA-TUO-935	226a	CU 1, 10-20 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	226b	CU 1, 10-20 cm	<i>Lepus</i> sp.	jackrabbit	tibia	no
CA-TUO-935	236a	CU 1, 20-30 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	242a	CU 1, 20-30 cm	unidentified mammalia	small mammal	metatarsal	no
CA-TUO-935	249a	CU 1, 30-40 cm	<i>Odocoileus</i> sp.	deer	cervical vertebra	no
CA-TUO-935	249b	CU 1, 30-40 cm	<i>Lepus</i> sp.	jackrabbit	tibia	no
CA-TUO-935	264a	CU 1-nw crevice, 40-62 cm	<i>Odocoileus</i> sp.	deer	metapodial	no
CA-TUO-935	264b	CU 1-nw crevice, 40-62 cm	<i>Urocyon cinereoargenteus</i>	gray fox	maxillary 2 nd molar	no
CA-TUO-935	289a	Trench 5 soil sample	<i>Sylvilagus</i> sp.	cottontail	humerus	no

Note: table shows the samples from among the different site collections. Table is organized by site, beginning with those from New Don Pedro, followed by Columbia Junior College, and last is CA-TUO-935.

Five faunal samples were selected from CA-TUO-395, a part of the Columbia Junior College collection. These samples were provided in 2018 by the Tuolumne Me-Wuk for scientific analyses following the conclusion of the collection's loan to California Department of State Parks and Recreation. CA-TUO-395 was excavated under the direction of Francis Riddell in 1968–69. The site was discovered by bulldozers during a parking lot expansion at the college. Subsequent excavations by archaeologists revealed the remains of three structures: a dance house and two house pits, all of which showed signs of having been burned. Visible signs of heat

exposure within the TUO-395 collection include cracking and warping of cortical bone (mainly for faunal remains but some human as well), a fully calcined appearance (both faunal and human), blackening of the cortical bone visible at fracture points (faunal only), bluish coloring indicative of a possible anoxic heating environment (both), gray-scale charring (both), and a general chalky appearance (both). Teeth frequently were often limited to calcined dentin, including roots and occlusal surfaces, where the enamel had detached, or charred pieces of enamel. Faunal samples were taken from amongst the bone collections for the three loci. The five selected samples represent two jackrabbits and three deer. The three deer samples are from different excavation contexts to minimize the likelihood they represent the same animal. The same is true for the jackrabbit samples. As a vast majority of faunal remains showed evidence for cremation, burning, or heat exposure, the jackrabbit and deer samples were among the few that showed minimal to no outward signs of heat exposure. However, of these five samples, neither of the jackrabbit samples produced collagen, and only one deer produced reliable results.

The bulk of the faunal samples are from 2014 excavations at CA-TUO-935, currently curated at California State University, Sonoma (Sonoma State University or SSU). A request for a loan, with a letter of support from the Tuolumne Me-Wuk, was approved in December 2020, during the COVID pandemic. University of California-mandated lab closures, and state of California stay-at-home orders, led to significant delays in processing these materials, and the loan was re-approved by the SSU facilities director in June 2022.

CA-TUO-935 is an ancient to historic-era site on property currently owned and managed by Pacific Gas and Electric (PG&E). The site has served as a part of PG&E's network of hydroelectric facilities since 1928, and part of the hydroelectric facilities for other companies since 1898 (Wohlgemuth 2015a). In accordance with FERC regulations and Section 106, during

the trenching for replacement of underground cable and ground rods in 2014, Far Western Anthropological Research Group, of Davis, CA, was hired to undertake archaeological mitigation, in collaboration with the Tuolumne Me-Wuk tribe (Wohlgemuth 2015a).

The faunal remains recovered during excavation totaled 1,198 bone fragments, with a combined weight of 453.9 grams, which were spread among 17 different contexts (e.g., trenches/units, levels, and screen sizes). In Table 5-1, the sample identifiers for TUO-935 relate to these separate contexts. No faunal analysis had been undertaken on this collection prior to isotope sampling for this research. Target mammal species for sampling included deer, lagomorphs, and rodents with small home ranges, such as gophers or squirrels, and a few carnivores were also sampled based on tooth morphology. Bird bone was noted within the collection, but it was not sampled. No fish bones were identified. The sample target weight for a faunal specimen was one gram to one third of a gram, to ensure that enough collagen could be extracted for isotopic analysis. In nearly all instances, bone fragments weighed within this range, and thus the entire fragment was taken and consumed in analysis. For a few larger specimens, only a small portion of bone was removed and used, the remainders were returned to the original provenience bags.

Sample selection and identification for TUO-935 involved spreading all faunal remains from a single context bag on a tray, and sorting each individual provenience one at a time. For example, if two bags belonged to the context of a single trench, only one was spread out at a time and surveyed. Specimens (a bone, tooth or fragment thereof; Lyman 2008) that could be identified to type of skeletal element (e.g., long bone, axial fragment) and as large mammal or small mammal were separated and the remaining fragments were returned to their context bag and set aside. Skeletal elements having a visible landmark, such as a tubercle, nutrient foramen,

or ridge were selected to aid in the identification process. Specimens lacking landmarks and which could not be identified beyond mammal size-class were not selected, except in the few cases where identifiable fragments were limited within certain excavation contexts.

Unfortunately, these few fragments did not survive chemical processing, suggesting diagenetic processes had affected the samples.

Next, a visual inspection was undertaken to avoid sampling any specimen that may have been burned or exposed to heat alteration. Some contexts only contained bones that were visibly stained or darkened. It was not known at the time whether this represented burning, soil staining, or exogenous fluid staining—as might be associated with a hydroelectric facility, such as oil. Few specimens, or none, were taken from these contexts. Unlike TUO-395, none of the specimens showed visible signs of heat alteration beyond a surficial dark-brown color, which *could* have been soil staining. As an example, in Figure 5.2a-c, three deer specimens are shown, each from different contexts. Sample 42b, shown in Figure 5.2a, returned viable isotopic results, while 226a and 104b (Figs.5.2b-c) did not. Notice that 42b and 226a are similarly colored, while 104b exhibits the “dark staining” present on many of the samples. Overall, sample results from this collection were highly variable in degree of preservation, something I discuss further in the results section.

Following the visual preservation inspection, each potential large mammal bone was compared with UC Davis Zooarchaeology Laboratory’s comparative animal skeletal collection, and in consultation with Dr. Christyann Darwent. Within each context, I focused on not sampling the same individual more than once. However, some contexts only contained large mammal samples. In these cases, up to two bones that showed visible signs of different burial conditions (i.e., different colors or states of preservation) were taken if suitable samples were encountered.

Only a single bag from any given context was examined at a time, so no commingling occurred among different proveniences.

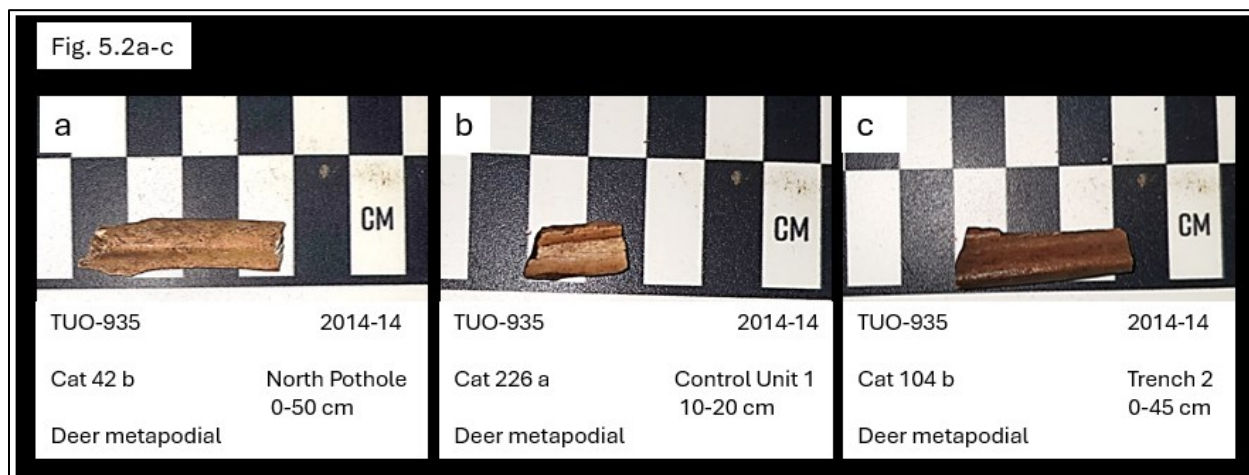


Figure 5.2a-c TUO-935 Faunal Photographs

Photographs show three deer metapodial samples from CA-TUO-935 from different contexts. a) a “well preserved” sample which returned viable stable isotope results. b) a “poorly preserved” sample that did not survive chemical processing. c) a “poorly preserved” sample with dark staining, which survived chemical processing, but did not return reliable stable isotope results.

Each selected sample was assigned an identifier for provenience in accordance with the master catalogue provided by SSU, and an alphabetical identifier, a-d, to denote the sub-sample within a context. Each sample was placed into its own bag with a label. Photographs, with a scale, were taken from multiple angles for each individual sample. Examples of these faunal samples are shown in Figure 5.2a-c (above) and Figure 5.3a-f (below). A thumb drive with digital copies of the photographs and spreadsheet of selected samples, which included preliminary identifications, weights, and associated photographs, was returned with the collection to Sonoma State in February 2023.

5.3.2 Expectations

To outline expectations for the isotopic analyses of the faunal remains, I discuss the feeding habits and territory size of sampled animals, below. However, I restrict this information to species which produced reliable isotopic results, such as that indicated by C:N, %C, %N, %S,

C:S, N:S, and to a lesser extent, % collagen yield (Ambrose 1990; Guiry and Szpak 2021; Nehlich and Richards 2009). These expectations are organized into Table 5-2, for easy reference. The table is organized by taxa, and includes very generalized information, such as expectations for how these compare to the range for deer, or to the average of the deer in each of the isotopes analyzed, where deer are listed first. However, the descriptions outlined below include more detail. Of note is that each of the taxa is somewhat unique in the food types preferred and territory or home range size, especially the deer, who are either migratory or resident. It is because the deer are the most numerous within the samples that all comparisons of expected variation within and among the other taxa are made against the expectations for this species.

Table 5-2 Expectation Summary

Taxa	Classification	Feeding Habit	Home Range	$\delta^{13}\text{C}$ Expectation	$\delta^{15}\text{N}$ Expectation	$\delta^{34}\text{S}$ Expectation
Deer	herbivore	generalist browser	varied; 650 m ² to migratory	average for landscape	widest range	reflect average range for region
Elk	herbivore	mixed browse and graze	large and variable, with herd	within deer range	within deer range	outside deer range
Jackrabbit	herbivore	generalist	0.2–1.4 km ²	lower than deer av.	< deer av.	in deer range
Pocket gopher	herbivore	root specialist, otherwise generalist	3–37 linear meters	mean near deer av.	mean < deer average	in deer range
Golden mantled ground squirrel	herbivore	fungi, and herb specialist	0.0375 km ²	between gophers and deer	< deer average	between deer and gopher av.
Coyote/dog	carnivore	opportunistic carnivore	2–4.5 km ² , or with humans	+1–1.5‰ from herbivore av.	+3–5‰ from herbivore av.	within deer range

Note: table shows the summarized expectations for the different light stable isotopes for each of the sampled taxa as described in the text. Expectations are based on the ecology of the animals, including feeding habits and territory or home range size, and made against those for the deer. Carnivore expectations are made against those of the herbivores for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, and against deer for $\delta^{34}\text{S}$. “av.” means average; only species common names are shown.

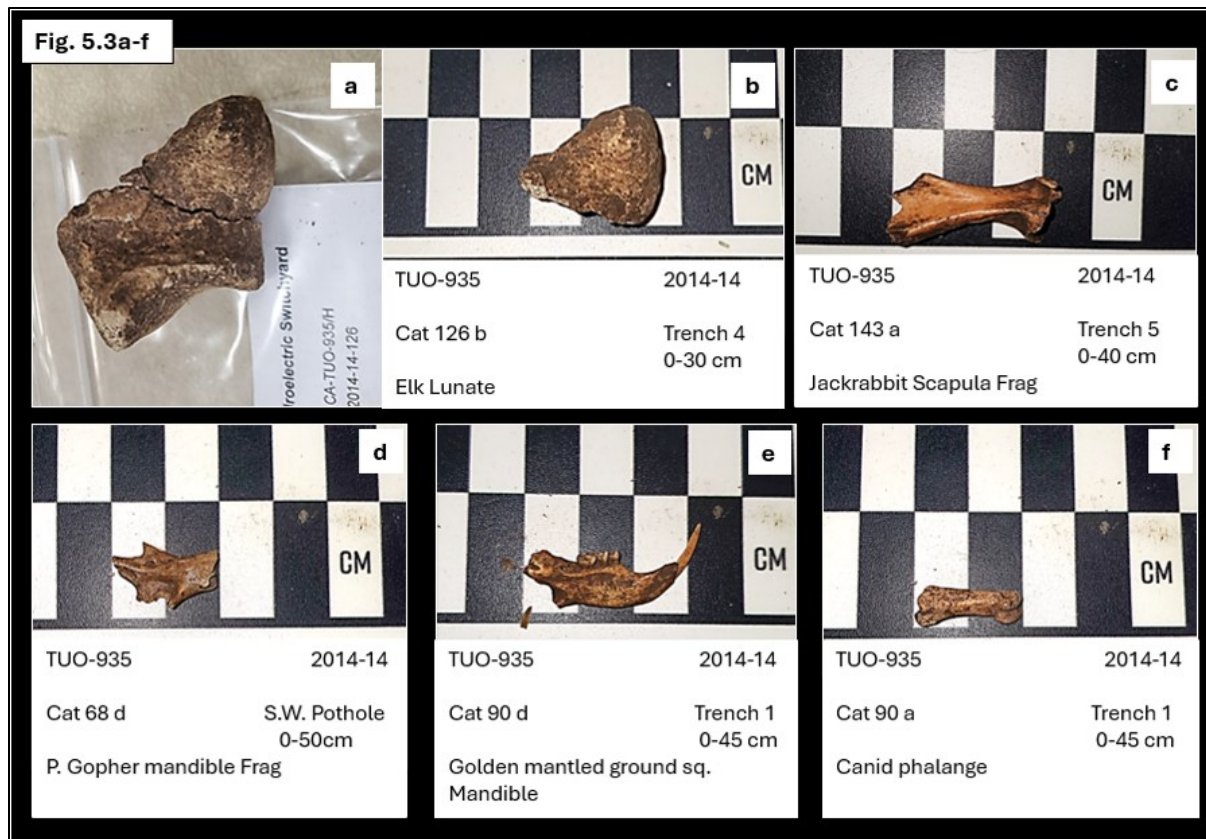


Figure 5.3a-f “Well Preserved” Fauna from CA-TUO-935

Photographs show five different taxa sampled from CA-TUO-935 which returned reliable results; **a**) elk lunate, with portion to be sampled; **b**) Sampled portion of elk lunate; **c**) Jackrabbit scapula; **d**) Pocket gopher mandible; **e**) Golden mantled ground squirrel mandible; **f**) Dog/coyote phalanx.

In Chapter 4: , I predicted that herbivore diets should separate on $\delta^{13}\text{C}$ depending on the degree of reliance on angiosperms versus gymnosperms. I return to this expectation, presented in the results section.

Artiodactyls

Deer: Black-tailed deer (*Odocoileus hemionus columbianus*), and California mule deer (*O. h. californicus*) are the two sub-species of deer that inhabit the west central Sierra Nevada, and they range between resident deer and migratory (Calvert 2025). Examples of deer samples are shown above. While blacktail deer generally inhabit the lower foothills below the snowline, California mule deer range up to the high Sierra in summer (Calvert 2025; Leopold et al. 1951).

In Tuolumne County today, one of the major migratory herds is the Jawbone Herd, which has a well-documented migration history (Leopold et al. 1951). Deer in this area are generalist herbivore browsers who may forage on spring grasses, forbs, manzanita, choke-cherries, tender shoots of many species, acorns, pine nuts, as well as bark, lichen, mountain mahogany, and ceanothus (Calvert 2025; Grinnell and Storer 1924). Deer are generally crepuscular, and prefer to forage at dawn and dusk, but will forage at other times as needed (Calvert 2025). Because variation exists in resident versus migratory deer, home ranges vary. Although, resident blacktail deer typically have a home range of 650–1,200 m (Whitaker et al. 2019), migratory mule deer inherit the migration routes of their mother, and have larger home ranges that overlap with others in their herd (Loft et al. 1989).

Overall, the expectation is that deer should exhibit a similar range of variation as humans, who are known to move seasonally to access resources. I provide a fuller examination of this expectation in the next chapter. Specifically, for $\delta^{34}\text{S}$, the expectation is that deer will represent the average range, and the mean value should be comparable to that predicted geologically, averaging around 4 to 6‰.

For carbon, I expect a wide range of isotopic variation, depending on if the deer sampled was migrant or resident, however, some of the variation will likely be due to environmental conditions, as plants are sensitive to variation in precipitation within this habitat, hence $\delta^{13}\text{C}$ could vary over time. The average $\delta^{13}\text{C}$ of the deer should represent of the average $\delta^{13}\text{C}$ for the landscape at the time the deer lived, plus a few permil.

The $\delta^{15}\text{N}$ of the deer collagen is also expected to range widely, as deer have specific dietary needs, in terms of protein content, which has been shown to vary with location,

precipitation, and life stage (Pekins and Mautz 1988; Scrivner et al. 1988; Stewart et al. 2003). Because of this, I expect the widest range in $\delta^{15}\text{N}$ for deer.

Elk: Tule elk (*Cervus canadensis nannodes*) is a subspecies of elk or wapiti endemic to California, whose ideal habitat did not include the Sierra Nevada (Whitaker et al. 2019). In general, tule elk show a preference for more open terrain and less forested areas, unlike that which characterizes most of the Sierra Nevada (Lanman et al. 2024; McCullough 1969), but is similar to the foothill woodland. However, recent research has identified some use of the range by elk during the few centuries leading up to and into the historic era (Lanman et al. 2024), although these accounts are well to the north of the study region in the vicinities of Lake Tahoe and Honey Lake. In particular, elk ranging through the west central Sierra Nevada were likely sink populations, pushed into marginal habitats from population pressures or predation pressure in the Central Valley marshlands. Broughton et al. (2023) suggest a similar situation for elk inhabiting some areas of the San Francisco region.

Only one elk specimen was identified within the selection of faunal samples, the lunate shown in Figure 5.3a–b. Because so few elk specimens exist from Sierran contexts, I have included two pictures of this specimen. Figure 5.3a shows the entire specimen, with the piece broken off as a sample, while Figure 5.3b shows the sampled piece in relation to a scale bar.

Elk, like deer, are herbivorous ruminants, but their diets differ from those of deer. Where elk show a preference for leguminous shrubs and forbs (Broughton et al. 2023; McCullough 1969), deer are more dietary generalists. However, elk will consume a greater amount of grasses than deer when the available forage is restricted to grasses versus shrubs and trees (Gogan and Barrett 1995; Stewart et al. 2003). Tule elk are herding animals, with large seasonal home ranges, and herd densities and home range are highly variable (Whitaker et al. 2019). Local

circumstances, such as the availability of preferred forage or water, primarily dictate herd movements (McCullough 1969; Mohr et al. 2022; Whitaker et al. 2019).

I do not expect the elk sample to show a great deal of difference from the deer samples for $\delta^{13}\text{C}$, as both are ruminants and base their diets on C_3 resources. As there is only one elk sample, I expect that its $\delta^{13}\text{C}$ value will fall within the range exhibited by the deer. As well, I also expect the $\delta^{15}\text{N}$ of the elk to fall within the range exhibited by the deer, mainly because of similarities in digestion, but differ from deer in dietary variation. If the elk had spent a great deal of its life in the Sierra Nevada foothills around the Tuolumne area, then its $\delta^{34}\text{S}$ should fall within the deer range. If, however, it only occasionally foraged in the region, or was hunted outside the region and brought back (as it is a large meat package valued by humans), I expect the $\delta^{34}\text{S}$ to fall outside the local range. Considering that most elk ranged more widely across the expanse of the Central Valley, with different geological substrates according to runoff from Sierran rivers, a preference for marshy habitats, and the possibility of being hunted outside the region and brought back to the site, I expect the latter.

Leporids

Jackrabbit: The black-tailed jackrabbit (*Lepus californicus*) was the only member of the family Leporidae that returned reliable stable isotope results (Figure 5.3c). A few specimens of desert cottontail (*Sylvilagus audubonii*) were identified and processed, but returned results that did not meet preservation criteria; hence, I focus only on the former. Please note that only one specimen returned reliable results, however, if in the future more hares are tested isotopically from this region, these expectations should still hold and may serve as a guideline for future interpretations.

Black-tailed jackrabbits are ubiquitous throughout the Central Valley, Lower and Upper Sonoran Zones, and may be occasionally encountered within the Lower Montane Forest and chaparral, below the annual snowline (Jameson and Peeters 2004; Laws 2007; Schempf and White 1974; Schoenherr 2017; Storer and Usinger 1963). Home ranges vary between 0.2 and 1.4 km², and they prefer areas where visibility is not obscured by tall grasses or dense forest (Best 1996). Black-tailed jackrabbits are dietary generalists and hindgut fermenters, who typically feed at dusk or at night depending on weather conditions (Best 1996; Ugan and Coltrain 2011). At dusk or night also is when C₃ plants tend to have the highest water potential, and hence have open stomata and greater discrimination against ¹³C. Technically, this could serve to make hare $\delta^{13}\text{C}$ values more negative than animals that habitually feed during daylight on leaves.

Hares prefer shrubs and forbs to grasses, but will eat either when available, and are important dispensers of seeds (Best 1996). They are typically non-obligate drinkers, as long as daily forage provides up to 68% of water, especially in summer (Best 1996). Some coprophagy and urea recycling are present within the species at times, which suggests that fecal excretions are of greater nutritional quality than available forage; for urea, this may be reabsorbed to conserve water during periods of hot weather (Best 1996; Hirakawa 2001; Ugan and Coltrain 2011). Although black-tailed jackrabbits consume cecotrophs, or soft fecal pellets, the relationship between cecotrophy and urea recycling remains uncertain. Urea is typically recycled through the hindgut, and because cecotrophs are produced in the cecum and consumed directly, this process may allow jackrabbits and other small-bodied herbivorous mammals to recover nitrogenous compounds and microbial nutrients that would otherwise be lost (Best 1996; Hirakawa 2001; Somerville et al. 2018; Ugan and Coltrain 2011).

While hares may pursue similar vegetation as deer, because of their preference for feeding at dusk and night, I expect hare $\delta^{13}\text{C}$ to be more negative, or lower, than average for most other fauna. Due to cecotrophy and the uncertainties regarding recycling of urea, it is possible that $\delta^{15}\text{N}$ may be reduced compared to the ruminants, as microbial digestion of ingested cecotrophs should lead to more efficient nutrient intake and may minimize nitrogen losses, as suggested by Ugan and Coltrain (2011). Finally, I expect the hare $\delta^{34}\text{S}$ will fall within the range exhibited by the deer, but will represent a highly localized value that should correlate with the local geological substrate. While mass-capture of hares from outside the region is a possibility, the site from which the hare was recovered (TUO-935) is more than twenty km from the valley margin, where we might expect different values for $\delta^{34}\text{S}$. The likelihood that a single hare was hunted outside of the region and brought back is low.

Rodentia

Gophers: Two species of gopher, Botta's pocket gopher (*Thomomys bottae*) and the mountain pocket gopher (*Thomomys monticola*), likely represent the gophers in the faunal sample. Figure 5.3d shows an example of a mandible, which was the element most frequently encountered for these species. It is possible that the gophers both served as food, and were intrusive into the archaeological context—their presence with archaeological sites is almost ubiquitous within California—however, none of the samples here showed outward signs of being consumed. Their inclusion within this isotopic faunal analysis is to represent those taxa with the most restricted home range, and as taxa that may be the greatest dietary generalist.

Pocket gophers, in general, favor the roots, forbs, and corms that grow underground, but have also been observed feeding above ground, and will feed on grasses, shrubs and trees when present or as needed (Grinnell and Storer 1924; Ingles 1952; Teipner et al. 1983; Verts and

Carraway 1999). They have been characterized as true dietary generalists, and will consume almost any above and below-ground vegetal material (Commendador and Finney 2016; Verts and Carraway 1999). Pocket gophers have also been shown to feed on mycorrhizal fungi, and are excellent spreaders of spores via their droppings, which benefit some species of oak and pine within similar forest ecosystems (Allen and MacMahon 1988; Taylor et al. 2009). Cecotrophy is also expected within this genus (Grant 2014).

Pocket gophers do not hibernate during winter and remain active year round (Grinnell and Storer 1924; Ingles 1952; Teipner et al. 1983). The average lifespan has been estimated to range between two to three years, and to a maximum of five (Grinnell and Storer 1924; Ingles 1952; Teipner et al. 1983). Burrows, or home ranges, may extend anywhere from three to 37 linear meters (Ingles 1952; Teipner et al. 1983). While territories largely overlap among individual pocket gophers, burrows and tunnel systems do not intersect those of another individual (Grinnell and Storer 1924; Ingles 1952; Teipner et al. 1983). Burrows may be abandoned by one gopher and then reoccupied by another gopher at a different point in the year, so home territories vary throughout the lives of these species, but at a highly localized scale (Grinnell and Storer 1924; Ingles 1952; Teipner et al. 1983).

I expect the mean value of $\delta^{13}\text{C}$ of gophers to be similar to that for deer. Even though roots have been shown to be isotopically heavier than leaves (Badeck et al. 2005; Cernusak et al. 2009), which should lead to less negative $\delta^{13}\text{C}$ values in root-consumers. *Because* gophers consume more than just roots, and all roots they do consume represent a wide mix of C_3 plants, their mean $\delta^{13}\text{C}$ value should be representative of the environmental average, similar to the deer. However, unlike the expectation for $\delta^{13}\text{C}$, because gophers consume cecotrophs, this should lead

to better nutrient absorption and more efficient N management. This would equate to a narrower range of $\delta^{15}\text{N}$ values for gophers than deer.

Gophers tend to be highly localized, and should display local $\delta^{34}\text{S}$. Because local $\delta^{34}\text{S}$ can vary across short distances with soil depth and among plant parts—especially roots versus leaves—the variation exhibited by the gophers may be greater than the deer based on diet. However, I expect the mean $\delta^{34}\text{S}$ for gophers to fall within the same range as the underlying bedrock, and to fall within the range exhibited by the deer.

Squirrel: Two squirrels are represented by the faunal sample. However, of the two, only one returned reliable results, shown in Figure 5.3e, and is discussed below. The other was identified as a California gray squirrel, and nitrogen results are not considered reliable likely because of burning or heat exposure.

One specimen of golden-mantled ground squirrel, (*Callospermophilus lateralis*), was identified and returned valid isotopic results. This mandible is shown in Figure 5.3e. It is a small-bodied diurnal squirrel, with an average weight ranging between 136-245 g (Jameson and Peeters 2004:220; Jesmer et al. 2011). It is widespread, occupying burrows throughout the Western United States, and is mostly found in mountainous environments in mixed hardwood and pine forests, and in cleared regions of lower elevations (Jameson and Peeters 2004; McKeever 1964). The golden-mantled ground squirrel is classified as asocial, with home ranges averaging 0.0375 km², but overlapping with others (Jesmer et al. 2011). The species shows a preference for feeding on hypogeal fungi (e.g., truffles), although herbaceous seeds and leaves (e.g., mule ears [*Wyethia mollis*]) also make a sizeable contribution to their diets (McKeever 1964; Pyare and Longland 2001; Tevis 1952). As a small-bodied herbivorous rodent, cecotrophy is also expected. Typically,

the species begins hibernation in late fall, and awakens to begin foraging in early spring, although this is dependent on snowpack at higher elevations (McKeever 1964).

The expectation for the $\delta^{13}\text{C}$ value of the one specimen is that it should fall within the same range as gophers and possibly the deer, likely between the two as their diet overlaps that of both species. For $\delta^{15}\text{N}$, I expect the squirrel to be on the lower end of deer, closer to gophers mainly due to the targeting of fungi and cecotrophy. I also expect $\delta^{34}\text{S}$ to fall between the range of the deer and gophers given the differences in home range size among the three.

Carnivores

A few species of carnivores were sampled, including badger, bear, coyote/wolf/dog (*Canis* sp.), and a gray fox. Unfortunately, none except the *Canis* produced valid C and N results, and the results of the remaining samples suggested that burning or exposure to high temperatures had altered the N content of most of these specimens (this was also true for many of the other specimens analyzed). As such, only the *Canis* is discussed below.

The *Canis*, represented by a proximal phalanx, shown in Figure 5.3f, could not be distinguished to species, although it likely belonged to either *Canis latrans* (coyote) or an Indigenous domestic dog, *Canis lupus familiaris*, based on body size. The coyote is classified as an opportunistic feeder, with wide dietary variation that includes berries, fruits, and vegetables as well as meats of various birds, rodents, hares, and other mammals (Bekoff 1977). Recent work detailing coyote diet suggests a continuum between omnivory and carnivory, indicating considerable plasticity to their diets (Webster et al. 2024). While the exact diets of domesticated dogs from Indigenous communities are unknown, many have speculated that, beyond opportunistic hunting, dogs were provisioned with human scraps, and possibly human feces (Hillis et al. 2020; Rick et al. 2011). The home-range size of coyotes varies with latitude,

suggesting increased dietary constriction at northern latitudes as home ranges are larger; however, typical territory size ranges between 2 to 4.5 km² for both males and females (Gompper and Gittleman 1991). While, for domesticated dogs, a home range comparable to that of their human counterparts can be assumed, which is larger than that covered by coyotes.

In both instances, whether the sample represents an Indigenous dog or a coyote, I expect both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to indicate one trophic level increase above its main protein source. More specifically, I expect the dog/coyote sample to show at least a one permil enrichment in carbon compared to the average for sampled herbivores, or a subset of herbivores, and a three permil enrichment in nitrogen compared to the average for the herbivores. In general, the diet of this one dog/coyote may be comparable to the humans within the next chapter. I expect the $\delta^{34}\text{S}$ of this dog/coyote to fall within the range of the herbivores, given that the meat portion, or protein portion of the diet for this animal should reflect that for the average of its diet, with no trophic enrichment.

5.3.3 Sample Processing and Submission Methods

All samples were weighed and photographed, cleaned of any visible external or interior detritus using a scalpel. All samples were then mechanically cleaned with a diamond tip bit using a hand-held rotary drill or Dremel. For specimens that contained cancellous bone, the bone was split, the cancellous bone removed, and then mechanically cleaned.

Following mechanical cleaning, samples were sonicated in deionized filtered water (dH₂O) in five-minute increments, with water decanted and replaced each increment until the water remained clear after sonication. Samples were then placed into individual lab-grade weigh boats to dry for up to a week. After drying, sample weights were again recorded.

Chemical processing for collagen extraction followed a modified Longin (1971) procedure. Samples were placed into individual 20ml glass scintillation vials, enough 0.5M HCL was added to cover the sample, and sample vials were placed in refrigeration at 4°C. HCL was replaced every other day until samples were demineralized, or stopped reacting, for a period lasting up to two weeks. Samples that took longer than two weeks to demineralize were then assessed for demineralization and condition. Those that were still reacting after two weeks were left in the process of demineralization until they were finally demineralized. Those that had demineralized as expected were rinsed to neutrality in deionized filtered water, drained, and 0.125M NaOH was added (enough to cover the sample), and left to soak for 24 hours.

Some samples did not survive the NaOH step and had dissolved completely within the NaOH solution, and were discarded. This has been noticed previously by other researchers for bones that have been burned (Schurr et al. 2008). For those that survived, NaOH was then decanted, samples were again rinsed to neutrality, and HCL-buffered water (pH3) was added to each sample, and caps replaced. Samples were then placed into a 60°C scientific oven to solubilize the collagen pseudomorphs for up to a week. The pH3 solution was added as needed during the solubilization process. Solubilized collagen was pipetted into individual pre-weighed 20mL glass scintillation vials, frozen, then lyophilized to remove remaining moisture. Prior to submission for stable isotope analysis, the collagenous protein extracts were weighed to calculate percent collagen yield—a weak measure of sample preservation.

For submission for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis, between 0.5 to 1.2mg of collagen was weighed into a pre-formed tin (Sn) capsules. These capsule samples were submitted to the UC Davis Stable Isotope Facility (UCD SIF) and run on a Elementar vario EL cube elemental analyzer interfaced to an Elementar VISION IRMS (Elementar Analysensysteme GmbH,

Langenselbold, Germany). During analysis, samples were interspersed with reference material replicates of Chitin, Amaranth Flour, Caffeine, Enriched Alanine, Glutamic Acid, Scallop, and Nylon Powder. These reference materials have been previously calibrated against international reference materials, including IAEA-600, USGS-40, USGS-41, USGS-42, USGS-43, USGS-61, USGS-64, and USGS-65. Each sample's provisional isotope ratio was measured relative to a reference gas peak analyzed with each sample. These provisional values were finalized by correcting the values for the entire batch based on the known values of the included laboratory reference materials. The final delta values are expressed relative to international standards VPDB (Vienna Pee Dee Belemnite) for carbon, and Air for nitrogen. The long-term standard deviation is 0.2 ‰ for $\delta^{13}\text{C}$ and 0.3 ‰ for $\delta^{15}\text{N}$. For this project, the mean standard deviation for reference material replicates for $\delta^{13}\text{C}$ was $\pm 0.11\text{‰}$, and $\pm 0.07\text{‰}$ for $\delta^{15}\text{N}$. The mean absolute accuracy for calibrated reference materials in this analytical run was $\pm 0.05\text{‰}$ for $\delta^{13}\text{C}$, and $\pm 0.08\text{‰}$ for $\delta^{15}\text{N}$.

For $\delta^{34}\text{S}$, collagen samples were weighed into preformed tin capsules on a microbalance at the UCD SIF lab. Sample weights ranged between 6 to 11.4 mg. Stable isotope ratios of ^{34}S in solid samples were measured using an Elementar vario ISOTOPE cube interfaced to an Isoprime PreciSION IRMS (Cheadle Hume, Stockport, UK). During analysis, samples were interspersed with reference material replicates of Cysteine, Bovine Gelatin, Glutathione, Blue-green algae, Salmon muscle, and Taurine to monitor and allow for correction of any potential variation in drift and linearity. These laboratory reference materials have been directly calibrated against IAEA S-1, S-2, and S-3, as well as NBS-127, SO-5, and SO-6. The long-term reproducibility of this method is $\pm 0.4\text{‰}$. Final $\delta^{34}\text{S}$ values are expressed relative to Vienna Canyon Diablo Troilite. The mean standard deviation for reference materials for this project was $\pm 0.69\text{‰}$, with a mean accuracy for calibrated materials measured as $\pm 0.15\text{‰}$.

Both prior to, and after receiving the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results of the faunal samples, 12 were submitted to International Chemical Analysis Inc. ([ICA](#)), in Damascus, MD, for AMS radiocarbon dating. ICA uses AMS technology in a tracer-free environment (no enriched or ^{14}C -labeled samples are permitted), and has provided thousands of dates over the years (more than ten) they have been in business. One sample had previously been submitted to Direct AMS, who were unavailable to process the remaining faunal samples at the time of this project. Of the 13 faunal samples submitted for AMS ^{14}C analysis, all but one produced results. One sample (TUO-935 68a) is thought to have had wet collagen by the time it arrived and produced no AMS results—nor did it produce reliable stable isotope results, and curiously one sample (TUO-935 68b) which produced a reliable AMS date did not produce *any* $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results. For both samples, % collagen yield was not a reliable indicator of collagen preservation, and despite producing 4.4 and 1.9 mg collagen, respectively, neither sample had reliable $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results. This may speak to the preservation issue encountered at TUO-935 for the faunal samples, where even a darkened color without any other outward appearance (as compared to the remains from TUO-395, which showed cracking and warping), indicated sample preservation issues. All AMS dates were calibrated using CALIB rev.8, version 8.2 (Stuiver and Reimer 1993), and are reported below in both uncalibrated and calibrated forms.

5.3.4 Estimating Precipitation from Faunal Remains

Broughton et al. (2023:SI) supply collagen $\delta^{13}\text{C}$ values and radiocarbon dates on the elk from the King Brown site (CA-SAC-29), as well as collagen $\delta^{13}\text{C}$ from modern-era samples, which provides a very convenient way to test collagen-based $\delta^{13}\text{C}$ precipitation estimates using Kohn's (2010) Equation 2 (see also Chapter 4.3.1, Eq. 6). However, this may contra-indicate some of the findings from Broughton et al. (2023) regarding climate change during the MCA.

Interestingly, Broughton et al. (2023) found no evidence for climatic perturbations, such as the MCA drought, that would explain the pattern of resource depression or elk hunting, based on the paleoclimate model and weak correlations between the light stable isotopes. Because of my interest in how climate and the environment can affect human foraging decisions, I more closely examined the collagen $\delta^{13}\text{C}$ results from Broughton et al. (2023). While their analysis of the modern elk samples is only briefly mentioned, and served as a way for them to test if there were differences in the environmental settings between two locations where modern elk herds are found; like the archaeological estimates, no mention of a comparison between modern and archaeological elk populations was made for $\delta^{13}\text{C}$.

However, if the averages of collagen $\delta^{13}\text{C}$ from their archaeological samples from King Brown are compared to those of the modern elk samples (Broughton et al. 2023), there are differences. This is especially true after accounting for atmospheric differences in $\delta^{13}\text{CO}_2$ between the two periods (i.e., the Suess effect). The average $\Delta^{13}\text{C}$ for archaeological specimens (King Brown, 14.7‰) is less than the modern by 2.2‰ (Point Reyes, 16.9‰) to 0.81‰ (Cache Creek, 15.5‰); archaeological-era $\delta^{13}\text{CO}_2$ was estimated according to each specimen's calibrated radiocarbon range; while the modern was estimated for the period 2016-2018 based on collection dates. This suggests less rainfall during the period covered by the archaeological specimens compared to the modern. This is an important factor to consider. While the King Brown site is not located in Cache Creek/Bear Valley or Point Reyes, the archaeological elk herds would have ranged more widely across the landscape than their modern counterparts who lived within these latter two localities. This suggests that archaeological elk experienced highly variable precipitation patterns, which because of averaging across a broader swath of land, should have acted to remove much of the difference between precipitation in the Cache

Creek/Bear Valley location and the Lower Sacramento Valley if paleoprecipitation was equivalent to that experienced in the modern era. Precipitation in Bear Valley between 2010–2018 averaged around 661 mm, with an annual high of 1,020 mm in 2017 and a low of 146 mm in 2013 (PRISM Group 2025a). This record indicates high precipitation variability in Cache Creek/Bear Valley, but the modern elk from this region still indicate greater precipitation than that experienced by the archaeological herds in the Lower Sacramento Valley.

Instead of relying on a paleoclimate model, I reexamined the collagen $\delta^{13}\text{C}$ from the King Brown archaeological specimens with the understanding that there was a difference between the modern specimens and the archaeological specimens that could not be accounted for by differences in atmospheric $\delta^{13}\text{CO}_2$ alone. This reevaluation is meant to facilitate comparisons of estimated precipitation between the Central Valley and the west Central Sierra Nevada over the last 3000 years. However, there is some uncertainty in the most robust method for calculations, and the reliability of estimated precipitation from collagen $\delta^{13}\text{C}$ values. I chose to work with the collagen values provided by Broughton et al. (2023) because, despite collagen reflecting dietary protein, it should be more comparable to my sample set data, and if estimating precipitation from collagen $\delta^{13}\text{C}$ is successful, then it should work for apatite values as well.

I first use Broughton et al.'s (2023) modern-era samples to test Kohn's (2010) regressions against precipitation data from PRISM Group (PRISM Group 2025a, 2025b) for Tomales Bay/Point Reyes and Cache Creek/Bear Valley, from which the modern samples were collected. I treated the sample data as if they were from archaeological contexts. The modern samples were collected between 2017 and 2019 (Broughton et al. 2023), and like archaeological specimens, exact animal age at death is unknown. Of note is that a $\delta^{13}\text{C}$ collagen-diet offset of -5.1‰ (Kohn 2010) grossly overestimated precipitation, and no correlation was found between

the modern precipitation records and the precipitation estimates, even if $\delta^{13}\text{CO}_2$ was adjusted up to -8.6‰ which is the average for 2018 alone (Belmecheri and Lavergne 2020). As such, I used a $\delta^{13}\text{C}$ collagen-diet offset of -4‰, and the average $\delta^{13}\text{CO}_2$ (Belmecheri and Lavergne 2020) from the period 2008 to 2018 to adjust collagen $\delta^{13}\text{C}$ from the elk samples to $\Delta^{13}\text{C}$ using the derivative of Eq. 2 from Chapter 4. Latitude and longitude of collection points were provided in Supplementary Appendix C (Broughton et al. 2023), which I used to create an average point—one point per geographical area, Point Reyes and Cache Creek—to represent the data I would need to extract precipitation data from PRISM Group (2025a, 2025b). Because elk range widely but are more confined within the boundary of the Point Reyes National Seashore, owing to its unique geography and use as ranchland, I selected a spot on the landscape that would capture some of the variability in precipitation between lowlands and hills. I added each $\Delta^{13}\text{C}$, latitude, and estimated elevation into the formula.

Precipitation estimates were separated into groups according to age classification (adult and juvenile/yearling) provided by Broughton et al. (2023), and material type (antler versus bone/tooth). For antlers, knowing that they are shed every year, grouping them together made more sense, as they should reflect one precipitation period per antler. Bones, which remodel slowly, were grouped with teeth, as they should be comparable for elk. Juveniles were grouped with yearlings, as they should represent similar values as antlers, while all adults were grouped together. This process was repeated for both sample set locations. The precipitation estimates were then averaged for each of the created groups and compared to the PRISM Group (PRISM Group 2025a, 2025b, 2025c) annual and monthly precipitation records for the period 2008 to 2019 to see where the strongest correlations were. Instead of using monthly precipitation, as with

the oak samples from Chapter 4, I used the annual record in this instance as, although a more coarse-grained measure, it still captures general precipitation trends.

No groups showed any correlations with precipitation patterns prior to 2010, which suggests that all animals were younger than a 2010 birth year, or that the sampled bones had remodeled and erased the pre-2010 values. The average $\delta^{13}\text{CO}_2$ was then adjusted and 2008–2009 were removed from the average, and precipitation estimates were recalculated. As a double check on the estimates within each group, I also averaged all groups for a location together, and checked the precipitation estimate for that average against the 2010–2018 average precipitation. By doing this, I was able to narrow the timeframe, and further adjust $\delta^{13}\text{CO}_2$ to better reflect that experienced by the elk and the foods they ate. For the Cache Creek area, no further adjustment was needed. However, the average precipitation for the Point Reyes group indicated that the time frame was too long. The time frame for the Point Reyes group was further adjusted to 2016–2018, where $\delta^{13}\text{CO}_2 = -8.5\text{‰}$, as all samples were collected in mid-April of 2019. Because these are modern samples, which can be directly compared to precipitation records, and because of the direct link between diet and $\delta^{13}\text{C}$, I expect a reasonably strong correlation between collagen $\delta^{13}\text{C}$ and precipitation, despite collagen $\delta^{13}\text{C}$ reflecting mainly dietary protein. This issue is discussed in the results section, below.

Note that PRISM Group (2025c) are monthly precipitation records for the same period and location in Point Reyes. This record (PRISM Group 2025c) allowed me to deal with the single sub-adult rib from this locality, and based on its individual precipitation estimate, it was grouped with the antlers as the time frames overlapped, otherwise this sample was anomalous and showed no correlation with yearly totals. Also of note, the antler samples from Point Reyes were comprised of two pieces of the same antler, but I treated them as individual samples since

they represented overlapping points in time. As well, for the Point Reyes group, I separated the bone samples from North and South Tomales Bay, as they showed some minor differences.

In Chapter 6, I use the $\delta^{13}\text{C}$ and radiocarbon dates on the elk from King Brown to see how they align with estimates from the Sierra Nevada faunal and human samples as a check on broad-scale paleoclimate models. A robust comparison between the Sierra and King Brown faunal precipitation estimates is not possible at this time, as there are too few Sierran faunal samples which date earlier than 600 cal BP, while the majority of the King Brown samples (Broughton et al. 2023) are older than this date. However, with the inclusion of humans, a comparison may be possible. For now, below, I use the archaeological specimens from King Brown to estimate precipitation over the last 3,000 years for the Lower Sacramento Valley, and the fauna from the Sierra Nevada contexts mainly for the last 600 years. Estimated precipitation from these two sets of faunal remains comes from averaging the individual precipitation estimates according to the range of the calibrated radiocarbon dates. There is overlap among AMS age ranges, to determine how samples should be grouped, I used calibrated median dates.

5.4 Results and Discussion

5.4.1 Results and Discussion: $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{34}\text{S}$, AMS ^{14}C , and Preservation

Table 5-3 shows the results of the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{34}\text{S}$, and AMS radiocarbon dating on the well-preserved samples, while Table 5.4 shows the summary statistics for these samples. Table 5-3 is organized by taxa and Sample Identification information. Collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ quality control criteria applied here include: weight % C above 5.2; weight % N above 1.8; atomic C:N between 2.9 and 3.8; and collagen yield above 1% (Ambrose 1990; DeNiro 1985; Guiry and Szpak 2021). For samples where $\delta^{34}\text{S}$ was assayed, the measures of preservation (weight % S

between 0.15 and 0.35%, Atomic C:S of 600±300, and Atomic N:S of 200±120) (Nehlich and Richards 2009) are provided. For atomic N:S, Nehlich and Richards (2009) recommended a range between 200±100, while I use a larger error range of ±120 based on their results for modern chinchillas and guinea pigs, where the N:S ratio falls below 100 as it did for the archaeological gophers studied here. This protocol is similar to what is recommended by Privat et al. (2007) for archaeological specimens, yet it is still more conservative than their N:S above 60. Also shown in Table 5-3, AMS radiocarbon dates are presented as uncalibrated and calibrated (years BP; median rounded to the nearest 5; and range at 98.5% confidence). Calibrated forms are from CALIB online (Stuiver and Reimer 1993). Only samples which met all quality control criteria are shown in Table 5-3 and Table 5-4. Some samples that only partially met quality control criteria are further shown in Table 5-5 and discussed below, while those outside of acceptable measures of preservation can be found in Appendix B.

Table 5-3 Summary Results of Isotopic Analyses and Collagen Quality Control

<i>Taxa</i>	<i>ID</i>	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)	% C	% N	%S	C:N	C:S	N:S	^{14}C	±	Med cal BP	2σ cal BP
Deer	TUO-300 unk 15f	-21.0	7.1	-	38	13	-	3.45	-	-	2460	30	2560	2365 - 2705
Deer	TUO-314 unk 7Bf	-20.5	3.3	-	39	15	-	3.12	-	-	545	26	545	520- 625
Deer	TUO-395 325f	-19.4	4.4	6.9	55	20	0.3	3.27	435	133	1640	30	1520	1410 - 1685
Deer	TUO-935 42b	-20.7	4.5	5.6	43	15	0.3	3.37	340	101	270	30	320	0- 440
Deer	TUO-935 104a	-21.7	3.1	3.0	45	16	0.3	3.26	443	136	230	30	205	0- 420
Deer	TUO-935 119a	-20.6	4.7	5.0	45	16	0.3	3.28	469	142	160	30	165	0- 285

<i>Taxa</i>	<i>ID</i>	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	$\delta^{34}\text{S}$ (‰)	% C	% N	%S	C:N	C:S	N:S	^{14}C	$\pm$	<i>Med cal BP</i>	2σ <i>cal BP</i>
Deer	TUO-935 119b	-20.7	4.8	5.9	77	27	0.3	3.27	761	232	490	30	520	500-545
Elk	TUO-935 126b	-21.7	5.3	-0.5	48	15	0.3	3.76	392	104	200	30	185	0-305
Jack-rabbit	TUO-935 143a	-22.3	2.5	6.2	49	17	0.3	3.29	477	145	630	30	600	555-655
Pocket gopher	TUO-935 68c	-21.2	2.6	6.5	45	16	0.3	3.25	396	121	670	30	635	560-670
Pocket gopher	TUO-935 68d	-18.6	3.6	1.8	41	14	0.3	3.30	317	96	210	30	185	0-305
Pocket gopher	TUO-935 180b	-21.2	3.7	-	40	14	-	3.30	-	-	-	-	-	-
Pocket gopher	Tuo-300 B11f	-21.5	3.4	6.2	35	12	0.3	3.31	272	82	-	-	-	-
Gm. ground squirrel	TUO-935 90d	-19.1	2.4	4.1	45	16	0.3	3.27	412	126	2030	40	1970	1840 - 2100
Coyote / Dog	TUO-935 90a	-19.4	6.2	4.1	39	14	0.3	3.30	335	101	380	30	445	320-585

Note: table is organized by taxa. and includes Sample ID, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{34}\text{S}$, weight percent C, weight percent N, and weight percent S, C:N, C:S, and N:S, as well as uncalibrated radiocarbon dates and error; calibrated median dates (shown in cal BP), 95.4% confidence interval (2σ) ranges (cal BP). Dark vertical borders separate sample information from isotopic, quality control result, and radiocarbon information. Percent collagen yield is not shown, but ranged between 1 to 18%. Dark horizontal bars indicate separation among taxa/Family as in text. ID is sample identifier; weight percent is shown as “%” and represents atomic mass; weight % S is only shown to the nearest tenth; $^{14}\text{C} \pm$ represents radiocarbon error; “Med. cal BP” means Median calibrated radiocarbon date in years BP; a dash (-) indicates no data.

Nearly all samples which passed the quality control criteria were well preserved, while the elk was questionable. A closer examination of the elk indicated that, according to the criterion and experiments outlined by Guiry and Szpak (2021), its collagen results may have been slightly altered (up to 1‰ for carbon) by humic contaminants not removed by the NaOH step, but the amount of humic contamination likely was not enough to affect more general interpretation, which is why it is included here. The isotopic results for this elk are comparable to

those presented by Broughton et al. (2023) for elk from the King Brown site, shown in Table 5-6 for comparison. If the $\delta^{13}\text{C}$ of the elk from TUO-935 is adjusted up by a full 1‰ it still falls within the narrow range exhibited by elk at King Brown. The $\delta^{15}\text{N}$ of the elk also falls within the range of values exhibited by the King Brown elk specimens. As such, the elk from TUO-935 is included with the well-preserved samples, and I make every attempt to cautiously interpret its diet, and residential status as either local or non-local to the Sierra Nevada.

Table 5-4 Summary Statistics for Faunal Results

Taxa Grouping:	Mean $\delta^{13}\text{C} \pm \text{SD}$	Range $\delta^{13}\text{C} \text{‰}$	Mean $\delta^{15}\text{N} \pm \text{SD}$	Range $\delta^{15}\text{N} \text{‰}$	Mean $\delta^{34}\text{S} \pm \text{SD}$	Range $\delta^{34}\text{S} \text{‰}$
<i>Deer</i>	$-20.6 \pm 0.69\text{‰}$	-21.7 to -19.4	$4.6 \pm 1.32\text{‰}$	3.1 to 7.1	$5.3 \pm 1.32\text{‰}$	3.0 to 6.9
<i>Artiodactyls</i>	$-20.8 \pm 0.74\text{‰}$	-21.7 to -19.4	$4.6 \pm 1.29\text{‰}$	3.1 to 7.1	$4.3 \pm 2.47\text{‰}$	-0.5 to 6.9
<i>Gophers</i>	$-20.6 \pm 1.38\text{‰}$	-21.5 to -18.6	$3.3 \pm 0.5\text{‰}$	2.6 to 3.7	$4.8 \pm 2.17\text{‰}$	1.8 to 6.5
<i>Rodentia</i>	$-20.3 \pm 1.38\text{‰}$	-21.5 to -18.6	$3.1 \pm 0.6\text{‰}$	2.4 to 3.7	$4.6 \pm 1.90\text{‰}$	1.8 to 6.5
<i>Herbivores</i>	$-20.7 \pm 1.07\text{‰}$	-22.3 to -18.6	$4.0 \pm 1.29\text{‰}$	2.4 to 7.1	$4.6 \pm 2.22\text{‰}$	-0.5 to 6.9
<i>All Fauna</i>	$-20.6 \pm 1.08\text{‰}$	-22.3 to -18.6	$4.1 \pm 1.37\text{‰}$	2.4 to 7.1	$4.6 \pm 2.13\text{‰}$	-0.5 to 6.9
<i>All Fauna (excluding Elk)</i>	$-20.6 \pm 1.08\text{‰}$	-22.3 to -18.6	$4.0 \pm 1.38\text{‰}$	2.4 to 7.1	$5.0 \pm 1.55\text{‰}$	1.8 to 6.9

Note: table summarizes the range, mean and sample standard deviation for the assayed light isotopes according to different groupings, such as taxon, family, herbivores, all fauna, and all fauna excluding the elk. “SD” means standard deviation.

If we compare the number of samples from Table 5-1 to those in Table 5-3, we can see that out of 58 samples, only 15 returned reliable isotopic results, a return rate of just under 25%. This low rate of return on investment in time and money may be one reason why more isotopic analyses are not done on faunal remains from the west-central Sierra Nevada. It may also explain why fewer faunal analyses exist for this region. Relatively high fracture rates, diagenesis, and pre-depositional heating or burning affect many, while all contributed to poor preservation and small faunal assemblage sizes. As mentioned previously, the dark staining exhibited on many of the faunal remains from TUO-935 was assumed to be from soil staining, as I did not observe any

graying, black streaks, or ashy powder during sample drilling. However, based on the isotopic results presented here, the dark staining may have been more than soil staining and was probably indicative of pre-depositional heating, such as from cooking, or from post-depositional forest fires resulting in heating of soils, which would have created a slightly anoxic environment that affected the color and stable isotope ratios.

One clue to bone heating lies with the samples that returned high C/N ratios, quality control results indicating addition of exogenous C, or most likely, the loss of N. Table 5-5 shows the samples that only partially met all quality control criteria, or which may have one plausible value despite failing to meet the quality control measures (see also Appendix B). Numbers highlighted in red and with an asterisk are those suspected of being diagenetically altered or which failed to meet the collagen quality control criteria. The $\delta^{13}\text{C}$ may be viable for some of these specimens because it is highly conservative across temperatures below 220°C (McNeill et al. 2025; Schurr et al. 2008, 2015). But the loss of N in most samples with altered % N and $\delta^{15}\text{N}$ results suggest pre-depositional heat alteration from cooking or fires. Heating over open coals, boiling, and cremation all have been shown to significantly alter bone collagen $\delta^{15}\text{N}$ and % N when temperatures exceed ~295° C (Sarancha et al. 2022; Schurr et al. 2008, 2015). Five samples in Table 5.5 met criteria for Atomic C:N, but failed to meet the minimums for weight percent C and N. With these samples, the weight percent C and N were low (< 2%), indicative of preservation issues, and in some instances despite a “good” collagen yield above 1%. This may be due to some samples having exogenous materials, such as salts that lack C and/or N, but have NaCl, O, and H.

Table 5-5 Examples of Preservation Issues

Taxon	Sample ID	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	wt.% C	wt.% N	Atomic C:N	% col. Yield
Deer	TUO-935 90C	-19.2	* 2.9	3.9	* 0.2	* 24.31	3.9
Deer	TUO-935 104B	*-24.6	* 2.6	* 0.7	* 0.2	3.66	* 0.5
Deer	TUO-935 196A	*-26.3	* -2.4	* 0.7	* 0.2	3.63	* 0.9
Deer	TUO-935 264A	-24.7	* 2.9	5.3	* 1.5	* 4.09	* 0.8
Jackrabbit	TUO-935 131B	-24.8	* -1.5	5.4	2.0	3.12	3.4
Cottontail	TUO-935 53B	*-27.9	* 21.6	* 1.5	* 06	3.04	9.9
Badger	TUO-935 196B	*-24.9	* -0.9	* 1.5	* 0.6	2.97	* 0.5
Bear	TUO-935 143B	-22.3	6.8	11.5	2.5	* 5.38	* 0.9

Note: table lists some of the results for poorly preserved or heat-affected samples which failed to meet all collagen quality control criteria. Values shown in red and marked by an asterisk are those that failed to meet criteria or which are suspect. “wt. % C” refers to atomic weight percent carbon; “wt. % N” refers to atomic weight percent nitrogen; “% col. Yield” means percent collagen yield.

In addition, some $\delta^{13}\text{C}$ values may also be more negative than would be expected for archaeological samples of the same species within the same region (e.g., deer). These results suggest bones were heated to higher than 220 °C, exogenous carbon with low $\delta^{13}\text{C}$ has affected these values, or both. The black bear canine has plausible $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, but failed to meet the main quality control criteria used by most isotopic studies, including C:N. Because the percent weight of N for the black bear sample is lower than expected, it calls into question the value for $\delta^{15}\text{N}$, despite the fact that the value *looks* plausible. It is possible that exogenous carbon precipitated into the dentinal matrix following burial, for example, if the tooth had been broken prior to burial. One sample, TUO-131b (jackrabbit), met all minimum standards for quality control criteria, but returned an anomalous negative $\delta^{15}\text{N}$ value. I rejected this sample as I can think of no plausible situation in which this is representative of an in vivo value for a coprophagist animal who lived in the warm and seasonally dry, low elevations of the Sierra Nevada. In short, all of these samples met *some* of the quality control criteria, but most also had unexpectedly high or low $\delta^{15}\text{N}$ values, and were rejected on one basis or another. Table 5-5

highlights why multiple quality control criteria for collagen samples should be used in all collagen-based isotopic studies, and echoes sentiments expressed by Guiry and Szpak (2021). The selection of archaeological faunal bones from western Sierra Nevada contexts for isotopic analyses may need to focus only on bones that show no dark staining, no cracking, no warping, and resemble only the most well-preserved bones. Although this approach will severely limit the number of samples available for isotopic analyses, it will save money and time in the long run.

Table 5-6 Quick Comparison of Elk

Study:	Site/Sample	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
This study	CA-TUO-935 126b elk	-21.7‰	5.3‰
Broughton et al. (2023)	King Brown (CA-SAC-29) elk	$-20.8 \pm 0.6\text{‰}$; -22.3– -19.4‰	$6.5 \pm 1.1\text{‰}$; 3.3–8.2 ‰

Note: table provides summary statistics for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of elk from the King Brown Site (CA-SAC-29) and the elk from CA-TUO-935. For King Brown, summary statistics include average, standard deviation, and a minimum to maximum range, while the elk from CA-TUO-935 is represented by single values.

Viable $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results are presented graphically in Figure 5.4. Here, the different taxa are color-coded, herbivore size class is shown by different symbols, the mean for all fauna is indicated by a black diamond, and error bars represent one standard deviation (SD). In this figure, the deer exhibit the greatest variation in $\delta^{15}\text{N}$, while the gophers exhibit the greatest variation in $\delta^{13}\text{C}$. The greater variance in $\delta^{13}\text{C}$ for gophers compared to deer was somewhat unexpected, especially since the minimum and maximum gopher values are from gophers at the same site. However, this spread may represent temporal or climatic differences, or differences in the plant species available to a geographically constrained area. However, when the $\delta^{13}\text{C}$ averages for deer and gopher are compared, they are equivalent. The elk falls within the range of deer for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, as expected based on feeding habits. The coyote/dog is about one permil more positive than the herbivores' average $\delta^{13}\text{C}$ (Table 5-4) as expected, but its $\delta^{15}\text{N}$ value is only 2.2‰ higher than the average for the herbivores. This result is somewhat

unanticipated given the expected range of trophic-level shifts in terrestrial environments.

However, if only the small-bodied mammals are considered, their average $\delta^{15}\text{N}$ is 3.0, which places the canid 3.2‰ higher representing one full trophic level. Perhaps the coyote/dog had greater access to small-bodied mammals than meat from herbivores, especially if it represents a coyote. However, it is also possible that human provisioning and fecal consumption could have created a similar situation for $\delta^{15}\text{N}$, if it was an Indigenous dog.

Overall, small-bodied mammals tend to have lower $\delta^{15}\text{N}$ than the larger-bodied mammals, as expected due to coprophagy, but they show greater variance in $\delta^{13}\text{C}$ than compared to the deer (Figure 5.4). For example, the single ground squirrel had the lowest $\delta^{15}\text{N}$, and its $\delta^{13}\text{C}$ value was the second highest, which may be due to mycophagy as well as the ingestion of cecotrophs. However, it did meet expectations for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. On the opposite end of the $\delta^{13}\text{C}$ spectrum is the jackrabbit, who had the most negative (lowest) value. This sample met the general expectation that its $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ would be lower than the average for deer. As this was a small sample of small-bodied mammals, it is surprising that the range of $\delta^{13}\text{C}$ exhibited by these different taxa was so large compared to the deer. However, I also expect with larger sample sizes, the degree of overlap with deer would increase significantly at both ends of the $\delta^{13}\text{C}$ continuum for C_3 consumers. Because of the variation in $\delta^{13}\text{C}$ exhibited by the paleobotanical samples, the range exhibited by the herbivores with different dietary preferences should be expected. However, as all of these animals consume a mix of C_3 plants, the general expectation is that variation in $\delta^{13}\text{C}$ at the plant level will still be reduced when it is transferred up the food chain to herbivores because many plants are averaged together over the animals' lifetime within their bone collagen. A comparison of predicted values based on paleobotanicals and herbivore diets is examined below.

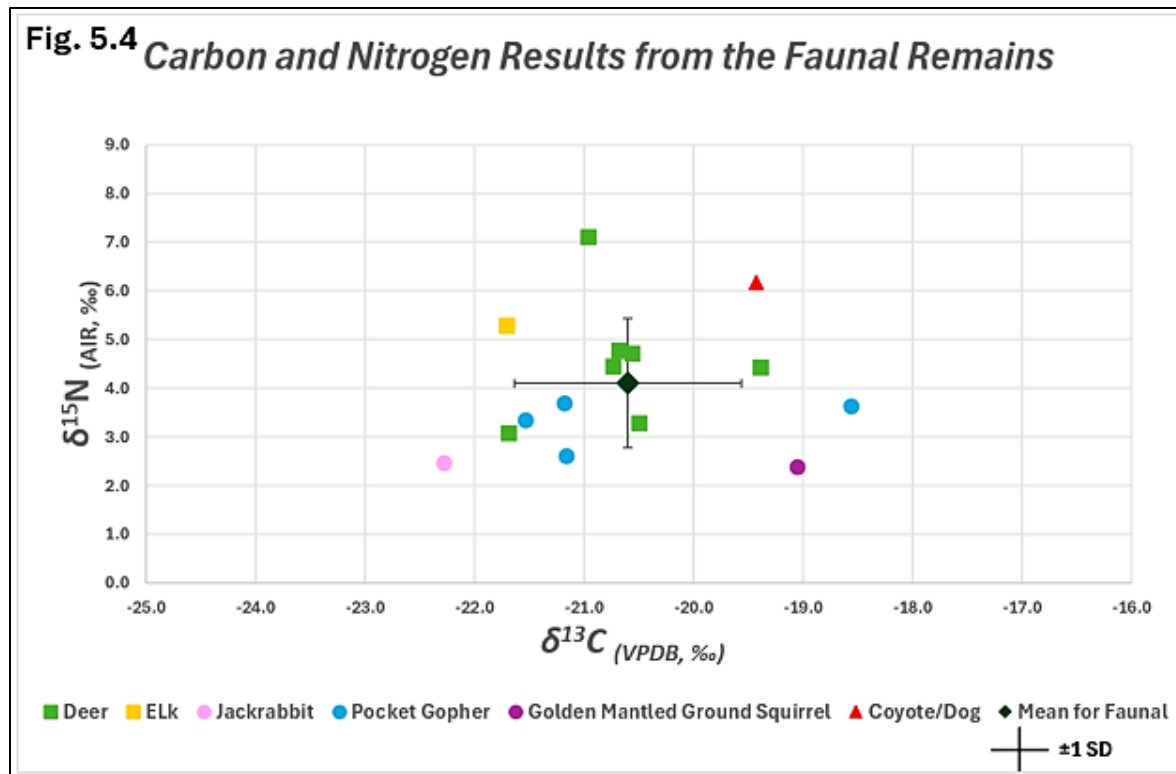
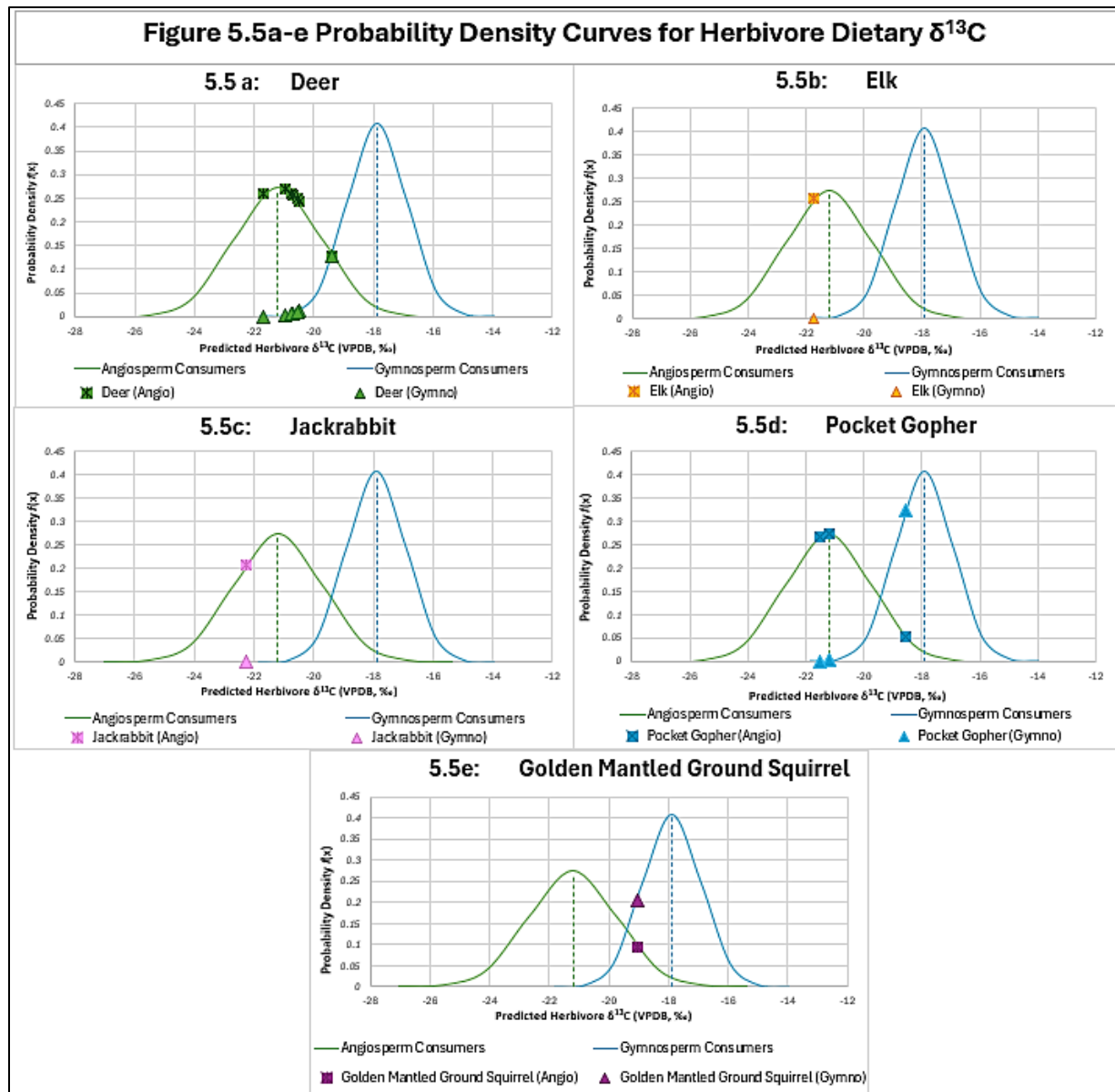


Figure 5.4 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ Results for the Faunal Remains
 Biplot of the faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results shows large-bodied herbivores are squares; small-bodied herbivores are circles, and the carnivore is a triangle. Color coding separates the different taxa. Black diamond is the average for all fauna and error bars show ± 1 standard deviation (SD).

Figures 5.5a-e show how the herbivore $\delta^{13}\text{C}$ values align with those predicted from the probability density distributions for angiosperms and gymnosperms from Chapter 4. I assume the faunal collagen $\delta^{13}\text{C}$ follows a normal distribution. As this distribution was previously indicated for plants (Diefendorf et al. 2010; Kohn 2010b), and as herbivore collagen $\delta^{13}\text{C}$ is a bulk average of $\delta^{13}\text{C}$ from dietary protein garnered from plants, these collagen $\delta^{13}\text{C}$ averages should also conform to a normal distribution. In these figures, each individual animal's collagen $\delta^{13}\text{C}$ value is represented by two points indicating the probability density function associated with consuming angiosperms (squares) versus gymnosperms (triangles). These probabilities were calculated using the predicted standard deviations for herbivore $\delta^{13}\text{C}$ from the paleobotanical samples, and were applied to the herbivores under study. The animals' diets are discussed below

in light of these probability distributions, radiocarbon dates, and alternative explanations from $\delta^{15}\text{N}$. Actual probabilities, discussed below, were derived for each animal by normalizing the two density functions so that probabilities add to 100%. Because the *Canis* is not an herbivore, it is discussed separately.

In Figure 5.5a, the deer $\delta^{13}\text{C}$ values (dark green) are shown in relation to where they fall on the probability density curves for angiosperms and gymnosperm consumers. All probabilities for strict angiosperm consumption are higher than for possible gymnosperm contributions, with the exception of one deer. Normalized probabilities for all but the one deer range between 99 and 95%, indicating angiosperm-based diets. The single deer in the mixed feeder region is likely a deer where the diet was split 50-50 between angiosperms and gymnosperms, or the diet included angiosperms that experienced drought over one third of this deer's life. This deer dates to between 1466 and 1587 cal BP, a time during which there are no known major droughts in California. However, in drought conditions, $\delta^{15}\text{N}$ would be expected to increase in plants (Handley et al. 1999; Ogaya and Peñuelas 2008), which should lead to an increase in $\delta^{15}\text{N}$ in consumer tissues. Importantly, compared to the average $\delta^{15}\text{N}$ for deer (4.6‰), this deer's $\delta^{15}\text{N}$ of 4.4‰ does not seem to indicate drought because it would signify that all (but one) of the deer experienced drought according to the $\delta^{15}\text{N}$, which is not congruent with the $\delta^{13}\text{C}$ values. In short, this one unusual deer appears to reflect a mixed angiosperm and gymnosperm diet.



Figures 5.5a-e Probability Density Curves for Herbivore Dietary $\delta^{13}\text{C}$
*The different herbivore taxa are shown plotted on the herbivore probability density curves. Individual animals are paired points indicating angiosperm versus gymnosperm probability density functions; **a)** Deer; **b)** Elk; **c)** Jackrabbit; **d)** Pocket Gophers; **e)** Golden Mantled Ground Squirrel. For each graph, squares denote angiosperm probability density functions, triangles indicate gymnosperm probability density functions.*

Figures 5.5b shows where the elk's diet (orange points) falls within the probability density distributions. As indicated, there is almost no chance this elk consumed gymnosperms. Its entire dietary protein came from angiosperm plants in a region of the curve that represents the

range for grasses and manzanita and only the most well-watered oaks within the Sierra Nevada. The elk, which dates to between 139 and 225 cal BP, lived during the Little Ice Age (LIA) when conditions are thought to have been cooler, and at times wetter. As such, the indication from Figures 5.5b is that the elk likely lived when few plants within the Sierra Nevada or Central Valley experienced moisture stress. The slightly above average $\delta^{15}\text{N}$ of this elk might indicate some drought-stressed plants were consumed; however, this interpretation is in contrast to that indicated by the $\delta^{13}\text{C}$. Instead, the $\delta^{15}\text{N}$ of this elk suggests two different possibilities: 1) it was in poor health, or 2) the area and foods it ate were slightly higher in $\delta^{15}\text{N}$ than what is suggested by the average $\delta^{15}\text{N}$ for deer. This result might be expected in the Central Valley, as it is lower in elevation, hotter, and drier during summer compared to the Sierra Nevada. Why would this elk wander into the Sierra Nevada if conditions were favorable in its preferred habitat? Possibly this elk was not living in the Sierra Nevada region, but rather it was hunted elsewhere and transported to the site. Alternatively, it may have wandered into the low elevations of the foothills where it was killed, but it would not have been a long-term resident.

Figures 5.5c shows the jackrabbit diet (pink marker) compared to the two probability density distributions. The jackrabbit's collagen, as mentioned before, had the most negative $\delta^{13}\text{C}$ of all the fauna, and as indicated by the graph. Thus, this jackrabbit relied on grasses and shrubs that were well watered. There is almost no chance this hare ate any gymnosperm products as a part of its diet. The hare dates to between 553 and 656 cal BP, near the end or just after the MCA. This period should have been wetter and cooler than the MCA or even today, which is reflected by the lowest $\delta^{13}\text{C}$ value in the study. This environmental interpretation is further corroborated by the $\delta^{15}\text{N}$ of this hare, which was among the lowest for all taxa, suggesting well-watered conditions during the hare's lifetime.

The diets of the pocket gophers are shown in Figures 5.5d in relation to the two probability density curves. There are four gophers represented here, but two overlap such that they are indistinguishable, and sit at the peak of the curve for angiosperms. These two gophers are from different excavation locations at the same site, and thus they are highly unlikely to be the same gopher. For most pocket gophers, it appears that the bulk of their diet comes from angiosperm products, as expected, given that there are more angiosperm than gymnosperm plants in most of the Upper Sonoran Zone of the Sierra Nevada, which is where these gophers lived. However, as also shown by the graph, one gopher had much greater gymnosperm contributions (86% probability) to its diet than angiosperms (14% probability), or alternatively that gopher lived during a period of drought conditions. Gophers tend to have short lifespans, so a drought lasting the majority of their life (1-3 years) is plausible. However, this particular gopher dates between 142 to 221 years cal BP, during the LIA, and is contemporaneous with the radiocarbon dates for the elk. Although small droughts are bound to have occurred during the LIA, the most plausible explanation is that the gopher's $\delta^{13}\text{C}$ actually reflects a heavier use of gymnosperm resources, such as might be expected to occur if it lived near the base of a pine tree and regularly accessed the roots as food, with only minor contributions from angiosperms to its diet. This is further corroborated by the $\delta^{15}\text{N}$ of this gopher, which is within instrumental error of two of the three other gophers. The $\delta^{15}\text{N}$ is also lower than the mean for all herbivores, and the mean for the deer.

One gopher stands as an outlier in its $\delta^{15}\text{N}$, and it also overlaps $\delta^{13}\text{C}$ at the peak of the angiosperm distribution. This gopher was dated to between 628 and 672 cal BP, falling at the end of the MCA. Interestingly, its $\delta^{15}\text{N}$ is nearly identical to that of the jackrabbit dating to the same period, which would suggest the MCA may have ended earlier in the Sierra Nevada than

previously considered, as both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ indicate well-watered conditions. However, this needs more corroboration than two faunal samples.

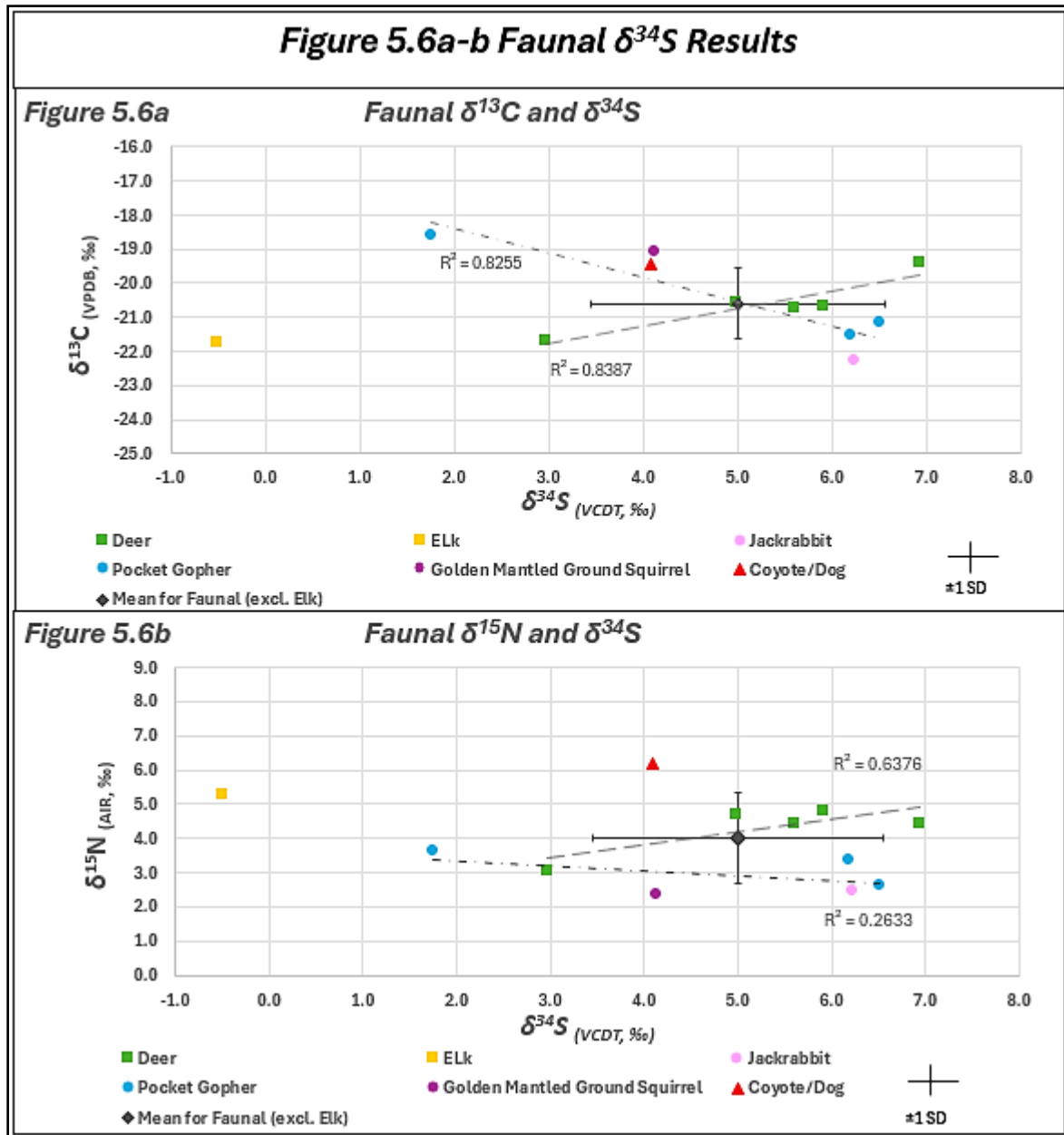
Last in the line of figures is the golden-mantled ground squirrel, whose $\delta^{13}\text{C}$ probabilities are shown in Figures 5.5e. As expected, this small ground squirrel likely relied on a mix of gymnosperm and angiosperm products, but its diet is more heavily weighted towards gymnosperms (69% vs 31% for angiosperms). Interestingly, this result could also indicate the $\delta^{13}\text{C}$ of some fungi within its diet are on the less negative side of the $\delta^{13}\text{C}$ continuum and comparable to well-watered gymnosperms, given this species' known mycophagy. Because this animal dates between 1840 and 2100 cal BP, it is possible it experienced drought conditions during its lifetime, which might account for the slightly higher (less negative) $\delta^{13}\text{C}$. However, the $\delta^{15}\text{N}$ of this squirrel does not suggest drought during its lifetime, as it is the lowest of all the taxa assayed. Hence, this ground squirrel fed on more gymnosperm than angiosperm products, and possibly fungi which likely reflect minor carbon enrichment compared to the detritus on which they grow.

Twelve samples had $\delta^{34}\text{S}$ results which passed the quality control criteria outlined above, and are shown in Figures 5.6a-b. Dot-dash lines represent trendlines for small mammals, long dashed lines represent trendlines for deer. Large-bodied herbivores are represented by squares, small-bodied herbivores are shown as circles, and the carnivore is shown as a triangle. Individual taxa are separated by color. The means (black diamonds) and standard deviations (SD; bars) for all Sierran fauna exclude the elk. The low $\delta^{34}\text{S}$ value (-0.5‰) for the elk (yellow square) mark it as an outlier from other fauna in the region. Based on the geological and soil $\delta^{34}\text{S}$ values, which range from 1.6–6.9‰, particularly around the main Tuolumne body of the granitic batholith, we should expect most faunal values to fall within and just above this range, which the elk does not.

This finding corroborates the findings from the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analyses discussed above. As such, the elk may have wandered into the lower elevations of the Sierra Nevada where it was hunted, or may have been hunted in the Central Valley, but in either case, it was not a resident of the Sierra Nevada.

In Figures 5.6a, faunal $\delta^{34}\text{S}$ values are plotted against the corresponding $\delta^{13}\text{C}$ values. As shown in Figure 5.6a, gopher $\delta^{34}\text{S}$ values (blue dots) represent a slightly larger range than even the deer (green squares), however, because gophers do not migrate and it is possible that some of the deer did migrate, I expect these two taxa to represent the range of values that should be expected of Indigenous people who lived within this region. The highest $\delta^{34}\text{S}$ value is from a deer from the Columbia College Collection (who is also the gymnosperm consumer), while the next highest and the lowest, are from two gophers from TUO-935. All other taxa, except the elk, fall within this range; this includes a gopher from the most south-westerly site of TUO-300, as well as the Canis. In general, the Canis might better represent what should be expected of the average for $\delta^{34}\text{S}$ of the Indigenous people, as it is the only animal that would include meat within its diet, and possibly range alongside the humans.

In Figures 5.6a, a closer examination of the $\delta^{34}\text{S}$ versus the $\delta^{13}\text{C}$ indicates there may be some differences between the deer and the small-bodied mammals. For deer, there seems to be a tentative but strong ($R^2 = 0.84$) positive relationship in $\delta^{34}\text{S}$ as $\delta^{13}\text{C}$ increases, indicated by the long-dashed line, while the small-bodied mammals *seem* to show a strong ($R^2 = 0.83$) negative relationship between increasing $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$, indicated by the dot-dashed line. Although the sample size is small, and these linear relationships may be a circumstance of chance, there are a few possible explanations for such a pattern.



Figures 5.6a-b Faunal $\delta^{34}\text{S}$ Results

Figures show $\delta^{34}\text{S}$ values plotted against the $\delta^{13}\text{C}$ (a) and $\delta^{15}\text{N}$ (b) results. Squares represent large-bodied herbivores, circles represent small-bodied herbivores, a triangle represents the carnivore. Black diamonds represent the mean values for all fauna excluding elk, error bars shown at $\pm 1\text{SD}$. Dot-dash lines represent trendlines for small mammals, long dashed lines represent trendlines for deer.

First, the two endmembers representing the highest $\delta^{13}\text{C}$ and the lowest and highest $\delta^{34}\text{S}$ are represented by the gopher and deer who had some gymnosperm contributions to their diets. There is a general expectation that leaves and fruiting bodies of plants will be more enriched in

$\delta^{34}\text{S}$ than roots or stems (Tarrant and Richards 2024; Tcherkez and Tea 2013). The difference in $\delta^{34}\text{S}$ between the gopher with gymnosperm contributions to its diet and that of the deer with gymnosperm contributions suggests that the roots eaten by the gopher were depleted in $\delta^{34}\text{S}$ compared to the leaves, nuts, other above-ground plant parts consumed by the deer. However, this relationship among different plant parts has not been well studied in natural systems, and has mainly focused on herbaceous angiosperms (Tarrant and Richards 2024; Tcherkez and Tea 2013). It is because of this small sample size and the uncertainties regarding differences among plant parts that this explanation needs further testing.

Second, previous work within the Sierra Nevada along an elevation transect from 470 to 2890 m asl indicated a linear correlation between increasing MAP with increasing elevation, as well as an increase in foliar $\delta^{34}\text{S}$ from 4.7‰ in low elevations to 5.8‰ in the higher elevations (Yi-Balan 2013:36). This result suggests that at low elevations, $\delta^{34}\text{S}$ should be lower because of reduced bacterial activity and dryer soils, and higher at high elevations because it is moister. While this might explain part of the pattern for the small-bodied mammals, it is unexpected as they do not migrate over long distances, and human transport decisions for small-bodied creatures would suggest the energetic cost to transport a small-bodied creature over long distances far outweighs the caloric benefit. Hence, it is mainly because of the gymnosperm contributions to this gopher's diet and to that of the ground squirrel that the linear relationship is so strong for the small-bodied mammals. If we account for an offset between gymnosperms and angiosperms and adjust the diets of these two small-bodied mammals, the strong linear relationship between $\delta^{34}\text{S}$ and $\delta^{13}\text{C}$ for the small-bodied mammals disappears.

However, removing or adjusting the diet of the gymnosperm-consuming deer does not remove the linear trend, although it does slightly weaken the relationship (R^2 of 0.83—not shown

in graph). This result suggests that territory size and possibly migration status may be responsible for the pattern seen in deer, but not for the small-bodied mammals. If we consider the two end-members of deer, the strict-angiosperm consumer with the lowest $\delta^{34}\text{S}$ and lowest $\delta^{13}\text{C}$ and the one with gymnosperm contributions and the highest $\delta^{34}\text{S}$, the low $\delta^{34}\text{S}$ deer may represent a resident deer who foraged strictly within the overlapping mosaic of the Upper Sonoran Zone and the Lower Montane Forest, during a period when plants were not drought-stressed (LIA). As indicated by Figures 5.6a, the remaining deer all have higher $\delta^{34}\text{S}$ and *may* represent those that migrate, where individual forage preferences may account for differences in $\delta^{13}\text{C}$ between those who targeted angiosperms, and the one who ate some gymnosperms.

Third, the range of $\delta^{34}\text{S}$ of the small-bodied mammals with and without the gymnosperm contributions to diet suggests highly localized variation in $\delta^{34}\text{S}$ may be due to differences in rooting depth of plants and access to different soil-sulfur pools, and hence differences in dietary preferences among the small-bodied mammals. For example, plants with deeper rooting depths may have reduced access to labile sulfate, because deeper soils typically experience anoxic conditions that should be preferred by anaerobic sulfate-reducing bacteria (Tarrant and Richards 2024; Tcherkez and Tea 2013; Yi-Balan 2013). Hence, animals which feed on roots as well as above-ground plants parts may be more affected by the different rooting depths of the varied plants (considering that the roots may be depleted relative to the surrounding soil and the leaves), and should exhibit the most variation in $\delta^{34}\text{S}$. This explanation might account for some of the variation among the gophers, and may indicate that most of the gophers ate angiosperms whose roots were shallow (and had greater access to organic sulfur), while the one gopher had a home base near the roots of a deeper-rooted pine.

Figures 5.6b shows the animals' $\delta^{34}\text{S}$ in relation to their $\delta^{15}\text{N}$. As indicated by the two trend lines, there are again linear relationships between $\delta^{34}\text{S}$ and $\delta^{15}\text{N}$ for both the small-bodied mammals and the deer, but the relationships are weaker for $\delta^{15}\text{N}$ than for $\delta^{13}\text{C}$. This is particularly true for the small-bodied mammals, where gymnosperm contributions to diets greatly influenced the trend. However, as this relationship between $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ is weak ($R^2 = 0.27$), it might suggest plant $\delta^{15}\text{N}$ is more constrained at the local scale of home ranges and across the various food sources consumed by the small-bodied mammals due to their home territories within the same biotic community. As well, all of the small-bodied taxa within this sample were probably cecotrophic, which would reduce $\delta^{15}\text{N}$ because of the enhanced nutrient cycling. It also reinforces the idea that gymnosperm contributions were driving the pattern observed in the small-bodied mammals when $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ were compared. Additionally, all of the small-bodied mammals, except the ground squirrel, date to periods during the LIA, where collagen $\delta^{15}\text{N}$ values could be an indication of the increased moisture and a cooler climate associated with that period.

In Figures 5.6b, when the deer are considered, the pattern is weaker (R^2 of 0.63) for $\delta^{15}\text{N}$ vs $\delta^{34}\text{S}$ than it was for carbon and sulfur (R^2 of 0.84), but the same general trend still exists. This relationship among the deer may emphasize differences between migratory versus resident deer. Because plant $\delta^{15}\text{N}$ values should be highest in the Upper Sonoran Zone, lowest in the Lower and Upper Montane Forests, and again higher in the Subalpine Zone (Amundson et al. 2003; Moreland et al. 2023), we might expect resident deer to have lower overall $\delta^{15}\text{N}$ values, whereas migrant deer should have higher $\delta^{15}\text{N}$ values. This is because migratory deer $\delta^{15}\text{N}$ values should represent time-weighted averages amongst all of the zones, while resident deer are likely averaging only between two zones, one high and one low (Upper Sonoran Zone and Lower

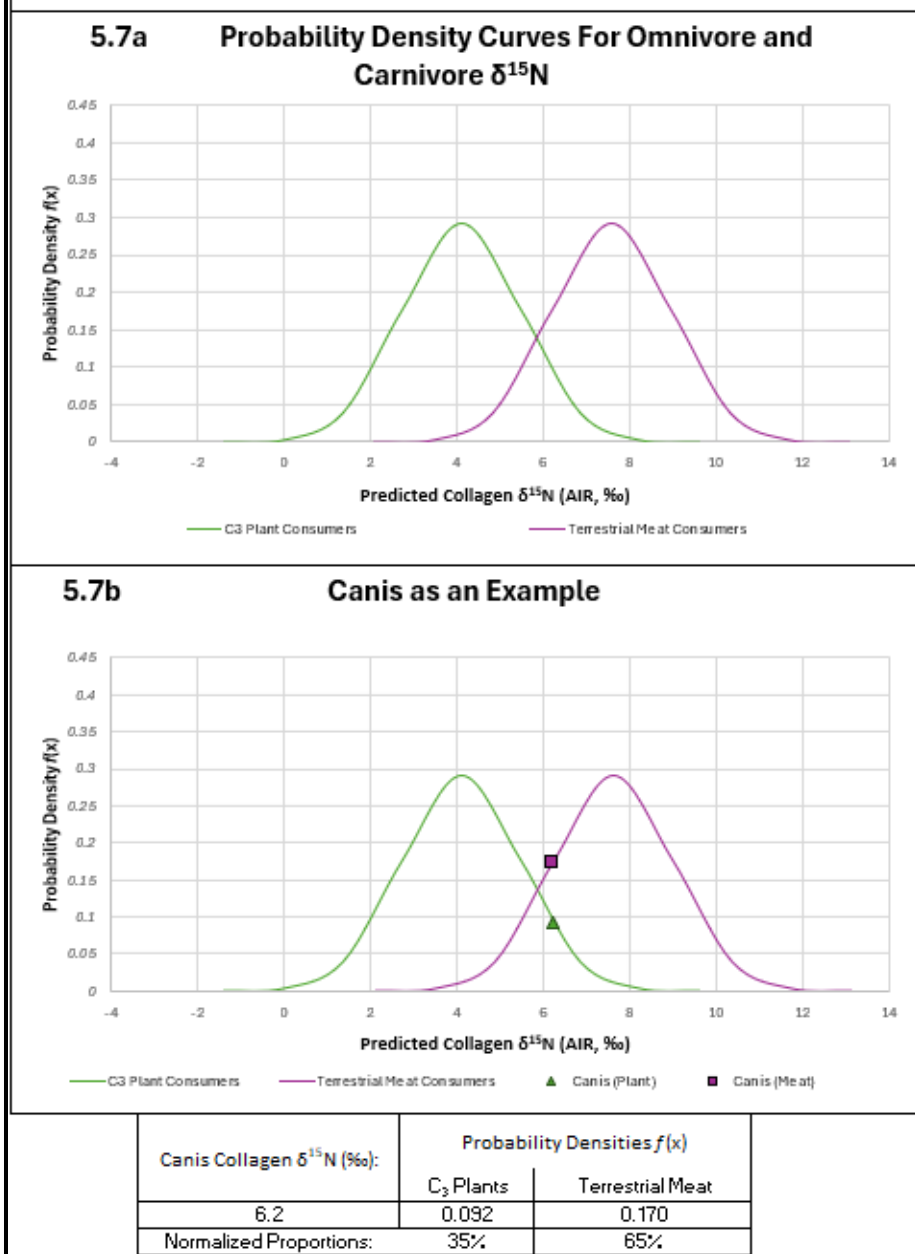
Montane Forest). Hence, it is possible that as deer slowly migrate upslope with the spring snow melt, but quickly move downslope in fall, less time is spent in the zones with the lowest $\delta^{15}\text{N}$ than in either of the high $\delta^{15}\text{N}$ zones if accounting for lifetime averages for time spent within zones. Because the $\delta^{34}\text{S}$ is expected to be higher within the higher elevations, together with the possible pattern for $\delta^{15}\text{N}$, this may account for the preliminary trend seen within the deer assemblage.

Again, this is a small sample of faunal material, and these ecological hypotheses need further testing. It is not the purpose of this chapter to fully explore the possible movements of deer, but rather to expand on isotopic baselines to inform on human values. However, as human ecology begs an understanding of the surrounding ecological profiles of the foods the humans consumed, these interpretations add value to the ultimate goals.

5.4.2 Results and Discussion: Modelling $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ Forward to Carnivore and Omnivore Collagen Values

Similar to how the probability density curves were constructed for herbivore $\delta^{13}\text{C}$ are the probability density curves constructed for $\delta^{15}\text{N}$, shown in Figures 5.7a-b. The $\delta^{15}\text{N}$ curves were constructed from the faunal $\delta^{15}\text{N}$ values (excluding the Canis), then modelled forward one additional trophic step (+3.5‰) (DeNiro and Epstein 1981; DeNiro and Schoeninger 1983; Eerkens et al. 2021) to represent the omnivore and carnivore diets which included meat. I used the $\delta^{15}\text{N}$ standard deviation for all fauna from Table 5-4 ($\pm 1.37\text{‰}$) and apply it to the $\delta^{15}\text{N}$ modelled values for omnivores and carnivores. The curve shown in green in Figures 5.7a-b represents the expected range for collagen $\delta^{15}\text{N}$ where plant proteins considered, while the purple curve is the expected range for terrestrial meat-consumers.

Figure 5.7a-b Probability Density Curves for $\delta^{15}\text{N}$



Figures 5.7a-b Probability Density Curves for $\delta^{15}\text{N}$

The figure represents curves constructed from faunal remains to estimate dietary importance of plants versus meat for omnivores and carnivores. a: shows the two curves as conceptualized; b: shows the Canis as an example of the application. Bottom of (b) shows a explanation in table form for how probability density functions are turned into normalized probability proportions.

As an example, Figures 5.7b shows how the Canis plots onto the two very simple curves.

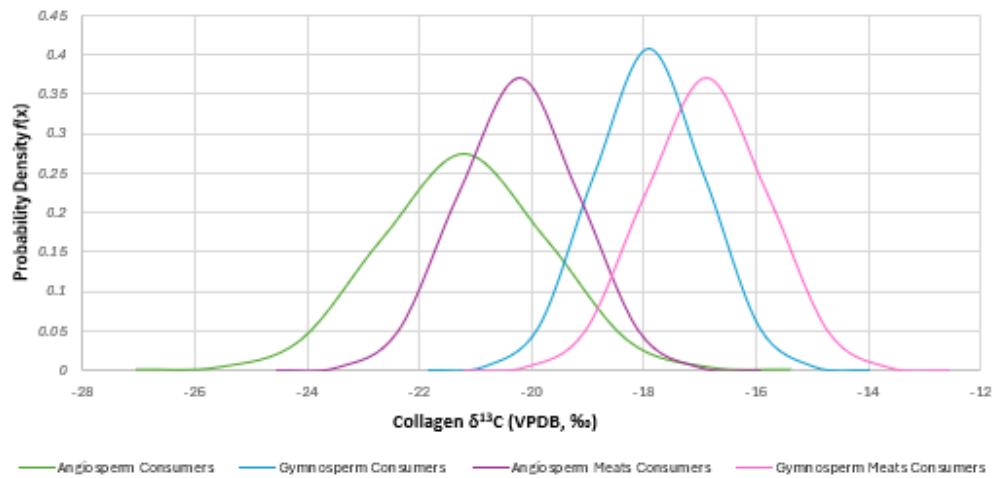
The table of normalized probabilities attached to Figure 5.7b indicates that up to 35% probability

of total dietary protein is from C₃ plant $\delta^{15}\text{N}$ within its diet, while the majority (65% probability) is from meats consumed. I discuss the diet of the *Canis* more below, because of the surprising amount of plant proteins that are implicated. I expect some of the humans to fall within this same general area of overlap among the two curves, given the archaeological evidence of extensive use of pine nuts and acorns among the pre-contact Indigenous people from the Sierra Nevada.

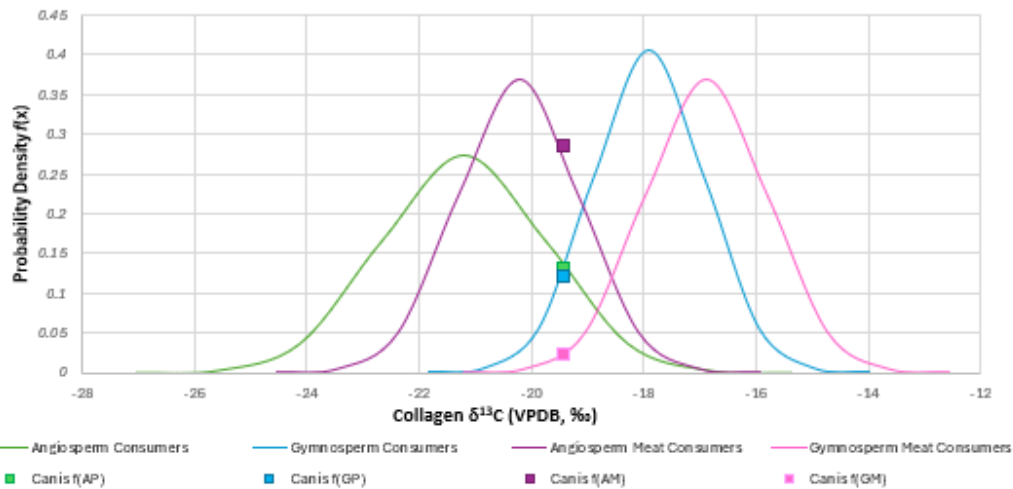
A four-source model for $\delta^{13}\text{C}$ was constructed from the original for the herbivores, plus a 1‰ offset for the difference observed between herbivore and predator collagen. This is shown in Figures 5.8a-b, which uses the angiosperm-gymnosperm predictions, together with those produced by the faunal results to create probability density curves for the omnivore and carnivore collagen $\delta^{13}\text{C}$ values. Angiosperm (green) and gymnosperm (blue) curves are represented as originally conceptualized. This model for omnivore and carnivore collagen $\delta^{13}\text{C}$ goes a step further than the herbivore model, as it includes two new probability density curves that account for the small trophic enrichment associated with $\delta^{13}\text{C}$ between herbivores to carnivores (since I am modelling collagen to collagen), where a +1‰ offset is used (Bocherens and Drucker 2003; Krajcarz et al. 2025). These two new curves use the means from the angiosperms and gymnosperms, shifted by +1‰ (less negative), and the standard deviation of $\delta^{13}\text{C}$ for all fauna (Table 5-4, $\pm 1.08\text{‰}$) to understand the expected $\delta^{13}\text{C}$ values for omnivores and carnivores for meats consumed. The meat protein density curves in Figure 5.8a also assume collagen $\delta^{13}\text{C}$ of meat-eaters follows a normal distribution. So, for every individual's collagen $\delta^{13}\text{C}$, there would be four points, each with an associated probability density function. For proportional probabilities, these would then be summed, and each divided by the sum total.

Figure 5.8a-b Probability Density Curves
for $\delta^{13}\text{C}$ of Meat-included Diets

5.8a Probability Density Curves For Omnivore and Carnivore $\delta^{13}\text{C}$



5.8b Canis Example



Canis Collagen $\delta^{13}\text{C}$ (‰):	Probability Densities $f(x)$			
	Angiosperm	Gymnosperms	Angiosperm-based Meat	Gymnosperm-based Meat
-19.4	0.131	0.120	0.286	0.024
Normalized Probabilities:	23%	21%	51%	4%

Figures 5.8a-b Probability Density Curves for $\delta^{13}\text{C}$ of Meat-included Diets
Figures show the conceptual model for omnivores and carnivores (a); and the *Canis* as an example of how the curves are applied (b). Bottom of (b) is a table graphic detailing the probability density functions for the *Canis* and the associated normalized probability proportions.

This idea is illustrated in Figures 5.8b at the bottom with the *Canis* example. This example for the *Canis* is the interpretation of the protein-based $\delta^{13}\text{C}$ of its diet. Figures 5.8b shows where the dietary protein $\delta^{13}\text{C}$ (-19.4‰) of the *Canis* falls in relation to the probability density distributions. The probability density distributions are not normalized in the graph, and hence are independent measures, but this serves as an example for how human diets will be interpreted.

As indicated by the graph (Fig. 5.8b) and the attached table, the coyote/dog (*Canis*) has a ~44% probability that plant proteins contributed to its diet, split between greater angiosperm contributions (23%) than gymnosperm contributions (21%). However, the majority of the probability, ~55.6 %, lies with the meat proteins, split between more angiosperm-consuming animals (51%) than gymnosperm-consuming animals (4%). Given the evidence, if it is a coyote, it was local to the region, and may have included greater amounts of plant food within its diet than originally expected, and focused its hunting efforts on smaller-bodied prey species, such as hares, ground squirrels, and the like. This type of hunting behavior has recently been documented for areas where the population density of coyotes is low, as there are fewer packs, and packs may be smaller and unable to take down larger prey as successfully as larger packs (Hayward et al. 2023). However, if it is an Indigenous dog, then it might be somewhat expected that it may have had greater plant protein contributions to its diet, given table scrap provisioning may have included plant products such as acorn gruel, or rancid pine nuts.

5.4.3 Results and Discussion: Modelling Precipitation from Faunal $\delta^{13}\text{C}$

The posterior probability distributions for the AMS radiocarbon-dated samples are shown in Figure 5.9. As shown, most samples (77%) are younger than 700 years, while three of thirteen are older than 1,500 years. Of note, the majority of the faunal samples fall in the period after the

MCA, during the LIA, which is thought to have been a cooler, and at times, wetter than the MCA. The precipitation estimates from the faunal samples and humans will allow this comparison in the next chapter. Here I make some preliminary estimates. For a full diachronic analysis, it is necessary to combine data from Broughton et al. (2023:Supplementary Information), which contains too few LIA samples, to robustly compare their data with that from Tuolumne.

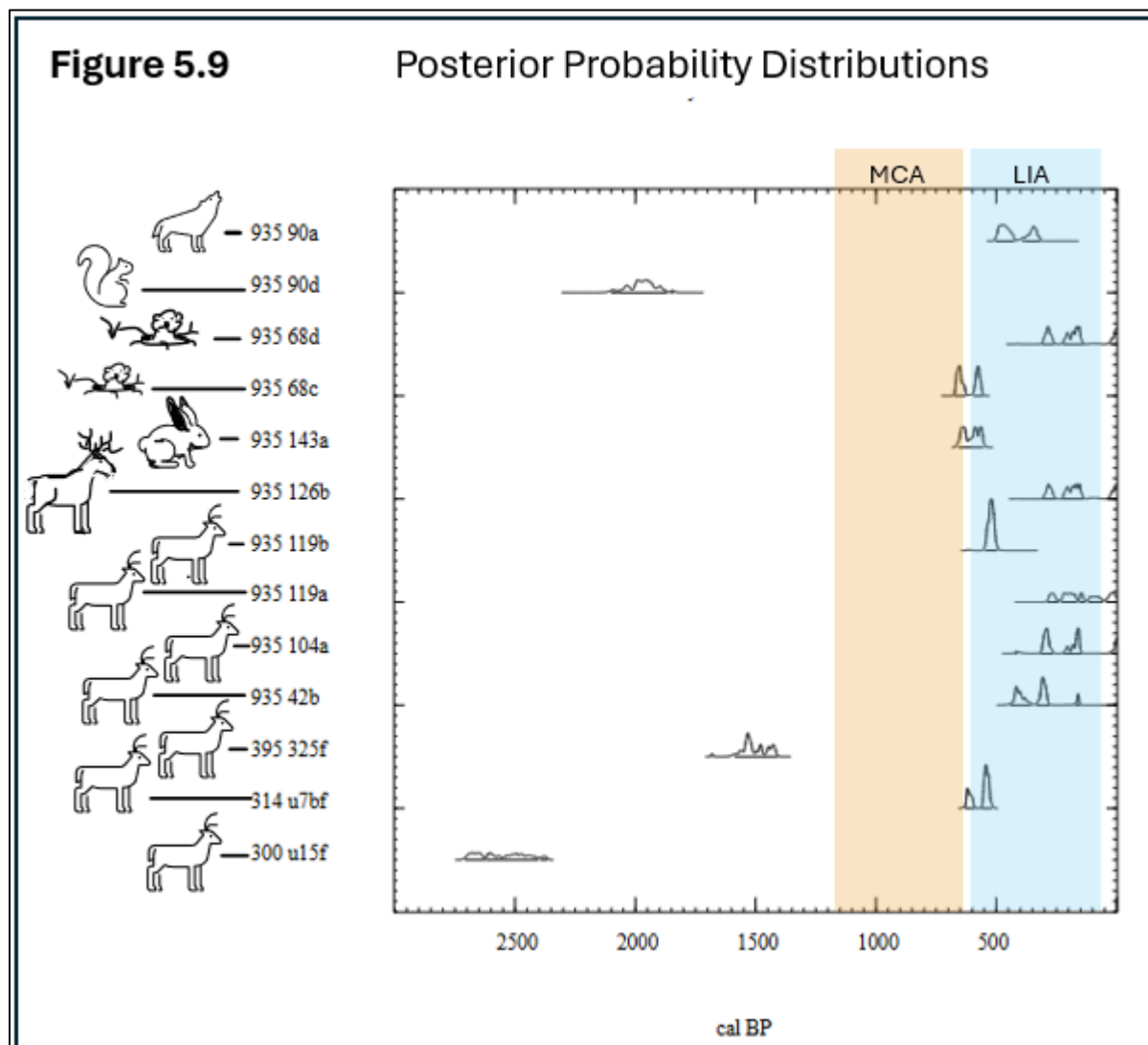


Figure 5.9 Posterior Probability Distributions
 Posterior probability distributions from Calib 8.1 online for the AMS dated faunal samples from the Sierra Nevada are shown. Notice that most are younger than 1000 years. The entries are organized by taxa, the top is the coyote/dog, next is the ground squirrel, and then two gophers, one hare, an elk, with remainder as deer at the bottom. Orange-shaded bar highlights MCA; blue shaded bar highlights LIA.

I first used the modern elk samples from Broughton et al. (2023) to determine the best method for estimating precipitation from faunal $\delta^{13}\text{C}$ values. I used a type of wiggle match, where precipitation periods are readjusted as the equation is run with multiple values for modern $\delta^{13}\text{CO}_2$. This narrows the time frame for the year of death of the animal when monthly precipitation records are used. The assumption is that this type of wiggle-matching will be better suited for testing if the formula can be applied to collagen $\delta^{13}\text{C}$ values of C_3 -consumers.

As a quick review on the method, I first applied a diet-tissue offset for collagen $\delta^{13}\text{C}$ of -4‰ to all of the modern elk samples to move their values closer to that of the expected average $\delta^{13}\text{C}$ of their dietary protein. A 5.1‰ offset (e.g., Kohn 2010) between diet and collagen $\delta^{13}\text{C}$ was too much, and using this offset with modern samples grossly overestimated precipitation no matter how samples were grouped (or separated), nor how precipitation periods (months/years) were applied. For juveniles/sub adults, I did consider a trophic enrichment factor that relates to bone remodeling in juveniles after the weaning period, however, for simplicity I decided to keep the same offset used for adults. Because death dates were unknown, similar to how archaeological specimens' death dates are unknown, I used the average $\delta^{13}\text{CO}_2$ for the period 2010-2018 (-8.4‰) and applied it to the modern elk samples to remove any effect from atmospheric $\delta^{13}\text{CO}_2$.

This averaging introduced some error in precipitation estimates after applying Eq. 2 (Kohn 2010), but mainly for those from Point Reyes. The results suggest the death dates for the Point Reyes group were more recent than those from the Cache Creek localities. This may also be partially explained by the longer period of collection among the Cache Creek samples (from Feb. of 2017 to Nov. of 2019) as compared to the Point Reyes samples (mid-April, 2019) (Broughton et al. 2023:SI). The time frame for $\delta^{13}\text{CO}_2$ was readjusted for the Point Reyes group,

reflecting the period 2016-2018 (-8.51‰). I also considered precipitation estimates from the different sub-groups for each locality as well as the groups' total estimates as a way to refine the time frames, mainly once they were compared with recorded precipitation from PRISM Group (2025a, 2025b, 2025c). With archaeological samples pre-dating the Suess Effect (Keeling 1979; Suess 1953; Tans et al. 1979), this should not be an issue as long as calibrated dates are used to estimate atmospheric $\delta^{13}\text{CO}_2$, and averaged when needed. These modern faunal-sample precipitation estimates are presented in Table 5-7 and shown graphically in Figure 5.10a-b.

Table 5-7 Estimated and PRISM-derived Average Precipitation Values

Location	Sample group (elk)	Sample material / age class	Broughton et al. (2023) sample IDs	Est. average precip. (mm)	PRISM years	PRISM average precip. (mm)
Cache Creek/Bear Valley (500 m asl)	Antlers	All age classes	4503, 4497–4499	795	2016–2018	794
Cache Creek/Bear Valley (500 m asl)	Bone	Juvenile/subadult	4502, 4494	717	2014–2017	748
Cache Creek/Bear Valley (500 m asl)	Bone/tooth	Adults	4453–4456, 4496, 4500–4501, 4504	531	2011–2016	554
Cache Creek/Bear Valley (500m asl)	All samples	All	All	633	2011–2018	627
South Tamales Bay (50m asl)	Antlers and juvenile rib	All age classes	4449.1, 4449.4, 4446	1230	2016–2017	1202
South Tamales Bay (50m asl)	Bone/tooth	Adults	4447, 4448, 4450	1073	2016–2018	1072
North Tamales Bay (50m asl)	Bone/tooth	Adults	4451, 4452	1205	2016–2017	1202
All Tamales Bay (50m asl)	All samples	All	All	1165	2016–2018	1072

Note table is associated with Broughton et al. (2023:Supplementary Information) modern faunal samples (elk) from Cache Creek/Bear Valley and Point Reyes National Seashore. Green shading helps to highlight the Cache Creek/Bear Valley sample; blue shading highlights those from Point Reyes National Seashore (North Tamales Bay and South Tamales Bay). PRISM Years refers to the precipitation record accessed which showed correlation with estimate precipitation from elk; total annual precipitation was used here. “asl” refers to above sea level; “Est” means estimated; “Precip” means precipitation.

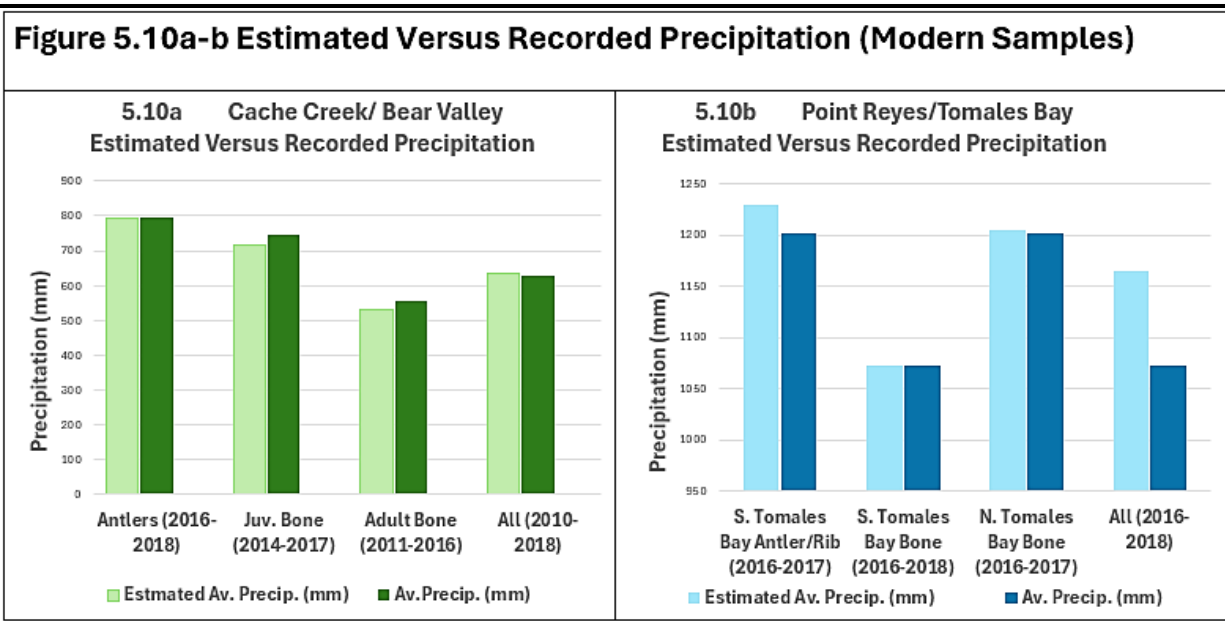


Figure 5.10a-b Estimated Versus Recorded Precipitation (Modern Samples)
 Figure shows two bar graph series, separated by location; a) Cache Creek/Bear Valley (green shades; left), and b) Point Reyes/ Tomales Bay (blue shades; right). Point Reyes receives greater rainfall than Cache Creek/Bear Valley. Data for modern fauna from Broughton et al. (2023: SI) were used to test application of equation 2 (Kohn 2010), and estimates were compared against modern records of precipitation from PRISM Group (2025a; 2025b; 2025c).

As indicated by Table 5-7, there are strong correlations (Person's $R^2 = 0.993$) between the grouped precipitation estimates and the grouped recorded precipitation. While those for Cache Creek/Bear Valley show very close approximations to recorded precipitation, whether separated by the groupings or considered together and averaged as one estimate (Figure 5.10a), only the grouped estimates from Point Reyes show good correlations between the estimated and recorded precipitation (Figure 5.10b). When all samples from Point Reyes are averaged, the estimate is off by 93mm from what the average was for the few years covered by those samples. One possible reason for this is that most samples overlapped in the 2016 to 2017 range, while only one sample showed overlap with 2018. Thus, a weighted average may be more appropriate for estimating precipitation when multiple samples closely overlap in the same short time period. However, this issue should be lessened for archaeological samples, since in most instances the possible period

the sample belongs to is much longer than a three-year span exemplified by the modern samples from Point Reyes. This did not seem to be an issue for the Cache Creek/Bear Valley area samples, as the estimated precipitation from the group average was quite close to the average recorded precipitation covered by these samples, despite small overlaps in time periods.

Comparing the two bar graphs in Figure 5.10a-b, the estimated and recorded precipitation is much higher at Point Reyes than in Cache Creek/Bear Valley. This is noticeable by the individual collagen $\delta^{13}\text{C}$ values from these two locations, as well as from the estimated precipitation (since it is a linear regression), and it is what Broughton et al (2023) were testing with these modern samples. These two regions differ in biotic communities as well as in average precipitation, and highlight an important factor to consider when using archaeological fauna. Importantly, when considering the appropriate scale of land coverage of faunal samples (i.e., territory or home range), estimating precipitation from $\delta^{13}\text{C}$, differences among regions need to be considered due to inherent differences in how landforms affect precipitation, such as orographic uplift across hills and mountains, rain shadows, coastal regions, as well as valleys. Averaging precipitation estimates from within the same geographic region, landform, and time frame should yield better estimates. For interconnected regions, such as valley and hillside/mountainside, broad comparisons are possible, particularly for valleys that depend on water from rivers originating in the mountains, such as the Central Valley.

In general, faunal collagen $\delta^{13}\text{C}$ seems to correlate with precipitation, especially when averaged over a number of samples, i.e., averaging removes noise from individual samples and is applicable to longer periods examined by archaeologists. In Table 5-8, a few individual sample precipitation estimates are shown in relation to the recorded precipitation averaged over a few years, as well as for month/year combinations, where the $\delta^{13}\text{CO}_2$ was adjusted to show how the

estimated precipitation changes, and how it can affect interpretations of modern samples, especially in wetter regions.

Table 5-8 Adjusted $\delta^{13}\text{CO}_2$ and Effects on Precipitation Estimates

ID	Elk Age/part	$\delta^{13}\text{C}$ (‰)	$\delta^{13}\text{CO}_2$ #1 (‰)	Time #1	Precip est. #1 (mm)	Rec'd Precip #1 (mm); yrs	$\delta^{13}\text{CO}_2$ #2	Time #2	Precip Est. #2 (mm)	Rec'd Precip #2 (mm); yrs	Rec'd Precip #3 (mm); mo.s	Mo./Yrs #3
4447	Adlt bone	-24.7	-8.51	2016-2018	985	1072; yrs	-8.46	2014-2017	<i>1010</i>	1011	1011	01/2014-12/2017, 4 yrs
4448	Adlt vert.	-24.7	-8.51	2016-2018	<i>1009</i>	1072; yrs	-8.48	2015-2018	<i>1025</i>	916	1022	08/2014-07/2018, 4 yrs
4450	Adlt rib age 5	-25.1	-8.51	2016-2018	<i>1225</i>	1072; yrs	-8.48	2015-2017	<i>1246</i>	1202	1244	02/2015-03/2017; 25 mo.s
4446	Sub-adlt, rib	-25.3	-8.51	2016-2018	<i>1383</i>	1202; yrs	-8.51	2016-2018	<i>1383</i>	1202	1398	09/2016-04/2018, 20 mo.s

Note: table shows how $\delta^{13}\text{CO}_2$ can affect precipitation estimates. A small selection of the modern Point Reyes elk sample data (Broughton et al. 2023:SI) are shown against the $\delta^{13}\text{CO}_2$ used for all samples from that location ($\delta^{13}\text{CO}_2$ #1, shown in gray) versus tailored estimates of $\delta^{13}\text{CO}_2$ (indicated by $\delta^{13}\text{CO}_2$ #2; blue). Tailored $\delta^{13}\text{CO}_2$ estimates are shown in blue tones along with the adjusted precipitation estimates and correlating precipitation periods from PRISM Group (2025b, 2025c). Recorded precipitation #3 and Month/Years relate to the tailored $\delta^{13}\text{CO}_2$ where the same period of time was covered, but monthly records were used instead of annual and are intended to show a fine scale analysis. Estimated precipitation totals are shown as italicized. Age/part refers to estimated age at death and skeletal part that was sampled (Broughton et al. 2023); "Adlt" means Adult; "Yrs" means years; "Precip" means precipitation; "est" means estimate; "Rec'd" means recorded; "mo.s" means months.

Individual estimates, shown in Table 5-8, are more difficult to correlate with precipitation that is averaged by years, but these samples still show a relationship with groups of years, and groups of months plus years, depending on the sample material. One difficulty in constraining and correlating individual modern precipitation estimates is the Suess Effect (Keeling 1979; Suess 1953; Tans et al. 1979) and uncertainty surrounding which average of atmospheric $\delta^{13}\text{CO}_2$ should be applied to individual samples when sample age of death of the is unknown. This issue is primarily a problem for modern samples, where atmospheric $\delta^{13}\text{CO}_2$ is constantly increasing and affects precipitation estimates derived from the log-linear regression of Kohn (2010). This is

shown in Table 5-8 between the estimates achieved from the different $\delta^{13}\text{CO}_2$ applied to samples 4447 and 4448. While the difference is on the order of tens of millimeters of rain, it is enough to change the years correlated with the precipitation estimates from these two elk samples. Had it been easy to explain why different $\delta^{13}\text{CO}_2$ was applied to each sample, rather than one single value applied to all samples from a location, as in Table 5-7, estimated precipitation may have been closer to the average precipitation for some sample groups. However, as this was meant to replicate an archaeological situation, one offset seemed best and the most straightforward to explain.

As indicated by Table 5-8, if monthly precipitation records are used (PRISM Group 2025c), instead of yearly, the average precipitation for a given period can be tailored to estimate when the animal's bone collagen is in equilibrium with its diet, following the weaning period, assuming it is not a calf. Ribs samples appear to have a faster turnover time and represent shorter periods of precipitation (de Gruchy et al. 2024; Matsubayashi and Tayasu 2019; Sealy et al. 1995). This issue is illustrated here with two individuals. For sub-adult sample 4446, 20 months seemed to equate well with bone collagen being in equilibrium with adult diet (Table 5-8, last column [mo.s/Yrs #3]). There is a strong, positive correlation (Person's $R^2 = 0.999$) between the five-year-old adult rib, sample 4450, and 25 months of precipitation (calculated as total precipitation/2.083 years) between 2015-2017. This fine-tuned tailoring would only be effective for modern samples as it relies heavily on recorded precipitation to make judgment calls for adjusting $\delta^{13}\text{CO}_2$ and precipitation time frames. But this application could be useful for ecologists addressing how climate change affects diet selection in wild populations when samples are collected opportunistically. Such a project might seek out curated samples as control groups, where the samples are from the modern era and known location. Then, opportunistically

collected wild samples from the same region might inform on the changing ecology of the species in relation to diet choices and precipitation. As well, although somewhat tedious due to the variability in atmospheric $\delta^{13}\text{CO}_2$ during the modern era, this opens the possibility of alternative ways to document collagen turnover rates among different bones of some species, providing they were on a strict wild C_3 diet and precipitation was the main factor driving variation in plant $\delta^{13}\text{C}$ values.

Given the positive and significant correlation between precipitation estimated from modern faunal $\delta^{13}\text{C}$ and recorded precipitation, I applied Kohn's (2010b:Eq. 2) log-linear regression to the elk collagen $\delta^{13}\text{C}$ from the King Brown site (Broughton et al 2023) and to the Sierra Nevada faunal collagen $\delta^{13}\text{C}$. Importantly, Kohn (2010) suggested a collagen-diet $\delta^{13}\text{C}$ offset of -5.1‰. However, when the paleobotanical mean (-25.2‰) is compared to the mean for all Tuolumne faunal samples who had strict angiosperm diets (-21.1‰), the difference is -4.1‰. I have used a -4.0‰ collagen-diet offset to model and interpret consumer values. Given the results from modelling collagen $\delta^{13}\text{C}$ to diet $\delta^{13}\text{C}$ to precipitation from the modern elk samples, a -5.1‰ offset has already been implicated as too large, and would overestimate paleoprecipitation. However, precipitation estimates based on modern elk $\delta^{13}\text{C}$ values showed a strong, positive correlation with recorded precipitation using the -4.0‰ offset, which is what I use for the archaeological specimens. For the animals that showed reliance on gymnosperms, and the canid, the difference between mean $\delta^{13}\text{C}$ and angiosperms is -6.1‰, suggesting a larger offset is necessary. For herbivores, the calculation is straightforward, where the normalized probability of gymnosperm contributions is multiplied by the difference in mean $\delta^{13}\text{C}$ between angiosperms and gymnosperms (-3.3‰), and that number is subtracted from the animals $\delta^{13}\text{C}$ values as the diet offset of -4‰ is applied. If the gymnosperm contributions are not accounted

for when modelling precipitation estimates, the results are negative precipitation values—this was true when estimating precipitation from the paleobotanical samples, and is true for some of the gymnosperm-consuming fauna.

For carnivores and omnivores, the four source $\delta^{13}\text{C}$ model requires a longer back-calculation towards angiosperm values. To control for gymnosperm contributions to the coyote/dog's diet, and to estimate the corresponding angiosperm-based dietary value, I used the following model:

$$\delta A = \delta C - 3.3p(G) - 4p(P) - 5p(M) \quad (2)$$

where δA is the estimated angiosperm value, δC is the consumer collagen value, $p(G)$ is the total probability of gymnosperm contribution, $p(P)$ is the total probability of plant contribution, and $p(M)$ is the total probability of meat contribution. The term $p(G)$ includes both direct gymnosperm plant contributions, $p(GP)$, and gymnosperm-derived meat contributions, $p(GM)$. Likewise, $p(P)$ is the sum of angiosperm plant contribution, $p(AP)$, and gymnosperm plant contribution, $p(GP)$, while $p(M)$ is the sum of gymnosperm-derived meat contribution, $p(GM)$, and angiosperm-derived meat contribution, $p(AM)$. This formulation allows the consumer collagen value to be adjusted for the modeled contributions of plant type and trophic pathway, producing an angiosperm-centered estimate for comparison with local plant baselines, and enables the value to be used to estimate precipitation, as it now resembles that of an angiosperm.

For estimating $\delta^{13}\text{CO}_2$, I used the recommended data set from Belmecheri and Lavergne (2020), and for each sample, averaged the $\delta^{13}\text{CO}_2$ based on the most probable calibrated range of radiocarbon dates. This averaging does not make much difference for specimens older than 600 years (up to ~10,000 years) as $\delta^{13}\text{CO}_2$ is around $-6.42 \pm 0.02\text{‰}$, but for younger samples $\delta^{13}\text{CO}_2$ fluctuates starting at about 1400 CE, and steadily increases from -6.31‰ at 1660 CE, correlating

with the very beginnings of the industrial revolution (Belmecheri and Lavergne 2020). This slow increase makes a difference in precipitation estimates, as discussed above for the modern elk samples from Broughton et al. (2023).

Paleoprecipitation estimates are provided in Table 5-9, organized by region and calibrated median radiocarbon date in cal BP. Few of the radiocarbon dates align between the King Brown site elk (which are mostly older) and the Sierra Nevada fauna (which are mostly younger). For the Sierra Nevada fauna, paleoprecipitation estimates ranged between 296 and 889mm. The average estimated precipitation between 0- and 670-years cal BP for the west central Sierra Nevada is 462 mm. For the southern Sacramento Valley fauna (Table 5-9), paleoprecipitation is estimated to have ranged between 38 and 738 mm, with an average of 321mm. This overall average is misleading because it spans over 3,200 years and includes the drier MCA. Breaking this down further, the MCA-era precipitation for the south Sacramento Valley is estimated to have averaged 331 mm, while the LIA is estimated to have averaged around 461 mm, which is similar to the 462 mm estimate from the Sierra Nevada assemblage. Prior to the MCA, precipitation may have been even less. However, over time, both locations show an increasing trend of precipitation, although the pattern is stronger for the King Brown assemblage than for the small Sierra Nevada assemblage.

Table 5-9 Estimated Precipitation from Faunal Remains-Individual Results

Site	cal years CE/BCE	Med cal BP.	Sample ID	Taxon	$\delta^{13}\text{C}$ (col.; ‰)	Elev. (m asl)	Lat. (DDN)	Diet offset	$\delta^{13}\text{CO}_2$ (‰)	Est. Precip (mm)
King Brown	1829 CE	121	ACRF# 3826	Elk	-21.7	9	38.432	-4.00	-6.53	532
King Brown	1776 CE	174	ACRF# 3842	Elk	-21.1	9	38.432	-4.00	-6.52	353
King Brown	1563 CE	387	ACRF# 3383	Elk	-21.4	9	38.432	-4.00	-6.38	482
King Brown	1461 CE	489	ACRF# 3835	Elk	-21.4	9	38.432	-4.00	-6.40	476
King Brown	1085 CE	865	ACRF# 3829.1	Elk	-21.4	9	38.432	-4.00	-6.44	463

Site	cal years CE/ BCE	Med cal BP.	Sample ID	Taxon	$\delta^{13}\text{C}$ (col.; ‰)	Elev. (m asl)	Lat. (DDN)	Diet offset	$\delta^{13}\text{CO}_2$ (‰)	Est. Precip (mm)
King Brown	1025 CE	925	ACRF# 3385	Elk	-21.6	9	38.432	-4.00	-6.44	528
King Brown	1023 CE	927	ACRF# 3378	Elk	-20.9	9	38.432	-4.00	-6.44	322
King Brown	1000 CE	950	ACRF# 3823	Elk	-20.0	9	38.432	-4.00	-6.41	136
King Brown	995 CE	955	ACRF# 3836	Elk	-21.0	9	38.432	-4.00	-6.41	356
King Brown	995 CE	955	ACRF# 4272	Elk	-20.7	9	38.432	-4.00	-6.41	280
King Brown	993 CE	957	ACRF# 3384	Elk	-21.0	9	38.432	-4.00	-6.41	356
King Brown	993 CE	957	ACRF# 4267	Elk	-21.2	9	38.432	-4.00	-6.41	412
King Brown	975 CE	975	ACRF# 3388	Elk	-20.8	9	38.432	-4.00	-6.40	307
King Brown	968 CE	982	ACRF# 3377	Elk	-21.4	9	38.432	-4.00	-6.40	476
King Brown	961 CE	989	ACRF# 3382	Elk	-20.8	9	38.432	-4.00	-6.40	307
King Brown	959 CE	991	ACRF# 4271	Elk	-20.7	9	38.432	-4.00	-6.40	282
King Brown	949 CE	1001	ACRF# 3844	Elk	-20.8	9	38.432	-4.00	-6.39	309
King Brown	944 CE	1006	ACRF# 3824	Elk	-21.2	9	38.432	-4.00	-6.39	418
King Brown	942 CE	1008	ACRF# 3825	Elk	-22.1	9	38.432	-4.00	-6.39	738
King Brown	941 CE	1009	ACRF# 3828	Elk	-21.7	9	38.432	-4.00	-6.39	581
King Brown	938 CE	1012	ACRF# 3852	Elk	-20.0	9	38.432	-4.00	-6.39	139
King Brown	933 CE	1017	ACRF# 3841	Elk	-22.3	9	38.432	-4.00	-6.39	826
King Brown	933 CE	1017	ACRF# 4259	Elk	-20.5	9	38.432	-4.00	-6.40	237
King Brown	928 CE	1022	ACRF# 4265	Elk	-20.7	9	38.432	-4.00	-6.39	285
King Brown	926 CE	1024	ACRF# 3380	Elk	-21.0	9	38.432	-4.00	-6.39	361
King Brown	925 CE	1025	ACRF# 3387	Elk	-21.2	9	38.432	-4.00	-6.39	418
King Brown	923 CE	1027	ACRF# 3851	Elk	-20.8	9	38.432	-4.00	-6.40	307
King Brown	920 CE	1030	ACRF# 4261	Elk	-20.9	9	38.432	-4.00	-6.40	332
King Brown	908 CE	1042	ACRF# 3386	Elk	-20.9	9	38.432	-4.00	-6.40	332
King Brown	901 CE	1049	ACRF# 3379	Elk	-20.4	9	38.432	-4.00	-6.40	215
King Brown	826 CE	1124	ACRF# 4260	Elk	-20.9	9	38.432	-4.00	-6.41	330
King Brown	783 CE	1167	ACRF# 3381	Elk	-19.6	9	38.432	-4.00	-6.41	70
King Brown	730 CE	1220	ACRF# 3840	Elk	-20.5	9	38.432	-4.00	-6.41	235

Site	cal years CE/ BCE	Med cal BP.	Sample ID	Taxon	$\delta^{13}\text{C}$ (col.; ‰)	Elev. (m asl)	Lat. (DDN)	Diet offset	$\delta^{13}\text{CO}_2$ (‰)	Est. Precip (mm)
King Brown	730 CE	1220	ACRF# 4263	Elk	-20.5	9	38.432	-4.00	-6.42	232
King Brown	725 CE	1225	ACRF# 4269.1	Elk	-20.4	9	38.432	-4.00	-6.42	211
King Brown	712 CE	1238	ACRF# 4268	Elk	-19.4	9	38.432	-4.00	-6.43	38
King Brown	675 CE	1275	ACRF# 4264	Elk	-19.7	9	38.432	-4.00	-6.43	82
King Brown	898 BCE	2848	ACRF# 4266	Elk	-20.5	9	38.432	-4.00	-6.41	235
King Brown	900 BCE	2850	ACRF# 3846	Elk	-20.5	9	38.432	-4.00	-6.41	235
King Brown	957 BCE	2907	ACRF# 3850	Elk	-20.1	9	38.432	-4.00	-6.41	154
King Brown	969 BCE	2919	ACRF# 4270	Elk	-20.3	9	38.432	-4.00	-6.41	193
King Brown	1067 BCE	3017	ACRF# 3849	Elk	-20.0	9	38.432	-4.00	-6.41	136
King Brown	1073 BCE	3023	ACRF# 3848	Elk	-20.8	9	38.432	-4.00	-6.41	304
King Brown	1108 BCE	3058	ACRF# 3847	Elk	-20.5	9	38.432	-4.00	-6.41	235
King Brown	1250 BCE	3200	ACRF# 4262	Elk	-20.4	9	38.432	-4.00	-6.41	213
TUO-935	1785 CE	165	119A	Deer	-20.6	832	38.033	-4.00	-6.37	296
TUO-935	1765 CE	185	126B	Elk	-21.7	832	38.033	-4.00	-6.39	645
TUO-935	1765 CE	185	68D	Pocket Gopher	-18.6	832	38.033	-6.36	-6.39	385
TUO-935	1745 CE	205	104A	Deer	-21.7	832	38.033	-4.00	-6.32	665
TUO-935	1630 CE	320	42B	Deer	-20.7	832	38.033	-4.00	-6.33	350
TUO-935	1505 CE	445	90A	Coyote/dog	-19.4	832	38.033	-5.40	-6.45	343
TUO-935	1430 CE	520	119B	Deer	-20.7	832	38.033	-4.00	-6.37	325
TUO-314	1405 CE	545	Unk 7Bf	Deer	-20.5	247	37.813	-4.00	-6.36	257
TUO-935	1350 CE	600	143A	Jack-rabbit	-22.3	832	38.033	-4.00	-6.40	889
TUO-935	1315 CE	635	68C	Pocket Gopher	-21.2	832	38.033	-4.00	-6.41	450
TUO-395	430 CE	1520	325F	Deer	-19.4	694	38.030	-5.29	-6.43	304
TUO-935	20 BCE	1970	90D	Golden Mantled Ground Squirrel	-19.1	832	38.033	-5.80	-6.41	360
TUO-300	610 BCE	2560	Unk 15F	Deer	-21.0	238	37.676	-4.00	-6.41	361

Note: table details the estimated precipitation from the faunal collagen $\delta^{13}\text{C}$ from the Sacramento Valley (King Brown) and Sierra Nevada (Tuolumne sites). Major geographic separation is marked in the table by a double-bottom border, with the King Brown (Broughton et al. 2023) information and estimates above, and the Sierra Nevada estimates and information below. Note: Latitude is rounded to the

thousandths place to protect site locations, but the very similar precipitation estimates can be achieved from the data shown. “col.” means collagen; “Elev.” means elevation, shown as m asl (meters above sea level); “Lat” means Latitude, shown as DDN (decimal degrees north); “Est” means estimated; “Precip” means precipitation, shown as mm.

Something interesting about these two locations is the King Brown site could represent fauna that were more reliant on the Sacramento River drainage system, which has headwaters mainly from the American River and north, while the Sierran fauna would represent those reliant on the drainages which feed the San Joaquin River system. Storm tracks switch on decadal to centennial scales, and thus the fauna from these two regions may indicate opposing patterns for paleoprecipitation, i.e., when it is wet in the north, it tends to be dry in the south, and vice versa. Likewise, the Jetstream is hypothesized to switch around 40°N latitude (Dettinger et al. 1998, 2011) on an oscillating basis. Possibly part of the confounding factors involving interpretations of MCA precipitation is that the Jetstream may have switched at some point during the MCA, and thus far records have only given us part of the picture. Thus, depending on study location and length of time, evidence could both support a paleo-drought as well as wet conditions. If more datasets or fauna were available, a robust comparison could be made. Despite the dates not aligning for a robust comparison here, Table 5-9 shows that paleoprecipitation was likely lower in the past than during the modern era. It contains the information that would provide data necessary to replicate this analysis, or to add to other existing datasets to make regional comparisons. With more $\delta^{13}\text{C}$ data available from radiocarbon-dated faunal remains from additional sites, there is the possibility of creating more fine-scaled and stronger paleoprecipitation estimates.

Table 5-10 shows how different portions of the 3,000-year time span play out for both assemblages. The dates shown are based on the minimum and maximum range for AMS dates that were within 20 years of each other for median dates, or longer spans when there were fewer

available samples with overlapping dates. Calibrated median dates (shown in Table 5-9) were used to estimate periods of overlap for the 2σ ranges within the Broughton et al. (2023) assemblage. Table 5-10 more clearly shows the trend for increasing precipitation over the last 3,000 years, but mainly for the southern Sacramento Valley. This comparison is graphically illustrated in Figure 5.11. The top panel, labeled “Sierra Nevada” in purple, shows seven grouped estimates. Younger periods show greater variation, and 555–670 cal BP is the highest estimate at 669 millimeters based on two samples—one from a jackrabbit that seems anomalously high (889 mm), while the other (pocket gopher; 450 mm) is more in line with the data from the Southern Sacramento Valley. The bottom panel in Figure 5.11, representing the group-averaged estimates for the southern Sacramento Valley, covers a longer span of time. In general, for both regions, older periods exhibit lower precipitation estimates, while younger periods are more variable but show increasing precipitation between 500 to 0 cal BP.

Table 5-10 and Figure 5.11 also indicate that certain periods within the MCA era may have been drier than others. For example, at the beginning of the MCA, with age brackets of 1090 to 1300 cal BP, estimated precipitation is only 160 mm in the southern Sacramento Valley, while for the previous period (930–1260 cal BP), it is estimated to have been around 363 mm. Furthermore, near the end of the MCA, here falling within the brackets for 795 to 965 cal BP, indicates higher precipitation, averaging around 438 mm.

Table 5-10 Averaged Precipitation Estimates by Time Period for the Sierra Nevada and Southern Sacramento Valley.

Region	Date range (cal BP)	Estimated precipitation (mm)	# samples
Sierra Nevada	0-305	442	3
Sierra Nevada	0–440	507	2
Sierra Nevada	320–625	323	3
Sierra Nevada	555–670	669*	2
Sierra Nevada	1410–1685	304	1
Sierra Nevada	1840–2100	360	1
Sierra Nevada	2365–2705	361	1

Region	Date range (cal BP)	Estimated precipitation (mm)	# samples
Southern Sacramento Valley	0–305	443	2
Southern Sacramento Valley	300–515	479	2
Southern Sacramento Valley	795–965	438	3
Southern Sacramento Valley	915–1050	308	5
Southern Sacramento Valley	930–1260	363	20
Southern Sacramento Valley	1090–1300	160	5
Southern Sacramento Valley	2775–2930	235	2
Southern Sacramento Valley	2845–3005	173	2
Southern Sacramento Valley	2945–3335	222	4

Note: Estimated precipitation values are reported in millimeters. The main table lists precipitation estimates by calibrated BP date range and sample count. Sierra Nevada is highlighted lavender; Southern Sacramento Valley is highlighted green. Grouped precipitation estimate marked with an asterisk () is thought to be affected by an anomalously high value from a jackrabbit estimate.*

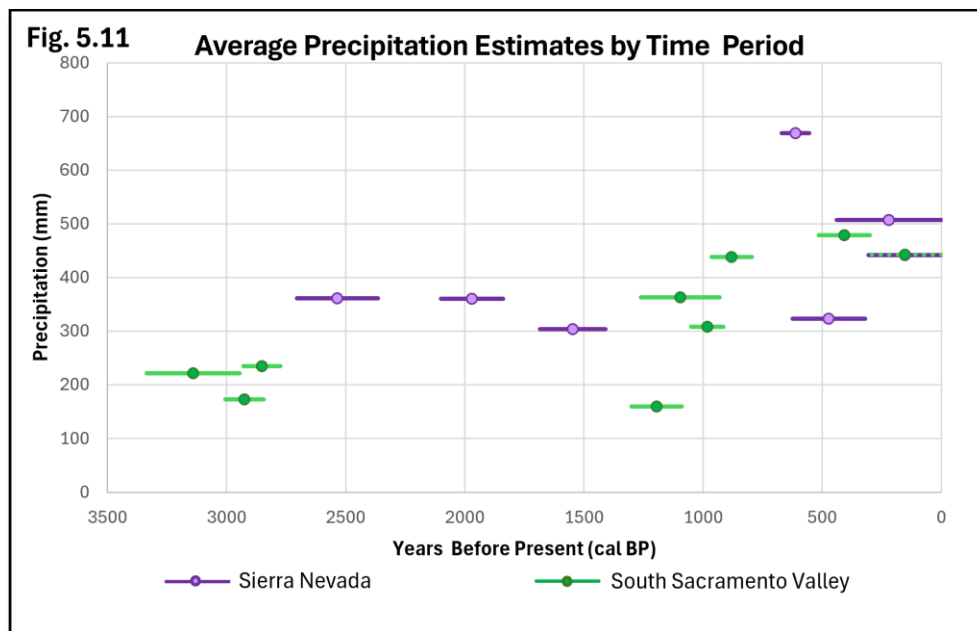


Figure 5.11 Averaged Precipitation Estimates by Time Period for the Sierra Nevada and Southern Sacramento Valley

Figure summarizes Table 5-10. Horizontal bars show grouped calibrated age ranges in cal BP, and points mark the average estimated precipitation value for each group. Sierra Nevada values are shown in purple and Southern Sacramento Valley values in green. The Sierra Nevada estimate for 555–670 cal BP includes the high jackrabbit-derived precipitation estimate.

The effects of the MCA on northern California west of the Sierra Nevada summit continue to be in question. Clearly droughts affected many of the eastern Sierra Nevada and Great Basin lakes during the MCA (Graham and Hughes 2007; Kleppe et al. 2011; Lindström 1990; Stine 1994), but what about on the slope that experiences orographic uplift? In Chapter 6, the data presented here is combined with that of the Indigenous people living in the Sierra Nevada to estimate paleoprecipitation. What is clear at this point is that precipitation has gradually increased over the last 3,000 years, but the variability in precipitation is likely greater now than it was during the archaeological periods examined here. If average paleoprecipitation was lower, the effects may have been muted compared to the modern era droughts. This is mainly because drainages downslope of a dam are completely dry during low-precipitation years, while in the past at least some water may have been flowing.

5.5 Conclusion and Summary

In this chapter I began with a short discussion of the chapter's goals, and moved on to a brief review of C cycling and routing in animal and human diets in section 5.1.0. As well, within the same section I briefly discussed N and S isotopes and their cycling within natural systems, and noted the presence of a trophic level effect for N, but not for S. Throughout, general expectations were presented for the faunal collagen sample results for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$ based from plant and geologic studies within the region. In section 5.2.0, a brief overview of the faunal record for the western Sierra Nevada was provided, focusing on ideas surrounding resource depression in Central California, alternative explanations, and how this has not been evident in the Sierra Nevada region. Of importance is that deer seem to comprise the bulk of the Sierran Nevada faunal assemblages throughout time, alongside numerous other small-bodied taxa that

have lower frequencies within faunal analyses. I suggested two possible explanations for this lack of change: 1) human population pressures never reached a threshold that caused any apparent resource depression, and 2) despite population sizes, a heavy reliance on pine nuts and acorns as proteinaceous resources offset some of the pressure to hunt, and animal populations were never depleted. While these ideas are not mutually exclusive, they pave the way for a discussion of such ideas in Chapter 6, where I analyze the diets of the Indigenous people using light stable isotopes from their remains.

Importantly, the faunal data presented here aimed to create isotopic baselines to understand and interpret human values within the west central Sierra Nevada, especially for $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$, as these two stable light isotopes were not investigated with the paleobotanicals. And a second impetus was to examine the possibility of estimating paleoprecipitation using collagen $\delta^{13}\text{C}$ from faunal remains, as well as from human collagen $\delta^{13}\text{C}$ values.

In the next section, 5.3.0, I detailed the materials used within this isotopic faunal study, discussed the sample selection and identification process and provided tables and pictures of some of the remains to highlight some of the fauna selected and their state of preservation. In section 5.3.1, I laid out some specific expectations for each taxon sampled, based on their observed dietary habits and territorial or ranging behavior. This information was summarized in Table 5-2. Section 5.3.2 covered sample processing and submission methods, where I began a brief survey of some of the preservation issues encountered while processing samples and after receiving results. Section 5.3.3 discussed the methods for estimating paleoprecipitation from faunal remains, where I explained the use of modern faunal results from Broughton et al. (2023) as a means to figure out the best approach.

Section 5.4 marked the beginning of the results section, where I first outline the criteria for acceptable sample results. This led into a short discussion that which concluded with the idea that many of the faunal samples from CA-TUO-935 had been heat-affected, which was not noticeable while cleaning and processing many of the samples. I then discussed the sample results in light of the expectations that were outlined, and discussed how the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of the different taxa compared to each other and the expectations. Next, the $\delta^{13}\text{C}$ results for each taxa were individually discussed as per the model created from the paleobotanical remains in Chapter 4. These results were graphically displayed in Figures 5.5a-e. Although the majority of the fauna relied most heavily on angiosperm resources, some showed the expected values for gymnosperm consumption, mainly a gopher, a ground squirrel, and one deer. The $\delta^{34}\text{S}$ results were discussed next, first in relation to $\delta^{13}\text{C}$, then relative to $\delta^{15}\text{N}$. Within these results, there were discussions of how gymnosperm consumers drove opposing linear relationships between $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ in both deer and small-bodied mammals, whereas for $\delta^{15}\text{N}$ the relationship was weaker. One salient point was that part of the trend in the deer is likely the result of migratory versus resident deer.

In Section 5.4.2, the diets for omnivore and carnivores were modelled forward from the paleobotanical and faunal results to create two new models, one for $\delta^{13}\text{C}$ where meats are included alongside the angiosperm and gymnosperm curves, and one for $\delta^{15}\text{N}$ which included C_3 plants and meat. The diet of the canid was analyzed within this section, and used as an example for how human values would be interpreted using such models. The interpretation for the canid concludes that although it ate primarily meat (~55%), it also had some angiosperm and gymnosperm contributions to its collagen $\delta^{13}\text{C}$.

Last within the results, Section 5.4.3 first discussed estimating precipitation from modern elk from Broughton et al. (2023) as compared to recorded precipitation. Within this discussion

were some important points for how fine-scaled tailoring of monthly precipitation compared to the estimated precipitation may open new avenues of research in ecology and biology, for instance in tracking climate change effects on the paleoecology of C₃-consuming taxa. I then moved on to a discussion of the results of applying Kohn's (2010) log-linear regression to archaeological fauna from the Sierra Nevada and the King Brown site in southern Sacramento Valley. I discussed how gymnosperm-consuming animals' collagen $\delta^{13}\text{C}$ could be adjusted to reflect equivalent estimates of precipitation to angiosperm consumer-based estimates. The most important two points from the paleoprecipitation estimates are that it can be done, and it seems to have a strong correlation with recorded precipitation when modern fauna are used, and second, that paleoprecipitation was lower in the past 3,000 years, but has increased into the modern era. In Chapter 6, these results will be used as baseline estimates to establish expectations for the human samples.

Chapter 6: A Diachronic Stable Isotope Investigation of Paleodiets, Migration, and the Influence of Climate on the Indigenous People of the West Central Sierra Nevada, CA

What can human diets tell us about society? Although this question is broad, two focal questions drive this research in the west-central Sierra Nevada: 1) what are the relationships among settlement structure, human mobility, environment, and diet; and 2) how do humans adapt to short and long-term climatic changes? Hunter-gatherers who inhabited the west-central Sierra Nevada region over the last 4,000 years experienced multiple droughts. However, the most intense, and perhaps the most well studied, was an episodic period of droughts known as the Medieval Climatic Anomaly (MCA), ca. 1050–675 BP (Graham and Hughes 2007; Stine 1994). This chapter examines how human diets changed over the last ~4,000 years and evaluates how these changes relate to shifts in residential and logistical mobility, with a particular focus on whether periods of environmental stress, such as the MCA, correspond to broader reorganization in subsistence and landscape use.

Prior to the MCA, archaeology of the region indicates human groups in the area were residentially mobile and focused on gray pine nuts as the staple plant food for storage (Rosenthal 2011a; Whelan 2016). Previous research implicates the MCA (e.g., Moratto 1984) as the main driving mechanism behind a marked shift in settlement and subsistence patterns, wherein residential mobility decreased, and acorns became the staple food for storage and consumption. However, other research suggests that the greater importance of acorns over time represents a strategy to increase the quantity of storable foods for winter and questions the role of the MCA as the prime reason for changing settlement patterning (Rosenthal 2011c). More recent research within the region has explored this change through relative abundances of paleobotanical

remains and suggests that one explanation for a shift from higher residential mobility and gray pine nuts, to lower residential mobility, greater logistical mobility, and acorns, is increased opportunity costs related to women's foraging and childcare (Whelan 2016; Whelan et al. 2013).

Here I explore dietary choices in a diachronic context. I perform three analyses: 1) a diachronic analysis of diet using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ alongside AMS dates (Section 6.3.1); 2) a diachronic analysis of mobility using $\delta^{34}\text{S}$ paired with AMS dates (Section 6.3.2); and 3) an analysis of the application of Kohn (2010:Eq.2) to human $\delta^{13}\text{C}$ (collagen) values to estimate paleoprecipitation (section 6.3.3).

I first use the stable isotopes of carbon and nitrogen to better understand the human dietary position in relation to the plant and faunal results covered in Chapters 4 and 5. This is accomplished by applying the $\delta^{13}\text{C}_{\text{collagen}}$ and $\delta^{15}\text{N}_{\text{collagen}}$ results from human individuals to two models, one for $\delta^{15}\text{N}$ and one for $\delta^{13}\text{C}$. These models start with probability density functions (PDFs), proportions are then normalized, and uncertainty in predicted values is propagated assuming independence of source distributions and combined with long-term instrumental error in quadrature, which enables tests of model functionality. I then take a diachronic perspective and analyze group-level patterning. AMS radiocarbon dates provide temporal data for approximately 80% of the sampled burial population under study, and represents 83% (56/67) of those for which stable isotope values are available. The radiocarbon dates, calibrated to median dates and a two-sigma confidence range, are used to understand change over time, offering one of the largest radiocarbon-dated datasets for the region.

My primary aim is to understand how and when diets changed over the last 4,000 years, given the theoretical implications of dietary change for settlement strategies, residential mobility, and overall foraging behavior. I use carbon and nitrogen stable isotope data in conjunction with

available archaeological evidence to test ideas about the timing of dietary changes, as diet is a sensitive measure of environmental stress. Additionally, I use sulfur stable isotope ratios to identify locals versus non-locals, as cultural changes during the most recent 1,100 years could be attributed to population immigration, as well as changes to residential mobility, settlement patterns, and territoriality.

Last, I test if human collagen $\delta^{13}\text{C}$ values can be applied to Kohn's (2010) Equation 2. The goal is to see if paleoprecipitation estimates from human collagen track known climatological changes, such as drought and increased precipitation. I use the data from Chapters 4 and 5 to help estimate where human values should fall.

As omnivores, humans represent a distinct dietary subset that, because of the inclusion of meat, may obscure precipitation estimates from their $\delta^{13}\text{C}$ collagen values. However, because consumption of meat, primarily deer, was consistent over time for the sample set, the expectation is that most differences in $\delta^{13}\text{C}_{\text{collagen}}$ should derive from the plant-protein portion of the diet and environmental influences on such. A further complicating factor to extracting precipitation estimates from human $\delta^{13}\text{C}_{\text{collagen}}$ is the inclusion of pine nuts within the diet, since gymnosperms tend to have less negative $\delta^{13}\text{C}$ values than most angiosperms (Gea-Izquierdo et al. 2021; Goodwin et al. 2022; Klein 2014; Knops and Koenig 1994; Kohn 2010b; Mathias and Thomas 2021; Sade et al. 2012; Tardieu and Simonneau 1998; Tieszen 1991), which is expected to show in the human collagen if pinenuts were a major dietary resource.

In short, despite these complicating factors, this chapter aims to test the viability of Kohn's (2010) formula on human dietary estimates of precipitation. I attempt to account for the inclusion of gymnosperm resources by excluding gymnosperm-associated contributions through an angiosperm-only renormalization step after back transforming $\delta^{13}\text{C}_{\text{collagen}}$ to plant-scale $\delta^{13}\text{C}$

using two trophic offsets. This moves the estimated human diet into the range expected for angiosperm plants.

Uncertainty in estimated precipitation is reduced by averaging within time periods, which is shown by standard deviations among individuals in each time-period bracket, standard errors of the mean, and 95% confidence intervals. As well, averaging a few individuals at a time may also reveal trends missed by bulk averaging within bins. The small-group averaging, as with the three-point running average, is more likely to track past climatological changes since human bone and bulk tooth collagen already represent a broader time-average of dietary inputs than plants and animals alone, albeit mostly from the protein component of the human diet. The expectation is that human $\delta^{13}\text{C}_{\text{collagen}}$ will correlate with paleoprecipitation estimates.

6.1 Archaeological, Environmental, and Theoretical Context

Given the archaeological and environmental information covered in Chapters 2 and 3, these Indigenous peoples faced significant and widespread drought periods during the MCA (1050–675 cal BP) (Anderson and Carpenter 1991; Brunelle and Anderson 2003; Büntgen et al. 2011; Cook et al. 2004; Graham and Hughes 2007; Graumlich 1993; Kirby et al. 2012; Kleppe et al. 2011; Knight et al. 2024; LaMarche 1973; Lindström 1990; Lloyd and Graumlich 1997; Lyon et al. 2020; Meko et al. 2001; Scuderi 1993; Stine 1994), followed by cooler and possibly wetter conditions during the Little Ice Age (LIA) (650–50 cal BP) (Clark and Gillespie 1997; Phillips et al. 2009). The Sierra Nevada region remains one of the best-studied areas throughout California in terms of paleoclimatic research. While some of the more recent paleoclimate records suggest the middle portion (2000–2500 cal BP) of the Late Archaic (3000–1100 cal BP) may have experienced periodic droughts and climate instability (Knight et al. 2024; Lyon et al. 2020, 2025;

Street et al. 2012), the MCA droughts during the Recent Prehistoric I period (RP I) are well-studied, and include a number of trees that once grew along now inundated lake margins (Kleppe et al. 2011; Stine 1994).

Many have questioned whether and how Indigenous people in the west-central Sierra Nevada were affected by these droughts. Changes in mobility, settlement strategy, food storage preferences, territoriality, and technology are suggested to have taken place during RP I—the culture-historical period overlapping the MCA—given the well-established pattern of cultural florescence evident in the Recent Prehistoric II (610–50 cal BP; RP II). RP II began shortly after the conclusion of the MCA and contrasts with the longstanding pattern of cultural continuity that preceded the MCA (Davis and Moratto 1988; Hunt 2004; Leftwich 2010; Moratto et al. 1988; Morgan 2009b; Rosenthal 2011a, 2012; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005).

While there are many similarities between the Late Archaic and Recent Prehistoric periods, such as dietary resource use, there are also a few major differences that have yet to be explained by socioeconomic hypotheses. For example, despite thorough testing of the archaeological record against the expectations of behavioral ecological theories, we still lack an explanation as to *why* settlement patterns differ between the most recent archaeological period, RP II, and the Late Archaic (3000–1100 cal BP), as socioeconomic reasons do not seem to be the cause (Rosenthal 2011a). Considering the ambiguity of the archaeological record during RP I (the paucity of single component sites dated to this period), and the cultural differences observed between the Late Archaic and RP II (Moratto 2002; Moratto et al. 1978; Rosenthal 2011c; Wohlgemuth 2005), there is clear evidence for a disruption in settlement or a change in land use (Rosenthal 2008a:74). The potential causes and consequences for which require further consideration.

Diet is one of the more sensitive measures of environmental stress, whether it is tallied from faunal and paleobotanical remains, or interpreted from stable isotope data in concert with such remains. While the faunal and paleobotanical evidence from the west-central Sierra Nevada is limited during the MCA period, dietary evidence preceding the MCA suggests a long period of continuity. Throughout time, diets consisted mainly of deer, gray-pine pinenuts, and acorns, supplemented by small seeds, fruits/berries, small prey (Rosenthal 2008b; Rosenthal et al. 2011a; Wohlgemuth 2005). Presumably, they also included greens, roots, tubers, and possibly mushrooms (Anderson and Lake 2013) but there is scant archaeological evidence to support the ethnographic data. Evidence from paleobotanical remains indicate that early diets centered on the collection of gray pine pinenuts with relatively less acorn collection, but after the MCA there is a relatively greater focus on acorns. Deer always dominate faunal assemblages. Acorns had supplanted pine nuts by RP II, as measured by ubiquity indices (Rosenthal et al. 2011a; Whelan 2016; Whelan et al. 2013). What remains unclear, however, is the timing of the switch to a greater reliance on acorns, as the archaeological period coinciding with the MCA is not well known. We do not know, for example, if the switch was gradual or punctuated, as fine-grained temporal control of paleobotanical remains has been hampered by mixed deposits as well as a paucity of sites dating to the MCA. Based on multiple quantitative and theory-driven analyses of the west-central Sierra Nevada, Rosenthal (2011c:235) found no obvious socioeconomic motivation that would explain the disjunct between Late Archaic and RP I/RP II assemblages—drought remains a viable catalyst for some of these observed changes.

With water as a limiting resource during drought, ancient Native Californians needed to develop novel solutions to environmental fluctuations, such as changing group mobility patterns as well as the possibility of different dietary patterns. For example, contemporary hunter-

gatherers, such as the !Kung San in South Africa, decreased their residential mobility during drought years and settled near permanent water sources while also adapting their foraging strategies to target lower-ranked resources (Lee 1979). Overall, this strategy results in fewer residential moves per year, larger aggregations of people, higher overall logistical mobility, as well as a wider diet-breadth.

In the central Sierra Nevada, the MCA is hypothesized to have created a situation in which hunter-gatherers reordered the rank of preferred resources for storage from a front-loaded resource (pine nuts) to a back-loaded resource (acorns), and residential mobility became increasingly restricted as the drought continued. Front-loaded resources are those that require significant processing prior to storage, while back-loaded resources are those in which processing costs are delayed until after storage but prior to use (Bettinger 2009). This reordering suggests that time constraints on foraging versus other activities may have become more pronounced as overall mobility changed. To investigate this premise, Whelan et al. (2013) offered a reason for why acorns came to be preferred over gray-pine pinenuts. Using the opportunity costs model, they showed how acorns, as a back-loaded resource would be preferred over pine nuts—a front-loaded resource—when the demands on women’s labor between foraging and childcare were at odds; however, this reason only holds true for the period after residential mobility had already decreased, for which we still lack a suitable explanation. The main premise of Whelan et al. (2013) is that as the costs of foraging bouts increase due to the reduced residential mobility, foraging further from the residential base favors easily gathered and stored items with processing costs that could be delayed until the resource was needed, resolving the time conflict between foraging and childcare by moving the majority of processing costs to periods when processing and childcare were not mutually exclusive tasks. The question of when

this took place has remained elusive, as it is linked to why a reduction in residential mobility occurred at all.

However, Whelan et al. (2013) argue that despite drought conditions, resources would have been encountered at the same rate as during non-drought periods, but these resources would simply have moved up slope. I suggest there are other considerations for resource structure during drought periods that are at odds with the premise that resources would have been encountered at the same rate as non-drought periods (Whelan et al. 2013). While it is true that major plant resources, such as nut-producing gray pine and some oak species, would have shifted upslope, we need to consider the time frame for that change to occur and for new trees to reach maturity for nut production, as well as the period of die off and reduced seed production due to constraints on water and temperature and how this affects phenology (i.e., forcing it to occur earlier in the year, as discussed in Chapters 2 and 4). Not to mention increased residential mobility if resources have moved further upslope.

In general, there is a time lag between drought onset and plant community movement (Hill et al. 2023), which is among the slowest for trees (Bréda et al. 2006; Brodersen et al. 2019; Kelly and Goulden 2008; Savage and Vellend 2015; Willson and Jackson 2006). This lag is especially pronounced for dry habitat pines that produce large seeds, such as gray pine, which are exceptionally slow growing (Krugman and Jenkinson 1974). We also must account for how the landscape was managed by fire, as forest density was much lower in the past than currently, although this probably favored oak groves at the expense of pines and other trees that were not used as cultural resources (Anderson and Rosenthal 2015; Anderson and Carpenter 1991; Anderson and Smith 1997; Hull and Moratto 1999; Klimaszewski-Patterson et al. 2023). This factor would have affected the quantity of viable trees to produce seeds at the time of a major

drought, although we do not know if gray pine was a managed resource as the way oaks are thought to have been. While Whelan et al. (2013) may be correct in their interpretation of why acorns became the preferred nut crop for storage, given reduced mobility and trade-offs between childcare and foraging, they do not offer a reason for reduced residential mobility, leaving drought as a possible explanation for the change in settlement strategy. Also, as previously suggested, the timing of such a change is unclear.

If people moved upslope, out of the Upper Sonoran Zone and into the Lower Montane forest, as the majority of site locations (except for the Don Pedro sites) suggest for the MCA period, because of the time-lag between drought onset and the upslope movement of trees/biotic communities, fewer nut-producing pines would have initially been encountered. Those pines that were suitable would have been sugar pine, which tends to restrict itself to more mesic habitats, while black oaks would have remained a viable option, given their climate sensitivity is less than sugar pine (Fryer 2007b; Habeck 1992). As well, acorns were never absent from the diets of the Indigenous communities of the western Sierra, as indicated by paleobotanical records (Rosenthal et al. 2011a; Whelan 2016; Whelan et al. 2013)—they were simply not as heavily relied upon as pine nuts prior to the MCA according to these records. In theory, even though collagen represents the protein portion of the diet, the differences between pine nuts and other plant taxa and their dietary inclusion should be distinguishable through time, similar to how C₄ resources such as maize are noticeable in human collagen. This difference should identify when the proposed shift from pine nuts to acorns occurred and whether it was gradual or more punctuated.

One possible way to explore and narrow down the factors that contributed to the observed changes in settlement and residential mobility is the use of $\delta^{34}\text{S}$, as it can distinguish between locals and non-locals in terrestrial environments (Lamb et al. 2023:2; Nehlich et al. 2010;

Richards et al. 2001), provided appropriate baseline values are known, such as the faunal data in Chapter 5. This method works because of minimal isotopic fractionation (less than 1‰) as sulfur is passed up the food chain from primary consumers (Nehlich 2015). Sulfur isotope data enables tracking of ingroup versus outgroup variance over time, such as if an outgroup had moved into the region during some portion of the last 4,000 years. In addition, the changing variance in $\delta^{34}\text{S}$ across time should identify the timing and nature of the reduction in residential mobility.

In this chapter, I posit a possible explanation for the reduced residential mobility. I suggest permanent and reliable water sources, such as rivers, were targeted for settlement to reduce the risk of being without water during ongoing droughts, such as during the MCA. One way to test this is through the variance in $\delta^{34}\text{S}_{\text{collagen}}$ across multiple segments of time. Also informative is the possibility of determining locals versus non-locals, as the timing of Me-Wuk immigration to the region has long been in question (e.g., Moratto 1984). The historical linguistics for this region (Golla 2011) was heavily informed by archaeological determinations made by Moratto. However, cultural changes interpreted by Rosenthal (2011a) were minimal compared to those proposed by Moratto (Moratto 1984, 2002; Moratto et al. 1988) for the pre-1100 cal BP period. As such, while Golla (2011) may be correct in the order of dialectical change, his timing may be off. Observed archaeological changes may not equate to a Me-Wuk immigration into the area circa 1,000 cal BP, but instead may represent adaptations to a changing environment in combination with new technological innovations. The use of sulfur isotopes on the populations inhabiting the foothill region, which sits at the border between the Sierra Nevada proper and the Central Valley, may be most informative for disentangling or clarifying group movement through time.

Regardless of non-locals, which should show as outliers, the expectation is a decrease in the variance of $\delta^{34}\text{S}_{\text{collagen}}$ during prolonged drought periods as compared to the period before prolonged drought. A decrease in the variance of $\delta^{34}\text{S}_{\text{collagen}}$ should indicate a reduction in residential mobility, as people would be more restricted in the amount of territory covered during their lifespan, and an aggregation around a local source, such as a permanent water source, should cause the variance, or spread around the mean, to be reduced. Alternatively, this can be simplified to a simple reduction in variance in $\delta^{34}\text{S}_{\text{collagen}}$ for any period when residential mobility was reduced, which should be the expectation for periods that experienced drought or territorial circumscription.

In order to evaluate whether reduced residential mobility is due to environmental (drought) factors, cultural factors (increased territorialism), or some combination, chronological comparison of the variance in $\delta^{34}\text{S}_{\text{collagen}}$ is needed. In the case of the onset of or increased territorialism, the expectation is that once territorialism is in place, or has increased, residential mobility would not be relaxed again in subsequent periods of time (i.e., where relaxed it would be indicated by greater variance in $\delta^{34}\text{S}_{\text{collagen}}$). According to Rosenberg (1998:660), it is not other groups who are territorial which exert continued pressure to maintain territorialism, but the nascent groups that have the potential to develop if population pressure produces territorial compression. From this premise, it would take a reduction in population across not one group, but many, to relax population pressure to the point where territorial boundaries could not be economically maintained. The thought here is that as groups shift to a new equilibrium in terms of diet and territory size, a status quo is needed to maintain enforcement of territorial boundaries. If the population is reduced, territorial boundaries can no longer be guarded or maintained as they once were, which leaves open the possibility of relaxed territorialism. If the population is

not reduced, yet territorial expansion occurs, the outcome is typically violence. As covered in Chapter 3, the few instances, or markers of increased violence in the Sierra Nevada region do not correlate with the MCA drought given direct radiocarbon dates on human remains; rather this violence happened after the MCA, during RPII.

For reduced residential mobility due to environmental factors, I expect later periods to show greater variance in $\delta^{34}\text{S}_{\text{collagen}}$. This holds because, if environmental conditions were the only factor leading to restricted residential mobility, once a new equilibrium was reached, via dietary adaptations, technological innovations, or both, residential mobility would not necessarily be expected to remain restricted once environmental conditions improved or environmental obstacles were overcome. In this sense, restricted residential mobility is costly in terms of time spent foraging—much in line with what Whelan et al. (2013) have argued.

If technological innovation or dietary adaptation can overcome the obstacle of a deteriorated environment, then there would be no reason for residential mobility to remain restricted. That is, unless the main restriction to residential mobility was access to reliable water resources. While water may not have been an issue in the Sierra Nevada during winter, even during drought years, as winter is the main precipitation, the summer and fall would be highly restricted in terms of water access during drought years. For example, it has been estimated that precipitation totals were no more than 60-65% of what is considered normal by today's patterns during MCA droughts (Graham and Hughes 2007; Kleppe et al. 2011; Stine 1994), which were also accompanied by warmer temperatures, documented in tree rings from the Sacramento watershed, and south to the White Mountains (Graumlich 1993; Meko et al. 2001; Millar et al. 2006).

In terms of hydrology, there is a lag between the effects of early snowmelt years on the subsurface water storage that serves to replenish many of the low flow streams, creeks, and rivers throughout the Sierra (Godsey et al. 2014; Lapides et al. 2022; Tague and Peng 2013). When subsurface moisture conditions are in a deficit prior to or during snowmelt, often following drought years or warm winter years, evapotranspiration and water demand from plants above ground coupled with the subsurface deficit effectively deplete the subsurface water storage zone (Godsey et al. 2014; Lapides et al. 2022; Tague and Peng 2013). Hence, even when an “above average” precipitation year occurs following early melt years and/or below-average precipitation years, the resulting mid-late year streamflow is still reduced from what is normally observed with above average precipitation (Lapides et al., 2022).

To put the MCA conditions in perspective, given earlier discussion of snowpacks and drought (see Chapter 2), major water shortages that reduced river flows and caused significant lake level declines would have certainly been noticeable to the people living in the Sierra at the time, as would any concurrent vegetational changes such as die-offs, upslope movements, or reduced secondary production (seeds, nuts, fruiting). If we consider the reduced river flows as valid, then we also need to consider that the many perennial streams and seasonal creeks may have also been affected, as most contribute to river flows. Sites located away from streams and rivers in the lower elevations may have decreased in use or been abandoned during the MCA, and more reliable water sources, such as the major rivers, were likely sought out. This sentiment echoes that of Wohlgemuth (2005) and Rosenthal (2011c:235–236), who have also suggested the MCA drought may have affected settlement patterns in areas located away from major rivers.

In this line of logic, if acorns were used year-round as a dietary supplement, they would necessitate settlement near a reliable water source, such as a river, during multi-year drought

conditions. Perennial and seasonal water sources, such as creeks and streams, would entail unnecessary risk for settlement even if acorns were stored nearby, because these acorns run the risk of not being processed when most needed. However, even as late winter/early spring has long been touted as the lean period (as few fresh resources are available), a reliance on acorns as a way to make ends meet still necessitates settlement near a reliable water source year-round. During drought years, we should expect a heavier reliance on acorns to make ends meet, simply because we should expect a widening in diet breadth. Alternatively, with pine nuts, there is no settlement restriction as they do not require water for processing after storage, they simply require time up-front to prepare them for storage. Hence, if acorns came to be preferred for storage and use as a dietary stop-gap, settlement near reliable water would have been necessary; however, if pine nuts were still the preferred stored resource for storage, settlement anywhere within a day's walk of reliable water should be expected, as drinking water could have been stored or transported.

The most difficult scenario to distinguish in terms of $\delta^{34}\text{S}_{\text{collagen}}$ variance is whether reduced variance is because of *both* increased territorialism and water as a limiting resource. While the expectation for territorialism is a continued reduction of variance in $\delta^{34}\text{S}_{\text{collagen}}$ in subsequent time periods, the opposite is expected for drought. If these were to co-occur, we might expect the variance in $\delta^{34}\text{S}_{\text{collagen}}$ to remain low in subsequent periods despite the alleviation of drought conditions simply because once territorialism is in place, it is expected to be maintained. If these factors were to co-occur within the same time period, such as the RP I and MCA, a closer examination of the period in question might inform on which may have occurred first, given the premise outlined above for territorialism versus drought.

In sum, we do not know the exact timing of the switch from pine nuts to acorns nor whether it was gradual or abrupt. Also, the question remains, why was there an upset to settlement locations and a reduction in residential mobility? An influx of outsider movement into the region, increased territoriality by groups already inhabiting the region, an adaptation to drought conditions, or a combination of all three may have been at play. However, some of these variables are testable using stable isotopes and the study of diet within a diachronic framework.

6.2 Materials and Methods

All analyses performed here (paleobotanical, faunal, and human) were undertaken with permission and support of the Tuolumne Me-Wuk, the most likely descendants of the human remains. The Tuolumne Me-Wuk requested scientific analyses on the ancestral remains from the New Don Pedro sites after they had been repatriated but prior to their reburial. I have been privileged to work with these remains prior to their inhumation. The remains from CA-TUO-935 were discovered during CRM excavations in 2014. They were sampled with permission from the Tuolumne Me-Wuk and returned to the tribe for re-inhumation, prior to the beginning of this project. The data from these individuals is used here, with their permission. The burial collection from Columbia College had been on loan to California State Parks from the Tuolumne Me-Wuk. After the loan expired, the tribe brought the collection to the University of California, Davis, for scientific analyses. I am grateful to have been able to work with these remains as well.

The ongoing relationship between archaeologists and the Tuolumne Me-Wuk has been built on trust, and a shared curiosity to know more about their ancestors. While this type of working relationship is not unheard of, it is rare within California, and I am honored to have

been a part of it. Our hope is that such examples of collaborative research built on a foundation of trust become more prevalent in future generations.

6.2.1 Materials- Burial Collection and Site Backgrounds

In this section, I briefly cover the backgrounds for each burial collection and for CA-TUO-935. Some of the sites represented by these burial collections were discussed previously in Chapters 3, 4, and 5, and thus they are only briefly reviewed here. For orientation, general site locations, two major rivers, the Stanislaus and Tuolumne, and the town of Groveland are shown in Figure 6.1, a map of the study region.

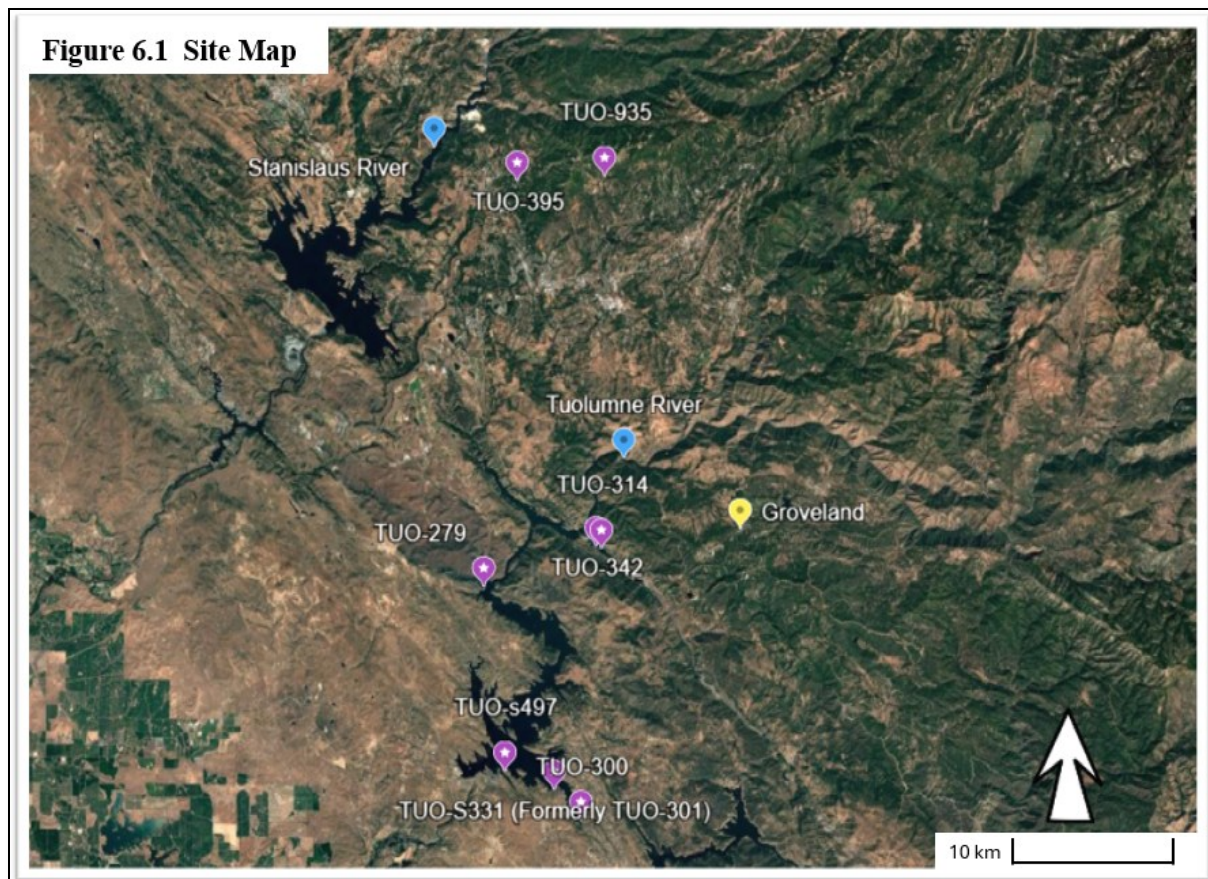


Figure 6.1 Map of Human Sample Sites.

Satellite image shows the human remains sites (Pink Star Markers) in relation to each other, to the two major rivers in the area (Stanislaus River and Tuolumne River; blue markers), and to the town of Groveland (yellow marker). Map satellite image is attributable to Google Earth 2026.

Importantly, no site was further than 40 km (straight line) from any other site on the map, while distances to the two major rivers are less. Site distances are detailed Table 6-1, which presents a matrix showing the relationship of each site to the others. The main thrust of this section is to provide brief descriptions and short histories on these burial collections and the sites from which they were unearthed.

Table 6-1 Site Distance Matrix (km)

REFERENCE SITE:	TUO-935	TUO-395	TUO-314	TUO-342	TUO-279	TUO-S497	TUO-S331	TUO-300
TUO-300	39.6	39.5	16.7	16.9	15.5	5.6	2.5	0
TUO-S331	37.9	37.4	15.1	15.2	13.1	3.3	0	—
TUO-S497	37.1	36.1	14.9	14.9	11.4	0	—	—
TUO-279	26.3	24.9	7.6	7.3	0	—	—	—
TUO-342	22.8	22.9	0.2	0	—	—	—	—
TUO-314	23.1	23.4	0	—	—	—	—	—
TUO-395	5.5	0	—	—	—	—	—	—
TUO-935	0	—	—	—	—	—	—	—

Note: table shows the distance (km) from one site to another in matrix form. The values provided, shown to the closest 1/10 kilometers, are linear measurements that do not account for topographic relief. “0” marks the comparison of a site’s distance to itself; dashes (—) are used to denote relationships that have already been covered within the table.

New Don Pedro Burial Collection

The majority of human skeletal materials included in this study were recovered during excavations in 1970 and 1971 from the impound area of the New Don Pedro Reservoir. The collection was housed at San Francisco State University’s (SFSU) Treganza Museum until 2014, when the skeletal materials were repatriated under the Native American Graves Protection and Repatriation Act (NAGPRA) to the Tuolumne Me-Wuk tribe, who were identified as the most likely descendants (MLDs). Skeletal materials were temporarily transferred to UC Davis to undergo isotopic and DNA analyses at the request of the tribe, prior to their planned reburial (Hull et al. 2016).

The main source of information regarding these excavations was a report published in the Treganza Museum Anthropology Papers, and edited by Moratto in 1971. However, Moratto (1971a) underestimated the number of individuals unearthed during those excavations, according to the records produced by the SFSU NAGPRA teams (San Francisco State University 2014a, 2014b, 2014c). According to Moratto (1971a) 16 burials were recovered from two sites: four from TUO-279 and 12 from TUO-300. Excavation notes and provenience information on burial boxes and bags indicate four sites were represented by the New Don Pedro burial collection, CA-TUO-279, -300, -314, and -328 (San Francisco State University 2014a, 2014b, 2014c). Of these four, TUO-328 had a single human bone, a phalanx, which, unfortunately, did not survive chemical processing. As such, this site is not discussed further. The contexts of the burials from the remaining three sites, TUO-279, -300, -314 are described in more detail below.

TUO-279 was a midden site located on a peninsula that jutted into the Tuolumne River. Situated at approximately 200 m (~650 ft) in elevation, the site was within the low rolling hills of the Upper Sonoran Zone. Excavations were carried out from November 1970 through January 1971 (Henn 1971; Moratto 1971), as flooding of the New Don Pedro Reservoir had already begun months prior (Barnes 2010:11). Prior to excavation, the site had been damaged by a bulldozer cut (Moratto 1971).

According to Moratto (1971:45, 162), four burials were unearthed from TUO-279, but only three were extracted; burial three was left in situ. The three excavated burials (B1, B2-individual 1, B2-individual 2, and B4) were accounted for by the NAGPRA inventories carried out at San Francisco State University; however, additional remains within TUO-279 burial boxes were later identified (San Francisco State University 2014a). These remains were in burial bags marked most often with provenience information, though occasionally not, and. they were

assigned the prefix Unk (for unknown) by the SFSU NAGPRA personnel (San Francisco State University 2014a). For consistency, we retained the Unk prefix for all undocumented burials from this site, as well as the other two Don Pedro sites. There were an additional five “Unk” individuals identified for TUO-279 for a total of nine individuals.

TUO-300 was a large midden site with one visible house pit, located along Rogers Creek within a small valley about four km to the southeast of the Tuolumne River. Excavated by Moratto and a large crew in the fall of 1970 through the winter of 1971, CA-TUO-300 is the largest and least disturbed site from the Don Pedro excavations (Moratto 1971:78, 80). The only apparent disturbance was a large bulldozer cut outside of visually-estimated site boundaries (Moratto 1971: Map IV-D-1). The site sat at 238 m (780 ft) elevation and was surrounded by Upper Sonoran Zone flora and fauna (Moratto 1971:78).

TUO-300 yielded the largest number of excavated human remains. Eight burials were recovered from under the floors of a house pit, and a few of these included multiple individuals. Half of the burials were lain beneath cairns and most of those had been placed in a flexed position (Moratto 1971:106). A number of other human remains were encountered, mostly disarticulated bones scattered amongst the other units not associated with the house pit (Moratto 1971:106–107). Moratto (1971:162–163) details twelve burials excavated from this site. Burials 4 and 12 were not relocated by the NAGPRA teams, although they note that two of the unknown individuals (UNK 7b and UNK 5, respectively) found in unlabeled bags match the descriptions of these burials (San Francisco State University 2014b). NAGPRA inventories documented a minimum number of individuals (MNI) of 39 (San Francisco State University 2014b).

CA-TUO-314 was a large midden site, possibly once a village, situated on the south bank of Moccasin Creek about 1.6 km from its confluence with the Tuolumne River (Moratto

1971:130). Prior to dam construction activities, TUO-314 had been home to the Golden Chain campground (San Francisco State University 2014c). Of the excavated sites, it had been the most damaged by earthmoving equipment and stump removal prior to archaeological excavation. Charles Slaymaker (Moratto 1971) noted that hundreds of ancestral remains littered the ground but only a few patches of the original ground surface remained intact. Local residents said prior to work performed by the earthmoving equipment, a low mound, about two-meters high was present at the site (Moratto 1971:129–131). Numerous ash lenses, an intact cairn, a rock feature, and a disturbed house floor with post-hole impressions were visible prior to excavation (Moratto 1971).

Despite damage to the site, excavations focused on burials that remained in situ, as well as some moderate surface collection (Moratto 1971: 129-131). Beyond Slaymaker's written impression of the site (Moratto 1971:129-134), no formal analysis was undertaken. Slaymaker's notes document 14 individuals, which had been disturbed by earthmoving equipment; however, it is unclear if all 14 or only five were exhumed (Moratto 1971: 132-134; San Francisco State University 2014c). NAGPRA inventories for this site noted some bags labelled as belonging to TUO-314, additionally some of the unlabeled bags found within the TUO-279 burial boxes account for the missing burials and surface collections (San Francisco State University 2014c). SFSU NAGPRA teams assessed all remains associated with this site, and estimated an MNI of 20 (San Francisco State University 2014c).

The Columbia College Collection

The human remains that comprise the Columbia College collection come from four sites, CA-TUO-S331 (formerly -301), -342, -395, and -487. Of these four, TUO-395 is referred to as the Columbia College site, while the other three are associated with surface surveys conducted

around the New Don Pedro Dam by Frank A. “Fritz” Riddell (CA Dept. of Parks and Recreation 1996; Riddell 1970a, 1970b) prior to Moratto’s 1970–71 excavations. After the curational loan with California State Parks had expired, the Tribe brought these remains to UC Davis with a request for further analysis. Only human remains were recovered from the three surface collection sites (CA-TUO-s331, -342, -487), whereas CA-TUO-395 was a full site excavation and recovery. Beyond human cremains, archaeologists had recovered numerous cultural and burial-associated artifacts (such as beads) as well as dietary remains (faunal bone and charcoal). For ease of organization, I begin with the surface survey sites.

Riddell surveyed CA-TUO-S331 in May of 1970; at the time of his survey, the site was recorded as CA-TUO-301 (Riddell 1970b). The site was located along the northern portion of Rogers Creek at an elevation of around 222 m, approximately 2.5 km from CA-TUO-300 and about 3.6 km from the creek’s confluence with the Tuolumne River (Moratto 1971: Map III). The exact distance to the historic Tuolumne River is unknown. The La Grange Reservoir and the old Don Pedro Dam were constructed in 1893 and 1923 respectively, and thus they altered the distance to the river, as the waters were impounded (Moratto 1971: 1–2). Riddell (1970b) described the site as a small village with 14 visible mortar holes within a partially exposed bedrock outcrop. It had been badly damaged by a bulldozer cut, but Riddell (1970b) felt that the site still held significant archaeological information. Among the items collected during survey was a human occipital bone fragment (Riddell 1970b). The occipital fragment lacked any identifiable features from which to estimate sex; however, I estimated the age at death to 16–35 years based on the lambdoidal suture closure (Buikstra and Ubelaker 1994; White and Folkens 2005).

Another of the sites surveyed by Riddell (1970a) that produced human remains was CA-TUO-342, which he surveyed in April of 1970. Located along Moccasin Creek, it was about 1.4 km from the creek's confluence with the Tuolumne River, and about 200 meters from TUO-314. This estimated location is based on a comparison of Moratto's (1971) Map III with the 7.5' quad provided with the site record. Riddell (1970a) noted that the site was, at the time of survey, occupied by a trailer court. Whether this trailer court was the same as the campground referred to by Slaymaker (Moratto 1971a; San Francisco State University 2014c) for TUO-314 is unknown, but it is suspected. CA-TUO-342 is noted by Riddell (1970a) as a village site with a possible associated cemetery. The site was estimated to be at about 213 m asl, surrounded by Upper Sonoran Zone vegetation, with introduced vegetation (fruit trees, grape vines) at the site at the time of survey (Riddell 1970a). A single human premolar was collected from the surface. I identified this tooth as a lower left first premolar (LLP3), based on the root and crown morphology, as well as wear facets (Buikstra and Ubelaker 1994; White and Folkens 2005). This tooth did not produce any viable stable isotope results, and thus it was not submitted for radiocarbon dating. As such, these remains are not considered further.

Riddell also surveyed and collected human remains from another site in the vicinity of Don Pedro Reservoir. However, there is some confusion as to which site it is, as it could have been TUO-487, TUO-S497 or TUO-S487 (CA Dept. of Parks and Recreation 1996). According to the California Department of Parks and Recreation (1996), the site record is missing from the Office of Historic Preservation files, and it is not plotted on any of the maps. For labelling purposes, I use TUO-S497 because it is suggested by the DPR form, although the burial inventory from 1992 suggests TUO-487 as the site trinomial. The site was along Lucas Gulch, northwest of the Blanchard fire station, but it is not the current site recorded as TUO-497 (CA

Dept. of Parks and Recreation 1996). Maps indicate that TUO-S497 would not have been far from TUO-S331, as Lucas Gulch is a short distance to the northwest of Rogers Creek and the Blanchard fire station. Today most of this area is completely inundated by the impound waters, and thus the map pin I use is only an estimate based from where Rogers Creek would have intersected Lucas Gulch along its northern terminus.

Fifty-six items collected from this site retained the label “Lunface collection,” mentioned in 1987 paperwork (CA Dept. of Parks and Recreation 1996), among these were two human parietal bone fragments that did not refit. These two parietal fragments were received for scientific analysis with the Columbia College Collection. They exhibited a similar condition to each other (similar coloration, deterioration), and are likely from the same individual given the context of the surface collection. However, I treated them as separate samples during chemical processing. The smaller piece did not return any collagen and is not considered any further. The larger piece, labelled as TUO-S497-A, included a section of either the coronal or sagittal suture margin, which indicated sutural closure and indicates this cranial fragment belonged to an adult (Buikstra and Ubelaker 1994; White and Folkens 2005). This bone fragment yielded enough collagen for both stable isotope analysis and radiocarbon dating.

Located on the campus of Columbia Junior College in Columbia, CA, CA-TUO-395 was discovered by bulldozers during a parking lot and drive access expansion. Arrangements were made for Riddell to excavate the site as part of an archaeology field methods class (CA Dept. of Parks and Recreation 2018; Daniels 1969). The site was excavated by students under Riddell’s supervision during fall 1968 and spring 1969. According to Daniels (1969), five house pits were visible, as well as a large impression of what was interpreted to be a historic roundhouse. Of these structures, the roundhouse and two house pits were excavated (CA Dept. of Parks and

Recreation 2018). All showed signs of being destroyed by fire (CA Dept. of Parks and Recreation 2018; Daniels 1969). Heron (1968) and Daniels (1969) note that the site had been heavily disturbed prior to excavation. The site was called *Wolango-su*, which may have been the village name, given the presence of the roundhouse (CA Dept. of Parks and Recreation 2018).

Over 60,000 objects were recovered; however, 59,667 are glass beads, most of which are fire-affected (CA Dept. of Parks and Recreation 2018; Daniels 1969; Heron 1968). The remaining objects are a mix of Indigenous and Euroamerican-style artifacts, and include unidentified glass and glass slag, metal eye hooks, buttons, nails, charcoal, a shell bead, as well as some faunal remains (CA Dept. of Parks and Recreation 2018). Excavated from among the structures were two burials (one per house pit) and one cremation (roundhouse). The large number of beads were found with the cremation, next to a fire pit within the roundhouse (Daniels 1969).

The collection was repatriated to the Tuolumne Me-Wuk in 1992, and then loaned to CA DPR until 2018. When the loan expired, I was granted access by the Tuolumne Me-Wuk to sample the collection when it was loaned to UC Davis. I sorted and photographed the human remains to estimate MNI. All remains were highly fragmentary, and sometimes the only identification possible was “long bone fragment” or “calcined bone fragment.” Despite these limitations, there were no repeated skeletal elements (e.g., no two left femurs nor two upper right first molars) within each of the loci identified within the burial collection catalog. However, there were notes and accession numbers in the collection documentation suggesting that some remains were not associated with either of the house pits nor roundhouse, as there were seven different accession number suffixes. Notably, nearly all bones from every context outwardly showed signs of having been heat affected. For example, many exhibited cracking and warping

while others were fully calcined, shades of gray and blue, or had charred black interiors (medullary cavity)—this was true for both the human remains as well as most of the faunal remains. Most teeth were calcined dentin, including roots and occlusal surfaces where the enamel had become detached, or charred enamel fragments. Some of these bone and tooth examples are shown in Figure 6.2a-c. Sampling was limited among the human remains, which I discuss in more detail in the next section.

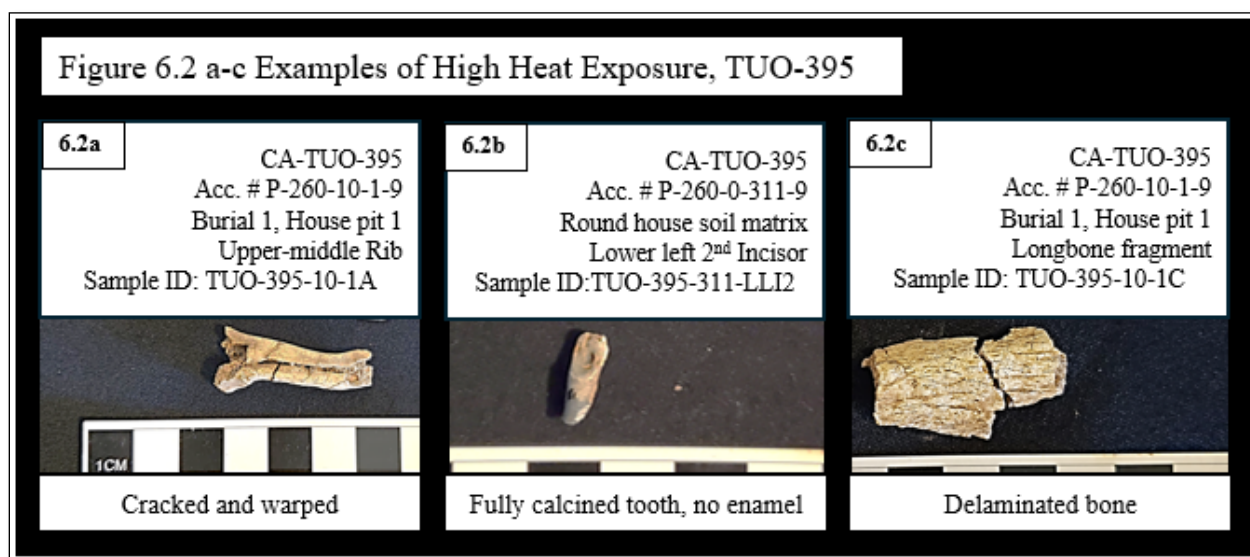


Figure 6.2a-c Examples of High Heat Exposure, TUO-395

Figure shows some of the more identifiable remains from TUO-395 which exhibited exposure to high temperatures; a) a rib fragment that was sampled which exhibited cracking and warping; b) a fully calcined tooth, where the enamel was absent as if it had “popped off”, yet the dentin retained some of its original shape; c) a delaminated longbone fragment, with a rough surface, friable texture, and grid-like breakage.

CA-TUO-935

The remains from CA-TUO-935 were discovered during CRM excavations in 2014. They were sampled with permission from the Tuolumne Me-Wuk and returned to the tribe for re-inhumation prior to the start of this project. CA-TUO-935 is an ancient to historic-era site on property currently owned and managed by Pacific Gas and Electric (PG&E). The site has served as a part of PG&E’s network of hydroelectric facilities since 1928, and part of the hydroelectric

facilities for other companies since 1898 (Wohlgemuth 2015b). In accordance with FERC regulations and Section 106, Far Western Anthropological Research Group was hired to undertake all archaeological related tasks during trenching for replacement of underground cable and ground rods in 2014 (Wohlgemuth 2015b).

During excavation, disarticulated human remains were encountered among multiple loci at the site. Given the long history of site disturbance, mainly associated with the hydroelectric features, but also older goldmining, ranching, and homesteading activities, the discovery of disarticulated human remains was not completely unexpected (Wohlgemuth 2015b). Data from these individuals are used here, with permission of the Tuolumne Me-Wuk. Twelve individuals were sampled, and nine returned viable stable isotope results.

6.2.2 Methods: Sampling Procedure for Human Remains

The human remains sampled from the New Don Pedro burial collection (CA-TUO-279, -300, -314, and -328) were selected based on the NAGPRA inventories provided to the Tribe. Our selection protocol involved an attempt to sample each of the individuals listed in the NAGPRA inventories. We aimed to sample bones that typically afford better preservation due to thicker cortical walls, were minimally fractured, or showed minimal diagenesis. We also attempted to sample first and third molars, when present in maxillae or mandibles, as well as bone from the same individual, as these would provide complimentary data. Typically, about one gram of bone was sampled from each individual. Few teeth were sampled, as dental attrition was extensive within the skeletal elements that retained teeth. Loose, or disassociated teeth were avoided.

In a few instances, two bones were sampled from one individual (as tallied by the NAGPRA inventory) to account for different states of preservation among remains, or to discriminate among non-refitting elements from the same burial context. For example, we

encountered one burial listed as an MNI of one (CA-TUO-314, Burial 2), yet the two halves of the mandible did not refit and exhibited different states of dental wear. Thus, for this burial, we sampled both mandible halves and treated them as separate individuals, Burial 2A and Burial 2B. In other cases, only a single bone was present, which was either too small or preservation was too poor—these individuals were not sampled. Appendix C1 provides details from the NAGPRA inventories as well as our sample selection notes. For those samples in which collagen was extracted, burial information is provided in Table 6-2, below, organized by collection and site.

In the case of the remains from the Columbia College collection (CA-TUO-395, -s331, -342, and -s497), inventory and accession records provided by State Parks were used alongside my own inventory and analysis. Sample ID was based on the accession number followed by an alphabetic identifier in the case of multiple human remains. For example, with TUO-s497, the accession number and an alphabetic identifier of A and B were used, as there were two human bones, while for -s331 and -342, which only had one bone each, the accession number was used. Regarding TUO-395, the Columbia College site, notes and accession numbers within the collection documentation suggested there were seven different contexts from which human remains were documented. TUO-395 Burial 2 (from house pit 2), accession number P-260-10-2-9, could not be relocated within the collection boxes at the time of inventorying, and was not assessed or sampled. All other human remains from TUO-395 were in highly variable states of preservation, and every attempt was made to sample only the least heat-affected bones. Working with interns, we visually assessed degree of burning (Stiner et al. 1995). When possible, both the exterior and interior surface of each bone were scored. Remains with an average score of “0” to “1” were selected. In order to maximize the possible number of individuals and successful collagen extraction, a few samples were taken from each of the accession number contexts from

among the suitable contenders when possible. For example, for TUO-395 accession number P-260-10-1, there were eight human remains (A-H), three of which were sampled. None of these human remains returned viable stable isotope values, indicating that preservation was an issue, although one did produce enough collagen to yield a radiocarbon date. Sample information for the Columbia College can be found in Table 6-2. Because of these preservation issues, only one individual is included in further analyses.

For CA-TUO-935, previously produced stable isotope data and some radiocarbon dates were provided to me alongside the site excavation report. The original sample selection protocol aimed to maximize the number of individuals by selecting samples from different parts of the site, from different demographic groups (e.g., adult vs juvenile), or by duplicating a particular element (e.g., left humerus) (Wohlgemuth 2015b:Appendix E). From the original report, nine out of 12 individuals returned acceptable stable isotope data. In the original report, four individuals had been radiocarbon dated; for this project we obtained radiocarbon dates for the remaining five individuals that produced stable isotope results. Sample information for this site is organized in Table 6-2, below.

Table 6-2 Sample List for Human Remains

Sample ID	Sex	Age at Death	Elements Sampled	Context
TUO-279 B1	ind.	Adult	vertebra	Unit 96, 60-80 cmbs
TUO-279 B2 Indiv.1	male	Adult (27-35y)	L. fibula, LLM1, LLM3	Unit 96, 67 cmbs
TUO-279 B2 Indiv.2	ind.	Adult	L. occipital	Unit 96, 60-80 cmbs
TUO-279 B4	ind.	Adult	R. tibia	Unit 96, 60-80 cmbs
TUO-279 Unk1	ind.	Adult	vertebra	Unit 96, 60-80 cmbs
TUO-279 Unk2	ind.	Adult	rib	Unit 87, 40-60 cmbs
TUO-279 Unk3	ind.	Adult	R. third metacarpal	Unit 137, 20-40 cmbs
TUO-279 Unk4 Indiv.1	ind.	Adult	rib	Unit X, 20-70 cmbs
TUO-279 Unk4 Indiv.2	ind.	Adolescent	vertebra	Unit X, 20-70 cmbs
TUO-300 B1	female	Adult	fibula	Unit M-6, 70 cm

Sample ID	Sex	Age at Death	Elements Sampled	Context
TUO-300 B2	ind.	Adult	L. zygomatic	Unit R-10, 55 cm
TUO-300 B3	male	Adult	tibia	Unit M-6, 90 cm
TUO-300 B5	ind.	Adult	tibia	Unit R-13, 179 cm
TUO-300 B6	ind.	Infant	crania	Unit O-4, 75 cm
TUO-300 B8	female	Young adult	mandible, LLM1, LRM3	Unit Q-7, 140 cm
TUO-300 B9A	female	Adult (old)	mandible, ULM1, ULM2	Unit R-10 and Q-10; 90 cm
TUO-300 B9B	ind.	Adult	radius	Unit R-10 and UQ-10; 90 cm?
TUO-300 B10A1	female	Young adult	mandible, LLM1, LLM3	Unit O-4, 105 cm
TUO-300 B10A2	ind.	Adult	rib	Unit O-4, 76 cm
TUO-300 B11A	ind.	Juvenile	longbone	Unit N-5, 96 cm
TUO-300 B11B	male	Young adult	premolar (P4)	Unit N-5, 60-80 cm
TUO-300 B13	ind.	Juvenile	rib	Unit N-6, 88 cm
TUO-300 Unk1	ind.	Juvenile	longbone	Unit N-7, 60-80 cm (burial bag)
TUO-300 Unk2 Indiv.1	ind.	Adult	longbone	Unit N-6, 40-60 cm
TUO-300 Unk3	ind.	Adult	femur	Unit P-11, 60-80 cm
TUO-300 Unk4	male	Adult	frontal bone	Unit S-7, 96 cm
TUO-300 Unk5	female	Adult (old)	L. femur, LRM3, M1 root	unknown-from unlabeled bag
TUO-300 Unk6	ind.	Adult	L. fibula	Unit P-4, 0-53 cm
TUO-300 Unk7A	ind.	Adult	femur, ULM1	Unknown-unlabeled bag
TUO-300 Unk7B	ind.	Juvenile	L. humerus	Unknown-unlabeled bag
TUO-300 Unk8	ind.	ind.	crania	Unit M-2, 80-100 cm
TUO-300 Unk9	female	Adult	L. mandible, LLM3	Unit N-3, 55 cm
TUO-300 Unk11	male	Adult	R. frontal bone	4-TUO-205 Unit P-5, 0-20 cm
TUO-300 Unk12	ind.	Adult	hand phalanx	4-TUO-205 Unit P-5, 120-140 cm
TUO-300 Unk13	ind.	ind.	rib	4-TUO-208 Unit R-5, 100-120 cm
TUO-300 Unk16A	female	Adult	left 4th metatarsal	non-human faunal bones bag
TUO-300 Unk16B	male	Adult	R. zygomatic	non-human faunal bones bag
TUO-300 Unk16C	ind.	Adult	rib, LLM3	non-human faunal bones bag
TUO-300 Unk18	ind.	Adult	rib	4-TUO-208 Unit P-5, 80-100cm
TUO-300 Unk20	ind.	ind.	R. temporal	4-TUO-208 Unit P-5, 60-80 cm
TUO-314 B2A	male	Adult	R. mandible, LRM1	North-east power-cut
TUO-314 B2B	ind.	Adult	L. mandible, LLM1, LLM3	North-east power-cut
TUO-314 B4A	ind.	Young adult	R. mandible, LRM1, LRM2, LRM3	Unit C, 45-60 cmbs
TUO-314 B4B	ind.	Adult	longbone	Unit C, 45-60 cmbs under cairn

Sample ID	Sex	Age at Death	Elements Sampled	Context
TUO-314 Unk1C	ind.	Juvenile	rib	Unit O-4, 75cm; S 155, W 100
TUO-314 Unk2A	ind.	Juvenile	rib	Surface scatter, western half of site
TUO-314 Unk2B Indiv.1	ind.	Adult	tibial	Surface scatter, western half of site
TUO-314 Unk2B Indiv.2	ind.	Adult	maxilla, URM2	Surface scatter, western half of site
TUO-314 Unk5A	ind.	Adolescent	fibula	unknown- from unlabeled bag
TUO-314 Unk6AR	ind.	Adult	rib	MNI of 2; context possibly related to B2
TUO-314 Unk6AL	ind.	Adult	longbone	MNI of 2; context possibly related to B2
TUO-314 Unk7A	male	Adult	tibial	MNI of 3; context possibly related to B2
TUO-314 Unk8A	male	Adult	temporal bone	Surface scatter, eastern half of site
TUO-314 Unk8B	ind.	Adult	longbone	Surface scatter, eastern half of site
TUO-314 Unk8C	ind.	Juvenile	rib	Surface scatter, eastern half of site
TUO-395 p-260-311A	ind.	Adult	mandible	Roundhouse soil matrix/cremation
TUO-395 p-260-311B1	ind.	Adult	mandible	Roundhouse soil matrix/cremation
TUO-395 p-260-311B2	ind.	Adult	frontal bone	Roundhouse soil matrix/cremation
TUO-395 p-260-311C	ind.	Adult	pelvis	Roundhouse soil matrix/cremation
TUO-395 p-260-311D1	ind.	ind.	lower rib	Roundhouse soil matrix/cremation
TUO-395 p-260-311D2	ind.	Adult	middle rib	Roundhouse soil matrix/cremation
TUO-395 p-260-311E3	ind.	Adult	humerus	Roundhouse soil matrix/cremation
TUO-395 p-260-0-312A	ind.	Adult	vertebra	No. Loc.#1; Arch context: 2/16/2010
TUO-395 p-260-0-313A	ind.	Adult	femoral head	No. Loc. #3; removed from artifact tray
TUO-395 p-260-0-313B	ind.	Adult	vertebra	No. Loc. #3; removed from artifact tray
TUO-395 p-260-10-1A	ind.	Adult	upper rib	Burial 1, housepit 1
TUO-395 p-260-10-1D	ind.	Adult	ulna	Burial 1, housepit 1
TUO-395 p-260-10-1E	ind.	Adult	pelvis	Burial 1, housepit 1
TUO-395 p-260-8-36A	ind.	ind.	longbone	Cremation, roundhouse interior
TUO-S331 p-022-38-8	ind.	Young adult	occipital bone	surface find/collection
TUO-342 p-022-35-9	ind.	Adult	LLP3	surface find/collection
TUO-S497 p-295-15-9	ind.	Adult	parietal bone	surface find/collection
TUO-935 18a	ind.	Adult	metatarsal	surface
TUO-935 18b	ind.	Adult	clavicle	surface

Sample ID	Sex	Age at Death	Elements Sampled	Context
TUO-935 21	ind.	Adult	rib	Trench 1
TUO-935 22	ind.	Adult	vertebra	Trench 3
TUO-935 26	ind.	Adult	fibula	Trench 9
TUO-935 27a	ind.	Adult	L. humerus	Trench 9
TUO-935 27b	ind.	Adult	L. humerus	Trench 9
TUO-935 29	ind.	Adult	R. humerus	Trench 9
TUO-935 56	ind.	Adult	tibia	Trench 9

Note: Information for all sampled human remains within this project are listed within this table; table is organized by site, based on collection attribution. New Don Pedro collection samples are listed first by site, followed by Columbia Junior College, and the last is TUO-935. Table provides sample ID, estimated sex, estimated age at death, elements sampled, as well as provenience information. Sample ID abbreviations as follows: “B”(prefix)-Burial; Unk-Unknown; Indiv (I or i)-Individual; 2) Age brackets used are as follows: Ind.-indeterminate; infant- less than two years old; Juvenile-age 5-12 years; Adolescent-age 12-19 years; Adult (young)-age 19-25 years; Adult- age 23-75 years; Adult (old) showed signs of advanced age. “cmts” means centimeters below surface.

6.2.3 Methods: Sample Processing and Submission

For human bone samples, about 1g of cortical bone was selected per sample, and all exposed surfaces drilled with a Foredom drill equipped with a diamond bit to remove any surface contamination. Prior to drilling, teeth were brushed with a toothbrush to remove exogenous material. Molars were then bisected lengthwise along the longitudinal axis (crown to root tip) with a slow-speed diamond-coated saw to isolate one root—following the procedure outlined in Eerkens et al. (2011)—with the other half reserved for additional processing such as serial sectioning. Single-rooted teeth were not cut. Drilling was undertaken to remove the enamel, any carious lesions, secondary dentin, cementum, adhering bone, and all surfaces in contact with bone or the burial environment. To remove any remaining loose exogenous material, all samples were sonicated a minimum of three times in dH₂O for five minutes each, with water being replaced between each sonication. This process was repeated until the water remained clear after sonication. Samples were drained and left to dry at ambient temperature.

Human bone and tooth samples were processed for collagen extraction following a modified Longin (1971) procedure. Following drying, samples were individually weighed, then placed into 20mL scintillation vials with 0.5M HCl for demineralization and stored in refrigeration. HCl was replaced every other day until demineralization was complete, up to two weeks for most bone samples, and occasionally longer for tooth halves. Following demineralization, samples were rinsed with dH₂O to pH-neutral. Samples were then soaked in 0.125M NaOH at room temperature for 24 hours within their own vials to remove humic acids, and then rinsed to pH neutral, immersed in pH3 water, and placed in an oven at 80°C for 24 hours to solubilize the collagen pseudomorph. Solubilized collagenous proteins were then centrifuged and pipetted into weighed new sterile glass scintillation vials. Samples that were not completely solubilized were placed back into the oven for another 24-hour cycle. This process was repeated until the entire sample was solubilized or no additional collagen could be extracted. Extracted collagen samples were refrigerated until the solubilization process was complete. Samples were then frozen and lyophilized (freeze dried) to isolate the collagen fraction.

For bone and tooth samples slated for C and N analysis, approximately 1mg per sample was weighed into preformed tin capsules on a microbalance and submitted to the UC Davis Stable Isotope Facility for measurement. Bone and tooth collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were measured by continuous-flow mass spectrometry through a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK). During each analytical run, samples were interspersed with several replicates of a minimum of three different UCD SIF laboratory standards. The laboratory standards included for these analyses were Bovine Liver, Nylon 6, Nylon 5, Glutamic Acid, and Enriched Alanine. These laboratory standards, which are selected by UCD SIF to be compositionally similar to the

samples being analyzed, were previously calibrated against NIST Standard Reference Materials (IAEA-600, USGS-40, USGS-41, USGS-42, USGS-43, USGS-61, USGS-64, and USGS-65). The samples' preliminary isotope ratios were measured relative to reference gases analyzed with each sample. These preliminary values were finalized by correcting the values for the entire batch based on the known values of the laboratory standards included. All C and N stable isotope data is expressed in permille notation (δ) in comparison to the international reference standards for carbon and nitrogen, Vienna PeeDee Belemnite (VPDB), and atmospheric N₂ (AIR), respectively. The long-term standard deviation for the UC Davis Stable Isotope Facility is 0.2 ‰ for $\delta^{13}\text{C}$ and 0.3‰ for $\delta^{15}\text{N}$.

For $\delta^{34}\text{S}$, collagen samples were weighed into preformed tin capsules on a microbalance and submitted to UCD SIF. Sample weights ranged between 6 to 11.4 mg. Stable isotope ratios of ^{34}S in solid samples were measured using an Elementar vario ISOTOPE cube interfaced to an Isoprime PreciSION IRMS (Cheadle Hume, Stockport, UK). During analysis, samples were interspersed with reference material replicates of cysteine, bovine gelatin, glutathione, blue-green algae, salmon muscle, and taurine to monitor and allow for correction of any potential variation in drift and linearity. These laboratory reference materials have been directly calibrated against IAEA S-1, S-2, and S-3, as well as NBS-127, SO-5, and SO-6. The long-term reproducibility of this method is ± 0.4 ‰. Final $^{34}\text{S}/^{32}\text{S}$ values are expressed in permille notation (δ) relative to Vienna Canyon Diablo Troilite.

While C and N results are available for a broader set of the population from TUO-300 and -314, the main focus here is on diachronic change and analyzing those with at least C, N and radiocarbon dates. The stable isotope results for undated burials can be found in Appendix C2. Additional isotopic analyses were conducted on bone apatite and serial-sectioned teeth. While

serial-sectioning was conducted on the other molar halves, this information is not included here as it is more pertinent to individual life-history patterns, rather than group-level analysis. Other analyses ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) were attempted on bone apatite, but due to analytical concerns they are excluded from my primary analysis. The apatite processing methods and results are provided in Appendix C3.

6.2.4 Methods: Testing Model Predictions and Group-level Patterns

Traditional biplots of $\delta^{15}\text{N}_{\text{collagen}}$ versus $\delta^{13}\text{C}_{\text{collagen}}$ values are an instructive place to start because they can provide a general sense of how the sample population compares, first to each individual point within the sample population, and second to food sources and other human populations. These displays work because they allow us to visualize general patterns among different human groups across landscapes, and they convey a broad view of where our expectations should lie for any particular group. However, they are limited by how much they explain as they only give a general sense of where the group of interest falls compared to other known foraging modes and groups of consumers.

Based on a comparison of $\delta^{15}\text{N}_{\text{collagen}}$ versus $\delta^{13}\text{C}_{\text{collagen}}$, previous research in the west-central Sierra Nevada concluded that the burial population under study occupied a distinctive isotopic space unique from other areas in California (Hull et al. 2016). A partial goal of this chapter is to explain how and why this isotopic space is unique. To improve on our understanding of the diet of the sample population, in Chapter 5 I created two models from which to discern the contributions of meat and plants to human collagen values, one for $\delta^{15}\text{N}_{\text{collagen}}$ and another for $\delta^{13}\text{C}_{\text{collagen}}$. These models are applied first to the whole sample population, then to subsets of the sample population based on radiocarbon dates. This will enable a better idea of how foraging patterns may have changed through time.

The first model, briefly reviewed here and shown in Figure 6.3, indicates what is expected for the human $\delta^{15}\text{N}$ based on the faunal data. The distribution of the faunal results is implemented as the expected range of $\delta^{15}\text{N}$ for humans where plants were the main source of nutrition. The faunal data average $\delta^{15}\text{N}$ was $4.1 \pm 1.37\text{‰}$, which suggests a majority of the humans should fall near 7.6‰ if meat from terrestrial resources was eaten regularly—assuming a $+3.5\text{‰}$ offset between $\delta^{15}\text{N}_{\text{diet}}$ and $\delta^{15}\text{N}_{\text{collagen}}$ (DeNiro and Epstein 1981; DeNiro and Schoeninger 1983; Eerkens et al. 2021). The horizontal axis represents the range of possible $\delta^{15}\text{N}_{\text{collagen}}$ values, where the far left would be represented by strict consumers of N-fixing plants, such as clover, and the far right would indicate those who included higher trophic-level meats (such as from carnivores, including possibly fish). For instance, along the horizontal axis, we should envision a small area on the left representing plants and the range of expected values of strict plant-consumers, such as with herbivores, and a much larger area moving to the right representing increasing reliance on meat from higher trophic levels.

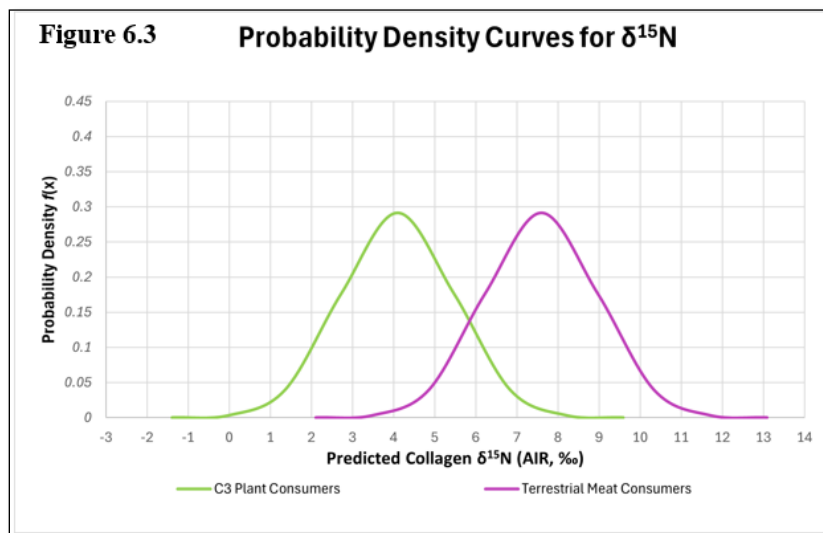


Figure 6.3 Probability Density Curves for $\delta^{15}\text{N}$
Figure shows the conceptual model for collagen $\delta^{15}\text{N}$ in the west- central Sierra Nevada. The model is based from the faunal data (chapter 5). Green curve represents that for consumers of plant-based dietary nitrogen, purple curve shows that expected for terrestrial-based meat consumers. Dietary offset used is 3.5 permil.

The power of this model is that it is simple, and is based on faunal data from within the same region and time frame. It allows for almost one full trophic level gain of $\delta^{15}\text{N}$ from the deer with the heaviest $\delta^{15}\text{N}$. Both curves represent probability densities that exist along a continuum. In the graph, the purple curve captures the expected range for humans who consumed meat regularly, with left of the peak indicating the expectations for decreasing proportions of small game, large game, and higher trophic level members, and the right of the peak representing increasing contributions from large game, or higher trophic level sources such as carnivores. The green curve represents plant contributions to human diets, and is based strictly from the faunal data, using the fauna as a proxy for a plant-only diet (excluding the *Canis*). Along this curve, the left of the peak represents greater dietary contributions from plants and plant parts lower in $\delta^{15}\text{N}$, while the right of the peak represents plants and plant parts higher in $\delta^{15}\text{N}$. There is a decrease in plant contributions as one moves further right towards the intersection with the faunal curve. As expected, there is overlap among the different food ranges along the continuum.

One expectation for this model is that a greater inclusion of plants into the protein budgets will lower the range of expected values closer to the intersection of the two curves. The two curves together represent the entire range of what is expected for human $\delta^{15}\text{N}$ within the landscape of the west-central Sierra Nevada given the plant and faunal data. Each human, once plotted, would have two probability density functions, one for plant consumption, the other for meat, each considered independently of the other. These would then be normalized into proportions, with the one for meats as a maximum contribution, while the one for plants represents their minimum protein contribution, where the proportion estimates are then dependent on the other probabilistically.

One thing must be kept in mind when considering collagen isotope ratios: proteins from meat will outweigh protein garnered from plants, simply because meat is mostly protein, while plants generally have much less protein by volume (Ambrose and Norr 1993; Schoeninger and DeNiro 1984). Additionally, all dietary $\delta^{15}\text{N}$ comes from protein (DeNiro and Epstein 1981; Fernandes et al. 2014), so plants, at the bottom of the food chain, will always be outweighed by meat for contributions to $\delta^{15}\text{N}_{\text{collagen}}$. Hence, while plant contributions to human $\delta^{15}\text{N}_{\text{collagen}}$ can be modelled, the probability of plant contributions to actual protein budgets will always be underestimated—representing a minimum probability—simply because collagen is mainly derived from nutritional protein, which is most dense in meats.

Based on the faunal results, individual human bone collagen $\delta^{15}\text{N}$ values are not expected to exceed $\sim 10.1\text{‰}$ unless carnivores or resources from aquatic environments, such as fish, were more frequently included in their diets. However, no fish were included within this study as they did not represent a major dietary resource archaeologically (Gobalet et al. 2004) and the faunal resources available at the time of sample selection did not include any identifiable fish bone. If fish were a dietary staple, we would expect human $\delta^{15}\text{N}_{\text{collagen}}$ values to range near the 10.1‰ mark and above simply because of the greater number of trophic levels in aquatic environments.

The $\delta^{13}\text{C}_{\text{collagen}}$ values correlate with dietary protein as well, but to a lesser extent. Whereas $\delta^{15}\text{N}_{\text{collagen}}$ is derived completely from protein, $\delta^{13}\text{C}_{\text{collagen}}$ receives contributions from protein ($\sim 75\%$) and macronutrient energy sources (fats and carbohydrates, $\sim 25\%$) (Fernandes et al. 2012). Given this understanding, plant use should be more visible in $\delta^{13}\text{C}_{\text{collagen}}$ measures. As such, the model for $\delta^{13}\text{C}_{\text{collagen}}$ (from Chapter 5) separates contributions to human $\delta^{13}\text{C}$ into angiosperm and gymnosperm plants as originally conceptualized for herbivores in Chapter 4, and

also considers contributions from angiosperm consumers and gymnosperm consumers (meats). Hence, there are four overlapping probability density curves rather than just two.

Based on the results in Chapter 4, and the faunal data modelling in Chapter 5, gymnosperm contributions will be less negative than those from angiosperms. This model is shown in Figure 6.4. The angiosperm and gymnosperm curves are represented as originally conceptualized, with angiosperm consumers along the green distribution, and gymnosperm consumers along the blue distribution. This model for omnivore and carnivore collagen $\delta^{13}\text{C}$ goes a step further than the model used for the herbivores, as it includes two new probability density curves that take into account the small trophic enrichment that happens with $\delta^{13}\text{C}$ between herbivores and carnivores (since I am modelling collagen to collagen), where a +1‰ offset is used here (Bocherens and Drucker 2003; Krajcarz et al. 2025). These two additional curves use the means for the expected range of the angiosperm and gymnosperm consumers, shifted by +1‰ (less negative), and the standard deviation of $\delta^{13}\text{C}$ for all fauna (Table 5-4, $\pm 1.08\text{‰}$) to understand the expected $\delta^{13}\text{C}$ values for humans where meat is concerned, essentially a 5‰ diet-collagen offset. The meat protein density curves in Figure 6.4 also assume collagen $\delta^{13}\text{C}$ of meat-eaters follows a normal distribution. Similar to the nitrogen model, humans plotted this way would have multiple probabilities, but in this case four per $\delta^{13}\text{C}$ result (instead of two).

This model differs from most other models that typically assume an $n+1$ for dietary proxies (e.g., stable isotopes). The general rule has been that for every isotope you should assume one additional dietary source. Thus for a single isotope, two are possible, and for a two-isotope model, three sources are feasible. Most often, however, the predictive power of the model declines if more than $n+1$ sources are added, as most often the additional sources

represent areas of overlap and can easily be subsumed into another category, such as C₃, C₄, or marine. With this model, we have a situation in which we already expect overlap, because gymnosperms and angiosperms are both C₃, and all terrestrial fauna would have consumed these C₃-based resources. Thus, under the original conception of the “dietary proxy n+1” model, we might simply conclude that all of the humans sampled ate a terrestrial C₃-based diet, which was readily apparent from the results of Hull et al. (2016).

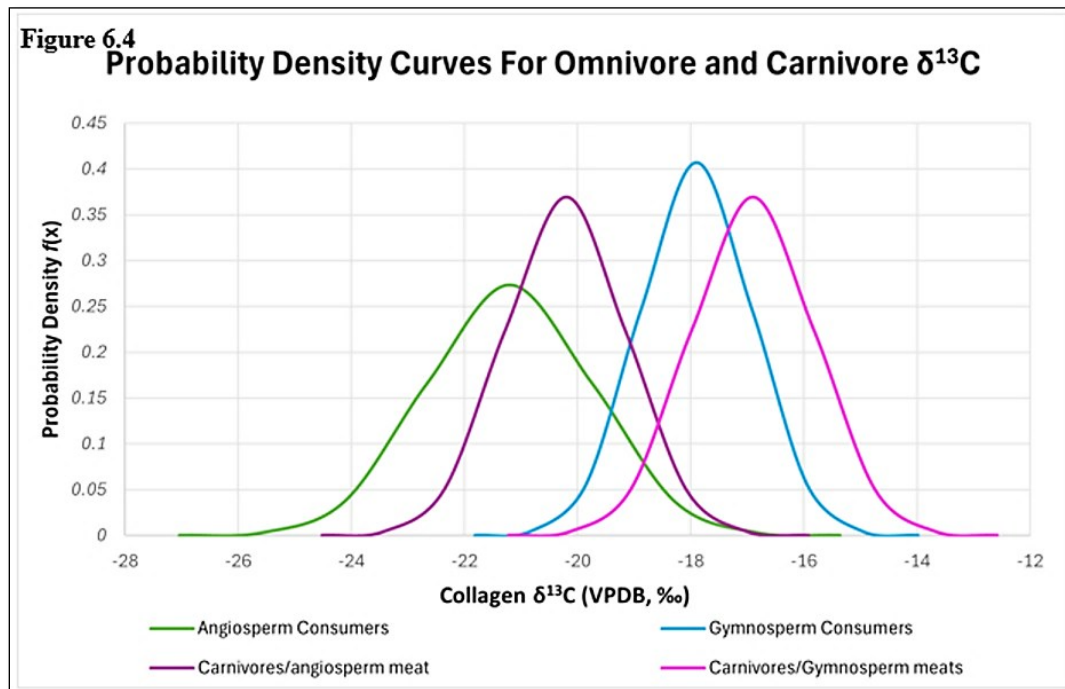


Figure 6.4 Probability Density Curves for Omnivore and Carnivore $\delta^{13}\text{C}$
The model is based on the plant data (Chapter 4) and shows where humans are expected to fall along four overlapping probability density distributions. The green curve represents the expected range for collagen $\delta^{13}\text{C}$ of omnivores who consumed mainly angiosperm plant-based protein, while the blue curves is representative of a gymnosperm-plant protein diet. These are the same as were used for herbivores in Chapter 5, where a four permille offset between plants and plant consumers was used. The purple probability density distribution represents the expected range of values for collagen $\delta^{13}\text{C}$ of consumers who relied on angiosperm-based meat protein, while the pink distribution represents the expected range for those who included gymnosperm-consuming animals within their protein budgets. The purple and pink distributions use a one permille offset between collagen of prey to consumer/predator and are modelled from the means of the two plant-consumer categories and the standard deviation of the fauna ($\pm 1.08\text{‰}$). Because this represents a monoisotopic dietary space, the expectation is that all distributions within this space will overlap. However, based on the plant data, some separation within this monoisotopic space is plausible.

One reason for using the paleobotanical and faunal data has been to try and separate some of these C₃-based resources into more distinct ranges, as gymnosperms simply do not exhibit the same range as angiosperms within this environment. As argued in Chapter 4, not all C₃ plants react to the same environmental conditions in a similar fashion. Hence, the separation of angiosperm-based resources versus gymnosperm-based resources for this particular model. While the isotopic space these humans occupy is monoisotopic, there are differences among food resources, specifically due to the use or inclusion of gymnosperms. It is this separation that allows for investigation into improving our understanding of this monoisotopic space.

Of special note, the far-right curve could also be applied to inputs from marine resources, since the expectation for marine inputs, such as anadromous fish, is to drive human collagen $\delta^{13}\text{C}$ toward increasingly less-negative values (i.e., what could be expected of coastal foragers or, to the furthest right, maize consumers). Hence, based on review of the fauna, few animals are expected to plot along the gymnosperm line, and as such contributions from gymnosperm-consuming animals should be the smallest probability in all cases. However, the caveat is that if the consumer's $\delta^{13}\text{C}$ indicates that gymnosperm-consuming animals were a major dietary source, based on normalized proportions, then marine-resource use remains a possible explanation *if* $\delta^{15}\text{N}$ is also higher than expected (i.e., greater than three standard deviations from the faunal mean or a full trophic level above that mean). However, should the $\delta^{15}\text{N}$ not suggest marine input, then the most likely scenario is that individuals with heavier $\delta^{13}\text{C}$ lived in dry environmental conditions and focused on the use of gymnosperm-based resources, such as pine nuts and low-trophic-level animals who may have also eaten gymnosperm-based resources, such as squirrels.

The goal of this exercise is twofold. First, to provide proportional estimates for dietary contributions from the four food groups for each individual. Second, is to provide a reconstructed approximation of each individual's total dietary $\delta^{13}\text{C}$. I acknowledge there is uncertainty surrounding a “correct offset” value for human $\delta^{13}\text{C}_{\text{collagen}}$ versus their foods, but I have attempted to circumvent this issue by using two offsets, one for plants and one for meat. I hold the dietary offset (4‰) between plants and plant-consumers constant, based on the paleobotanical and faunal modelling, as well as the testing of the offsets with precipitation estimates from modern samples (Chapter 5). I also consider the 5‰ offset between plants and meat consumers as fixed, given previous studies of prey $\delta^{13}\text{C}_{\text{collagen}}$ and predator $\delta^{13}\text{C}_{\text{collagen}}$ indicating a 1‰ enrichment from prey to predator (Bocherens and Drucker 2003; Krajcarz et al. 2025).

For both models ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$), I take a diachronic perspective and discuss how diet changed over time. The mean, median, minimum, and maximum values of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ are plotted on each model by time period. The aim is to construct time periods that consider individual lifetime experience relative to culture and environment. Hence, time “bins” were constructed in relation to, 1) calibrated median dates (cal BP) on collagen samples> the two-sigma calibrated radiocarbon dates for individuals on the cusp of period breaks> age at death determinations; 2) natural breaks in the calibrated sample dates; 3) archaeological time periods (e.g., RPII, RPI, LA); and 4) relevant environmental information (MCA, LIA). As such, the number of individuals is not equal among the bins, but the bins are consistent throughout my analysis. The Late Archaic period is divided into three separate bins, based on natural breaks in the calibrated dates; the last bin includes some Middle Archaic individuals. As this last bin

contains few individuals and spans a much longer time frame than any younger bin, it is interpreted conservatively.

6.2.5 Methods: Performance and Uncertainty Evaluation for the C and N Models

Model performance and uncertainty for both diet isotope models were evaluated using the same statistical framework. The predicted collagen isotope values were calculated as weighted mixtures of food group isotope distributions, $\delta_{pred} = \sum p_i \mu_i$, where p_i are normalized likelihood weights and μ_i are consumer-adjusted isotope means for each food group. Because the isotope distributions of the four food groups overlap substantially (because they are all within C_3 isotope space), I estimated diet contributions probabilistically using normalized likelihoods derived from the full normal probability density functions of each food group, rather than a deterministic mixing equation based solely on endmember means.

Uncertainty in predicted values was propagated assuming independence of food-group isotope distributions as $\sigma_{model}^2 = \sum p_i^2 \sigma_i^2$. Instrumental error ($\pm 0.3\text{‰}$ for $\delta^{15}\text{N}$; $\pm 0.2\text{‰}$ for $\delta^{13}\text{C}$) was incorporated in quadrature to obtain the total predictive uncertainty:

$$\sigma_{total} = \sqrt{\sigma_{model}^2 + \sigma_{instrument}^2}$$

The model's performance was evaluated using the standardized predictive residuals between the observed and predicted collagen isotope values.

6.2.6 Methods: A Way to Test Residential Mobility Through Time Using $\delta^{34}\text{S}$ in a Diachronic Context

For $\delta^{34}\text{S}_{collagen}$ to be meaningful as a geological tracer, it needs to exhibit, at most, a weak relationship with $\delta^{13}\text{C}$, and with $\delta^{15}\text{N}$. Ideally, $\delta^{34}\text{S}$ should show no correlation among $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$. If $\delta^{34}\text{S}$ is significantly correlated with either $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$, it would suggest a dietary rather than purely geological signal; in other words, a specific resource or group of resources (e.g.,

anadromous fish) are responsible for the trend (Privat et al. 2007). However, I do not expect this to be the case, given the archaeological faunal records, which show minimal use of fish and shellfish (Moratto 1971a; Rosenthal et al. 2011a:126). To evaluate whether $\delta^{34}\text{S}$ among human individuals is primarily reflecting geographic variation rather than diet, its relationship with collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ was assessed using correlation analysis. Weak associations were defined as correlations with absolute coefficients below 0.3 (e.g., less than 10% explained variance) consistent with limited covariation between $\delta^{34}\text{S}$ and $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$.

To distinguish locals from non-locals, I use the range, mean, and standard deviation in $\delta^{34}\text{S}_{\text{collagen}}$ from the fauna (Chapter 5) to establish the expected range for humans local to the region. The faunal baseline for $\delta^{34}\text{S}_{\text{collagen}}$ was derived from 11 archaeological animals recovered from CA-TUO-300, -314, -395, but mainly TUO-935. The dataset included deer (n=5), gophers (n=3), a ground squirrel (n=1), a jackrabbit (n=1), and one canid. The combined faunal mean for $\delta^{34}\text{S}$ was $5.0 \pm 1.62\text{‰}$. Different mobility patterns from the subsets of taxa (migratory versus localized), as well as size class (large vs small mammal), produced similar mean values (e.g., deer/large mammals: $5.3 \pm 1.32\text{‰}$; small mammals: $5.0 \pm 2.03\text{‰}$) indicating broadly consistent local sulfur isotope values across taxa. For the human samples, individuals are classified as local if their $\delta^{34}\text{S}_{\text{collagen}}$ values fell within ± 2 standard deviations of the faunal mean, representing the range from 1.8–8.2‰. Individuals outside of this range are interpreted as potential non-locals, representing those who spent the majority of their lives somewhere outside the local sulfur isotope landscape. For this analysis, only one measurement of $\delta^{34}\text{S}_{\text{collagen}}$ per individual is considered, where bone was preferred. However, tooth $\delta^{34}\text{S}_{\text{collagen}}$ values were used for some individuals when bone sulfur isotopes could not be measured. Sulfur-defined local and non-local individuals were compared with respect to $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using Welch's t-tests to evaluate

whether individuals with non-local $\delta^{34}\text{S}$ values also exhibit systematically different dietary isotope signatures. If $\delta^{34}\text{S}$ variation primarily reflects geographical origin rather than diet, non-local individuals should not differ significantly from locals in $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values.

Accompanying this analysis is an evaluation of each of the four main sites focusing only on locals, which acts as a check on the variance among time bins and ensures that variance observed within and among time bins is not an artifact of site locations. For the site-level analysis, the individual from CA-TUO-S331 is treated as a member of CA-TUO-300, as these sites were located along the same drainage (Rogers Creek) and are estimated to have been no more than 2.5km apart. As well, I focus on non-infant locals, as collagen from infants may not represent a true independent measure of sulfur baseline distributions given the possibility of maternal influence, rapid collagen turnover, and nursing-related dietary inputs. For this analysis, I use a one-way ANOVA of non-infant local individuals, where the null hypothesis is no statistically significant difference among sites.

Temporal mobility patterns were assessed by comparing the proportion of sulfur-defined non-locals to the local proportion among time bins to detect possible changes in the frequency of long-distance migration into the area. This approach enables a view of long-distance immigration into the region. As there are fewer individuals in the older time bins to make robust comparisons, I retain the original bin structure, but also collapse all Late Archaic individuals into a single bin. As such, I offer a fine-grained and a coarse-grained analysis of temporal long-distance mobility.

For the diachronic analysis, the time bins used for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ remain consistent to enable comparisons across time periods with respect to both diet and mobility. The analysis of only locals (non-infants) speaks to arguments around restricted residential mobility, where higher variance among locals indicates broader landscape use—higher residential mobility and

sampling more places across the landscape, versus lower variance, which is hypothesized to occur during drought or with territorial restriction—one spot on the landscape sampled with greater frequency throughout lifetimes reducing variance across a time period. However, after collagen quality control and the reduced number of individuals for which $\delta^{34}\text{S}$ measurements were possible, there are fewer individuals for which sulfur isotope analysis was possible ($n = 37$), and the number of individuals within each bin is reduced further when only locals are considered. Because of this issue, I offer two visual interpretations, one based on the same time bins as for the carbon and nitrogen that might hint at broader patterns within the more fine-grained analysis, and one in which all Late Archaic individuals are placed in one bin, despite a longer time frame. The collapsed Late Archaic Bin is only used for $\delta^{34}\text{S}$ mobility and variance analysis, as the thrust of the question concerns pre-drought versus drought mobility and variance within $\delta^{34}\text{S}$ distributions during these periods. Beyond a simple comparison of variance, I assess how much variance changes among Bins. For this I use the Brown-Forsythe test, implemented as a one-way ANOVA on absolute deviations from group medians for both the fine-grained analysis and the comparison of RP II and RP I to the condensed Late Archaic Bin.

6.2.7 Methods: Humans as Omnivores- Testing Kohn's (2010) Formula for Estimating Paleoprecipitation

In Chapter 5, I discussed the application of Kohn's (2010) Equation 2 to faunal remains to estimate precipitation. Based on a test of modern samples' $\delta^{13}\text{C}_{\text{collagen}}$ (Broughton et al. 2023), I found a positive and significant relationship between estimated and actual precipitation. I then applied this equation (Kohn 2010b:Equation 2) to the $\delta^{13}\text{C}_{\text{collagen}}$ of herbivore fauna from the King Brown site (Broughton et al. 2023) and to those from the west-central Sierra Nevada. While there is minimal overlap among the time periods covered by each dataset, the results suggest

paleoprecipitation was lower than today's average. Importantly, I suggest it may be possible to apply the equation (Kohn 2010b:Equation 2) to human $\delta^{13}\text{C}_{\text{collagen}}$ as well, provided the humans ate foods from a C_3 resource base. This equation (shown here as Equation 1) is as follows:

$$\begin{aligned} \Delta^{13}\text{C} (\text{‰}, \text{VPDB}) = & 2.01 - (1.98 * 10^{-4} * \text{elevation (m, asl)}) \\ & + (5.88 * \log_{10}(\text{MAP} + 300, \text{mm/yr})) \\ & + (0.0129 * \text{Abs (latitude, °)}) \end{aligned} \quad 1.$$

and requires solving for mean annual precipitation (MAP) after all dietary-collagen offsets have been applied. When working with paleobotanical, or paleo- apatite or collagen values of $\delta^{13}\text{C}$, the $\delta^{13}\text{CO}_2$ must be estimated from ice-core datasets as they are used to calculate $\Delta^{13}\text{C}$ (‰, VPDB). Here I used the $\delta^{13}\text{CO}_2$ dataset recommended by Belmecheri and Lavergne (2020) to convert human $\delta^{13}\text{C}_{\text{collagen}}$ to $\Delta^{13}\text{C}$ values after human collagen values of $\delta^{13}\text{C}$ were adjusted to reflect that of their angiosperm-only diet.

One of the complicating factors for applying this equation to human $\delta^{13}\text{C}_{\text{collagen}}$ is when gymnosperms (or other foods with less-negative $\delta^{13}\text{C}$) are staple dietary resources. In Chapters 4 and 5, I discussed that in the case of gymnosperm usage, with no adjustment for dietary offsets, paleoprecipitation estimates will often be negative, and clearly not useful. Another complicating factor when using human $\delta^{13}\text{C}_{\text{collagen}}$ is that humans are omnivores, and typically include some amount of meat in their diets, which skews $\delta^{13}\text{C}_{\text{collagen}}$ to less negative values given a small offset between prey and consumer $\delta^{13}\text{C}_{\text{collagen}}$, similar to generalist carnivores (Bocherens and Drucker 2003; Krajcarz et al. 2025). As such, I suggest the total dietary offset values for humans who consumed a mix of angiosperms and gymnosperm resources, as well as meat, will vary among

individuals once they are corrected for the gymnosperm contributions to the diet—similar to the fauna samples which indicated some gymnosperm resource use as covered in 5.4.2.

Here I aim to test the application of Kohn’s (2010: Eq. 2) formula to human $\delta^{13}\text{C}_{\text{collagen}}$ with the understanding that collagen dietary offsets will be variable and dependent on the estimated percentage of gymnosperm contributions to protein budgets. However, unlike in Chapters 4 and 5, I do not have modern human data with which to calibrate dietary offsets and test these relationships. Instead, I use the faunal data from Chapter 5 to calibrate the human dietary offsets, as well as the estimated percent contribution of gymnosperms based on the normalized probability individual gymnosperm consumption from the $\delta^{13}\text{C}$ model for omnivores and carnivores for the west-central Sierra Nevada. This approach is similar to how faunal estimates were modelled, and duplicates the process used for the canid. The main idea is that we are trying to adjust human $\delta^{13}\text{C}_{\text{collagen}}$ values to reflect strict contributions from angiosperms and angiosperm-consuming animals by controlling for the influence of gymnosperms. In the end, after controlling for gymnosperm contributions and dietary offsets, the human values should resemble an angiosperm plant, as did the fauna in Chapter 5.

To control for gymnosperm contributions to human diets, and essentially calculate backwards towards the angiosperm range, I used the following equation (Equation 2):

$$\delta A = \delta C - 3.3p(G) - 4p(P) - 5p(M) \quad 2.$$

where δA is the angiosperm value (target), C is the consumer (an individual’s $\delta^{13}\text{C}_{\text{collagen}}$), $p(G)$ is that individual’s total probability of gymnosperm contribution, $p(P)$ is their total probability of plant contributions, and $p(M)$ is their total probability of meat contributions. The term $p(G)$ can

be further defined as the probability of gymnosperm plant contribution, $p(\text{GP})$, *plus* the probability of gymnosperm meat contribution, $p(\text{GM})$. As well, $p(\text{P})$ can be further defined as the sum of the probability of angiosperm plant contribution, $p(\text{AP})$, and the probability of gymnosperm plant contributions, $p(\text{GP})$. The term $p(\text{M})$ is defined as the sum of the probability of gymnosperm meat contributions, $p(\text{GM})$, and the probability of angiosperm meat contributions, $p(\text{AM})$.

Importantly, I treat the 3.3‰ difference between the angiosperm and gymnosperm means as fixed. The logic is that this difference was found by testing random samples from multiple points in this environment over the last few millennia, and as such these random samples are representative of plant reactions to different environmental and climatic conditions. As well, I treat the dietary offset (4‰) between plants and plant consumers as fixed, based on modelling in Chapter 5 with modern faunal samples and precipitation records, as well as with archaeological herbivore samples. While there are uncertainties surrounding a “correct offset” value for human $\delta^{13}\text{C}_{\text{collagen}}$ values versus their foods, I have attempted to circumvent this issue by using two offsets, one for plants and one for meat. I consider the 5‰ offset between plants and meat consumers as fixed, given previous studies of prey $\delta^{13}\text{C}_{\text{collagen}}$ and predator $\delta^{13}\text{C}_{\text{collagen}}$ (Bocherens and Drucker 2003; Krajcarz et al. 2025). The error term associated with Kohn’s (2010) equation is accurate to within ± 100 mm for low-precipitation regions (i.e., those with annual rainfall averaging less than 2,000 mm/year, like the western slope of the Sierra Nevada). This error term is not propagated, but it is considered.

Uncertainty in the estimated precipitation is reduced by averaging among time bins, and is shown by a standard deviation among individuals in each bin, standard error of the mean, and a 95% confidence interval. Because binning smooths variation and can hide trends that may have

lasted only a few decades, or at most centuries, I took a slightly different approach and used a three-point running average, beginning with the oldest observations and moving forward in time. The three-point running average was also applied to each precipitation estimate's associated median dates (cal BP) so that these averaged-precipitation points fell within the correct bin. The three-point moving average is used to highlight broad temporal trends that may be masked by binning, especially among the more recent time periods.

6.3 Results: Radiocarbon Dates and $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{34}\text{S}$

The main focus of this chapter is a diachronic perspective on human diet and mobility. Table 6-3 shows the stable isotope results for all samples that returned radiocarbon dates, along with preservation metrics, and is organized by site and burial context. When possible, all stable isotope results were run on a single sample. Note that some individuals have multiple samples, as some initial samples did not produce enough collagen for all isotopic analyses. In these instances, multiple tissues (bones and teeth) were used to create an isotopic profile for the individual. For clarity, the column “Diet-Age Representation” indicates the ontogenetic age the analyzed sample refers to. For bone collagen values, these designations are based on the estimated age at death as reported in the NAGPRA inventories. For tooth collagen values, estimated ontogenetic age is based on root formation completion. As all teeth in this study were from adults, all tooth roots had completed formation prior to individuals' deaths and represent an upper age range.

Table 6-3 Stable Isotope Results for Radiocarbon Dated Samples and Preservation Metrics

SITE	Sample ID	Sample	Diet-Age representation	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{34}\text{S}$	%C	%N	%S	C/N	C/S	N/S
TUO-279	B1	vertebra	Adult	-17.7	6.4	—	36.88	12.31	—	3.50	—	—
TUO-279	B2 I1	fibula	Adult	-18.6	7.2	4.0	32.12	11.01	0.16	3.40	541	159
TUO-279	B2 I2	L. occipital	Adult	-18.4	7.0	4.9	31.72	11.06	0.16	3.35	532	159
TUO-279	B4	tibia	Adult	-18.6	7.1	4.9	29.86	9.88	0.14	3.53	560	159
TUO-279	Unk1	vertebra	Adult	-18.9	5.9	12.2	40.75	15.60	0.19	3.05	560	184
TUO-279	Unk2	rib	Adult	-18.8	6.5	—	37.24	12.80	—	3.40	—	—
TUO-279	Unk3	metacarpal	Adult	-18.6	6.9	4.1	43.05	14.95	0.18	3.36	644	192
TUO-279	Unk4 I1	rib	Adult	-17.6	8.1	5.0	42.59	14.50	0.18	3.43	648	189
TUO-279	Unk4 I2	vertebra	Juvenile	-18.4	5.9	14.8	40.48	16.29	0.22	2.90	482	166
TUO-300	B1	fibula	Adult	-19.1	6.6	10.5	39.31	14.17	0.26	3.24	407	126
TUO-300	B3	tibia	Adult	-18.3	9.2	10.7	40.95	14.28	0.23	3.35	479	143
TUO-300	B5	tibia	Adult	-19.1	7.5	8.1	40.14	14.52	0.29	3.22	375	116
TUO-300	B6	crania	Infant	-18.9	9.1	7.5	40.56	14.40	0.24	3.29	452	138
TUO-300	B8	mandible	Adult	-18.3	7.8	9.2	40.04	14.43	0.23	3.24	459	142
TUO-300	B9A	mandible	Adult	-19.4	7.7	—	37.25	13.01	—	3.34	—	—
TUO-300	<i>B9A</i>	<i>ULM1 root</i>	Juvenile	-19.5	7.5	4.7	28.54	9.26	0.34	3.59	<i>224</i>	<i>62</i>
TUO-300	B9B	radius	Adult	-19.2	6.6	8.1	39.25	13.63	0.23	3.36	449	134
TUO-300	B10A1	R. mandible	Adult (young)	-19.2	7.8	—	28.34	10.14	—	3.26	—	—
TUO-300	<i>B10A1</i>	<i>LLM1</i>	Juvenile	-19.1	8.9	5.5	16.58	5.60	<i>0.37</i>	3.45	<i>119</i>	<i>34</i>
TUO-300	<i>B10A1</i>	<i>LLM3</i>	Adult (young)	—	—	5.1	—	—	<i>0.40</i>	—	—	—
TUO-300	B10A2	rib	Adult (young)	-19.5	7.4	—	38.73	13.78	—	3.28	—	—
TUO-300	B11A	longbone	Juvenile	-19.8	7.6	6.0	39.20	14.06	0.25	3.25	420	129
TUO-300	B11B	Premolar (P4)	Adolescent	-18.8	9.2	5.6	37.16	12.63	0.30	3.43	332	97
TUO-300	<i>Unk1</i>	longbone	Juvenile	-19.8	7.9	8.2	38.36	12.24	0.29	<i>3.66</i>	356	97
TUO-300	Unk2 i1	longbone	Adult	-19.2	6.9	—	18.51	6.27	—	3.44	—	—
TUO-300	Unk4	crania	Adult	-19.8	8.2	—	37.20	12.58	—	3.45	—	—
TUO-300	Unk5	M1root	Juvenile	-19.2	8.0	—	28.05	9.46	—	3.46	—	—
TUO-300	Unk6	L. fibula	Adult	-18.1	8.4	4.1	42.88	15.48	0.22	3.23	514	159

SITE	Sample ID	Sample	Diet-Age representation	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{34}\text{S}$	%C	%N	%S	C/N	C/S	N/S
TUO-300	Unk7A	femur	Adult	-18.0	9.2	—	39.03	13.63	—	3.34	—	—
TUO-300	Unk7B	L. humerus	Juvenile	-19.1	8.4	5.4	40.20	14.03	0.23	3.34	470	141
TUO-300	Unk8	crania	Indeterminate	-19.6	6.8	—	39.68	14.00	—	3.31	—	—
TUO-300	Unk9	mandible	Adult	-19.3	8.2	4.8	41.27	14.33	0.22	3.36	494	147
TUO-300	Unk11	R. temporal	Adult	-18.6	8.1	2.9	36.12	12.87	0.17	3.27	568	174
TUO-300	Unk13	rib	Indeterminate	-18.8	8.4	—	40.41	13.90	—	3.39	—	—
TUO-300	Unk16B	R. zygomatic	Adult	-19.6	8.7	—	39.64	13.72	—	3.37	—	—
TUO-300	Unk16C	rib	Adult	-18.9	7.2	—	40.10	13.94	—	3.36	—	—
TUO-300	Unk16C	LLM3	Adult (young)	—	—	4.8	—	—	0.29	—	—	—
TUO-300	Unk18	rib	Adult	-19.4	8.2	—	39.48	14.06	—	3.28	—	—
TUO-300	Unk20	R. temporal	Indeterminate	-18.6	8.4	—	39.32	13.99	—	3.28	—	—
TUO-314	B2A	R. mandible	Adult	-18.7	6.6	—	27.66	9.08	—	3.55	—	—
TUO-314	B2A	LRM1	Juvenile	-19.1	6.9	3.8	46.95	15.69	0.24	3.49	525	150
TUO-314	B2B	L. mandible	Adult	-18.9	6.5	4.3	39.05	13.12	0.20	3.47	530	153
TUO-314	B4A	R. mandible	Adult (young)	-19.3	6.4	3.7	40.78	13.98	0.21	3.40	530	156
TUO-314	B4B	longbone	Adult	-19.3	6.9	3.6	33.14	10.88	0.22	3.55	407	114
TUO-314	Unk2A	rib	Juvenile	-19.8	5.6	—	39.39	14.23	—	3.23	—	—
TUO-314	Unk2Bi1	tibia	Adult	-18.8	7.1	3.6	40.96	14.85	0.21	3.22	521	162
TUO-314	Unk5A	fibula	Adolescent	-19.4	7.8	3.5	39.36	14.34	0.28	3.20	376	118
TUO-314	Unk 6A	longbone	Adult	-18.6	6.7	5.0	41.37	14.92	0.20	3.24	541	167
TUO-314	Unk7A	tibia	Adult	-18.9	6.5	5.1	41.54	14.75	0.21	3.29	535	163
TUO-314	Unk8A	temporal	Adult	-19.4	6.2	4.1	38.49	14.08	0.25	3.19	413	130
TUO-314	Unk8B	longbone	Adult	-17.8	8.3	—	40.92	14.87	—	3.21	—	—
TUO-935	18a	metatarsal	Adult	-19.1	6.9	2.4	41.94	14.46	0.18	3.38	621	184
TUO-935	18b	clavicle	Adult	-19.7	5.8	1.2	41.44	14.32	0.18	3.38	614	182
TUO-935	21	rib	Adult	-19.2	7.6	—	37.77	13.02	—	3.39	—	—
TUO-935	22	vertebra	Adult	-18.9	8.0	3.5	42.62	14.50	0.19	3.43	598	174
TUO-935	26	fibula	Adult	-19.0	8.3	5.6	43.56	14.88	0.18	3.42	645	189
TUO-935	27a	L. humerus	Adult	-19.5	6.5	3.8	41.28	13.90	0.18	3.47	612	176

SITE	Sample ID	Sample	Diet-Age representation	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{34}\text{S}$	%C	%N	%S	C/N	C/S	N/S
TUO-935	27b	L. humerus	Adult	-19.5	6.9	5.7	38.55	14.03	0.21	3.21	489	153
TUO-935	29	R. humerus	Adult	-18.9	7.5	4.7	43.11	15.00	0.18	3.35	639	190
TUO-935	56	tibia	Adult	-19.2	7.2	4.6	37.64	12.83	0.18	3.42	558	163
TUO-S331	38-8A	occipital	Adult (young)	-19.4	6.9	4.9	35.77	12.44	0.32	3.35	301	90
TUO-S497	15-9A	parietal	Adult	-20.1	8.3	—	31.22	9.30	—	3.92	—	—

Note: Stable isotope results and preservation metrics for all samples that were radiocarbon dated are presented and organized by site and sample ID. Within the table, a double underline border indicates the separation between sites. Any sample with questionable preservation is noted by red italicized text. Age determinations are the same used in Table 6-2. Diet-Age representation indicates the period of life the sample material represents. Sample ID abbreviations: B (as a prefix) - Burial; Unk.-Unknown; Indiv. (I, or i)-Individual. 2) Age brackets used are as follows: ind.-indeterminate; infant- less than 2 years old; Juvenile- age 5-12 years; Adolescent- age 12-19 years; Adult (young)- age 19-25 years; Adult- age 23-75 years; Adult (old)- showed signs of advanced age.

The quality control criteria for collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in this table was established using guidelines from DeNiro (1985), Guiry and Szpak (2021), and Ambrose (1990). For samples where $\delta^{34}\text{S}$ was assayed, the measures of preservation (weight % S between 0.15 and 0.35%, Atomic C:S of 600 ± 300 , and Atomic N:S of 200 ± 120) (Nehlich and Richards 2009) are shown. Please note that for atomic N:S, Nehlich and Richards (2009) recommended a range between 200 ± 100 , while I use a larger error range of ± 120 based on their results for modern chinchillas and guinea pigs. For their modern chinchillas and guinea pigs, the N:S ratio falls below 100, and it is similar to what was recommended by Privat et al. (2007) for archaeological specimens, yet is still more conservative than Privat et al.'s (2007) N:S above 60.

The humans from TUO-395 are excluded from Table 6-3 because most failed to return any measurement for nitrogen, and those that did return some measurement for nitrogen failed to meet any further collagen control criteria, rendering all human samples from this site uninterpretable. The single sample from CA-TUO-s497 returned questionable stable isotope results indicated by a C:N ratio close to 4, and thus it has been excluded from further analysis.

Another individual, TUO-300 Unk1, also has been excluded from further analyses based on a C:N ratio >3.60. All other individuals indicate acceptable collagen preservation, with C:N ratios falling between 2.90 and 3.60 (DeNiro 1985; Guiry and Szpak 2021).

Two individuals with tooth samples (data highlighted in red italicized text) from CA-TUO-300 returned $\delta^{34}\text{S}$ values on tooth collagen well within the range established by the fauna, yet exhibit questionable sulfur preservation as the weight % S, C:S, and N:S were all outside acceptable ranges, and are hence excluded from the sulfur mobility study. However, they are included in the dietary analysis as C:N indicated good preservation on bone values. One other sample, TUO-279 B4 had a lower weight% S than would normally be acceptable (by less than 1%), but the C:S and N:S values were well within the bounds, and thus it is included within the sulfur mobility study.

Initially, TUO-314 Unk 6A and TUO-314 Unk 7A were treated as separate individuals based on the NAGPRA inventories; however, based on similar stable isotopic values, overlapping radiocarbon dates, and provenience ambiguity, these two unknowns are likely from a single individual and thus are treated as a single individual. UNK 6A is shown in Table 6-3 and Table 6-4, but is not included within any further analyses. The same is true for TUO-300 B10A1 and B10A2, the latter of which is indistinguishable from the former in terms of radiocarbon dates, stable isotope values, and burial context. Hence B10A1 will be used for all further analyses as appropriate. I sought to further check if these were separate individuals through analysis of $\delta^{13}\text{C}$ apatite values, but because of instrument analytical issues I am not confident in the results. Hence, I take a conservative approach to these four samples and only focus on results for TUO-314 UNK 7A and TUO-300 B10A1 to prevent potential “double counting.”

The results of the radiocarbon dates on sampled individuals are shown in Table 6-4, organized by site and median calibrated date (rounded to the nearest 5-year increment). The calibrated median dates, 95% confidence interval, and age at death were assessed for each individual and form the basis for the five time periods or “bins.” In total, 56 individuals are presented; however, only 53 are further analyzed due to two individuals with questionable collagen preservation and two separate cases where two dated samples may represent a single individual.

The full set of median dates and 95% confidence intervals are shown in Figure 6.5, excluding the three samples mentioned above. In Figure 6.5, all individuals are color-coded to align with the bin to which they were assigned, and the figure is organized by median calibrated dates to separate individuals whose 95% confidence interval may have overlapped two bins. Bin 1 (pink; n = 11) corresponds to RP II, 145–600 cal BP, and the LIA. Bin 2 (lavender; n = 23) corresponds to RP I, 605–1050 cal BP, and the MCA. Bin 3 (light blue; n = 8) represents the late stage of the Late Archaic, a period of “good environmental conditions” and ranges between 1115–1775 cal BP. Bin 4 (dark blue; n = 5) represents the middle portion of the Late Archaic from 2035–2480 cal BP. Bin 5 (purple; n = 6) is the longest span of time, from 2725–4725 cal BP, or the late Middle Archaic through the early Late Archaic.

Table 6-4 Radiocarbon Results

Sample ID	Sample dated	Age at death	Sex	¹⁴ C BP	error ±	95% Range cal BP	Median cal BP	Cultural Period
TUO-279 B2 Indiv.2	L. occipital	Adult	ind.	1760	25	1715-1585	1650	LA
TUO-279 B4	tibia	Adult	ind.	1730	25	1700-1545	1615	LA
TUO-279 B1	vertebra	Adult	ind.	1050	20	1045-920	945	RP I
TUO-279 Unk1	vertebra	Adult	ind.	975	20	925-795	855	RP I
TUO-279 Unk4 Individual 1	rib	Adult	ind.	714	19	680-575	670	RP I

Sample ID	Sample dated	Age at death	Sex	¹⁴ C BP	error ±	95% Range cal BP	Median cal BP	Cultural Period
TUO-279 Unk4 Individual 2	vertebra	Juvenile	ind.	476	23	535-500	515	RP II
TUO-279 Unk2	rib	Adult	ind.	315	23	455-305	390	RP II
TUO-279 Unk3	metacarpal	Adult	ind.	205	25	300-0	180	RP II
TUO-279 B2 Indiv.1	L. fibula	Adult	male	170	30	290-0	175	RP II
TUO-300 Unk7A	femur	Adult	ind.	2947	26	3180-3000	3110	MA
TUO-300 B3	tibia	Adult	male	2840	25	3005-2865	2945	LA
TUO-300 B8	mandible	Adult (young)	female	2560	25	2750-2520	2725	LA
TUO-300 B9B	radius	Adult	ind.	2200	25	2310-2125	2235	LA
TUO-300 Unk2 Individual 1	longbone	Adult	ind.	2210	33	2330-2125	2230	LA
TUO-300 B5	tibia	Adult	ind.	1870	20	1825-1720	1775	LA
TUO-300 B6	crania	Infant	ind.	1760	25	1715-1585	1650	LA
TUO-300 Unk4	crania	Adult	male	1198	25	1240-1060	1115	LA
TUO-300 Unk8	crania	Ind.	ind.	1199	20	1175-1065	1115	LA
TUO-300 Unk16B	R. zygomatic	Adult	male	1042	21	970-920	945	RP I
TUO-300 Unk6	fibula	Adult	ind.	1000	24	955-800	920	RP I
TUO-300 B1	fibula	Adult	female	885	35	910-725	780	RP I
TUO-300 B11B	Premolar (P4)	Adult (young)	male	860	30	895-690	760	RP I
TUO-300 Unk9	mandible	Adult	female	840	21	785-690	735	RP I
TUO-300 B10A1	Molar (LLM1)	Adult (young)	female	810	30	770-675	710	RP I
TUO-300 Unk18	rib	Adult	ind.	753	22	725-665	680	RP I
TUO-300 Unk13	rib	Ind.	ind.	687	25	675-565	655	RP I
TUO-300 Unk11	crania	Adult	male	614	19	650-555	605	RP I
TUO-300 B11A	longbone	Juvenile	ind.	631	28	655-555	600	RP II
TUO-300 Unk1	longbone	Juvenile	ind.	635	22	660-555	595	RP II
TUO-300 Unk20	R. temporal	Ind.	ind.	554	22	625-525	550	RP II
TUO-300 Unk7B	L. humerus	Juvenile	ind.	543	19	625-525	545	RP II
TUO-300 B9A	mandible	Adult (old)	female	310	20	445-305	390	RP II
TUO-300 Unk5	LRM1 root	Adult (old)	female	280	30	445-155	375	RP II
TUO-300 Unk16C	rib	Adult	ind.	151	21	280-5	145	RP II
TUO-314 B2B	L. mandible	Adult	ind.	2440	25	2700-2360	2480	LA
TUO-314 B2A	R. mandible	Adult	m	2210	30	2325-2125	2230	LA
TUO-314 Unk7A	tibia	Adult	m	2075	25	2115-1945	2035	LA
TUO-314 Unk6A	longbone	Adult	ind.	2068	22	2110-1945	2030	LA
TUO-314 Unk5A	fibula	Adolescent	ind.	1059	23	1050-925	950	RP I
TUO-314 B4B	longbone	Adult	ind.	895	20	900-730	785	RP I
TUO-314 Unk2Bi1	tibia	Adult	ind.	862	21	895-695	760	RP I
TUO-314 Unk8A	temporal	Adult	m	848	32	795-680	745	RP I

Sample ID	Sample dated	Age at death	Sex	¹⁴ C BP	error ±	95% Range cal BP	Median cal BP	Cultural Period
TUO-314 Unk2A	rib	Juvenile	ind.	770	26	725-670	695	RP I
TUO-314 B4A	R. mandible	Adult (young)	ind.	760	35	730-660	690	RP I
TUO-314 Unk8B	longbone	Adult	ind.	234	19	310-0	285	RP II
TUO-935 56	tibia	Adult	ind.	4181	26	4835-4590	4725	MA
TUO-935 29	R. humerus	Adult	ind.	3401	25	3810-3570	3635	MA
TUO-935 27b	L. humerus	Adult	ind.	2570	20	2750-2545	2730	LA
TUO-935 22	vertebra	Adult	ind.	1480	20	1390-1310	1360	LA
TUO-935 18b	clavicle	Adult	ind.	1340	25	1300-1175	1280	LA
TUO-935 18a	metatarsal	Adult	ind.	1152	25	1175-975	1050	RP I
TUO-935 26	fibula	Adult	ind.	994	23	955-800	910	RP I
TUO-935 27a	L. humerus	Adult	ind.	755	20	725-665	680	RP I
TUO-935 21	rib	Adult	ind.	686	22	675-565	655	RP I
TUO-s331 38-8a	occipital	Adult (young)	ind.	960	30	925-790	850	RP I
TUO-s497 15-9a	parietal	Adult	ind.	900	30	910-730	800	RP I

Note: table details the samples that returned a radiocarbon date. Table is organized by site and median calibrated date (cal BP). Within the table, a double underline border indicates the separation between sites. Sample ID, sample material dated, age at death, estimated sex, uncalibrated date and error, the complete 95% confidence interval for calibrated dates (in cal BP), median date (in cal BP), and the cultural period experienced by the individual when alive are also shown. 1) Sample ID abbreviations: B (as a prefix) - Burial; Unk.-Unknown; Indiv. (I, or i)-Individual. 2) Age brackets used are as follows: ind.-indeterminate; infant- less than 2 years old; Juvenile- age 5-12 years; Adolescent- age 12-19 years; Adult (young)- age 19-25 years; Adult- age 23-75 years; Adult (old)- showed signs of advanced age. Cultural Period Abbreviations are as Follows: MA– Middle Archaic (7000-3000 cal BP); LA– Late Archaic (3000-1100 cal BP); RP I– Recent Prehistoric I (1100-610 cal BP); RP II– Recent Prehistoric II (610-100 cal BP).

Figure 6.5 shows that each temporal bin is represented by multiple sites. The largest bin (Bin 2; n=23) includes individuals from five sites, while the remaining bins include individuals from at least two sites. The site distribution indicates that temporal patterns in the radiocarbon dataset are not driven by the occupational history of a single site, but instead reflect broader regional patterns of settlement and burial. This interpretation is further supported by the site distance matrix (Table 6-1), which indicates that no site was further than 40 km from another, with the total study area an estimated 1600 km². CA-TUO-935 and TUO-300 overlap in occupation during Bin 5, while TUO-300 and TUO-314 overlap during Bin 4. While TUO-300

has the longest continuous occupational history within the region, it is never the sole representation of burials within any given time period.

To put these data in perspective, Figure 6.6 shows the burial frequency per century across the study area. In Figure 6.6, burial frequencies were normalized by both time and study area size and are expressed as individuals per century per 1000 km². These values are a relative proxy for demographic intensity rather than an estimate of absolute population density, or population size. Based on the numbers, burial frequency peaked in RP I, and stabilized by RP II. An increase is also noticeable in the middle Late Archaic (Bin 4) as compared to the early Late Archaic-late Middle Archaic (Bin 5). At face value, these data suggest a 250% (or 3.5-fold) increase in demographic intensity during the middle Late Archaic compared to the preceding period in Bin 5 (Figure 6.6). This result raises the question of whether this perceived increase is due to better preservation of slightly younger burials or whether it is due to an actual increase in burial frequency. The most parsimonious answer is that it is likely due to both. However, given that three of the burials from Bin 5 also belong to the early Late Archaic, and given there are more burials within Bin 5 compared to Bin 4, preservation may have played a role, but greater population intensity is more likely.

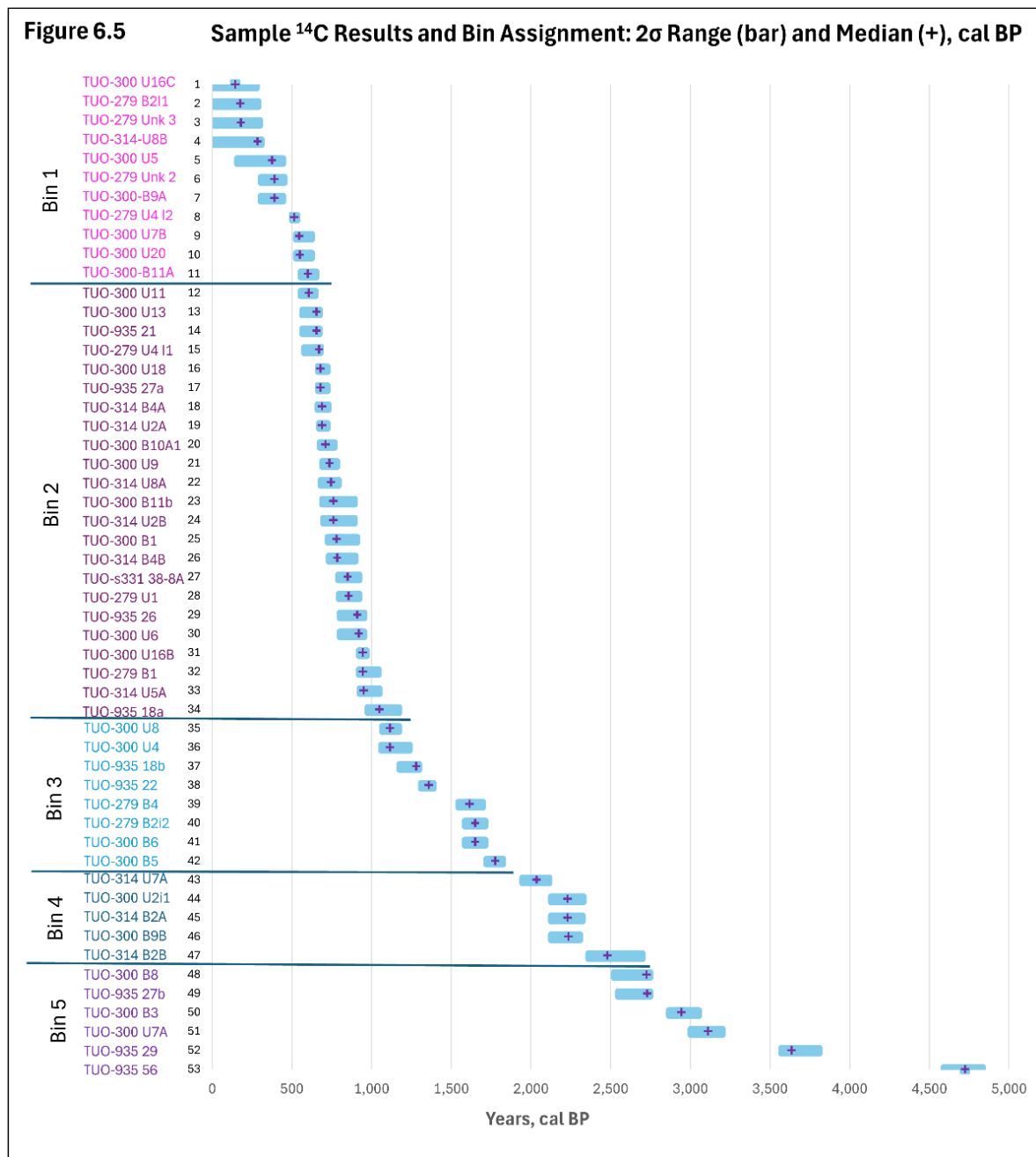


Figure 6.5 Sample ^{14}C Results and Bin Assignment

Figure shows the calibrated radiocarbon record for all burials used within further analyses within this chapter. Dates were organized by median calibrated dates (Calib 8.1). Bin assignments were determined by cultural period likely experienced during an individual's lifetime and by consulting the median calibrated date, 95% confidence interval, burial context and age at death for individuals whose 95% confidence interval overlapped two cultural periods. Individual samples are color-coded to align with Bin assignments, where Bin 1 (600-145 cal BP; $n=11$) is represented in pink, Bin 2 (1050-605 cal BP; $n=23$) is in lavender, Bin 3 (1775-1115 cal BP; $n=8$) is light blue, Bin 4 (2480-2035 cal BP; $n=5$) is dark blue, and Bin 5 (4725-2725 cal BP; $n=6$) is purple. Horizontal lines help to visually separate bins.

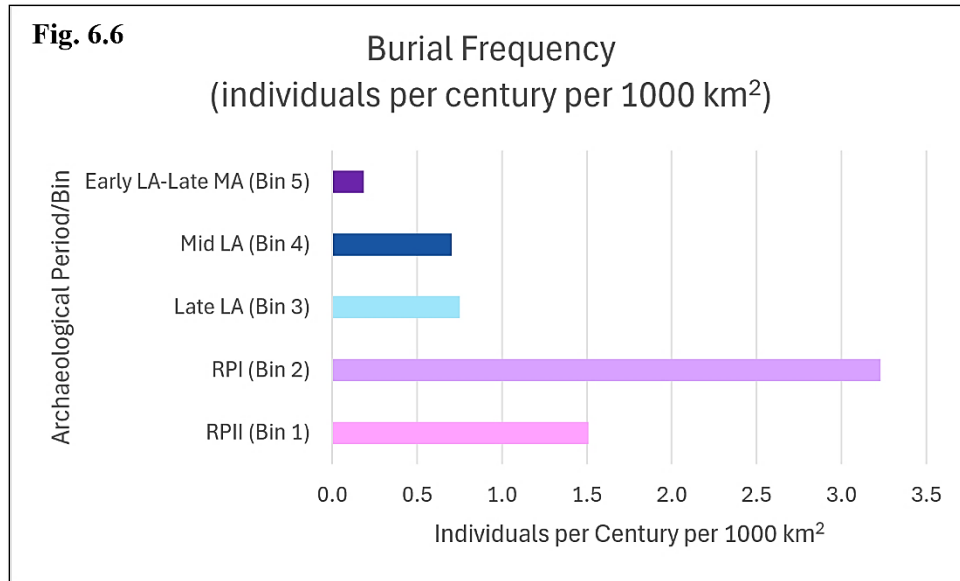


Figure 6.6 Burial Frequency (individuals per century per 1000 km²)
For each Bin, burial frequency (individuals per century/1000 km²) was calculated and should be considered as demographic intensity, rather than an absolute measure of population density. Bin 1 (RP II) is shown in pink; Bin 2 is RP I (lavender); Bin 3 Late LA (light blue); Bin 4 Mid LA (dark blue); Bin 5 Early LA to Late MA (purple). Two major increases in demographic intensity are represented by this graph, the first is from Bin 5 to Bin 4, and the second major increase is from Bin 3 to Bin 2; demographic intensity decreased from Bin 2 to Bin 1.

6.3.1 Results: Diachronic $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ Analyses

Figure 6.7 shows $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for all radiocarbon-dated individuals, and how they compare with each other, among sites, and among expectations based from other foraging regions sampled across Northern California. The means and standard deviations for the Tuolumne group are $-18.9 \pm 0.5\text{‰}$ for $\delta^{13}\text{C}$ and $7.4 \pm 1.0\text{‰}$ for $\delta^{15}\text{N}$, shown by the black marker and error bars (Figure 6.7). The Tuolumne individuals overlap among sites, but exhibit a distinct isotopic space compared to riverine, valley terrestrial, and coastal (brackish to marine) foraging regions. Also noticeable are that $\delta^{13}\text{C}$ is less negative than is typically expected for terrestrial foragers in this swath of California, while $\delta^{15}\text{N}$ is lower than even the valley foragers (mean $\delta^{13}\text{C}$ and SD = $-20.6 \pm 0.4\text{‰}$; mean $\delta^{15}\text{N}$ and SD = $8.7 \pm 0.6\text{‰}$). It is most probable that a group of linked resources, deriving mainly from plants and sometimes passed to animals, are driving the

trend in the Tuolumne samples. Accordingly, the most probable cause is not juvenile salmon or other anadromous fish, but is pine nuts and meat from animals consuming pine nuts within the foraging range of the Tuolumne individuals (see literature review in chapters 2–5).

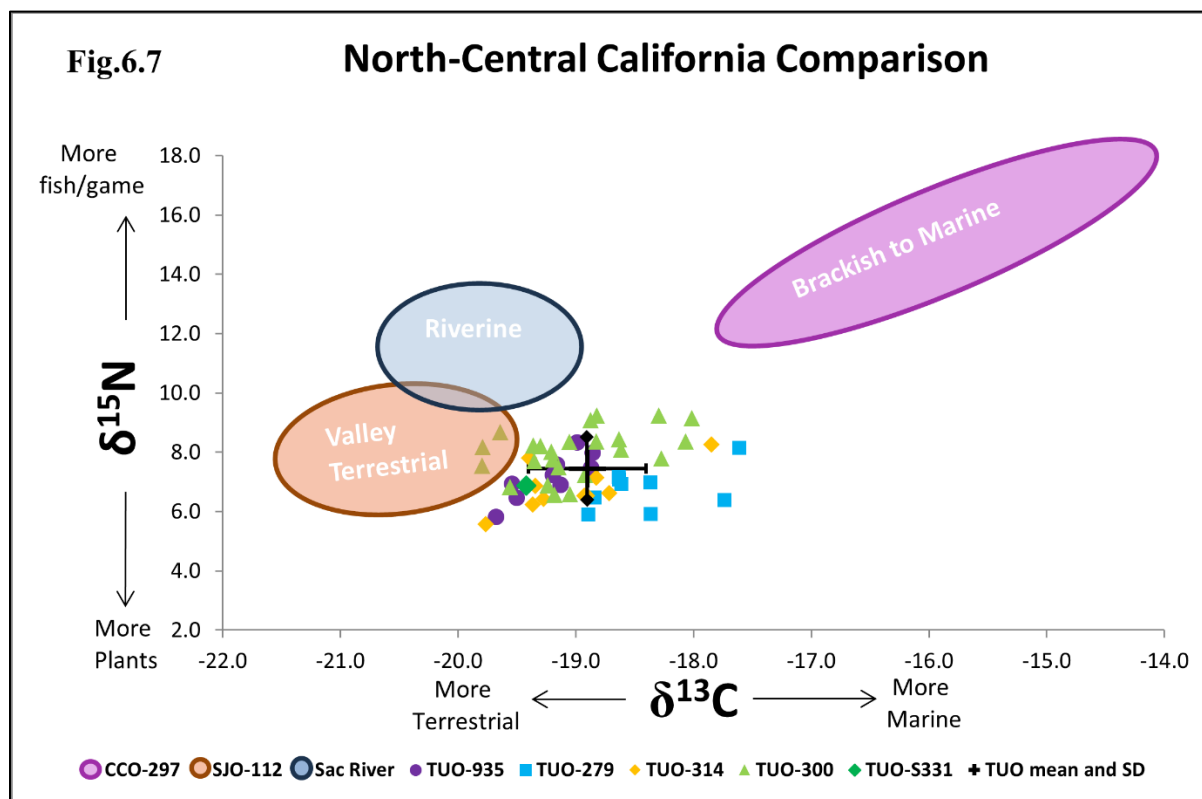


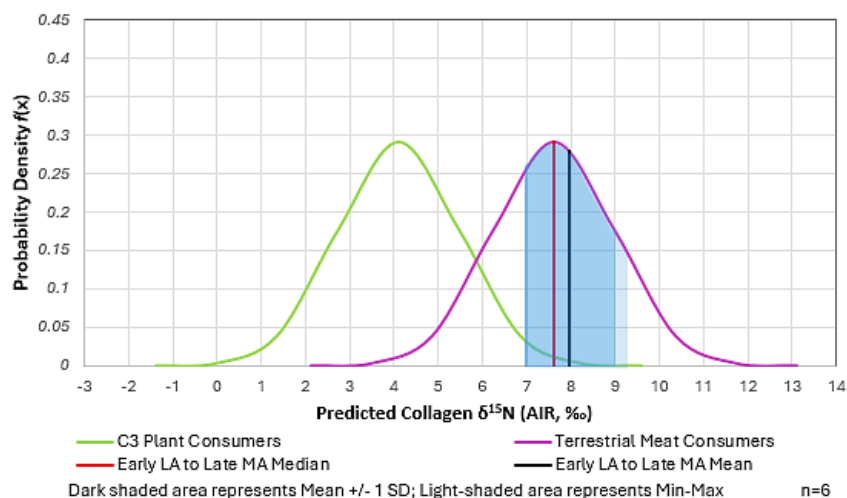
Figure 6.7 North-Central California Comparison
 Scatterplot shows the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results for radiocarbon dated individuals shown in Table 6-3 and which passed collagen quality control criteria in Table 6-4. Individuals are plotted by site (circle, square, diamond, and triangle markers) in comparison to other foraging regions across north-central California (ellipses). The mean and SD for all radiocarbon dated Tuolumne samples is represented in the biplot by the black plus marker and error bars, which represent the point and range of $\delta^{13}\text{C} = -18.9 \pm 0.5\text{‰}$, $\delta^{15}\text{N} = 7.4 \pm 1.0\text{‰}$. Tuolumne individuals occupy a distinct isotopic space in comparison to the other foraging regions.

Figure 6.8a-e show how the Tuolumne individuals plot along the expected probability density model for $\delta^{15}\text{N}$ by time bin (Bins 1-5; as delineated in Figure 6.5 and Figure 6.6). As discussed previously, the probability density curves for $\delta^{15}\text{N}$ were constructed using the faunal data from Chapter 5 as a baseline from which to model curves for the expected range and independent probability density functions (PDFs) for plant consumers and meat consumers

within this environment. Rather than show all individuals as points, for clarity, I instead use shaded areas to indicate the maximum and minimum values, and use dark shaded areas for ± 1 SD from the mean; means (black) and medians (red) are shown as vertical lines to enable a better estimate of which value along the x-axis the line (or point) is referring to. Where vertical lines cross the PD curves, these indicate the PDF for each food type considered. Within this set of analyses, each graph is accompanied by a small table of corresponding points for min, max, mean, median, and $\pm$ SD, and their associated PDF values. The shaded areas show the form of the distribution in each time period. These are not normalized values, but instead represent how the plotted PDF distribution of max, min, mean, median, and SD change for each period, indicating both similarities and differences among periods.

The $\delta^{15}\text{N}$ model performance was evaluated using predictive probabilities and standardized residuals among all individuals. The predictive p-values for individuals generally fell within moderate to high probability ranges (e.g., 0.43–0.98), indicating that observed $\delta^{15}\text{N}$ values are well-explained by the modelled plant and animal PDF curves. Predictive p-values were lowest for individuals in which the observed $\delta^{15}\text{N}$ values exceeded 9.0 ‰ (n=4), yet these predictive p-values were still above 0.2 indicating non-significance for fit. Of these four individuals, one was an infant, one was an adolescent male, another an adult male, and one an adult of indeterminate sex. Hence, higher $\delta^{15}\text{N}$ might be expected for at least three out of four of these individuals given that one was likely nursing and two were probably hunters with greater access to meat. The standardized residuals for all individuals were mostly centered near zero and remained within the expected bound of $|z| < 2$ (e.g., the greatest absolute value of z was 1.172, for the adolescent male), suggesting no systematic bias in the model predictions.

Fig. 6.8a Probability Density Curves Early LA - Late MA $\delta^{15}\text{N}$



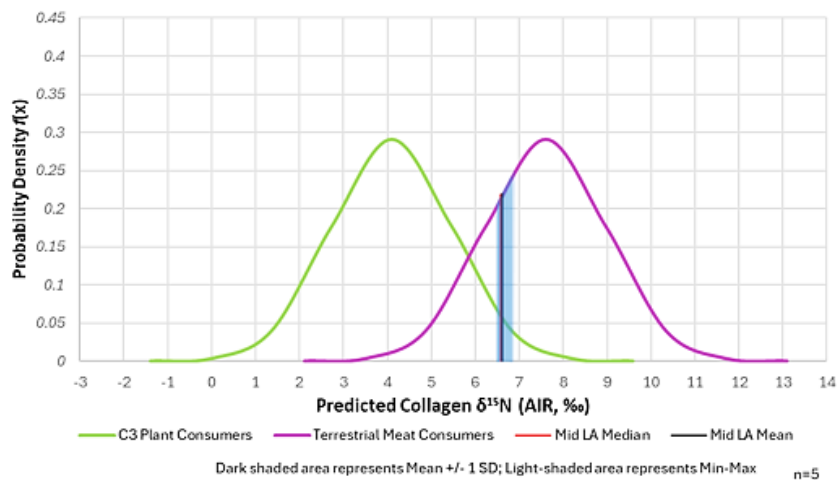
Early LA-Late MA: 2725-4725 cal BP

	min	mean	median	max	-1 SD	+1SD
$\delta^{15}\text{N}$	6.94	7.97	7.63	9.24	6.98	8.96
plant	0.034	0.005	0.011	0.000	0.032	0.001
meat	0.258	0.280	0.291	0.143	0.262	0.178

SD= 0.99

n=6

Fig. 6.8b Probability Density Curves Mid LA $\delta^{15}\text{N}$



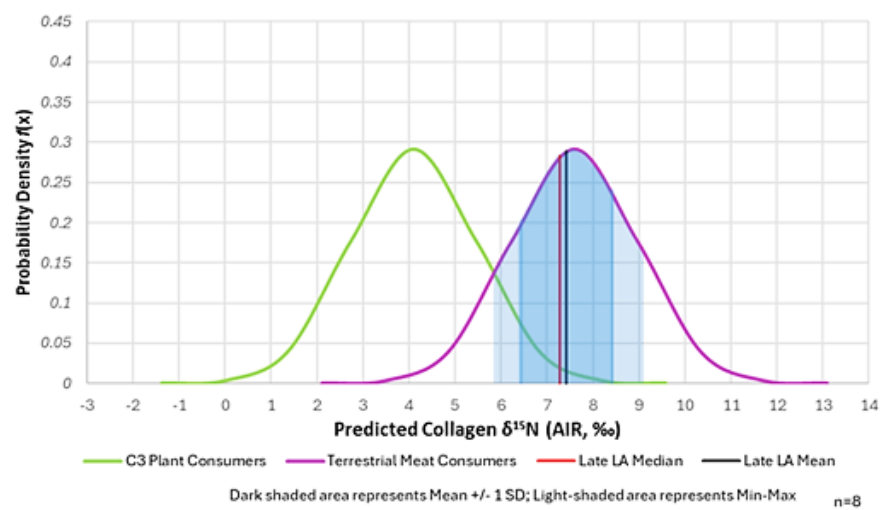
Mid-LA: 2480-2035 cal BP

	min	mean	median	max	-1 SD	+1SD
$\delta^{15}\text{N}$	6.53	6.62	6.57	6.88	6.47	6.77
plant	0.061	0.054	0.058	0.038	0.066	0.044
meat	0.214	0.225	0.219	0.253	0.207	0.242

SD= 0.15

n=5

Fig. 6.8c Probability Density Curves Late LA $\delta^{15}\text{N}$



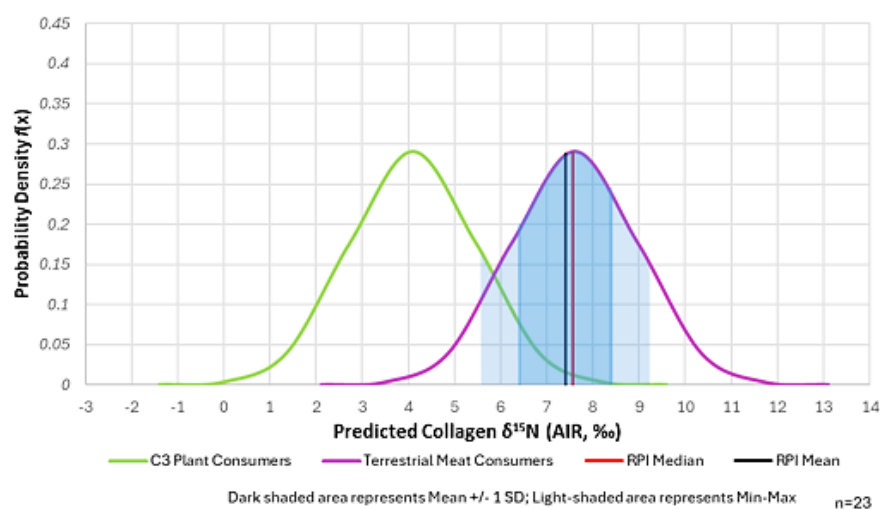
Late-LA: 1775-1115 cal BP

	min	mean	median	max	-1 SD	+1SD
$\delta^{15}\text{N}$	5.82	7.43	7.28	9.07	6.44	8.42
plant	0.133	0.015	0.020	0.000	0.068	0.002
meat	0.125	0.288	0.283	0.164	0.203	0.240

SD= 0.99

n=8

Fig. 6.8d Probability Density Curves RPI $\delta^{15}\text{N}$



RPI: 1050-605 cal BP

	min	mean	median	max	-1 SD	+1SD
$\delta^{15}\text{N}$	5.58	7.40	7.57	9.24	6.41	8.39
plant	0.163	0.015	0.014	0.000	0.071	0.002
meat	0.098	0.289	0.289	0.143	0.199	0.246

SD= 0.99

n=23

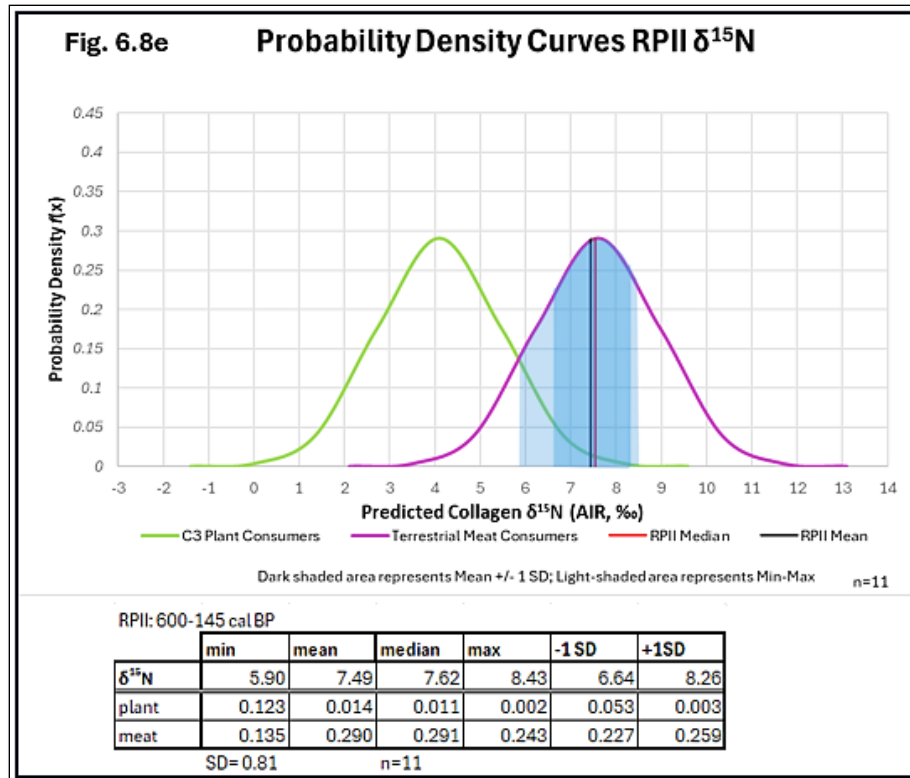


Figure 6.8a-e $\delta^{15}\text{N}$ Probability Density Curves by Temporal Period
Figure series shows how $\delta^{15}\text{N}$ values of the sample population change through time. The min, max, mean, median and $\pm 1\text{SD}$ are represented in each plot, where min, max and the range for SD are represented by shaded areas (light for min to max; darker for $\pm 1\text{SD}$), while means are indicated by black vertical lines and medians are shown by red vertical lines. Accompanying each graph is a table listing the data points represented in the graph, where for each $\delta^{15}\text{N}$ there are two Probability Density Functions (PDFs). a) Early LA through Late MA; b) mid LA; c) late LA; d) RP I; e) RP II.

While the model does tend to push higher $\delta^{15}\text{N}$ values towards a central mean, this is not unexpected given this is a basic two source probabilistic mixing model based on collagen values. The expectation is that it will tend to under predict at high $\delta^{15}\text{N}$ and over-predict at low $\delta^{15}\text{N}$, given that collagen is mostly reflective of protein, which is denser in meats. The results indicate that the two-source $\delta^{15}\text{N}$ model provides an adequate fit to the data and that the observed variation in $\delta^{15}\text{N}$ values can be accounted for by variation in the relative contributions of plant and animal protein to individual diets. Also, the model uncertainty incorporates both food-group

variance and instrumental error ($\pm 0.3\text{‰}$), and the residuals remained consistent with these combined sources of uncertainty.

Although the results for Figure 6.8a are cautiously reported, the overall trend indicates the majority of the population falls near the peak for meat consumers, while the mean is pulled farther to the right. That the spread of values fall within the high-mid PDFs for meat consumers could suggest a greater reliance on meat vs plant protein during this period. In contrast, Figure 6.8b shows the narrowest distribution among the bins, despite a small sample size, and indicates a dietary shift between the early Late Archaic/late Middle Archaic and the middle Late Archaic. By the later Late Archaic (Figure 6.8c) diets have expanded, as the range is larger than the preceding periods. The distribution of $\delta^{15}\text{N}$ is widest during RPI, as shown in Figure 6.8d. This indicates another dietary shift. Meanwhile, individuals in Figure 6.8e show a contraction of the range, and another dietary shift.

Of importance within Figure 6.8a-e, while mean $\delta^{15}\text{N}$ only changes by 1.35‰ between the period with the highest versus the lowest mean values, the main distributional pull is better illustrated through the positional change of medians versus means among the bins. This is best illustrated by comparing the later Late Archaic graph (Figure 6.8c) to that for RP I (Figure 6.8d). Between these two bins, the distribution of $\delta^{15}\text{N}$ shifts from an almost symmetrical right tailed (Figure 6.8c) distribution to a left tailed distribution (Fig. 6.8d), indicating dietary change between these two periods, mainly in the form of meat proteins. Also of importance is that the left-tailed distribution of Figure 6.8d trails the farthest of any distribution into the curve for strict plant consumers. After RP I, RP II (Figure 6.8e) indicates a further dietary shift, where the spread of values contracts. Curious among these is Figure 6.8b, which exhibits the narrowest variation in $\delta^{15}\text{N}$ among all bins. Usually, with a small sample size such as for Bin 4, the expectation is a

greater standard deviation, not smaller. Standard deviations are similar among all other bins except Bin 4, which may indicate a number of possibilities, from homogenization of the diet, widespread sharing of resources, poor hunting returns and a greater reliance on plants, or an influx of people into the region with broadly similar diets. Despite the small sample size for this bin, the narrow range requires further investigation as it was unexpected.

The $\delta^{15}\text{N}$ values for each bin are further illustrated in Figure 6.9, a series of box-and-whisker plots. These plots show the basic distribution of $\delta^{15}\text{N}$ among the different time periods represented by each bin, and are included for clarity. However, these plots do not consider any modeling and are simply distributions of the observed $\delta^{15}\text{N}$ values. In Figure 6.9, the means and medians follow the same pattern as in Figure 6.8a-e, and Bin 4 remains compressed and lower in $\delta^{15}\text{N}$ than any other bin.

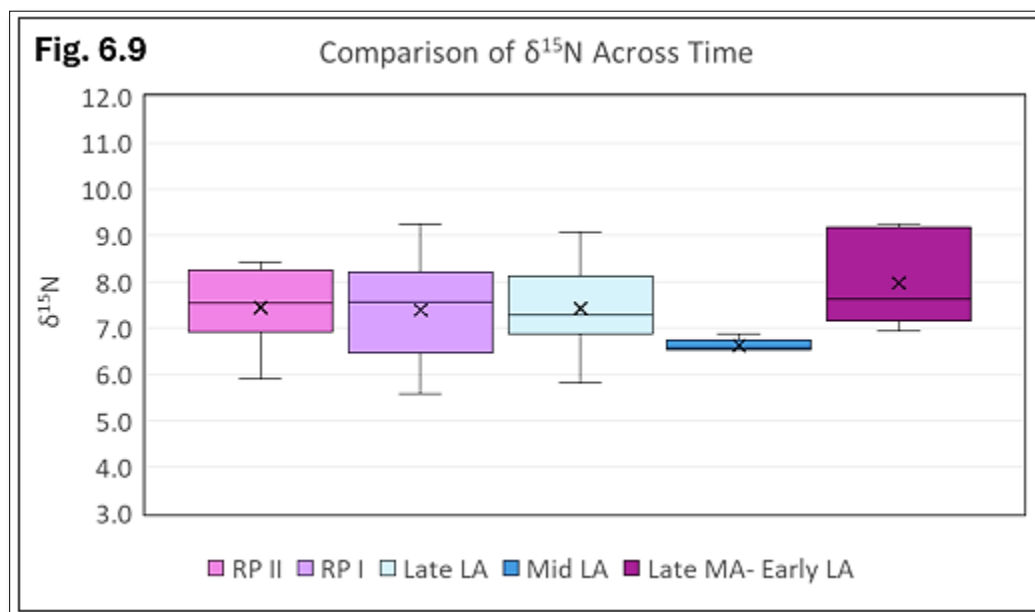


Figure 6.9 Comparison $\delta^{15}\text{N}$ Across Time

Series of box and whisker plots illustrate the distribution of $\delta^{15}\text{N}$ results for each time frame represented by the bins. These box plots use exclusive means, where means are marked by an X, medians are shown as lines, and whiskers indicate the range. Order of key is same order used for presentation of box and whisker plots: RP II (pink), RP I (lavender), Late LA (light blue), Mid LA (dark blue), Late MA-early LA (purple). No outliers are evident.

Thus far, meat contributions to $\delta^{15}\text{N}_{\text{collagen}}$ dominate interpretations of $\delta^{15}\text{N}$, and the normalized mean and median probabilities hover around 90% across all periods, as expected for $\delta^{15}\text{N}_{\text{collagen}}$ and meat. Within the study region, what is more uncertain is how the probability of plant consumption may have changed over time. A diachronic view of the normalized probabilities for plant consumption from $\delta^{15}\text{N}$ is depicted in Figure 6.10, which is a bar graph comparing how the normalized mean and median probabilities for plant consumption change over time, where normalized mean probabilities are shown in light green and medians are shown in dark green. As indicated in the graph, the mean and median normalized plant probabilities show broadly similar temporal patterns, although means are slightly elevated in some periods due to a small number of individuals with lower $\delta^{15}\text{N}_{\text{collagen}}$ values and hence higher plant contributions. Median probabilities better reflect the majority of the sampled individuals, or the central tendency of the sample.

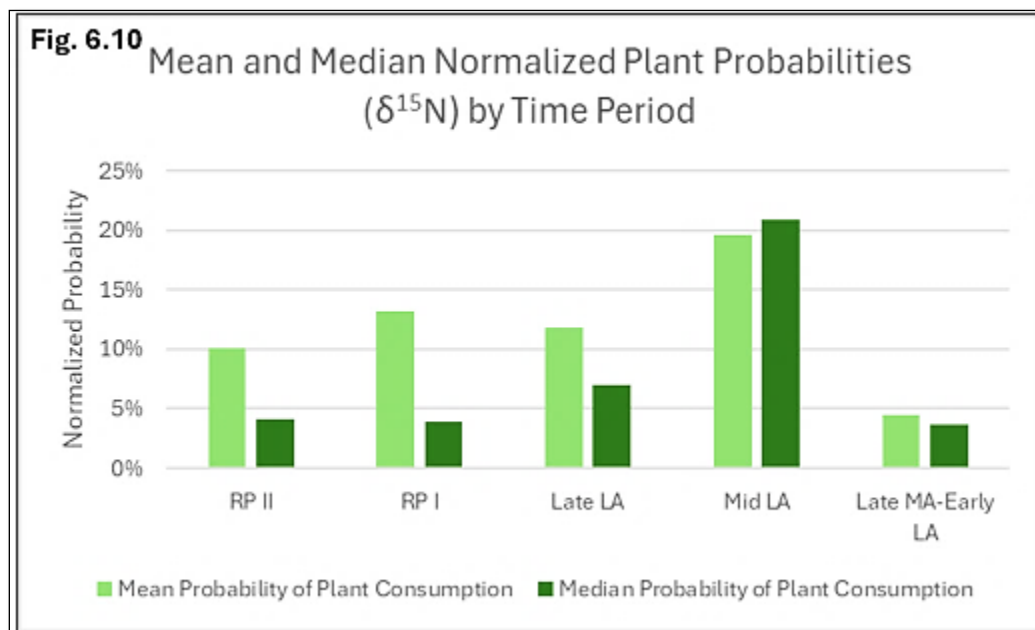
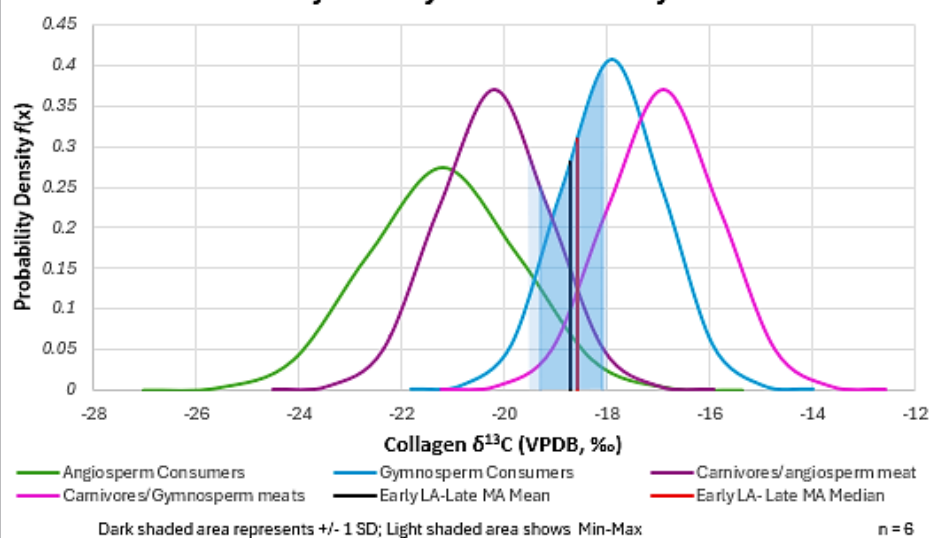


Figure 6.10 Mean and Median Normalized Plant Probabilities ($\delta^{15}\text{N}$) by Time Period
Bar graph compares the mean and median normalized probabilities of plant consumption from $\delta^{15}\text{N}_{\text{collagen}}$ across time periods. Mean normalized probabilities are shown in light green, while median normalized probabilities are shown in dark green. Plant contributions to protein portion of diet peaked during the Mid LA, and declined thereafter.

In Figure 6.10, the highest plant probabilities occur during the middle Late Archaic, which also exhibits relatively low within-period variation, suggesting plant contributions were more consistently represented across individuals. In contrast, plant probabilities decline following the middle Late Archaic, with median values remaining below ~10% in later periods, and indicating a reduced visibility of plant-derived protein in collagen among individuals within these samples. Importantly, the consistent detection of plant contributions in the $\delta^{15}\text{N}_{\text{collagen}}$ model indicates the plant resources were consistently present within the diet, despite the expected dominance of animal-derived protein in collagen. The decline in plant probabilities after the middle Late Archaic signals a shift in diet, where the lowest probabilities for plant protein during RP I and RP II broadly coincide with the introduction of the bow and arrow, suggesting another potential shift in diet, or environmental reactions to both drought and ice-age conditions. These possibilities are examined using $\delta^{13}\text{C}$, as drought conditions should shift $\delta^{13}\text{C}$ values toward less negative values, while cooler ice-age conditions should shift values toward more negative values, assuming increased moisture at lower elevations during cooler intervals within this Mediterranean climate.

The dietary implications of these shifts are then evaluated through the probability density curves generated for the $\delta^{13}\text{C}$ model (Figure 6.11a-e). Importantly, this model represents a monoisotopic system based on C_3 plants and carbon transfers up the food chain, which is illustrated by an overlap among the probability density distributions.

Fig. 6.11a Probability Density Curves For Early LA - Late MA $\delta^{13}\text{C}$

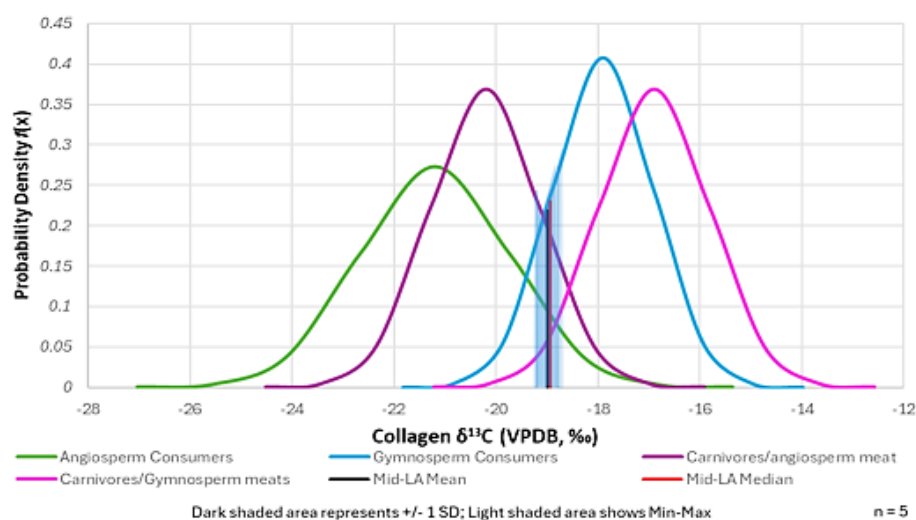


	Min	Median	Mean	Max	-1SD	+1SD
$\delta^{13}\text{C}$	-19.54	-18.58	-18.70	-18.02	-19.30	-18.10
APlant	0.143	0.055	0.063	0.025	0.117	0.029
Gplant	0.100	0.320	0.292	0.404	0.147	0.399
AMeat	0.306	0.120	0.141	0.048	0.261	0.056
GMeat	0.019	0.110	0.092	0.216	0.031	0.199

SD=0.60

n=6

Fig. 6.11b Probability Density Curves For Mid-LA $\delta^{13}\text{C}$



	Min	Median	Mean	Max	-1SD	+1SD
$\delta^{13}\text{C}$	-19.24	-18.93	-18.99	-18.72	-19.21	-18.78
APlant	0.111	0.082	0.087	0.065	0.108	0.069
Gplant	0.160	0.234	0.219	0.287	0.167	0.272
AMeat	0.249	0.185	0.197	0.144	0.243	0.156
GMeat	0.035	0.063	0.057	0.089	0.038	0.081

SD=0.21

n=5

Fig. 6.11c Probability Density Curves For Late-LA $\delta^{13}\text{C}$

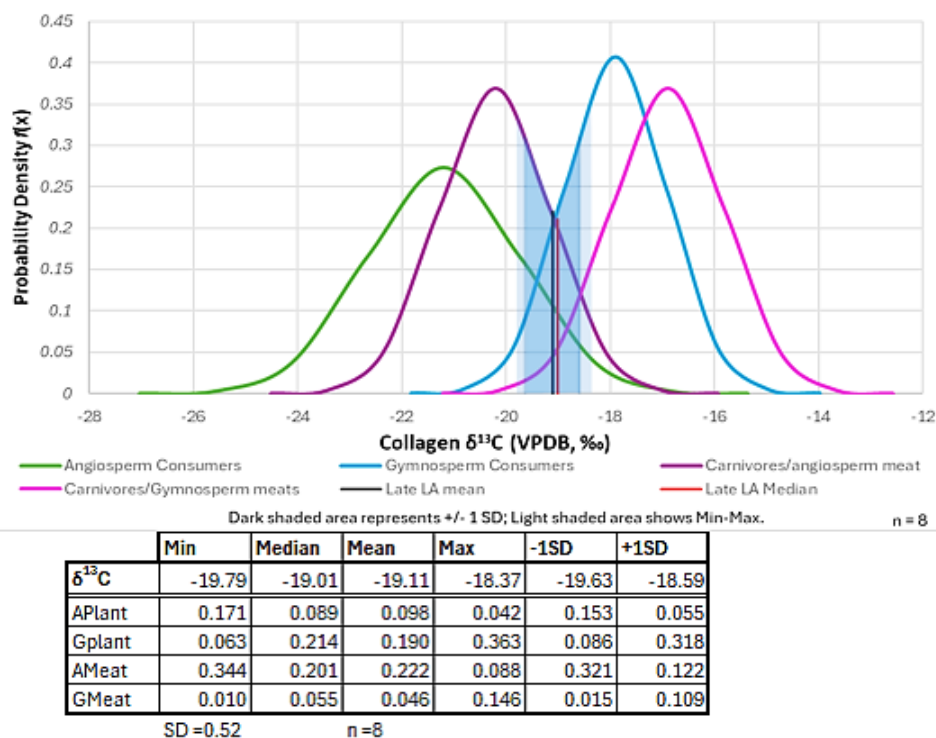
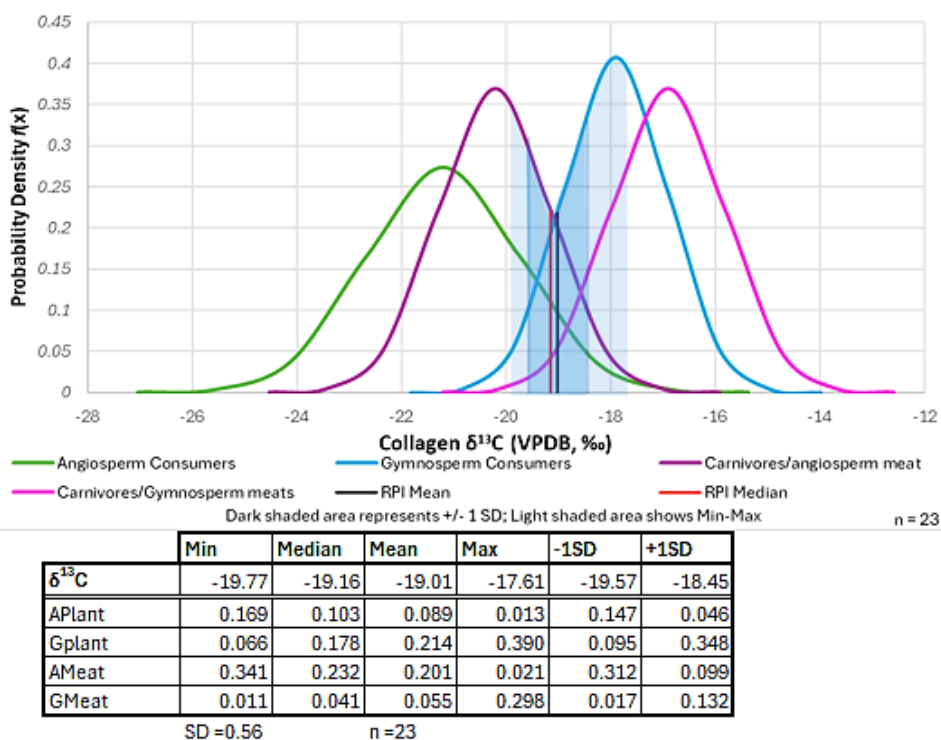


Fig. 6.11d Probability Density Curves For RPI $\delta^{13}\text{C}$



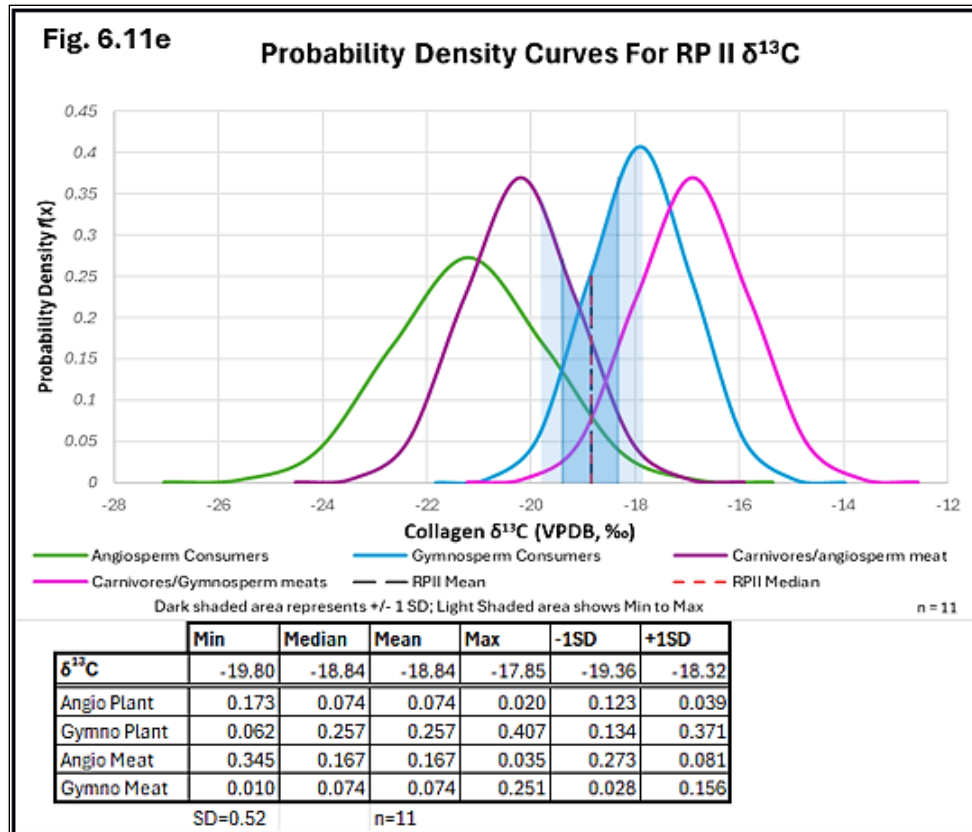


Figure 6.11a-e Probability Density Curves for Temporal Bin $\delta^{13}\text{C}$
 Plots show how the $\delta^{13}\text{C}$ values versus Probability Density Functions (PDF) values of the sample population change through time. Probability density distributions are plotted by temporal bin. The min, max, mean, median and $\pm 1\text{SD}$ are represented in each plot, where min, max and the range for SD are represented by shaded areas (light for min to max; darker for $\pm 1\text{SD}$), while means are indicated by black vertical lines and medians are shown by red vertical lines. Accompanying each graph is a table listing the data points represented in the graph, where for each $\delta^{13}\text{C}$ there are four PDFs. 6.11a) Early LA-Late MA; 6.11b) Mid-LA; 6.11c) Late-LA; 6.11d) RP I; 6.11e) RP II.

Because this is a four-source model that uses two dietary offsets for a single isotope (never recommended), but which exists within a monoisotopic landscape, to evaluate model uncertainty, first order uncertainty (including instrumental error = 0.2‰, and food-group SD) was propagated through the $\delta^{13}\text{C}$ dietary model for both food group probability density functions (PDF) and normalized dietary probabilities for *every individual*. Within the probability density distributions, PDF uncertainty among all individuals across all consumer food groups ranged between 0.004 and 0.05, averaging 0.02. For the normalized probabilities, propagated

uncertainty ranged between 0.01 to 0.06 across individuals and food groups, with an average of 0.04. These values indicate reasonable, or modest, uncertainty in dietary attribution, consistent with overlap among the modelled consumer-food group isotope distributions and instrumental error, and not model failure. The $\delta^{13}\text{C}$ model performance was evaluated using predictive probabilities and standardized residuals. Predictive p-values fall within the range 0.59 to 0.995 (median = 0.79), indicating that observed $\delta^{13}\text{C}$ values are well accounted for by the modelled dietary mixtures. Standardized residuals are centered near zero (mean = 0.19, median = 0.2) and fall within expected limits ($|z| < 0.6$), indicating that observed collagen values are closely matched by the model predictions and have a strong linear association (Pearson = 0.99) despite overlap among the modeled food groups.

Figure 6.11a-e demonstrate the potential shifts in diet through the $\delta^{13}\text{C}$ model. In Figures 6.11a-e, each graph represents one bin and shows how the group distribution plots along the four independent curves. Group distributions are represented by the minimum and maximum values within each period (bounds of the light shaded region), median (red line) and mean (black line) values, and $\pm 1\text{SD}$ (dark shaded area). Accompanying each graph is a table, with the $\delta^{13}\text{C}$ values and associated PDFs for each across the four consumer curves (i.e., “Angiosperm Consumers” refers to the expected values for humans and animals if angiosperm plants were the only foods consumed).

Similar to the dietary shifts noticeable within the $\delta^{15}\text{N}$ model curves in Figure 6.8a-e, dietary shifts are evident in $\delta^{13}\text{C}$ within Figure 6.11a-e. While Figure 6.11a warrants cautious interpretation, overall, the figure indicates a major reliance on gymnosperm plant resources, a mixed, but equivalent reliance on both angiosperm-based and gymnosperm-based meats, and a much smaller reliance on angiosperm plant resources while the SD for this period is the largest

among all periods examined. In contrast, Figure 6.11b shows the narrowest distribution. Within this figure, mean and median are separated by only 0.06 permille (far outside the range of instrument precision), while the entire distribution falls within an extremely narrow range of ~0.5 permille. This mimics the distributional range for $\delta^{15}\text{N}$ during this period, but in this case clearly indicates a dietary shift that shows a homogenization of the diet among all individuals, or in other words, diets for all individuals were quite similar. The dietary distribution expands in Figure 6.11c (Bin 3, later Late Archaic), with both mean and median decreasing from the earlier period, indicating a dietary shift to include slightly more angiosperm-based resources. This trend in increased use of angiosperm-based resources continues into Figure 6.11d (Bin 2), where the mean and median have swapped positions relative to the preceding period, indicating a right-tailed distribution with more angiosperm-based resources than any previous period, where the median (and bulk of people) have shifted to the left towards angiosperm plants. Notably, the expectation for drought to increase $\delta^{13}\text{C}$ (shift to less negative) values across the resource base (move to the right) further highlights an increased use of angiosperm-based resources during this RP I Bin, given the left-handed shift of most people. In Figure 6.11e, mean and median are indistinguishable (marked by overlapping dashed lines) and again moved to the right of the intersection of the distributions, suggesting increased use of gymnosperm-based resources despite the expectation for the cooler climate and possibly moister conditions (LIA) to move the $\delta^{13}\text{C}$ of the entire resource base to the left (more negative $\delta^{13}\text{C}$).

The distribution of individuals among the bins is further illustrated in Figure 6.12, which is a series of box-and-whisker plots for $\delta^{13}\text{C}$ across time. In this figure, probabilities for individual dietary resources are not included and the distribution relies only on observed $\delta^{13}\text{C}$ values.

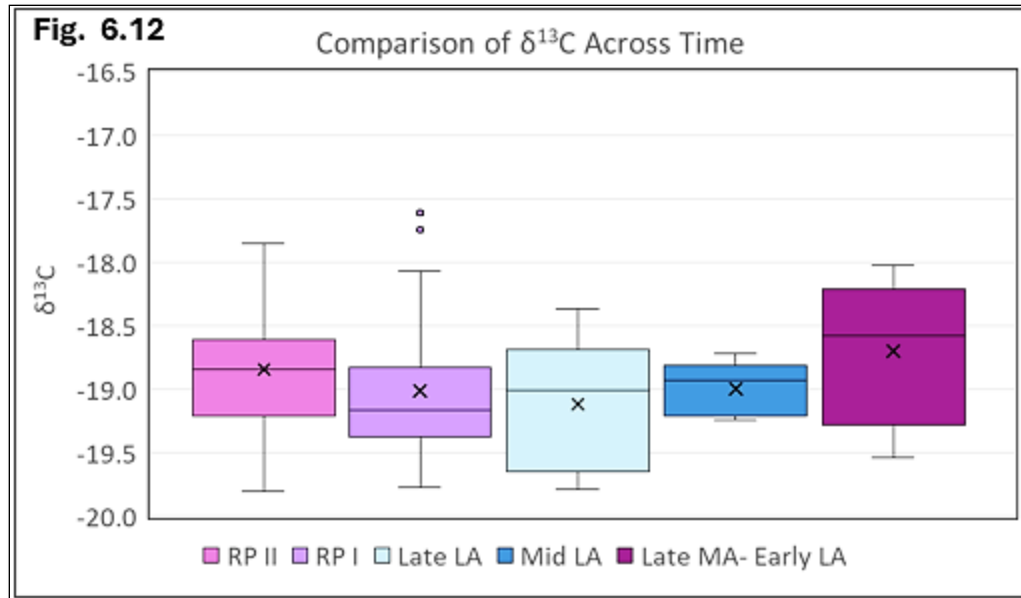


Figure 6.12 Comparison of $\delta^{13}\text{C}$ Across Time

The series of box and whisker plots, illustrates the distribution of $\delta^{13}\text{C}$ results for each time frame represented by the bins for RP II (pink), RP I (lavender), Late LA (light blue), Mid LA (dark blue), and Late MA to early LA (purple). These box plots use exclusive means, where means are marked by an X, medians are shown as lines, and whiskers indicate the range. Two outliers are evident in RP I. Highest median is in the late MA-early LA, lowest is in RP I.

Visible are four dietary shifts (Figure 6.12). First, there is a shift between Bin 5 (late MA-early LA) and Bin 4 (middle LA), indicating a narrowing of the diet probably due to homogenization via resource-sharing or broadly similar diets among individuals at different sites. The difference between the means and medians of Bin 5 versus Bin 4 suggests an increased reliance on angiosperm-based resources, however the cause of such an increase is unresolved given the available data for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ alone. For the later LA (Bin 3), means and medians retain their positions relative to each other within the previous bin, but the distribution widens as compared to Bin 4 (middle LA). This suggests another dietary shift, where means and medians are similar among the preceding and current period, but that some individuals included even more angiosperm plants within their diets (indicated by an increased range of more-negative $\delta^{13}\text{C}$) as compared to the previous period. As compared to the $\delta^{15}\text{N}$ boxplot for this period, the

$\delta^{13}\text{C}$ distribution is also wider, but covers a broader range of the angiosperm-based resources than is evident in $\delta^{15}\text{N}$ alone for plant resources. In RP I, there is another dietary shift, where the median is below the mean and the distribution becomes right tailed and indicates two outliers at the far right (upper portion) of the tail. The highest reliance on $\delta^{13}\text{C}$ -depleted resources is during this period, but given both the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ model data, this result is probably coming from angiosperm-based meats rather than plants alone. By RP II, the mean and median have equalized, and the distribution is again slightly left tailed with both mean and median showing increased $\delta^{13}\text{C}$ (less negative) values.

While, in general, the dietary shifts among bins are minimal in terms of mean and median values of $\delta^{13}\text{C}$, taken together with the distributions, they tell us that diet was not the same among all periods. This is clearly illustrated in Figure 6.13, a bar graph showing the median normalized probabilities for each food-consumer distribution across each bin. Median probabilities, rather than means, were chosen to represent each bin because they inherently indicate the central tendencies of the group distributions and are less easily swayed by any outliers. The median normalized probabilities for angiosperm plant consumers (Med. p_AP) are represented by green bars, gymnosperm plant consumer probabilities (Med. p_GP) are shown in blue, purple represents angiosperm meat consumer probabilities (Med. p_AM), and pink indicates gymnosperm meat consumer probabilities (Med. p_GM).

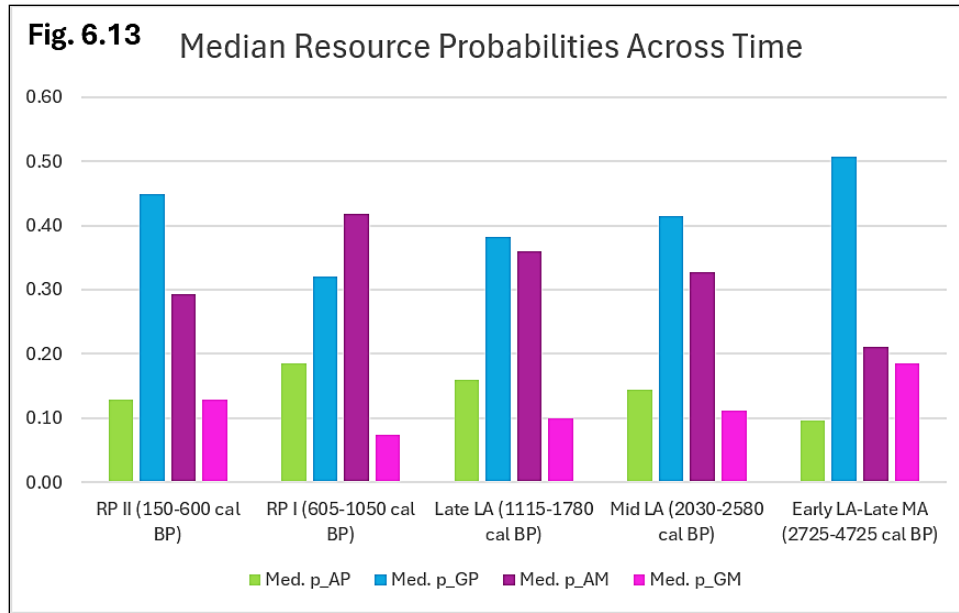


Figure 6.13 Median Resource Probabilities Across Time

Diachronic series of bar graphs which summarize the normalized probabilities of the four $\delta^{13}\text{C}$ consumer groups across the temporal bins. These bar graphs are organized by bin (youngest to oldest; RP II– Early LA-Late MA) and show the median normalized probabilities for each consumer group within each bin. The median normalized probabilities for angiosperm plant consumers are represented by green bars, gymnosperm plant consumer probabilities are shown in blue, purple represents angiosperm meat consumer probabilities, and pink indicates gymnosperm meat probabilities. There is a continued low presence of gymnosperm meats through time, but diets are dominated mainly by gymnosperm plant resources and angiosperm meats. Peak angiosperm plant use occurs during RP I.

As shown in Figure 6.13 (above), median normalized probabilities indicate a clear shift in resource use across time. From the early LA-late MA (Bin 5) into the middle Late Archaic (Bin 4), there is a marked reduction in gymnosperm-based resources (both plant and animal) accompanied by an increase in angiosperm-derived resources. This pattern continues into the later LA (Bin 3), where angiosperm plant and animal contributions remain elevated relative to earlier periods. During RP I (Bin 2), angiosperm-based resources reach their highest relative contributions, particularly for angiosperm-derived meat, while gymnosperm use remains comparatively reduced. In contrast, RP II (Bin 1) shows a reversal of this trend, with increased reliance on gymnosperm-based resources, including both plant and animal inputs, despite environmental expectations based on $\delta^{13}\text{C}$ values.

Overall, the temporal pattern suggests a long-term decline in gymnosperm resource use—likely reflecting reduced reliance on pine nuts—paired with increased contributions from angiosperm resources, especially meat and, to a lesser extent, what is likely acorn use. This trend is, however, reversed in the most recent period, when angiosperm contributions decline and gymnosperm-based resources increase again.

Figure 6.14 shows the normalized probability point estimates for angiosperm plant and gymnosperm plant consumption for *each individual* from 1400–100 cal BP, along with a three-point running average for the two plant categories which act as indicators of the overall trends through time. The error envelopes associated with each three-point running average trendline are shown above and below each trendline and are color-coded to match. Error envelopes around the three point running averages represent approximate propagated uncertainty ($\pm$) for each smoothed point, rather than a running average of the uncertainty values themselves. For each centered three-point average, uncertainty was calculated from the first order Taylor series uncertainties of the three contributing normalized probability estimates using standard propagation of uncertainty for an arithmetic mean. Because the running averages are used only to clarify longer-term trends, uncertainty was propagated for each smoothed point from the three contributing pointwise uncertainty estimates so that the figure reflects approximate error around the averaged values rather than around the unsmoothed observations.

Within Figure 6.14, the smoothed trend for angiosperm plant consumption first crosses above the trend for gymnosperm plant consumption around 1250 cal BP, and again briefly crosses again at ~700 cal BP. While the longer term trend is a reduction to gymnosperm reliance, gymnosperm use is unstable throughout RP I, and gains in use during RP II. The probability of gymnosperm use remains generally elevated relative to acorn for much of this span; however,

because the expectation is for the entire resource base to be shifted to less negative values during drought periods, the angiosperm use during drought periods is technically higher than what is depicted by the model, simply because during drought these resources also become less negative and can fall within the range for well-watered gymnosperms. Additionally, an important pattern emerges from this figure, where we can see strong fluctuation within a constrained general pattern of diet during the drought periods within RP I. This may indicate increased sensitivity in plant-resource use under constrained environmental conditions. Rather than implying wholly dissimilar strategies, this pattern may reflect adjustments within a widely shared strategy in which the nearest and most reliable storable resources were emphasized as local conditions shifted. Overall, it supports the idea of adaptive flexibility within an overall shared strategy.

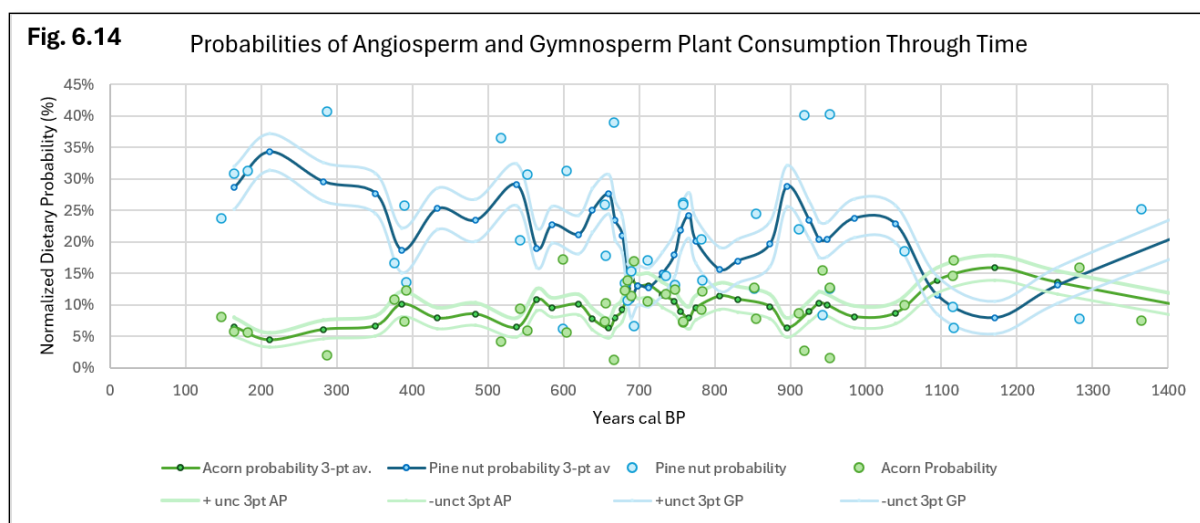


Figure 6.14 Probabilities of Angiosperm and Gymnosperm Plant Consumption Through Time
Scatterplot of normalized probabilities (%) for angiosperm and gymnosperm plant consumption through time (years cal BP) shows each individual's point estimates of their normalized probabilities of angiosperm plants (green circles) and gymnosperm plants (blue circles), as well as the trend (3-point running average) through time for each plant category (dark green line- angiosperm probability trend; dark blue line- gymnosperm probability trend). Shaded envelopes ($\pm$ uncertainty: angiosperm trendline- light green lines; gymnosperm trendline- light blue lines) show approximate propagated uncertainty for the 3-point running averages, calculated from the first-order uncertainties of the three contributing normalized probability estimates.

6.3.2 Results: Diachronic $\delta^{34}\text{S}$ Analysis and Mobility

A total of 37 radiocarbon-dated individuals returned $\delta^{34}\text{S}$ results with acceptable preservation. Figures 6.15a-b show the relationship of $\delta^{34}\text{S}$ with a) $\delta^{13}\text{C}$ and b) $\delta^{15}\text{N}$ among these individuals. A Pearson correlation coefficient (r , p -values, and r^2) was used to determine if $\delta^{34}\text{S}$ was tracking a dietary signal from either $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$. Figure 6.15a shows a positive but weak ($r = 0.189$, $r^2 = 0.0356$, $p = 0.26$) relationship between $\delta^{34}\text{S}$ and $\delta^{13}\text{C}$. This indicates $\delta^{13}\text{C}$ is only capable of explaining $\sim 3.5\%$ of the observed variation in $\delta^{34}\text{S}$ across the 37 individuals analyzed. While for $\delta^{34}\text{S}$ vs. $\delta^{15}\text{N}$, shown in Fig. 6.15b, the relationship is negligible ($r = -0.06$, $r^2 = 0.0039$, $p = 0.71$), and $\delta^{15}\text{N}$ is only able to explain $\sim 0.4\%$ of the observed variation in $\delta^{34}\text{S}$. These results indicate that sulfur isotope variation is largely independent of dietary variation and primarily reflects geographic differences in sulfur isotope baselines.

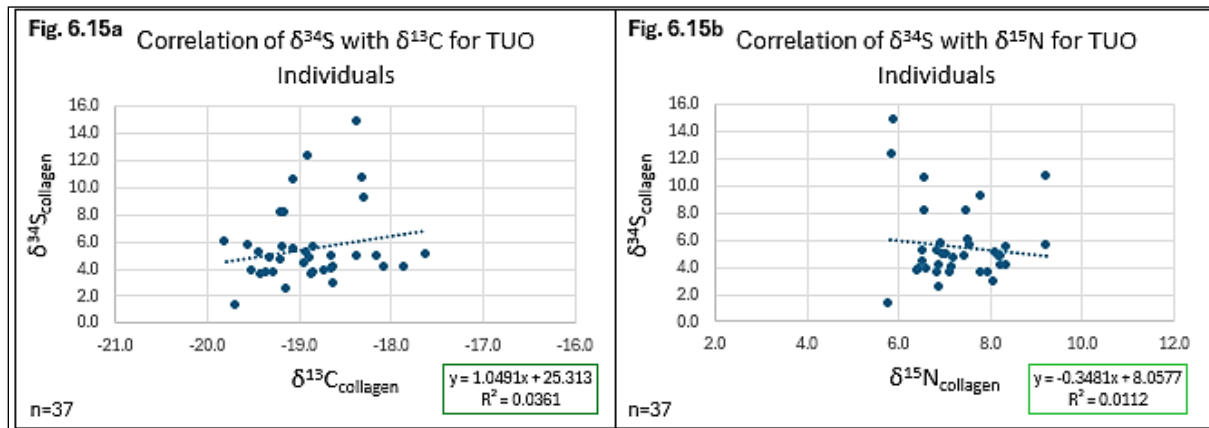


Figure 6.15a-b Correlation of $\delta^{34}\text{S}$ with $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$
 These two biplots show the relationship of $\delta^{34}\text{S}$ with a) $\delta^{13}\text{C}$ and b) $\delta^{15}\text{N}$. Pearson's r , r^2 , and p -values were further used to define these relationships, where r^2 is highlighted in green for each graph (a and b), and indicates the magnitudes of these relationships are weak to negligible.

To separate locals from potential non-locals, a local range was estimated from the faunal data (Table 5-4, excluding elk) using $\pm 2\text{SD}$ from the faunal mean $\delta^{34}\text{S}$. The local range for $\delta^{34}\text{S}$ is 1.8-8.2‰, based on those results. Six out of 37 individuals are classified as non-local using

this range. A Welch's t-test (two-tailed, unequal variance) was used to evaluate whether $\delta^{34}\text{S}$ of non-locals versus locals was driven by differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ among the two categories. Results indicate that sulfur-defined non-locals have indistinguishable $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from local individuals ($p = 0.59$ for $\delta^{13}\text{C}$; $p = 0.36$ for $\delta^{15}\text{N}$). $\delta^{34}\text{S}$ is not tracking $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ -based dietary differences. This additional comparison further supports the interpretation that $\delta^{34}\text{S}$ variation primarily reflects geographic differences rather than dietary behavior among the sampled individuals.

Site level $\delta^{34}\text{S}$ comparisons were conducted using only individuals classified as local so that differences among sites reflect local baseline variation rather than the influence of non-local individuals. As well, because infant collagen can reflect nursing-related dietary inputs and maternal isotopic signatures rather than independent local resource use, infants were excluded from analyses intended to evaluate site-level sulfur baseline variation. When restricted to local non-infant individuals ($n = 30$), $\delta^{34}\text{S}$ values do not differ significantly among sites (Brown-Forsythe: $F = 2.88$, $p = 0.055$), and site distributions overlap substantially. This is illustrated in Figure 6.16, a series of boxplots, organized by site among locals only (excluding infants). In the figure, the shaded area indicates the local range for $\delta^{34}\text{S}$.

Figure 6.16 indicates that local sulfur isotope values are broadly similar across the study area, although minor site-level variation may be present. The difference among site $\delta^{34}\text{S}$ means remains small (1.5‰) relative to the faunal local baseline range, supporting the use of a shared regional sulfur isotope framework for identifying non-local individuals and tracking variance across temporal bins.

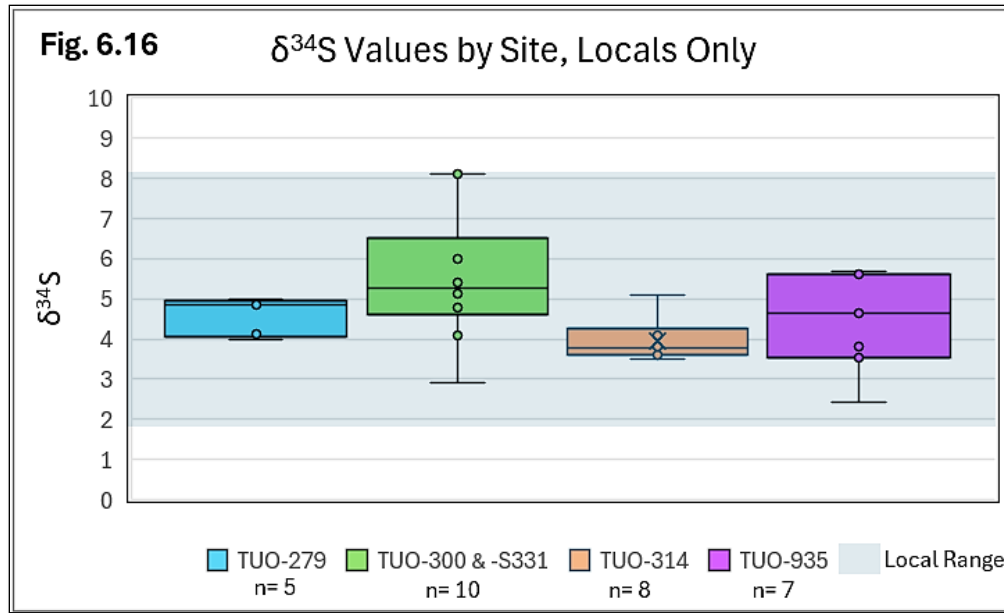


Figure 6.16 $\delta^{34}\text{S}$ Values by Site, Locals Only

Boxplots show $\delta^{34}\text{S}$ plotted by site and in relation to the local baseline range. Sites are color-coded: TUO-279 (blue); TUO-300 and -S331 (green); TUO-314 (orange); TUO-935 (purple). Local $\delta^{34}\text{S}$ baseline (1.8 to 8.2‰) is represented by the shaded area. The infant age-class was excluded from this analysis as it may not represent a true independent measure of local sulfur variation. Total number of individuals = 30.

As the $\delta^{34}\text{S}$ values of individuals is geographic in origin, rather than a dietary signal, Figure 6.17 shows how the 37 individuals are parsed among the temporal bins in relation to the local baseline range. This figure is intended to identify potential influxes of non-local individuals through time. Color-coding of bin members is the same as used for previous figures. Within the figure, the local baseline range for $\delta^{34}\text{S}$ is indicated by gray lines (maximum 8.2‰; minimum 1.8‰). Horizontal spacing of individuals within bins is used for readability.

Figure 6.17 indicates a continuous presence of individuals within the local $\delta^{34}\text{S}$ range over the past ~4,500 years. Six individuals are classified as non-local; however, these individuals are distributed across multiple bins rather than concentrated within a single period. This pattern suggests no discrete influx or replacement event within the study interval. Instead, Figure 6.17 shows that non-local individuals appear intermittently from the late Middle Archaic through RP II. The apparent absence of non-locals in Bin 4, the middle Late Archaic, likely reflects small

sample size and site composition as most individuals within this bin are from TUO-314, which among the sites, exhibits a narrow range of $\delta^{34}\text{S}$.

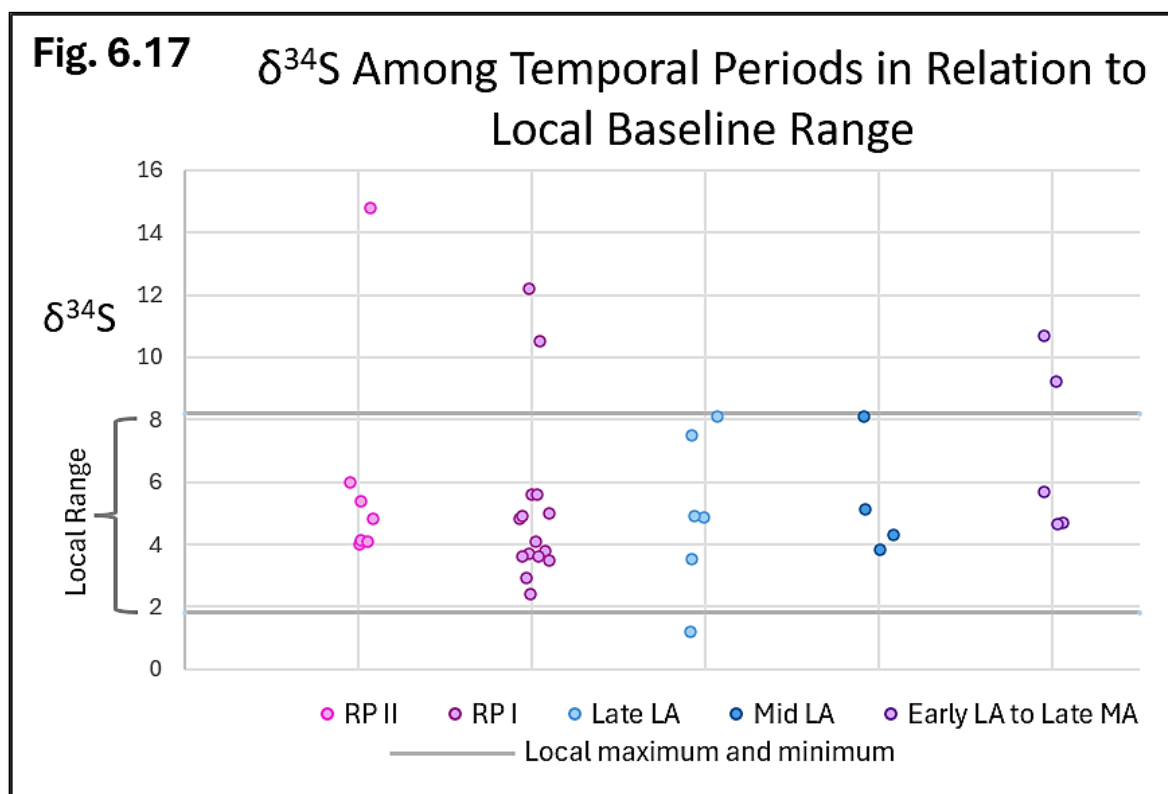


Figure 6.17 $\delta^{34}\text{S}$ Among Temporal Periods in Relation to Local Baseline Range
Scatter plot shows both local and non-local individuals in relation to the baseline range established from the faunal results. Color-coding of Temporal Bins is the same as within previous figures. Local baseline maximum and minimum $\delta^{34}\text{S}$ are shown by gray lines at 1.8 and 8.2‰. All age groups are represented within this graph; n = 37.

When expressed as percentages by period, shown in Table 6-5, this pattern remains broadly consistent across RP II through the later Late Archaic. However, both non-local individuals in Bin 5 fall within the early Late Archaic portion of that interval. To account for small sample sizes in earlier bins, all non-infant Late Archaic individuals are combined into a single bin (Bin 3a) which excludes the Middle Archaic individuals (n=2). Within this collapsed bin (Bin 3a) approximately half of all non-locals are from the Late Archaic period indicating a

modest increase in non-local representation during this period relative to others. Overall, non-local individuals comprise approximately 16% of the sample.

Figure 6.18 presents the $\delta^{34}\text{S}$ distributions by temporal bin using boxplots for local non-infant individuals and points for non-local individuals. Because $\delta^{34}\text{S}$ values do not differ significantly among sites, temporal binning is not expected to produce large distributional differences. Nevertheless, Figure 6.18 suggests a reduction in the range of $\delta^{34}\text{S}$ values during RP I relative to earlier periods. The summary statistics for this analysis are provided in Table 6-6. Variance is highest in the mid- and late- Late Archaic, and decreases during RP I with a further reduction in RP II, but differences in dispersion among bins are not statistically significant (Brown-Forsythe: $F = 0.64$, $p = 0.64$).

Table 6-5 Non-local Immigration Across Time

Temporal Groups	Count: total individuals	Count: non-local	% non-local
Bin 1 (RP II)	7	1	14%
Bin 2 (RP I)	15	2	13%
Bin 3 (late LA)	5	1	20%
Bin 4 (mid LA)	4	0	0%
Bin 5 (early LA–late MA)	5	2	40%
Total among all periods:	37	6	16%
<i>* Bin 3a (total Late Archaic)</i>	<i>12</i>	<i>3</i>	<i>25%</i>

*Note: table shows immigration into the west-central Sierra Nevada region over the last 4,500 years, as based on the radiocarbon-dated individuals' $\delta^{34}\text{S}$ values. The table illustrates how non-locals are partitioned among the temporal bins as % non-local and represents a fine-grained analysis of temporal patterns. *Bin 3a refers only to non-infants those whose age-at death, 2σ and median calibrated radiocarbon dates fell within the total Late Archaic period and is more coarse-grained due to the longer period covered by the original bins but may be more representative of general patterns.*

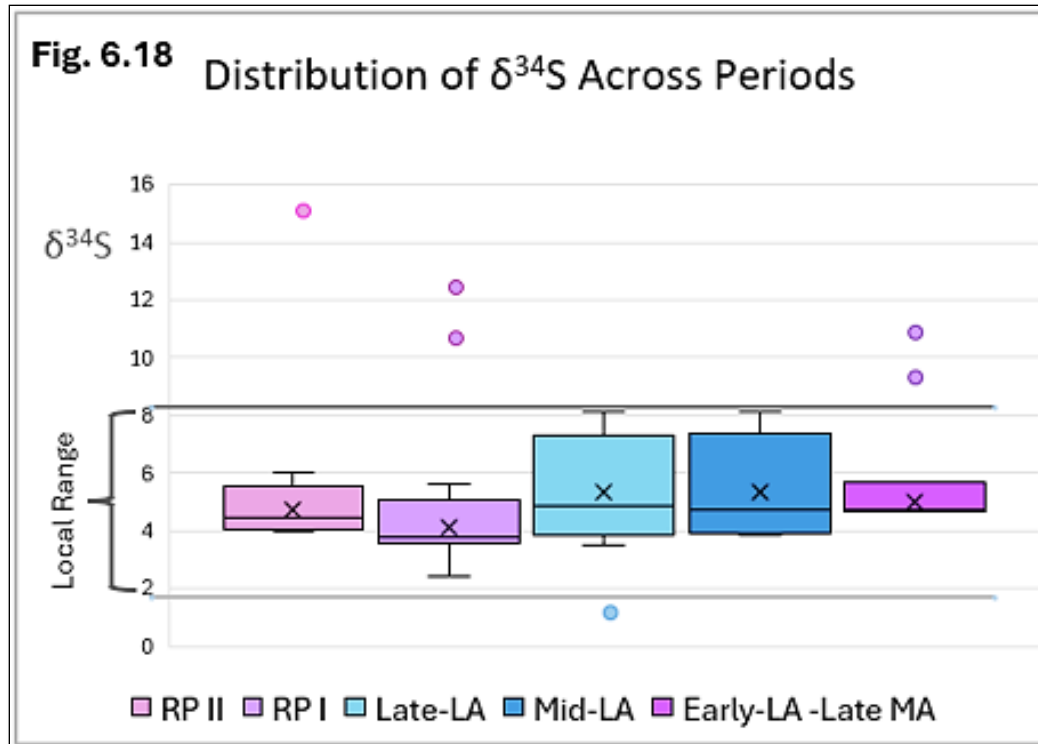


Figure 6.18 Distribution of $\delta^{34}\text{S}$ Across Periods-Part I

Graph shows the variance in $\delta^{34}\text{S}$ of local non-infants among the temporal periods by box plots, while non-locals are shown as outlier points in line with temporal period they are from and in relation to the local baseline range. Color-coding of temporal bins is the same as within previous figures. Local baseline max $\delta^{34}\text{S}$ is shown as a dark gray line, while minimum is shown as light gray. Note that number of individuals within each bin is unequal.

Table 6-6 Summary Statistics for Distribution of $\delta^{34}\text{S}$ Across Periods

Period and Median Date range (cal BP)	<i>n</i> (non-infant local)	Mean $\delta^{34}\text{S}$ (‰)	Median $\delta^{34}\text{S}$ (‰)	SD	Variance	<i>n</i> (non-local)	% non-local
RP II (150-600 cal BP)	6	4.7	4.5	0.83	0.68	1	14%
RP I (605-1050 cal BP)	13	4.1	3.8	1.01	1.01	2	13%
Late LA (1115-1780 cal BP)	4	5.3	4.9	1.95	3.78	1	17%
Mid LA (2030-2580 cal BP)	4	5.3	4.7	1.92	3.68	0	0%
Early LA-MA (2725-4725 cal BP)	3	5.0	4.7	0.58	0.33	2	40%

Note: Table shows summary statistics for the temporal bins (Figure 6.18), and includes the total number of non-infant locals, mean $\delta^{34}\text{S}$, median $\delta^{34}\text{S}$, SD, variance, number of non-locals, and percent non-locals for each temporal bin. Variance among bins increases from early LA-late MA bin through the late LA where it peaks, then is reduced from the Late LA into RP I, and again from RP I into RP II. Non-locals are not included within the calculations except as a percentage of bin population, shown in the far-right columns.

Because small sample sizes in earlier bins may influence variance estimates, Late Archaic individuals are also evaluated in collapsed form (Bin 3a) and compared with RP I and RP II (Figure 6.19; Table 6-7). The two Middle Archaic individuals are excluded from this comparison. Figure 6.19 indicates variance in the Late Archaic remains higher than in RP I and RP II, although variance is reduced compared to the fine-grained analysis. Table 6-7 shows that variance is more than twice as large in the late Archaic as in RP I and decreases further in RP II. Despite this pattern, these differences are not statistically significant (Brown-Forsythe: $F = 0.77$, $p = 0.39$). These results therefore indicate that while $\delta^{34}\text{S}$ variance decreases from the Late Archaic to RP I and remains relatively low in RP II, consistent with a decrease in territory size, this trend is descriptive rather than statistically supported.

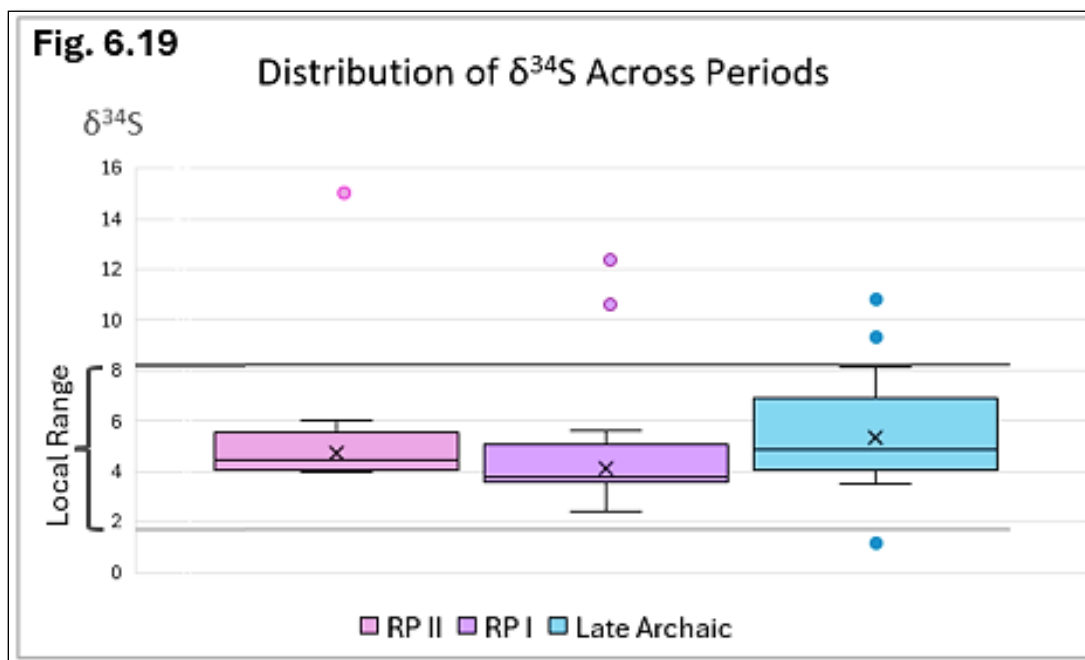


Figure 6.19 Distribution of $\delta^{34}\text{S}$ Across Periods-Part 2
Graph shows the variance in $\delta^{34}\text{S}$ of local non-infants among the temporal periods, where the Late Archaic is collapsed into one bin (Bin 3a). Non-locals are shown as outlier points in line with temporal period they are from and in relation to the local baseline range. Color-coding of temporal bins is the same as within previous figures, except for the Late Archaic which is represented by bright blue to designate it as different but related to the more fine-grained bins in previous figures. Local baseline max $\delta^{34}\text{S}$ is shown as a dark gray line, while minimum is shown as light gray.

Table 6-7 Distribution of $\delta^{34}\text{S}$ Across Periods with a Consolidated Late Archaic

Period and Median Date range (cal BP)	<i>n</i> (non-infant local)	Mean $\delta^{34}\text{S}$ (‰)	Median $\delta^{34}\text{S}$ (‰)	SD	Variance	<i>n</i> (non-local)	% non-local
RP II (150-600 cal BP)	6	4.7	4.5	0.83	0.68	1	14%
RP I (605-1050 cal BP)	13	4.1	3.8	1.01	1.01	2	13%
Late Archaic (1115-2945 cal BP)	9	5.4	4.9	1.68	2.81	3	25%

Note: table shows variance comparison when Late Archaic is collapsed into a single bin (Bin 3a) and accompanies Fig. 6.19. Time periods are color-coded to match bins. Non-locals are not included within the calculations except as a percentage of bin population, shown in the far-right columns.

To further evaluate changes within RP I, the period is subdivided into two intervals (RP I-a: 760–1050 cal BP; RP I-b: 605–735 cal BP) and compared with the Late Archaic (Bin 3a) and RP II in Figure 6.20 and Table 6-8. Although sample sizes are small, both the figure and table show a continued reduction in $\delta^{34}\text{S}$ variance, from the beginning of RP I-a through RP II. There is no indication of a return to higher variance within either of the RP I subdivisions. As with earlier comparisons, these patterns are descriptive and the reduction in variance is not statistically significant.

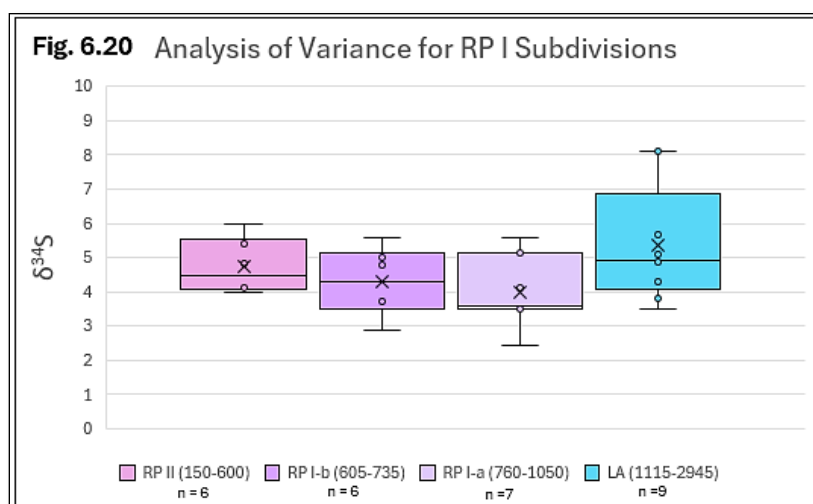


Figure 6.20 Analysis of Variance for RP I Subdivisions

Boxplots show variance from LA period to RPII. Late Archaic is collapsed into one bin (Bin 3a), and RP I is expanded to two bins (RP I-a and RP I-b). Noticeable is a small trend of reduction beginning in RP I-a and continuing through RP II. Largest reduction in variance is between LA and RP I-a.

Table 6-8 Distribution of $\delta^{34}\text{S}$ from RP I to RP II

Period and Median Date range (cal BP)	n (non-infant local)	Mean	Median	SD	Variance
RP II (150-600 cal BP)	6	4.7	4.5	0.83	0.68
RP I b (605-735 cal BP)	6	4.3	4.3	1.00	1.00
RP I-a (760-1050 cal BP)	7	4.0	3.6	1.07	1.14
Late Archaic (1115-2945 cal BP)	9	5.4	4.9	1.68	2.81

Note: table shows the variance in $\delta^{34}\text{S}$ across time periods LA (collapsed; Bin 3a) to RP II among non-infant locals. RP I is expanded into two periods (RP I-a and RP I-b) to allow insight into drought period variance. Table accompanies Fig. 6.20, is color-coded to match, and shows the summary statistics for these temporal periods.

6.3.3 Results: Omnivorous Humans and Kohn's (2010) Formula for Estimating Paleoprecipitation

The faunal paleoprecipitation estimates from the region (Chapter 5.4.3) indicate that paleoprecipitation estimates from human $\delta^{13}\text{C}_{\text{collagen}}$ should fall within ~300–600 mm for the period 2550–140 cal BP, if dietary offsets and gymnosperm contributions to their diets are accounted for and after application of Kohn's (2010: Eq. 2) formula. Given that the four-source $\delta^{13}\text{C}$ model for omnivores and carnivores showed good performance and a strong linear correlation between observed and predicted values, and where uncertainty for normalized values ranged between 0.01 and 0.06 across all individuals and food groups, I used Eq. 2 (this chapter) to remove gymnosperm contributions and shift predicted diet to angiosperm plant values. I then subtracted offsets from the observed $\delta^{13}\text{C}_{\text{collagen}}$ of each individual.

The dietary $\delta^{13}\text{C}$ offsets varied among all individuals (Table 6-9). Offset values were calculated individually for dietary $\delta^{13}\text{C}$ values. In Table 6-9, the “All Bins” category, mean, and median $\delta^{13}\text{C}$ dietary offset values are indistinguishable at 6.1‰, while SD was 0.7‰, and total

variance was 0.5‰. Dietary offsets ranged between ~5.0 and 7.6‰, with the largest offset coming from the individual with the greatest total gymnosperm contribution to their diet.

Table 6-9 Dietary Offset Summary, $\delta^{13}\text{C}$ (‰)

Period	n (individuals)	Dietary Offset Min ($\delta^{13}\text{C}$, ‰)	Dietary Offset Max ($\delta^{13}\text{C}$, ‰)	Dietary Offset Mean ($\delta^{13}\text{C}$, ‰)	Dietary Offset Median ($\delta^{13}\text{C}$, ‰)	Dietary Offset SD ($\delta^{13}\text{C}$, ‰)	Dietary Offset Variance ($\delta^{13}\text{C}$, ‰)
All Bins	53	5.0	7.6	6.1	6.1	0.7	0.5
Bin 1	11	5.01	7.45	6.29	6.33	0.71	0.50
Bin 2	23	5.03	7.59	6.00	5.80	0.72	0.52
Bin 3	8	5.01	7.00	5.93	6.05	0.75	0.56
Bin 4	5	5.67	6.52	6.07	6.18	0.35	0.12
Bin 5	6	5.26	7.33	6.47	6.68	0.84	0.71

Note: table shows the summary information for $\delta^{13}\text{C}_{\text{diet-collagen}}$ (dietary offsets) for all individuals, and among the Bins after gymnosperm contributions were removed from diet estimates. All Bins represents the total summary (shown to first decimal place, ‰) for all individuals regardless of time period, while Bins summaries are shown to two decimal places and are the same time period designations used throughout all analyses and are color-coded to match.

Table 6-9 also shows how the dietary offsets behave when broken down by period according to their bin assignments. The dietary offsets do not consider any expectations for less negative $\delta^{13}\text{C}$ baselines during drought periods, nor more negative $\delta^{13}\text{C}$ baselines during wet periods, as once precipitation estimates from each individual are calculated, they are averaged according to their bin assignments. In Table 6-9, the dietary mean and median offsets are comparable within bins, and the largest variation occurs between bins because they relate to different dietary contributions from gymnosperms among the different time periods. Importantly, based on the All Bins mean and median, a flat 6.1‰ could be used to adjust diet $\delta^{13}\text{C}$ values towards angiosperm values if gymnosperm use is suspected; however, this will cause more variation among individual estimates modeled precipitation.

Table 6-10 presents summary statistics for modelled MAP. Mean MAP estimates are displayed in Figure 6.20. MAP estimates vary modestly across temporal periods, ranging from a low mean of 367 mm in RP I to a high mean of 435 mm in the early-Late Archaic to late-Middle Archaic bin. Late Archaic bins show intermediate values (389–390 mm), while RP II exhibits slightly higher precipitation estimate (mean = 415 mm). The collapsed Late Archaic bin (Bin 3a) produced a mean of 398 mm, consistent with values observed in the separated Late Archaic bins. Standard deviations are similar across bins (± 38 – 62 mm), and substantial overlap in 95% confidence intervals indicates that differences among periods are relatively small (Table 6-10).

Overall, MAP estimates suggest temporal variation was moderate, with the lowest values occurring during RP I (Figure 6.21). The bar graph clearly indicates reduced precipitation during RP I as compared to all other periods. However, precipitation was not stable during this period, nor in any other period, and averaging across multiple individuals that each represent an average of “lifetime” precipitation smooths trends in highs and lows.

Table 6-10 Precipitation Estimates Summary

Bin	Period and Median Date Range (cal BP)	n	Mean MAP (mm)	SD ($\pm$ mm)	SE (mm)	MAP Min (mm)	MAP Max (mm)	95% CI low (t-dist; mm)	95% CI high (t-dist; mm)
1	RP II (150-600)	11	415	62	18	321	488	375	455
2	RP I (605-1050)	23	376	49	10	308	470	355	397
3	Late LA (1115-1780)	8	389	61	22	320	472	338	440
4	Mid LA (2030-2580)	5	390	38	17	347	440	342	438
5	Early LA-MA (2725-4725)	6	435	57	23	346	482	375	495
3a	Late Archaic (1115-2945)	16	398	58	14	320	482	367	429

Note: table shows the summary statistics of estimated precipitation (mm) for each Bin/Time period. All bins are the same time period designations used throughout all analyses, unless specified, and are color-coded to match. Note that the error associated with Kohn’s Formula is ± 100 mm for regions with less than 2000 mm MAP.

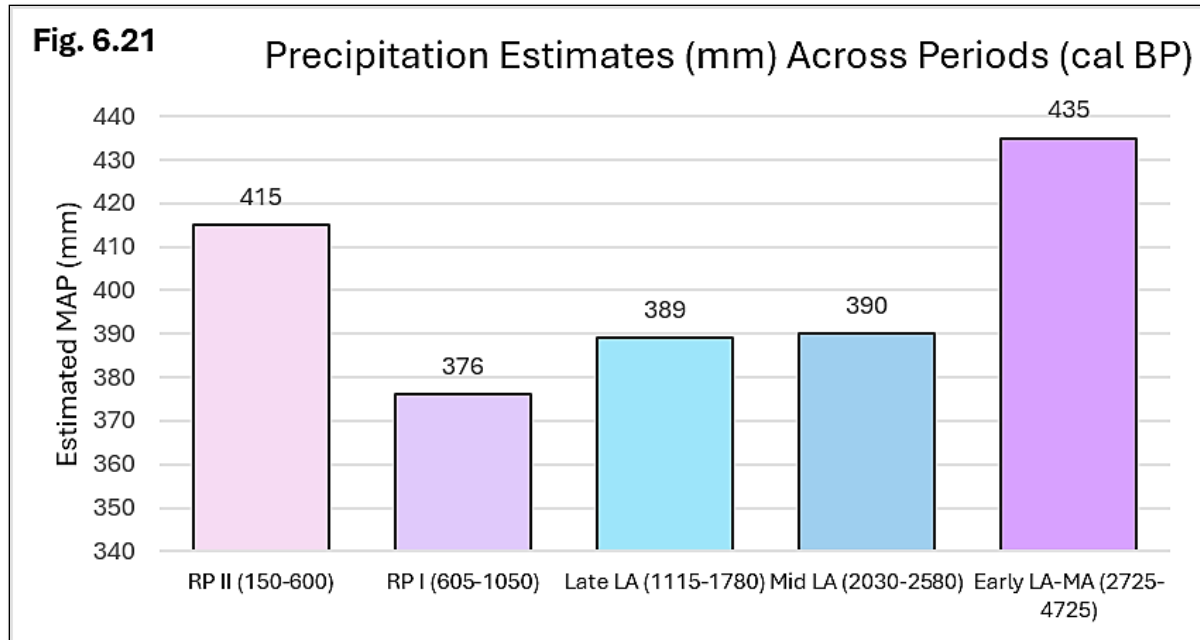


Figure 6.21 Precipitation Estimates (mm) Across Periods (cal BP)
Bar graph visually summarizes MAP for the period 4725 through 150 cal BP, as represented by the temporal bins. Graph is truncated at lower end and starts at 340 mm.

Figure 6.22a-b, a series of box and whisker plots color-coded according to bin, visually summarize the information from Table 6-10. Individual point estimates are shown within each plot to illustrate the spread of values, while mean values are indicated by X. Figure 6.22a indicates that although the overall spread of values is similar among periods, means and medians differ between periods. The mean values are the indication of the ecological signal. Figure 6.22b shows how the distributions of MAP estimates compare among RP II, RP I, and the Late Archaic Period representing Bin 3a from Table 6-10. The distributions largely overlap in range, although the total distribution of RP I (and points therein) are still lower than the Late Archaic (Bin 3a) and RP II.

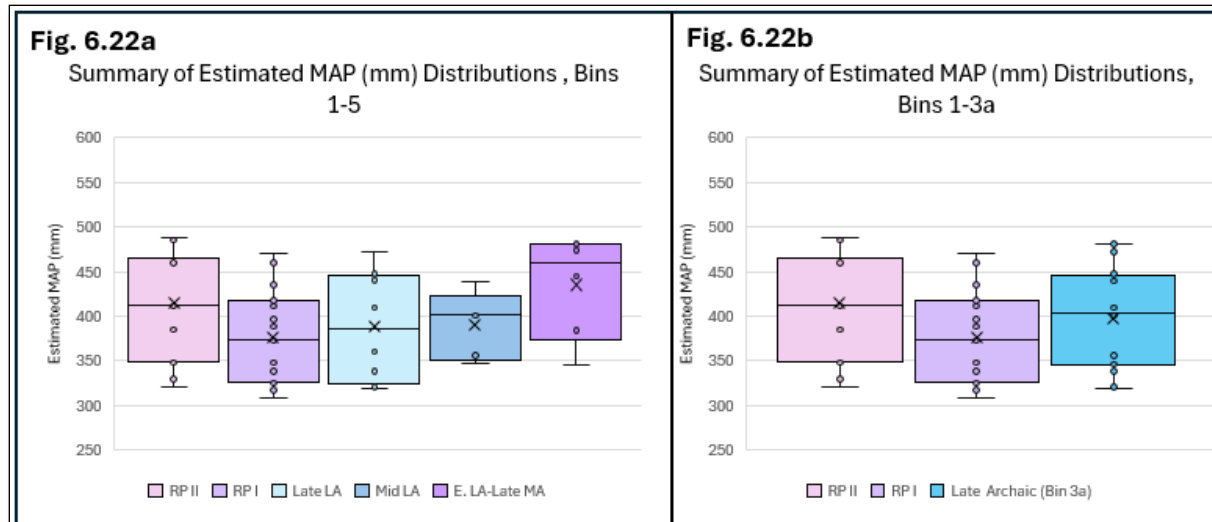


Figure 6.22a-b Summary of Estimated MAP (mm) Distributions
Box plots summarize estimated MAP (mm) distributions for each Bin (time period) from Table 6.10. Boxplots are colored according to bin. Individual point estimates are shown within each boxplot. a) shows the distributions for Bins 1-5; b) shows the distributions for Bins 1,2 and 3a.

Temporal trends are largely smoothed by binning. As such, Figure 6.23 shows the temporal pattern among individual point estimates. In the figure, the estimated precipitation values from all individuals were plotted against median calibrated radiocarbon dates to illustrate temporal patterning at the individual level. A 3-point running average, calculated from oldest to youngest estimates (and dates) was added as a descriptive smoothing function to highlight smaller temporal trends masked by binning. Because the primary interpretive focus is on the late-Late Archaic through RP II sequence, the figure is truncated to only show the last ~1800 years (cal BP) for clarity. The estimated MAP mean values from RP II through the late-Late Archaic (Table 6-10) are plotted as horizontal lines and color-coded to enable comparison. No error range is shown; however, given the small standard deviations indicated in Table 6.10, the conservative approach is to use that which is associated with Kohn (2010: Eq. 2), ± 100 mm.

Figure 6.23 indicates a greater degree of variability in MAP during RP I than in the preceding or following period. The Late Archaic shows less variation than RP I or RP II, mainly

due to fewer dates. However, a trend of decreasing precipitation is visible leading to the lowest value during the Late Archaic, where a low trough begins around 1200 cal BP and continues through to ~900 cal BP within RP I. The 3-point running average highlights a period of relatively low MAP estimates during RP I, corresponding with the lowest mean values observed in Table 6-10. Following RP I, MAP values increase modestly into RP II. Within RP II, a dip in values is visible mid-period, but the dip is short and has a difference of 34 mm within a 15-year span (375–390 cal BP). Overall, the variability indicated by the individual point estimates and the 3-point running average is not unusual for California.

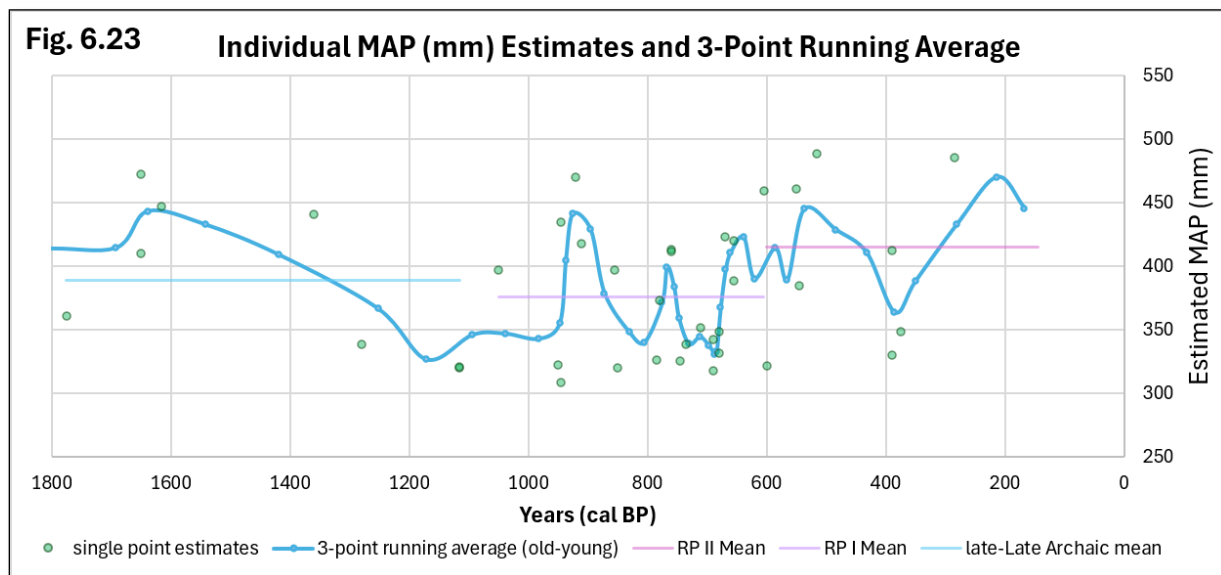


Figure 6.23 Individual MAP (mm) Estimates and 3-Point Running Average
Scatterplot displays estimated MAP (mm) at the individual level and uses a 3-point running average to highlight temporal trends. Individual estimates of MAP (mm) are indicated by green points (labelled single point estimates), 3-point running average is marked by the blue line and points, while MAP mean estimates are shown by horizontal bars color-coded to the appropriate bin/period. Note, the error range associated with Kohn (2010) is ± 100 mm.

6.4 Discussion

Initial analyses in 2016 of the individuals from the west-central Sierra Nevada indicated that a subset of the individuals studied here occupied a distinct isotopic space in relation to other

foraging regions across north-central California (Hull et al. 2016). Within this initial analysis, the we suggested that the use of pine nuts as a major dietary resource was driving this pattern.

Following analyses above, this explanation remains the most likely, especially after multiple isotopic tests of faunal and plant remains from across this region (Chapters 4 and 5). The results indicate isotopic differences between pine nuts and acorns, more broadly between gymnosperm and angiosperm plant resources, and among faunal remains further suggested that less negative $\delta^{13}\text{C}$ values were likely driven by use of gymnosperm resources.

What has remained less clear, however, is how these dietary patterns may have changed over time and how they relate to shifts in residential mobility, territoriality, and environmental conditions. Archaeological evidence suggests increasing reliance on acorns over pine nuts, potentially reflecting changes in storage preferences and residential mobility (Rosenthal 2011c; Whelan et al. 2013), but, the timing and context of these changes have been difficult to resolve, particularly within RP I deposits.

The goal of this chapter has been to evaluate how human diets changed over the last ~4,000 years and to assess whether these changes correspond to shifts in residential and logistical mobility patterns and demographic intensity, particularly during periods of environmental stress such as the MCA.

When considered together, the chronological, isotopic, and demographic data indicate that a substantial reorganization of society occurred during RP I (1,100-610 cal BP). This pattern has been suggested previously using a variety of archaeological indicators (e.g., (Hull 2005; Moratto 1984; Moratto et al. 1978; Rosenthal et al. 2011a; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005) but the combined isotopic and chronological framework presented here

allows for a more explicit evaluation of its timing and structure. In addition, minor changes are also evident during RP II and portions of the Late Archaic.

All of the sites within this study exhibit periodic use over millennia; however, demographic intensity is highest during RP I within the sites closest to the Tuolumne River, indicating an increase in the number of individuals represented in burial contexts relative to other periods. While this pattern may be coincidental, it is consistent with the expectations for increased reliance on reliable water sources during prolonged drought. Derived paleoprecipitation estimates in this study suggest relatively lower MAP values during this period, which is echoed by the averages from King Brown Elk (Table 5-10) for the same general time frame, while the human paleoprecipitation trend (Figure 6.23) is similar to that recorded by Morgan (2009b:Figure 3) in a broad sense. Together, these observations are consistent with higher environmental stress during RP I, as should be expected during drought, although they do not independently confirm an exact trend in paleoprecipitation.

Kathleen Hull (2005), within her time-perspectivism approach, has documented ethnographic information from the Yosemite area, which suggests that deteriorating environmental conditions were linked to population reductions within the area during this time frame. As well, despite a paucity of sites located in regions that might be considered hinterlands (i.e., away from major rivers), Hull and Moratto (1999; Moratto 2002) document a coalescence of only three sites adjacent to the Stanislaus River at lower elevations that are within this same time frame. Taken together with the demographic intensity presented here, this makes a compelling case which suggests on its surface that the MCA droughts likely played a role in reorganization and intensified use of fewer sites located along the major rivers within the lower elevations of the range.

This possible reorganization and intensified site use has implications for diet and mobility. First, if sites are more intensively occupied (albeit fewer of them), then it should follow that residential mobility decreased and logistical mobility increased. Second, if residential mobility decreases, diet needs to adapt to accommodate fewer residential movements and an increase to logistical mobility. Within RP I, this becomes a which came first scenario, where both diet and residential mobility are expected to change, and the possibility of figuring that out relies heavily on radiocarbon dated materials. Ergo, one of these things likely preceded the other.

Within the dietary analysis, the $\delta^{15}\text{N}_{\text{collagen}}$ values for the bulk of individuals dating to the Late Archaic are lower than in RP I or RP II, suggesting a greater reliance on plant proteins than in later periods. However, the total range of $\delta^{15}\text{N}$ during the Late Archaic is relatively broad, but the bulk of individuals are centered within a narrow range. This indicates that hunting returns were likely lower and more variable than in following periods because of the greater reliance on plants visible within $\delta^{15}\text{N}$.

While $\delta^{15}\text{N}_{\text{collagen}}$ values primarily reflect proteins from meat, plants also contain protein, especially nuts. Farris (1982) notes that within the Sierra Nevada, the pine nuts of gray pine and sugar pine contain a greater protein (25–21 g/100g, respectively) than do acorns of black oak and valley oak (3.8–4.8 g/100g, respectively). Therefore, it is likely the use of pine nuts explains the lower $\delta^{15}\text{N}_{\text{collagen}}$ values of the Late Archaic individuals, rather than simply all plants. This interpretation is also more likely given the $\delta^{13}\text{C}_{\text{collagen}}$ results of the Late Archaic individuals, which had a high probability of gymnosperm plant contributions. Individual diets are highly variable in terms of plant use and meat consumption, and they reflect mixed strategies for resource use particularly among plants. However, the overall trend through the Late Archaic was

a decrease in gymnosperm plant use and an increase in angiosperm-based plant and meat resources.

This dietary trend continued into RP I and is highlighted by higher overall $\delta^{15}\text{N}$ mean and median values. However, RP I $\delta^{15}\text{N}_{\text{collagen}}$ values also indicate a broader range of dietary compositions than in other periods, suggesting increased variability in the balance of plant and animal resource use among individuals. At the same time, modelled $\delta^{15}\text{N}_{\text{collagen}}$ values indicate a reduction in overall plant contribution relative to meat during this period. Together, these results align with expectations for the introduction of the bow and arrow, wherein individual meat returns may be higher and more variable, and the group pattern is more dispersed. This shift may also reflect an increased emphasis on hunting and possibly privatization of meat resources. By comparison, during RP II the range of $\delta^{15}\text{N}$ is reduced and shifted downwards, and the bulk of individuals occupied a narrower range similar to Late Archaic individuals. This difference would suggest lower individuality and less variability in meat resource use.

Similar to $\delta^{15}\text{N}$ during RP I, $\delta^{13}\text{C}$ values during this era indicate the heaviest reliance on angiosperm plant and meat resources, along with the widest range of values observed in any previous time period; it also highlights increased dietary individuality among a handful of individuals. However, the bulk of the RP I population exists within a narrower range than in the Late Archaic, which suggests a shared strategy of plant-resource use among the RP I population. This pattern supports the interpretation that acorn use became more prominent relative to pine nuts during this time.

Notably, the increased use of angiosperm-based resources detected through modelling occurs despite ecological expectations for less negative $\delta^{13}\text{C}$ values of the resource base under drier conditions. Changes within diets towards increased reliance on angiosperm-based resources

during RP I appear to have been greater than what the model was even able to capture. As well, this pattern only holds for RP I, as RP II individuals show a return to the use of gymnosperm-based resources, mainly pine nuts. This result was somewhat unexpected, given the archaeobotanical record for the region, which indicates greater use of acorns relative to pine nuts within RP II contexts (Rosenthal et al. 2011a; Whelan et al. 2013; Wohlgemuth 2005). Comparatively, RP II individuals also exhibit a wide range of $\delta^{13}\text{C}$ values among all periods, however as with RP I, the bulk of the population exists within a narrow range which reflects a shared strategy of resource use.

The combined interpretation for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ suggests the broadest use of the resource base occurred during RP I relative to any other period. Meat resources were more frequently included within diets, and individuals shared a strategy for plant resource use. Overall, the trend indicates broad use of the resource base through greater use of angiosperm resources, most likely acorns. Comparatively, the Late Archaic, especially the late portion of the Late Archaic, suggests that resource use was based more on resource availability than a shared strategy, unlike RP I and RP II.

In sum, in terms of diet, a trend towards greater inclusion of angiosperm-based resources begins within the Late Archaic, however, resource use is more narrowly focused and individual diets are highly variable indicating mixed strategies for plant use. By RP I, individual diets are still highly variable (wide dispersion from just a few individuals), but bound by a shared strategy of resource use, indicated by the majority of people occupying a condensed range as compared to the Late Archaic. Angiosperm-based resources are the greatest contributors to diets during this era, however, this is reversed in RP II, when gymnosperm-based resources become more prominent.

Finally, variance in $\delta^{34}\text{S}$ indicates a reduction in residential mobility during RP I relative to the preceding Late Archaic period divisions. When Late Archaic individuals are considered as a single group, this contraction remains evident and continues into RP II. Although the reduction in variance coincides with the onset of drought conditions, the continued low variance through RP II is not consistent with a drought-only model, which would predict a subsequent increase in mobility once the drought had concluded. Instead, this pattern is consistent with a reorganization of landscape use, likely reflecting increased territoriality. Despite the non-significance of the differences in variance, given other archaeological data, such as the use of bedrock mortars, an increase in territoriality is the most plausible explanation. Importantly, the vast majority of people within this study were determined to be local regardless of time period, suggesting that many of the cultural changes that took place between the Late Archaic and within RP I were in situ developments and not the result of outside incursions. If outside incursions did take place, it was most likely much earlier in time, perhaps the early portion of the Late Archaic, although even then burials of non-local individuals are sparse within this sample population.

Taken together, the results indicate that RP I represents a reorganization of not simply diet, but of mobility structure within the west-central Sierra Nevada sequence. Prior to this period, higher variance in $\delta^{34}\text{S}$ suggests broader residential mobility, consistent with more frequent residential moves across the broader landscape. During RP I, the decreased variance is a contraction in the spatial scale of foraging, indicating not just fewer residential moves per year, but a smaller amount of the landscape was used, even within logistical foraging bouts. Landscape use became more spatially constrained particularly within the early part of RPI, as five of the seven individuals exhibit highly similar $\delta^{34}\text{S}$ values, and the entire subset contains individuals from all five sites used within the analysis. During the latter portion of RP I, the distribution of

$\delta^{34}\text{S}$ values is fully gaussian, which, despite a slightly narrower range of values than the earlier portion of RP I, could indicate the stabilization of the residential pattern.

RP II indicates that this reorganization was not temporary. Although dietary patterns shift again, including a renewed increased use of gymnosperm-based resources (mainly pine nuts), sulfur isotope variance remains low, suggesting that reduced residential mobility persisted beyond the drought interval and despite better environmental conditions. This continued reduction in residential mobility, despite evidence for a increased pine-nut use, suggests the establishment of more bounded use of the landscape, consistent with increased territoriality. In this framework, drought may have contributed to the initial reorganization during the early part of RP I, but the sustained pattern of reduced residential mobility reflects longer-term changes in how this group organized movement and access to resources.

6.5 Conclusions

This chapter focused on the integration of diet, mobility, and drought within a diachronic context. Overall, the individuals within the lower elevations of the west-central Sierra Nevada seem to have intensively occupied a handful of sites along the Tuolumne River. Population intensity suggests the peak occurred during the RP I period, while experimental precipitation estimates indicate the lowest average and greatest variability of MAP during this period. This could be taken as an indication of a deteriorated environment due to drought.

Over the last ~4,500 years, diets shifted, with major changes becoming apparent during the Late Archaic period. The most profound reorganization to diet, mobility, and likely society as a whole, took place entirely within RP I. It is during RP I that residential mobility decreases from Late Archaic highs, and when acorns became major contributors to individual diets supplanting

pine nuts. Meat consumption increases during this time period, but seems highly variable among individuals and could be related to the introduction of the bow and arrow during this time. As well, individuals within the RP I period and into RP II exhibit a shared strategy of plant resource use, largely absent within the Late Archaic. Drought remains as a plausible factor for the decrease in residential mobility, however, by the latter portion of RP I, and into RP II, residential mobility remains constricted as compared to Late Archaic levels. This is interpreted as a signal of increased territoriality, in line with modern interpretations of bedrock mortar use. As well, by RP II pinenut use increases, reminiscent of the Late Archaic, and returns from hunting seem to stabilize. RP II likely reflects the stabilization of the residential pattern, although this is somewhat apparent during the latter portion of RP I. As well, dietary changes during RP I likely reflect of the start of a pattern documented during the ethnographic period as this shared plant resource strategy begins during this time.

Chapter 7: Discussion, Synthesis, and Conclusions

This dissertation began with a broad question: what can human diets tell us about society? In the west-central Sierra Nevada, that question is tied directly to long-standing debates over mobility, subsistence, and drought, especially within RP I and the Medieval Climatic Anomaly (MCA). From the outset, this project was driven by two related questions: first, what are the relationships among settlement structure, human mobility, diet, and environment; and second, how do humans adapt to short- and long-term climatic changes? In this region, those questions are especially important because the archaeological record suggests a major reorganization in subsistence settlement evident by RP II (Moratto 2002; Rosenthal 2011c), yet the causes and timing of those shifts have remained unresolved. To address these questions, this project used stable isotope analysis of paleobotanical, faunal, and human remains within a diachronic framework. The approach was designed to move beyond indices of food remains and instead evaluate long-term relationships among diet, mobility and drought through multiple lines of evidence.

Previous research in the region suggested a long-term pattern of wide landscape use, high seasonal residential mobility, and a strong reliance on pine nuts for winter storage prior to the MCA (Moratto 2002; Moratto et al. 1988; Rosenthal et al. 2011a; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005). Following the droughts, however, the archaeological record for RP II indicates a reorganized society in which residential mobility had decreased, logistical mobility had increased, and acorns became a more prominent storage resource (Moratto 2002; Moratto et al. 1988; Rosenthal et al. 2011a; Whelan 2016; Whelan et al. 2013; Wohlgemuth 2005).

Explanations for this shift have varied, including drought-related changes (Moratto 1984; Moratto et al. 1978; Wohlgemuth 2005), depopulation (Hull 2005, 1989; Hull and Moratto 1999; Moratto 1984, 2002; Moratto et al. 1978, 1988; Wohlgemuth 2005), cultural intrusion (Moratto 1984, 2002), and rising opportunity costs connected to women's foraging and childcare (Whelan et al. 2013). This dissertation was built to ask not simply whether change occurred, but when it occurred, how it was reflected in human diet, and offers isotopic evidence that could clarify the relationships among subsistence, mobility, and environmental stress.

Linked to these lines of research is an understanding of how even short-term drought can affect water resources at lower elevations within this heterogeneous environment, causing perennial creeks and streams to run dry, and the cascading effects of such events on plant communities (Belmecheri et al. 2016; Dettinger et al. 1998, 2011, 2018; Godsey et al. 2014; Shulgina et al. 2023; Tague and Peng 2013). In this regard, water is treated as a resource patch. Under this condition, women's residential settlement decisions (*sensu*-Zeanah 2004) would have had to account not only for access to plant foods, but also for dependable water from which daily foraging could be organized. This would have direct consequences for residential mobility, logistical mobility, and dietary change.

First, if water became a limiting resource during drought, then women's residential settlement decisions would have had to prioritize dependable water alongside access to plant foods suggesting that, during drought, settlement locations in the lower elevations should be near reliable water sources, and during non-drought intervals, this should be relaxed. From this, it is reasonable to expect that residential mobility would be reduced during drought intervals, such as the MCA and RP I, as there are only so many reliable water patches within the lower elevations. At the same time, residential mobility should be expected to be higher when water patches are

not reduced, such as during non-drought periods or glacial intervals at low elevations, such as the Little Ice Age and RP II. The caveat, however, is that residential mobility can also become restricted when territorialism increases. This was the driving force behind setting a local range for $\delta^{34}\text{S}$ using faunal data, and testing the human $\delta^{34}\text{S}$ variance across different periods of time in relation to the culture chronology. As well, this was the push to provide estimates of precipitation from all sample sets, even if only relative (as in the human case), as the estimates would act as a separate line of evidence for lower-versus higher precipitation periods.

Second, and much in line with the explanations offered by Whelan et al. (2013), if water became a limiting resource, and given that residential mobility would be reduced, then we should expect to see an increased reliance on plant foods that have low-upfront processing costs, such as acorns, and a reduced reliance on those that require more up-front processing effort, such as pine nuts. Her results suggested that as residential mobility decreased, the time-costs of front-loaded foods no longer made sense in light of equally ranked but more easily gathered and stored foods, given that both could be encountered at the same rate (Whelan et al. 2013). The ability to delay processing to a less-productive period of time, when there are fewer competing tasks, indicated that acorns should be preferred when the combined costs of logistical mobility and processing of pine nuts increased beyond that for acorns.

To understand and interpret human diets in relation to the local ecology in a meaningful way, paleobotanical and faunal remains from sites within the region were used to create isotopic baselines, which were then modelled forward to consumer values for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Additionally, the faunal remains were used to understand $\delta^{34}\text{S}$ distribution within the environment, and create a local range from which to compare human values of $\delta^{34}\text{S}$.

Within the paleobotanical set, $\delta^{13}\text{C}$ relationships among pine nuts and angiosperm taxa were found to exhibit meaningful differences within this monoisotopic system (all C_3 plants). This relationship has been observed elsewhere among different species of gymnosperms and angiosperms within Mediterranean environments (del Castillo et al. 2016; Gea-Izquierdo et al. 2021; Guehl et al. 1995; Martín-Gómez et al. 2017; Pausas et al. 2004; Poyatos et al. 2008). This difference between angiosperms and gymnosperms is useful, as two of the major plant resources investigated happened to be acorns and pine nuts, which represent two very different resources in terms of processing and storage.

As well, the paleobotanical and faunal remains indicated that $\delta^{13}\text{C}$ within the environment is sensitive to climate. While well known for C_3 plants, this was demonstrated first with $\delta^{13}\text{C}$ from tree rings, and was then used to model paleoprecipitation estimates from all sample sets as a secondary line of evidence for climatic fluctuation. While the results from the humans may not indicate perfect estimates of paleoprecipitation given the back-transformation to angiosperm-only values, they are in line with estimates achieved from the faunal remains and the paleobotanical remains. Taken together, RP I exhibited the lowest precipitation estimates, while averages from earlier and later periods were higher. When considered alongside environmental information, this suggests that the MCA droughts did have an effect on baseline $\delta^{13}\text{C}$ within this region, which is evident within the paleoprecipitation modelling.

The baseline consumer values for $\delta^{13}\text{C}$ were expressed as a four-source model so that within human diets, angiosperm and gymnosperm plant resources could be tracked, as well as meats from animals which had consumed these resources. The logic was based on the fact that this represents a monoisotopic system, but with major variation between the two plant clades within the system, where these differences would be transferred to all consumers. The faunal

results were used to create the model for $\delta^{15}\text{N}$, which aimed to track overall plant protein in relation to meat within human diets.

The aim of the diachronic dietary analysis for humans was to establish when angiosperm plants (mainly acorns, but also small seeds, and manzanita berries) became more prominent within diets in relation to gymnosperm plants (aka pine nuts), given the expectations of the opportunity costs model and explanations outlined by Whelan et al. (2013). As well, the spread around the median for the total $\delta^{13}\text{C}$ distribution of consumers within each time period was considered as a measure of how similar or different resource-use strategies were through time. Narrower distributions indicated a more shared strategy of plant-resource use, whereas broader distributions indicated greater dietary individuality and more mixed strategies among individuals. When considered together with the $\delta^{15}\text{N}$ results, these differences are also consistent with changing degrees of group dispersion across the landscape and point to changes within residential mobility.

Here I synthesize the preceding analyses to evaluate what the combined isotopic, archaeological, and environmental evidence suggests about subsistence change, mobility, and drought. The cumulative evidence indicates that substantial reorganization occurred during RP I, with implications for storage strategies, settlement location, residential mobility, and the use of reliable water sources. At the same time, the evidence also suggests that these developments cannot be reduced to a simple deterministic explanation where drought explains all of the changes. Instead, the findings point to a more complex process in which environmental stress, mobility, territoriality, and subsistence decisions became increasingly entangled.

One of the initial and most salient points is that the patterns within RP I were not due to cultural intrusion or the immigration of Me-Wuk speakers into the area based on the population

sampled here. The region and individuals represented within the burial collections show only a minor influx of individuals from outside the region during this era. As well, the clear presence of a resident population is apparent going back as far as the early Late Archaic and into the Middle Archaic. While there were more non-local individuals present within the burial population sample that dated to the Late Archaic as a whole ($n=3$), as compared to RP I ($n=2$) and RP II ($n=1$), the RP I influx of non-locals is more comparable to the same small influx indicated in the early portion of the Late Archaic in terms of number of non-local only. A higher number of people were local than non-local in RP I as compared to the early Late Archaic. In the early Late Archaic the small sample of five people over roughly the same amount of time as RP I has two non-local individuals. This actually indicates that all of the developments and patterns within the Late Archaic through RP II are most likely to have been in-situ developments, rather than the result of depopulation or cultural intrusion. This is mainly because there is not a strong signal of a non-local presence within the entire sample population. However, there is a signal for slow matriculation of non-locals over a very long period of time, but there is no evidence to suggest that the slow matriculation caused or is related to the punctuated change indicated during RP I.

Importantly, if considered alongside the lexical data (Freeland 1951; Freeland and Broadbent 1960; Golla 2011), the apparent disjunction between the timing of proto-Sierra Miwok into the northern area and the dialectical differentiations among the North, Central, and Southern Me-Wuk populations would align with the reduction to residential mobility during RP I. As well, rather than the small undifferentiated area imagined by Golla (2011:253), the area is more likely the entire western Sierra Nevada from the American River south to the Merced. There seems to be many reasons that people did not develop differentiated dialects earlier. One is likely due to high residential mobility during the Archaic, and secondly, because the region has

the same resource base, and last it is also adjacent to the Central Valley/ Plains Miwok region, which seems to have been occupied even earlier.

The diachronic analysis of diet points to a long trend of declining pine nut reliance throughout the Late Archaic, while contrasting increases are evident in the use of angiosperm plants (acorns, small seeds and manzanita berries) and angiosperm-based meats. This is most apparent in the latter portion of the Late Archaic as compared to preceding periods. So, diet was in a state of modification over a long period of time, with no unifying strategy and higher variation among individuals.

However, RP I indicates the greatest reliance on acorns and other angiosperm-based resources than any other period. The important point to note is that the environmental expectation is for $\delta^{13}\text{C}$ to actually become less negative across the resource base during drought. When considered together, this actually indicates an even greater reliance on angiosperm based resources as more individuals have more negative $\delta^{13}\text{C}$ values in RP I in contrast to other periods despite the expected shift in the baseline. This aligns well with the predictions from the opportunity costs model and the indication that women, when faced with increased costs of logistical foraging, turned to resources that were more easily gathered and stored and where processing costs could be delayed, as suggested by Whelan et al. (2013). This should also indicate a widely-shared economic strategy.

The shared strategy of plant resource use during RP I could tie into suggestions of when the bedrock mortar was introduced. The shared strategy is first and foremost an indication that a cultural phenomenon may be influencing what was a disparate plant use strategy during the latter portion of the Late Archaic. However, the shared strategy may also relate to how the overall environment was affected during RP I and the MCA droughts, which led women ultimately to a

similar resource use strategy (the increased use of acorns, for example). At this point, it is unclear whether the cultural phenomena was the creation and use of bedrock mortars, or an environmentally-induced cost benefits analysis of foraging decisions among all RP I individuals which resulted in a shared strategy. What is clear is that the shared strategy continued into RP II, but that the resource base it accessed was in fact slightly different than RP I. But, these possible explanations may not be mutually exclusive. Because residential mobility was reduced during RP I, the utility of portable mortars may have declined. As well, because there is an increased use of acorns and other angiosperm plants during RP I, the processing of these resources may be different enough to warrant greater investment in processing technologies, such as bedrock mortars. That the greatest reliance on angiosperm plants takes place during RP I and is related to reduced residential mobility may further indicate that the utility of portable mortars declined to such a low that the use of bedrock mortars made more economic sense, especially in light of reduced residential mobility. This should have some further testable hypotheses about where the older bedrock mortars are located, as this would indicate that those near the major rivers should be older than those found in disparate locations throughout the Lower Montane and Upper Montane forests.

The trend in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for meats during RP I, as compared to the late-Late Archaic, does align with the introduction of the bow and arrow during this time. Although higher $\delta^{15}\text{N}$ could be expected during drought, it would not be expected to show up in bone collagen values of adult human individuals as the turnover rate in bone collagen happens at a slower timescale than the resources it tracks. If this was purely an increase to baseline $\delta^{15}\text{N}$, the variability expressed across individuals should not be as great as it is and we would expect individuals to be more similar, not different, and they should instead reflect a pattern similar to

the Late Archaic. In contrast, the range of values is greater, there is more dispersion, which points to something other than just a shift in baseline $\delta^{15}\text{N}$. The most likely culprit would be a cultural phenomenon, not an environmental one. Hence, the best candidate is the introduction of a new technology, such as the bow and arrow. The $\delta^{15}\text{N}$ pattern during RP I suggests that hunting returns increased for many, but not all individuals, and in unequal amounts. This is interesting for two reasons. First, it suggests that there may have been a learning curve associated with the new technology that led to disparities in hunting success across individuals. Second, it also may indicate that meat resources were not as widely shared as compared to the Late Archaic, but that overall hunting returns were higher with the new technology.

Perhaps even more informative is that the dietary reorganization and focus on greater use of angiosperm plants apparent within RP I does not last into RP II. While both RP I and RP II exhibit a clear signal for a shared plant resource-use strategy, the majority of RP II individuals indicate a return to greater pine nut use. This seems to have been again a shared pattern, or a widely adopted strategy. When considered along with environmental expectations for the $\delta^{13}\text{C}$ of the resource base to have again shifted towards more negative values, the increase in $\delta^{13}\text{C}$ values across individuals is more striking. As well, the pattern in $\delta^{15}\text{N}$ amongst individuals indicates continued higher meat consumption, as with RP I, but that variability among the majority of individuals is reduced indicating that hunting returns among individuals were similar. This dietary shift during RP II is important archaeologically because it suggests that when the last MCA drought ameliorated, women re-evaluated their foraging goals and again returned to a heavier use of pine nuts as compared to angiosperm-based plants. This lends support to the idea that during drought, water became a limiting resource and that the number of water patches was reduced. It further indicates that residential mobility should likewise have increased.

Yet, when the pattern for $\delta^{34}\text{S}$ is considered from the Late Archaic through RP II, that is not what we see. Instead, $\delta^{34}\text{S}$ (using the Late Archaic as an example for high residential mobility) indicates that during the first part of RP I, residential mobility decreased, and it slightly decreased further during the second part of RP I, but, during RP II, it continued to stay reduced. While this may seem like a disjunction in the diet-versus residential mobility pattern, it is not, if we consider factors other than climate as the mechanism. Because the expectation for environmentally-induced reduction to residential mobility is dependent on post drought increased variance, the pattern observed negates climate-environment as a possible factor during RP II. This points to a culturally-mediated cause for the continued lower residential mobility. This suggests that territoriality should be the main driver during RP II and the reduced residential mobility.

When all three isotopic systems are considered together, the clearest reduction in residential mobility begins in RP I. The concurrent trends of reduced precipitation and reduced variance in $\delta^{34}\text{S}$ among locals are consistent with the interpretation that drought-related water limitation corresponded with this contraction in residential mobility. At the same time, the carbon isotope data indicate that the shift toward greater use of angiosperm plants and reduced reliance on pine nuts began earlier, in the middle of the Late Archaic, suggesting that dietary reorganization was already underway before the reduction in residential mobility became visible. The RP II reversal, in which results suggest a return to an increased use of pine nuts despite the lowest variance in $\delta^{34}\text{S}$, is especially important because it indicates that drought alone cannot explain the full pattern. Instead the results suggest that drought was the initial catalyst, for the changes that became evident in RP I, while cultural processes, especially increased territoriality, became the mechanism through which residential mobility remained low into RP II. Importantly,

this means that neither drought nor territoriality alone is sufficient to explain the sequence observed in the data. Rather, the combined isotopic results support a multicausal interpretation in which environmental stress helped initiate reorganization, while social processes structured its persistence through time.

While there are many complex ideas presented within this dissertation, a few of the more basic findings regarding stable isotope analysis of archaeological remains deserve further consideration. Although it is becoming increasingly more common to include local fauna within resource baselines, the use of paleobotanicals is less frequent. These resources represent highly valuable pieces of information that should be considered within most diachronic analyses of human diets. As illustrated, even in C_3 systems, variation can occur among different classes and clades of plants. This is especially true for regions where pine nuts are known to be a part of diets, as these generally do not react the same as angiosperm plants to the same environmental stimuli, whether it is drought, or increased warmth or colder temperatures. As well, within monoisotopic systems, it may be possible to parse more than the “n+1” food sources if foods within the resource base indicate mixed water use strategies, such as isohydricity and anisohydricity, as this should serve to separate foods along the carbon baseline. What was most clear from the analyses undertaken is that the use of the global baseline average for C_3 plants is not well suited for all applications of paleodietary reconstructions. As well, while $\delta^{34}\text{S}$ globally shows a great deal of variation, it seems to be an undervalued or underused isotope. Within certain regions, it may provide another proxy measure of mobility as it did here.

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Appendix A. Chapter 4 Supplemental Data

- 1) "Sample ID" contains the site identifier, and frequently which flotation sample the plant sample came from.
- 2) "plant" identifies the taxa.
- 3) $\delta^{13}\text{C}$ is the $\delta^{13}\text{C}$ measurement returned by UCD SIF.
- 4) "Amount (ug)" is the amount of measured total carbon returned by UCD SIF.
- 5) "Amount (mg)" is the submission weight of the sample, taken at the time of submission.
- 6) "(Amount (mg)*1000)" is the first step in calculating %C, or percent carbon.
- 7) "C Amount (ug)/ (Amount (mg)*1000)" gives %C; used to identify paleobotanicals that have been heated above a certain threshold and results in unreliable $\delta^{13}\text{C}$; cut-off used was 0.7, or 70%; anything above 70% is suspect.
- 8) Notes: ¹⁾"duplicate" indicates that a sample was split into two parts and both pieces submitted as separate samples to test reproducibility in measurement. Average $\delta^{13}\text{C}$ of sample 1 and sample 2 was used for analyses as long as both had %C < 0.7.
²⁾ "suspect" identifies samples with %C > 0.7.

Sample ID	plant	$\delta^{13}\text{C}$ (‰)	C Amount (ug)	Amount (mg)	(Amount (mg)*1000)	((C Amount (ug))/((Amount (mg)*1000))	Notes
TUO-935-GP1	gray pine	-22.82	485.40	0.791	791	0.61365	
TUO-935-GP2	gray pine	-22.01	434.04	0.783	783	0.55432	
TUO-935-GP3	gray pine	-23.12	619.64	0.962	962	0.64412	
TUO-935-A1	acorn	-25.72	476.32	0.898	898	0.53042	
TUO-935-A2	acorn	-25.93	512.71	0.832	832	0.61623	
TUO-935-A3	acorn	-23.56	624.76	0.988	988	0.63235	
018-TM-4 190 Ac	acorn	-25.00	485.87	0.858	858	0.56628	
018-TM-4 191 GP	gray pine	-21.64	512.89	0.964	964	0.53204	
018-TM-4 s2 SP	sugar pine	-22.24	296.41	0.511	511	0.58006	
MRP-1989 637 GP	gray pine	-21.73	531.33	0.936	936	0.56766	
MRP-1989 644 Ac	acorn	-24.87	511.66	0.849	849	0.60266	
MRP-1881 740 GP	gray pine	-20.86	447.85	0.796	796	0.56263	
MRP-1881 741 Ac	acorn	-24.99	456.43	0.743	743	0.61431	
CAL-277H-37-8-37-TP	sugar pine	-22.69	543.44	0.992	992	0.54782	
CAL-277H-40-8-37-TP	sugar pine	-23.05	662.00	1.160	1160	0.57069	

Sample ID	plant	$\delta^{13}\text{C}$ (‰)	C Amount (ug)	Amount (mg)	(Amount (mg)*1000)	((C Amount (ug))/((Amount (mg)*1000))	Notes
CAL-277H-8-8-37-TP	sugar pine	-21.89	333.28	0.557	557	0.59834	
CAL-277H-28-10-37-TP	sugar pine	-23.48	525.35	0.897	897	0.58567	
CAL-277H-37-10-32-A	acorn	-24.07	533.10	0.875	875	0.60926	
CAL-277H-8-10-32-A	acorn	-25.18	649.14	1.099	1099	0.59067	
CAL-277H-28-10-32-A	acorn	-25.08	546.02	0.926	926	0.58966	
CAL-277H-40-10-32-A	acorn	-24.84	582.16	0.999	999	0.58274	
TUO-5943-2-10-32-A	acorn	-25.51	705.67	1.069	1069	0.66013	
TUO-5943-2-16-31-GP	gray pine	-23.76	592.48	0.967	967	0.6127	
TUO-935 F3GPX	gray pine	-20.54	1078.46	1.892	1892	0.57001	
TUO-935 GPF1A	gray pine	-21.01	599.33	1.046	1046	0.57297	
TUO-935 GPF1B1	gray pine	-20.82	212.69	0.374	374	0.56868	
TUO-935 GPF1B2	gray pine	-20.21	877.51	1.542	1542	0.56907	duplicate
TUO-935 GPF1C1	gray pine	-20.81	443.60	0.828	828	0.53574	
TUO-935 GPF1C2	gray pine	-20.98	689.66	1.267	1267	0.54433	duplicate
TUO-935 GPF2A1	gray pine	-21.11	486.03	0.882	882	0.55105	
TUO-935 GPF2A2	gray pine	-21.43	401.98	0.733	733	0.54841	duplicate
TUO-935 GPF2B1	gray pine	-21.49	536.67	0.937	937	0.57276	
TUO-935 GPF2B2	gray pine	-21.35	397.37	0.689	689	0.57674	duplicate
TUO-935 GPF2C1	gray pine	-22.55	387.65	0.658	658	0.58913	
TUO-935 GPF2C2	gray pine	-21.95	451.48	0.792	792	0.57006	duplicate
TUO-935 GPF2D1	gray pine	-20.89	413.83	0.724	724	0.57159	
TUO-935 GPF2D2	gray pine	-21.24	649.19	1.132	1132	0.57349	duplicate
TUO-935 GPF3A1	gray pine	-21.39	999.28	1.701	1701	0.58747	
TUO-935 GPF3A2	gray pine	-21.79	615.37	1.075	1075	0.57243	duplicate
TUO-935 GPF3B1	gray pine	-23.27	561.31	0.949	949	0.59148	

Sample ID	plant	$\delta^{13}\text{C}$ (‰)	C Amount (ug)	Amount (mg)	(Amount (mg)*1000)	((C Amount (ug))/((Amount (mg)*1000))	Notes
TUO-935 GPF3B2	gray pine	-23.03	439.43	0.745	745	0.58984	duplicate
TUO-935 GPF3C1	gray pine	-22.98	439.69	0.803	803	0.54756	
TUO-935 GPF3C2	gray pine	-23.14	486.08	0.866	866	0.5613	duplicate
TUO-935 GPF3D1	gray pine	-20.36	667.39	1.229	1229	0.54304	
TUO-935 GPF3D2	gray pine	-20.38	590.80	1.082	1082	0.54603	duplicate
TUO-935 MZF1A1	manzanita	-26.60	819.25	1.3	1300	0.63019	
TUO-935 MZF1A2	manzanita	-26.11	1043.02	1.8	1800	0.57946	duplicate
TUO-935 MZF1B1	manzanita	-25.95	829.40	1.5	1500	0.55293	
TUO-935 MZF1B2	manzanita	-26.38	943.49	1.4	1400	0.67392	duplicate
TUO-935 MZF1C1	manzanita	-25.34	465.44	0.7	700	0.66492	
TUO-935 MZF2A	manzanita	-27.81	273.60	0.4	400	0.68401	
TUO-935 MZF2C	manzanita	-26.55	650.33	1.1	1100	0.59121	
TUO-935 MZF3A	manzanita	-24.31	355.56	0.8	800	0.44445	
TUO-935 MZF3B	manzanita	-25.26	602.37	1.0	1000	0.60237	
TUO-935 MZF3C	manzanita	-26.27	605.56	1.0	1000	0.60556	
TUO-935 MZF3D	manzanita	-24.25	941.63	1.7	1700	0.5539	
TUO-935 MZF4A	manzanita	-28.72	365.68	0.9	900	0.40631	
TUO-935 MZF4B	manzanita	-24.30	835.12	1.3	1300	0.6424	
TUO-935 ACF1A	acorn	-26.12	468.62	0.8	800	0.58578	
TUO-935 ACF1B	acorn	-26.07	550.10	1.3	1300	0.42316	
TUO-935 ACF1C	acorn	-22.36	607.80	0.9	900	0.67533	
TUO-935 ACF2A	acorn	-23.94	484.42	0.8	800	0.60552	
TUO-935 ACF2B	acorn	-22.86	435.59	0.8	800	0.54448	
TUO-935 ACF2C	acorn	-27.63	519.13	0.8	800	0.64891	
TUO-935 ACF2D	acorn	-25.42	346.64	0.8	800	0.4333	
TUO-935 ACF3A	acorn	-22.79	610.44	0.9	900	0.67827	

Sample ID	plant	$\delta^{13}\text{C}$ (‰)	C Amount (ug)	Amount (mg)	(Amount (mg)*1000)	((C Amount (ug))/((Amount (mg)*1000))	Notes
TUO-935 ACF3D	acorn	-22.87	1124.76	1.8	1800	0.62487	
TUO-935 ACF4	acorn	-26.81	867.51	1.5	1500	0.57834	
TUO-935 GSF2A	poa	-26.14	118.67	0.178	178	0.66671	
TUO-935 GSF2B	bromus	-23.88	177.18	0.293	293	0.60472	
TUO-935 GSF2C	festuca	-26.20	131.71	0.214	214	0.61549	
TUO-935 MZF2B	manzanita	-25.32	1273.50	1.8	1800	0.7075	suspect
TUO-935 ACF3C	acorn	-26.39	359.97	0.4	400	0.89992	suspect

Appendix B. Chapter 5 Supplemental Data

Notes for Stable Isotope Sample Table showing unreliable results

- 1) Site ID → CA-TUO-395 and CA-TUO-935
- 2) Sample ID is based from catalog numbers
- 3) Location is provenience.
- 4) Species show common name only
- 5) Sample is skeletal part
- 6) $\delta^{13}\text{C}$ returned by UCD SIF; an entry of “n/a” means sample was not submitted.
- 7) C (ug) shows total carbon in micrograms
- 8) $\delta^{15}\text{N}$ returned by UCD SIF
- 9) N (ug) shows total nitrogen in micrograms
- 10) C/N= (((C(ug)/N(ug))/(14/12))
- 11) % Col. Yield is percent collagen yield, and was calculated from total collagen weight (mg)/sample dry weight post drilling and sonication (mg); a “0” in this column indicates the sample did not survive chemical processing.

SITE	ID	Location	Species	Sample	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	% Col. Yield
TUO-395	283a	Housepit 1, burial 1	deer	lumbar vertebra	-26.3	4.23	17.7	4.43	2.51	4.405
TUO-395	283b	Housepit 1, burial 1	deer	metapodial	-24.9	21.15	11.5	1.25	19.75	1.120
TUO-395	283c	Housepit 1, burial 1	jackrabbit	humerus	n/a					0
TUO-395	317e	Dancehouse cremation	jackrabbit	tibia	n/a					0
TUO-935	42a	north pothole, 0-50	jackrabbit	astragalus	n/a					0
TUO-935	53a	South pothole, 0-50	deer	distal vestigial phalanx	-	-	-16.1	4.62		6.287
TUO-935	53b	South pothole, 0-50	desert cotton tail	astragalus	-27.9	10.75	21.6	4.12	3.04	9.846
TUO-935	53c	South pothole, 0-50	deer	metapodial	-25.2	8.96	-3.6	2.11	4.96	2.161
TUO-935	68a	SW pothole, 0-50	deer	navicular	-25.8	3.98	-	-		4.541
TUO-935	68b	SW pothole, 0-50	deer	tibia	-	-	-	-		0.247
TUO-935	90b	trench 1, 0-45	deer	metapodial	-	-	-	-		0.315
TUO-935	90c	trench 1, 0-45	deer	metapodial	-19.2	31.02	2.9	1.49	24.31	3.931
TUO-935	104b	trench 2, 0-45	deer	metapodial	-24.6	6.66	2.6	2.13	3.66	1.115
TUO-935	104c	trench 2, 0-45	jackrabbit	femur	n/a					0
TUO-935	119c	trench 3, 0-45	deer	metapodial	-24.8	36.10	6.8	3.94	10.68	1.858
TUO-935	119d	trench 3, 0-45	jackrabbit	tibia	-23.4	21.45	1.9	1.25	19.98	3.108
TUO-935	126a	trench 4, 0-30	deer	metapodial	n/a					0

SITE	ID	Location	Species	Sample	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	% Col. Yield
TUO-935	131a	trench 4a, 0-30	deer	tibia	n/a					0
TUO-935	131b	trench 4a, 0-30	jackrabbit	humerus	-24.8	27.25	-1.5	10.17	3.12	3.360
TUO-935	143b	trench 5, 0-40	black bear	canine tip	-22.3	80.77	6.8	17.53	5.38	1.858
TUO-935	143c	trench 5, 0-40	deer	vestigial metapodial	-25.4	12.50	2.2	5.10	2.86	1.702
TUO-935	143d	trench 5, 0-40	deer	tibia	-23.9	14.16	2.9	3.71	4.45	3.235
TUO-935	150a	trench 6, 0-45	deer	metapodial	-26.1	39.26	4.8	5.08	9.02	1.707
TUO-935	150b	trench 6, 0-45	gray squirrel	pelvis	-25.2	21.17	1.4	3.85	6.42	2.247
TUO-935	180a	trench 9, 0-40	jackrabbit	humerus	-27.7	10.32	6.0	2.21	5.45	1.046
TUO-935	180c	trench 9, 0-40	deer	metapodial	n/a					0
TUO-935	180d	trench 9, 0-40	deer	metapodial	-26.2	5.10	-7.7	1.04	5.73	2.833
TUO-935	196a	SW Pothole/Trench 4	deer	rib	-26.3	4.23	-2.4	1.36	3.63	1.508
TUO-935	196b	SW Pothole/Trench 4	badger	pelvis	-24.9	7.36	-0.9	2.89	2.97	1.520
TUO-935	196c	SW Pothole/Trench 4	wood rat	mandible	n/a					0
TUO-935	217a	CU 1, 0-10	jackrabbit	ulna	-26.9	7.71	-0.9	1.93	4.67	2.609
TUO-935	217b	CU 1, 0-10	jackrabbit	femur	n/a					0
TUO-935	217c	CU 1, 0-10	deer	cervical vertebra	-24.2	76.15	3.3	12.70	6.99	2.564
TUO-935	217d	CU 1, 0-10	large mammal	tibia	-25.5	17.24	-1.3	3.46	5.81	3.050
TUO-935	226a	CU 1, 10-20	deer	metapodial	n/a					0
TUO-935	226b	CU 1, 10-20	jackrabbit	tibia	n/a					0
TUO-935	236a	CU 1, 20-30	deer	metapodial	n/a					0
TUO-935	242a	CU 1, 20-30	small mammal	metatarsal	-26.0	6.51	-2.7	1.75	4.35	1.546
TUO-935	249a	CU 1, 30-40	deer	cervical vertebra	n/a					0
TUO-935	249b	CU 1, 30-40	jackrabbit	tibia	-25.7	7.92	-5.0	2.25	4.10	1.070
TUO-935	264a	CU 1-nw crevice, 40-62	deer	metapodial	n/a					0
TUO-935	264b	CU 1-nw crevice, 40-62	gray fox	maxillary 2nd molar	-25.7	7.92	-5.0	2.25	4.10	1.070
TUO-935	289a	Trench 5 soil sample	desert cotton tail	humerus	-26.0	3.87	-10.5	1.80	2.51	4.834

Appendix C1. Chapter 6-Notes on Don Pedro Collection

Part 1-Notes on burials from CA-TUO-279 (SFSU 2014a; Henn 1971).

Site Notes:

- Ca-Tuo-279 was located on a small peninsula which extended into the west side of the original Don Pedro Reservoir. The site is now inundated. Originally, the site was near the west bank of the Tuolumne River, about 2 miles north of the Big Creek tributary (Moratto 1971a:Map III). Ca-Tuo-279 comprised a relatively small area (ca. 50 x 40 meters) with deposits of lithics and midden soil extending to 80 cm. Henn (1971) described the site as a seasonal spring and summer camp. An unnamed seasonal drainage bordered the site on the south; this drainage served as a tributary to the Tuolumne River. It is notable that an outcrop of steatite and chert, which possibly served as a quarry, was located on the seasonal drainage about 3/4 mile west of the site.
- One box containing site material from Ca-Tuo-279 was found at the SFSU Romberg Tiburon Center in Marin county in 2011, after the original 1999 was conducted. From 2011-2012, all collections present at SFSU from Ca-Tuo-279, including bags labeled as shell, faunal, fish bone, artifacts, carbon samples, etc. were re-sorted by Department of Anthropology osteology students Andrea Guidara, Melissa Rodrigues, Mia Rodriguez, and Charlotte Schultz. All potential human bone was set aside by the students and reviewed by Dr. Mark Griffin in 2012. No additional human remains were identified.
- According to Henn (1971), a total of three burials were found during excavations at Ca-Tuo-279, only two of which were excavated. Edward Brennan (1971) who analyzed the human remains indicates that four discrete burials were uncovered. Burials 1, 2, and 4 were excavated. Burial 3 was not.
- The Ca-Tuo-279 human remains were inventoried by Julie London, NAGPRA Coordinator, on August 26 and 27, 1998. Prior to the inventory, the human remains collected from this site were stored in two burial boxes labeled "Tuo-279". These boxes contained 27 bags. Four of these bags were completely unlabeled. Most were labeled with site number, burial number, and/or unit of excavation. Several bags were labeled "Mocc" or "Moccasin", indicating they had been excavated from Ca-Tuo-314, the Moccasin Site. Bags were sorted according to site number when possible. As all human remains discussed by Brennan (1971) were accounted for in the bags labeled "Tuo-279", all unlabeled bags were inventoried as the Ca-Tuo-314 collection, which was previously unaccounted for [see Ca-Tuo-314 Inventory Synopsis for further detail]. When a burial number was not provided, individuals were sorted and inventoried according to excavation unit. **Human remains whose burial number could not be determined are designated with the prefix "UNK".**

Burial	Burial Particulars	NAGPRA MNI	OUR MNI
B1	According to Brennan (1971), Burial 1 was recovered from Unit 96 and consists of fragmentary postcrania and a right zygomatic representing one adult of indeterminate sex. The bag containing this burial indicated it was found at a depth of 60-80 cm. The field catalog indicates that an Olivella spire-lopped bead (catalog number 154-209) was found in association with this burial. Osteological examination confirmed that Burial 1 represents a minimum of one adult of indeterminate sex. Elements present include: one complete right zygomatic; two fragmented thoracic vertebrae; one right partial first metatarsal; one fragmented right proximal foot phalange; two right intermediate foot phalanges; and one left intermediate hand phalange. All epiphyses are fused and the vertebral centra display no billowing, indicating this individual had reached maturity prior to death. The remains are too fragmentary to accurately estimate sex.	1	1
B2, I1 and I2	According to Brennan (1971), Burial 2 was recovered from Unit 96. The skeleton, which was found in a tight flex, oriented to the northwest, was relatively complete and determined to be a young adult male. The bag containing this burial indicated it was found at a depth of 67 cm. The field catalog indicates that cut bird bone (154-205) was found in association with this burial. Osteological examination determined that Burial2 represents a minimum of two individuals : one young adult male, aged 27-35 years; and one adult of indeterminate sex. The second individual is represented only by a fragment of the left lateral occipital. The first individual is generally well-preserved, although the face of the skull is fragmented and partially absent. Long bones are complete, although some are fragmented. The sex of this individual was estimated based upon morphological aspects of the skull and innominate; both are classically male. The age of this individual was estimated based upon the morphology of the right and left pubic symphyses, which correspond to Todd Stage 5 and Suchey-Brooks Stage 4. All epiphyses are fused with the exception of the first and second sacral segments, which remain open. The dentition displays moderate to severe attrition. Mandibular abscesses are present inferior to the right and left canines. The pulp cavities of both maxillary canines are exposed.	2	2
B4	According to Brennan (1971), Burial 4 was recovered from Unit 96 and consists of one right femoral diaphysis and one right tibial diaphysis. This burial may have been associated with Burial 2. The bag containing this burial indicated Burial 4 was found at a depth of 60-80 cm. Osteological examination determined that Burial 4 represents a minimum of one adolescent or adult of indeterminate sex. One right femoral diaphysis and one right tibial diaphysis are present. The femur is charred along the linea aspera, but no other signs of cremation are evident. The remains are too fragmentary to accurately estimate sex.	1	1
UNK 1	The human remains inventoried as Burial UNK.1 were found in two burial bags. Both indicated the remains, like the previous burials, were recovered from Unit 96. A burial number was not indicated. The first bag contained remains recovered from a depth of "80 cm- Bdrt". The second contained remains recovered from a depth of 60-80 cm. Osteological examination determined that these remains represent a minimum of one adult of indeterminate sex. Elements present include: one complete axis; one complete atlas; two partial cervical vertebrae; two partial thoracic vertebrae; one right first proximal foot phalange; and one intermediate foot phalange. All visible epiphyses are fused. These remains are too fragmentary to estimate sex. The atlas and axis, which were found in separate bags, appear to articulate.	1	1
UNK 2	According to the burial bag, this burial, representing a minimum of one adult of indeterminate sex, was excavated from Unit 87, at a depth of 40-60 cm. Neither Henn (1971) nor Brennan 1971) indicate that any human remains were recovered from this unit. Elements present include: one partial cervical vertebra; one complete thoracic vertebra; five rib shaft fragments; and one intermediate hand phalange. All visible epiphyses are fused. These remains are too fragmentary to estimate sex. This individual is not known to be associated with any funerary objects.	1	1

Burial	Burial Particulars	NAGPRA MNI	OUR MNI
UNK 3	According to the burial bag, this burial, representing a minimum of one adult of unknown sex, was excavated from Unit 137 at a depth of 20-40 cm. Neither Henn (1971) nor Brennan (1971) indicates that any human remains were recovered from this unit. Elements present include one complete right third metacarpal and one complete intermediate hand phalange. All visible epiphyses are fused. These remains are too fragmentary to estimate sex. This individual is not known to be associated with any funerary objects.	1	1
UNK 4, I1 and I2	According to the burial bags, the human remains inventoried as Burial UNK.4 were recovered from Unit X at a depth of 20-70 cm. Henn does not indicate that a Unit X was excavated. Osteological examination determined that these remains represent a minimum of two individuals: one adult of indeterminate sex; and one adolescent of indeterminate sex. The adolescent is represented by two partial metatarsals. The bases of these metatarsals are absent; however, the heads are in the process of fusing to the shaft, indicating this individual had not yet reached maturity. Adult elements present include: one complete right talus; one left first cuneiform; two metatarsals; five foot phalanges; three hand phalanges; three metacarpals; five rib fragments; two thoracic vertebrae; and one cervical vertebra. Some remains were too fragmentary to determine which individual they belonged to. These include: one metacarpal; one metatarsal; one first rib; three rib shaft fragments; and one ilium fragment. All are too fragmentary to estimate sex. This individual is not known to be associated with any funerary objects.	2	2

Part 2: Notes on burials from CA-TUO-300 (Moratto 1971b; SFSU 2014b)

Site Notes:

- Ca-Tuo-300 was located on Roger Creek, about 7 miles east of La Grange. Roger Creek is a seasonal tributary of the Tuolumne River. The site area is now inundated by the New Don Pedro Reservoir (Moratto 1971 :Map III). The Roger Creek site comprised an oval-shaped midden area, measuring some 40 X 55 m, with cultural deposits some 160-180 cm in depth (Moratto 1971 :78). The site had been previously disturbed by a bulldozer cut. The site was notable for the amounts of clastic rocks (e.g. meta-cherts, slate) possibly indicating a lithic workshop. The presence of a structure was represented by a surface depression and floor remnants. The structure was probably the remains of an earth lodge, documented historically for the Sierra Miwok. The site was chosen for excavation due to the relatively undisturbed nature of the cultural deposits.
- Levy (1978:399) proposed that the Eastern (Sierra) Miwok may have occupied the Sierra Nevada only during the late prehistoric period (ca. post A. D. 500). The Mariposa Complex, possibly ancestral to the Sierra Miwok is a late period manifestation (Bennyhoff 1956). Ca-Tuo-300 produced three radiocarbon dates consistent with this ancestral Sierra Miwok cultural manifestation: A.D. 905, A.D. 915. and A.D. 1220. The radiometric dates are all from 50-70 cm depth. Cultural deposits, however, extended to 180 cm. Based on projectile point types and the presence of Haliotis disc beads in the lower levels, Moratto (1971 :94) proposed an initial date of A. D. 600 for the site. Small serrated Class 5-a (1) projectile points indicate a terminal date for the site around A.D.

1450. Moratto (1984:311-312) proposed that radiometric dates and artifact assemblages at Ca-Tuo-300 represented two separate components. The lower component, associated with the ca. A. D. 900-1200 dates, indicated use as a habitation site and a metachert workshop. The house remains dated from this era (ca. A.D. 915). This period also included a mortuary complex represented by "twelve fragmentary skeletons at or below the floor level" and characterized by "flexed burial, without surviving artifacts, under stone cairns" (Moratto 1984:312). The latter component, represented by an artifact assemblage including steatite disc beads, small flake tools and arrow points, dated from around A.D. 1500 to Euroamerican contact. The site was evidently a winter village for at least part of its use period. Roger Creek was ephemeral or dry during the summer. The house structure is similar to ethnographically documented Miwok winter houses. A fish spear was recovered; large fish would only be present in Roger Creek during winter and spring. Finally, the large numbers of clastic rocks may represent ovens for baking greens and root crops; a resource only available during the winter and spring.

- According to Moratto (1971: 108), a total of twelve burials, numbered 1 to 13 (the number 7 was not assigned), were excavated from Ca-Tuo-300. In addition, isolated and scattered human remains were found in units N-7 and R-13, both at a depth of 80-100 cm. Human remains were also found in unit 0-4 at a depth of 40-60 cm, but were not excavated. A C14 date of A. D. 905 was produced from deposits at the same level as Burial 2. Burial 9 was associated with a Desert Side-Notched point consistent with post 1500 B.P. occupation.
- Human Remains 2011-2012: Five boxes containing site material from Ca-Tuo-300 were found at the SFSU Romberg Tiburon Center in Marin county in 2011, after the original 1999 was conducted. From 2011-2012, all collections present at SFSU from Ca-Tuo-300, including bags labeled as shell, faunal, fish bone, artifacts, carbon samples, etc. were re-sorted by Department of Anthropology osteology students Andrea Guidara, Melissa Rodrigues, Mia Rodriguez, and Charlotte Schultz. All potential human bone was set aside by the students and positively identified by Dr. Mark Griffin in 2012.

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
B1	According to Moratto, Burial 1 was recovered from Unit M-6 at a depth of 70 cm. The burial, consisting of a female skeleton aged 35-55 years old, was found in a tight flex, oriented to the north. The burial was located on the floor of Structure 1, underneath a rock cairn. No artifacts were recovered in association. NAGPRA related osteological examination determined that Burial 1 represents a minimum of one individual, a female adult. Elements present include portions of the cranium, pelvic region, vertebral column, and long bone fragments. Although poorly preserved and fragmentary, this individual was determined to be a female based on the gracility of the skull and its sex-diagnostic characteristics, as well as on the width of the greater sciatic notch. The remains were too fragmentary to specifically age, although all observable epiphyses were fused, indicating the individual was adult at the time of death. Ankylosis of two lumbar vertebrae was observed. This pathology is consistent with a diagnosis of tuberculosis; however, ankylosis can be caused by a number of factors. *In 2011-2012, A proximal phalanx of the foot was found in a bag labeled "4-Tuo-208 M-6" at a depth of 60-80 cm. The phalanx measures 21 x 10 mm and is mostly complete. The epiphysis is fused, which is indicative of an adult individual and is consistent with the same adult female individual found in 1999. No funerary objects were associated with these remains.	1	1
B2	According to Moratto, Burial 2 was recovered from Unit R-1 0 at a depth of 55 cm. The orientation and position of the burial, consisting of an adult of indeterminate sex, was not determined. A radiocarbon date of 905 AD was obtained from the same level as the burial. No artifacts were recovered in association. Osteological examination determined that Burial 2 represents a minimum of one individual of unknown sex and age. Bones present include portions of the occipital and right frontal, left zygomatic, and hand elements. The remains were too fragmentary to sex or age.	1	1
B3	According to Moratto, Burial 3 was recovered from Unit M-6 at a depth of 95 cm. The burial, consisting of an adult of indeterminate sex, was found possibly flexed. Its orientation could not be determined. The poorly preserved burial was found underneath a rock cairn and underneath a solid house floor. No artifacts were recovered in association. Osteological examination determined that Burial 3 represents a minimum of one male adult individual. Elements present include portions of the pelvis and tibia. This individual was determined to be a male based on the width of the greater sciatic notch. The remains were too fragmentary to specifically age, although all observable epiphyses were fused, indicating the individual was adult at time of death.	1	1
B4	According to Moratto, Burial 4 was recovered from Unit M-6 at a depth of 105 cm. The burial, consisting of a child aged 5-7 years old, was found in a tight flex, on its right side, oriented to the west. The burial was located in a pit dug through a house floor, underneath a rock cairn. No artifacts were recovered in association. No human remains were found in the collection which could be definitively identified as Burial 4. This burial may be present, however, in the form of unlabeled remains.	Missing?	0

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
B5	According to Moratto, Burial 5 was recovered from Unit R-13 at a depth of 179 cm. The burial, consisting of an adult of indeterminate sex, was found in a tight flex, lying on its left side, possibly oriented to the north. The poorly preserved burial was located in close proximity to several large boulders. No artifacts were recovered in association. Osteological examination determined that this fragmentary burial represents a minimum of one adult of unknown sex. Elements present consist mainly of rodent-gnawed long bone fragments. The remains were too fragmentary to sex or specifically age, although all observable epiphyses were fused, indicating the individual was adult at the time of death. * 2011-12: Burial 5: Distal Humerus. Humeral Head, 3 Long Bone Fragments: The elements in a bag labeled "4-Tuo-300 RI3" and found at a depth of 120-140 cm includes the distal portion of a humerus, and three long bone fragments which represents a minimum of one adult individual. The distal portion of the humerus measures approximately 96 x 52 mm and exhibits damage at both the medial and lateral aspects of the trochlea and capitulum. The other fragments include what is likely a fragment of the humeral head and measures 38 x 32 x 15 mm; the other two non-diagnostic long bone fragments measure 37 x 17 mm and 32 x 18 mm. Sex and age could not be estimated due to the fragmentary nature of this burial, although fusion of the epiphysis of the humerus indicate the individual was an adult and is consistent with Burial 5. No funerary objects were associated with these remains.	1	1
B6	According to Moratto, Burial 6 was recovered from Unit 0-4 at a depth of 75 cm. The orientation and position of this burial, consisting of only an infant's skull, could not be determined. The burial was located underneath a rock cairn. No artifacts were recovered in association. Osteological examination confirms that this burial represents a minimum of one infant of unknown sex. Elements present include the left and right parietal, portions of the right frontal, a fragmentary occipital, one hand phalange, and one neural arch. Because of the individual's preservation and age, sex could not be accurately determined. The neural arch was unfused, indicating this individual was younger than three years of age at the time of death. This individual is not known to be associated with any funerary objects.	1	1
B7	According to Moratto, this burial number was not assigned. No human remains identified as Burial 7 were found present in the collection.	0	0
B8	According to Moratto, Burial 8 was recovered from Unit Q-7 at a depth of 140 cm. The orientation and position of this burial, consisting of an adult, aged 21-35 years, could not be determined. The skeleton was found underneath a rock cairn on the same level as a house floor. No artifacts were recovered in association. Osteological examination determined that this burial represents a minimum of one young adult, a probable female. Elements present include a nearly complete, though fragmented, mandible, left tibial diaphysis, and partial proximal hand phalange. Sex was determined based on prominence of the mental eminence, curvature of the mandibular ramus, and the overall faintness of observable muscle markings. The remains were too fragmentary to specifically age, although the relative lack of attrition observable on the right third molar suggests the individual is a young adult. This individual is not known to be associated with any funerary objects.	1	1

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	* 2011-2012:Burial 8: Cranial Fragment The element in a bag labeled "4-Tuo-208-Q7" and found at a depth of 0-20 cm includes a cranial fragment and represents a minimum of one individual of indeterminate age. The cranial fragment measures 36 x 44 mm, and includes a sutured edge, but lacks any additional morphology to identify its exact location. Age and sex could not be estimated due to the incomplete nature of the fragment, but the remains are consistent with Burial 8. No funerary objects were associated with these remains.		
B9	According to Moratto, Burial 9 was recovered from Units R-1 0 and Q-1 0 at a depth of 90 cm. The burial, consisting of an old adult female, was found in a tight flex, lying on its right side, oriented to the north. The burial was found with a large rock positioned next to the skull. A green chert point (catalog number 142-559) was found embedded in the spine. Pathology, consistent with spinal tuberculosis or carcinoma, was observed. Osteological examination confirms that this burial represents a minimum of one old adult female. Elements present include a partial, fragmented skull, portions of the hands and feet, long bone fragments, the pelvic region, right clavicle, and portions of both scapulae. Although poorly preserved and fragmentary, this individual was determined to be a female based on the width of the greater sciatic notch. Although the remains were too fragmentary to specifically age, osteoarthritic lipping of the vertebrae and the extreme porosity of observable bone suggests the individual is an old adult. In addition, the dentition displays severe attrition. Ankylosis of three lumbar vertebrae was also observed. One fragmented green chert point was found present with the remains. ***** Upon sample selection, it was found that the mandible sampled did not correlate with the condition of the radius. This was further corroborated with isotopic testing and radiocarbon assays.	1	2; see bolded note*****
B10	According to Moratto, Burial 10 was recovered from Unit 0-4 at a depth of 105 cm. The position and orientation of the burial, consisting of an adult aged 21-35 years, could not be determined. This burial was poorly preserved and most skeletal elements were missing at the time of excavation. No artifacts were recovered in association. <i>Osteological examination determined that Burial 10 represents a minimum of three individuals. One individual is a female adult, based on observations of the mandible. One individual is an adult of unknown sex. The third individual is a child of unknown sex represented by a complete femoral epiphysis.</i> #####2011-2012:##### <u>*The components of a bag labeled "4-Tuo-208 0-4" were originally found at a depth of 40-60 cm and include a left calcaneus, 1st proximal foot phalanx, left 2nd metatarsal, an intermediate foot phalanx, and cranial fragment. The calcaneus measures 78 mm in maximum length, and 40 mm in maximum width, however there are some damages on much of the cortical bone surrounding the calcaneus. The metatarsal measures 15 mm wide at the base and 64 mm long, but is missing the distal articular head. The 1st proximal phalanx measures 33 mm in length and 17 mm wide at the proximal end, and 16 mm at the distal end. The intermediate phalanx measures 29 mm long and 12 mm wide at the proximal end and 10 mm at the distal end, with some slight damages to the cortical bone at the proximal end. All of these remains represent at least one individual of indeterminate age and sex. The age and sex of the remains cannot be determined due to lack of context and slight damages to the bone. The remains are consistent</u>	3	2? See bolded note

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	with Burial 10. No funerary objects were associated with these remains. <u>**</u> The item in a bag labeled "4-TU0-209 0-4" and found at a depth of 60-80 cm includes a right foot navicular. This navicular represents at least one individual of indeterminate age and sex. The navicular measures 35 mm from the medial to lateral aspects and has a maximum width of 19 mm from the proximal to distal aspects. There is some damage to the plantar edge of the navicular. Due to the lack of context and the damage of the navicular, age and sex could not be determined. The remains are consistent with Burial 10. No funerary objects were associated with these remains <u>***</u>The element in a bag labeled "4-Tuo-208 0-4" and found at a depth of 74 cm includes a human cranial vault fragment. The fragment represents a minimum of one individual of indeterminate age. The cranial fragment measures 41 mm at its longest edge and measures 27 mm at the shortest edge which is parallel to the longest edge. The cranial fragment also measures 6.5 mm at its thickest portion. This cranial fragment lacks other diagnostic criteria to further determine vault location. Also, due to the fragmentary nature of the bone, the sex and age could not be determined. The remains are consistent with Burial 10. No funerary objects were associated with these remains. <u>****</u> A second rib fragment was found in a bag labeled "4-Tuo-208 0-4" at a depth of 76 cm representing one individual. The rib fragment measures 56 x 16 mm and mostly consists of the head, neck, and tubercle. Sex and age could not be determined due to the fragmentary nature of this burial. The remains are consistent with Burial 10. No funerary objects were associated with these remains. <u>*****</u>Three cranial fragments were found in a bag labeled "4-Tuo-208 0-4" at a depth of 60-80 cm. The largest fragment measure 22 x 21 mm. The other two fragments measure 10 x 20 mm and the other measures 23 x 10 mm. These fragments could belong to Burial 10 due to the same provenance information from the finds found in 1999 and 2010. Sex and age-at-death could not be estimated due to the fragmentary nature of this burial. The remains are consistent with Burial 10. No funerary objects were associated with these remains. ***** During sample selection, the remains of the child could not be relocated; sampling consisted of a rib and the mandibular ramus fragment. Although these two bones could have belonged to the same individual, the results for C, N, and especially O suggest that they possibly are not, they are close, but outside instrumental error. However, 14C was also close, with dates overlapping. For analysis purposes we treat the second sample as the second individual, but we do not include it with analyses for B10A1; there are doubts based on the closeness of the isotopes (different turnover rates among bones) and the possible same burial context. An alternative explanation is that these samples were of relatives, from the same household, who died near the same time.		

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
B11	According to Moratto, Burial 11 was recovered from Unit N-5 at a depth of 96 cm. The burial, consisting of a child aged 6-9 years old, was found oriented to the north. The burial was found near scattered large rocks which may have been the remnants of a disturbed cairn. It was located beneath a solid house floor. No artifacts were recovered in association. Osteological examination determined that Burial 11 represents a minimum of two adults: one adult of indeterminate sex; and one child, aged 4-6 years. The adult is represented by two isolated teeth displaying moderate attrition and one charred occipital fragment. According to the burial bag, the occipital was recovered from a depth of 40-60 cm. All other elements were found at the 80-100 cm level. The child's skeleton consists of a calvarium, four developing permanent teeth, and four long bone shaft fragments. The age of this individual was estimated based on dental development. #####2011-2012 Burial 11: *Left mastoid process of the temporal and an upper right canine (URC) : A mastoid process and an URC were found in a bag labeled "4-Tuo-208 N-5" at a depth of 60-80 cm representing a minimum number of one individual. The mastoid process measures 45 x 38 mm and is possibly male due to the size of the mastoid and the slight presence of the supramastoid crest. The canine tooth measures 12 mm from the occlusal crown to where the root broke, and 8 mm both mesic-distally and labial-lingually. Although it is an adult tooth, it is hardly worn. Age was estimated using occlusal attrition stages indicating an individual of approximately 15-20 years of age at death. The remains are consistent with Burial 11. No funerary objects were associated with these remains.	2	2 (juv. longbone; adult P4) and a gopher mandible
B12	According to Moratto, Burial 12 was recovered from Unit N-5 at a depth of 100 cm. The burial consisted of a probable female, aged 36-55 years old. Its orientation and position could not be determined. No artifacts were recovered in association. No human remains were found in the collection which could be definitively identified as Burial 12. This burial may be present, however, in the form of unlabeled remains. *** But See Unk 5***	Missing	0
B13	According to Moratto, Burial 13 was recovered from Unit N-6 at a depth of 88 cm. The burial consisted of a child aged 6-8 years old. Only the mandible and skull were present. Its orientation and position could not be determined. No artifacts were recovered in association. Osteological examination determined that Burial 13 represents a minimum of one individual: a child of indeterminate sex, aged 5-9 years. Only a fragmented skull and mandible, in addition to a few rib shaft fragments, are present. These are well-preserved. The age of this individual was estimated based on dental development. Permanent dentition is in the process of erupting. The basilar occipital is unfused at the lateral and synchondrosis epiphyses. * 2011-2012: A right mandible fragment and patella fragment were found in a bag labeled "4-Tuo-208 N-6" at a depth of 80-100 cm representing a minimum of one individual. The mandible fragment measures 66 x 31 x 6 mm and the patella measures 27 x 16 x 12 mm. Both of the bony elements are small in size, possibly indicating a subadult individual. According to the original site report, there was a child excavated from this unit at a depth of 88 cm where a fragmentary skull and mandible were found. However, <i>there was already a right mandible present in Burial 13, which indicates this belongs to a different subadult.</i> Burial 13 is considered to comprise 2 subadults. No funerary objects were associated with these remains.	2	1-rib sampled

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	** In 2012, a Burial UNK.2 was re-evaluated. The temporal bone originally mentioned in the 1999 report <i>actually belongs to a subadult individual, not an adult. Since Burial UNK. 2 and Burial 13 were both found in the same unit, it is likely the temporal bone belongs to Burial 13.</i> No funerary objects were associated with these remains.		
UNK 1	According to the burial bag, this burial, representing a minimum of one seven year old ($\pm$ 24 months) child of unknown sex, was excavated from Unit N-7, at a depth of 60-80 cm. Moratto indicates that <i>disarticulated human remains were recovered from this unit at a depth of 80-100 cm</i> (Moratto 1971:1 06). Elements present include portions of the deciduous and permanent dentition, and fragments of the right temporal, sphenoid, metacarpals, and long bones. Because of the individual's preservation and age, sex could not be accurately determined. The age determination was based on dental eruption and development. The permanent maxillary lateral incisor displays significant shoveling, consistent with a Native American ancestry. 48 uncatalogued modified lithics were found in the burial bag containing these remains. They have been designated with the prefix "UNC" for purposes of this inventory (1999). ***2011-2012: Four vertebral fragments were found in a bag labeled "4-Tuo-208 N-7" at a depth of 60-80 cm, representing a minimum of one individual. The only identifiable fragment is a partial axis vertebra which measures 30 x 19 mm and contains the dens and one superior articular facet. The other three vertebral fragments lack any identifiable features to ascertain which vertebrae they are. Sex and age could not be determined due to the fragmentary nature of this burial, however, since the axis vertebrae is relatively small, it could belong to a juvenile individual. The remains are consistent with Burial UNK1. since these vertebral elements were found in the same unit and depth as the juvenile individual previously found in 1999. No funerary objects were associated with these remains.	1	1
UNK 2	According to the burial bag, this burial, representing a minimum of one adult probable female, was excavated from Unit N-6, at a depth of 40-60 cm. Moratto indicates that only Burial13, a child, was recovered from this unit. Elements present include a partial right temporal (attributed to Burial 13 in 2012), partial right parietal, distal tibia fragment, and femoral diaphysis fragment. Although eroded and matrix-encrusted, this individual was determined to be a probable female based on the overall gracility of the mastoid process, however due to the re-evalutaion in 2012 (see below), UNK2 can no longer be defined as female. The remains were too fragmentary to specifically age, although all observable epiphyses were fused, indicating the individual was adult at the time of death. This individual is not known to be associated with any funerary objects. ***2011-2012: In 2012, Burial UNK.2 was re-evaluated. The temporal bone originally mentioned in the 1999 report actually belongs to a subadult individual, not an adult. Since Burial UNK. 2 and Burial 13 were both found in the same unit, it is likely the temporal bone belongs to Burial 13. No funerary objects were associated with these remains. ****The elements in a bag labeled "4-Tuo-208 N6" and found at a depth of 20-40 cm includes a human upper left first molar and represents a minimum of one adult individual. This single tooth measures approximately 12 x 12 mm, and using dental attrition scores the wear pattern would estimate the age of the individual to be between 10 and 20 years. Due to the fragmentary nature of this burial, sex could not be determined. The remains are consistent with Burial UNK.2. No funerary objects were associated with these remains.	2	2; one adult, one juvenile (m1 cap; which was returned)

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	*****A partial right tibial shaft fragment was found in a bag labeled "4-Tuo-208 N-6" at a depth of 80- 100 cm representing a minimum of one individual. The tibia shaft measures 166 mm in maximum length and 85 mm for maximum mid-shaft width. According to the original site report on Burial UNK. 2, there was an adult individual found in this unit at a depth of 40-60 cm. The report indicates that the bones found in this unit were eroded and matrix-encrusted, which matches the conditions present on this tibial shaft. This makes it likely that this tibial shaft is consistent with Burial UNK. 2. No funerary objects were associated with these remains.		
UNK 3	According to the burial bag, this burial, representing a minimum of one adult of unknown sex, was excavated from Unit P-11, at a depth of 60-80 cm. Moratto does not indicate that any human remains were recovered from this unit. This individual is represented only by a matrix-encrusted portion of the left femoral diaphysis. A note written on the burial bag containing this individual stated that the element "seems like [an] isolated find". This individual is not known to be associated with any funerary objects.	1	1
UNK 4	According to the burial bag, this burial, representing a minimum of one probable male of unknown age, was excavated from the southeast quadrant of Unit S-7, at a depth of 96 cm. Moratto does not indicate that any human remains were recovered from this unit. This individual, represented solely by a nearly complete, although fragmented, frontal, was determined to be a probable male based on the robusticity of the supraorbital ridges and glabella. The remains were too fragmentary to age. This individual is not known to be associated with any funerary objects.	1	1
UNK 5	This burial was found in unlabeled bags. Its unit of excavation is not known. Osteological examination determined these human remains, consisting of a partial postcranial skeleton and four isolated teeth, represent a minimum of one individual: a middle to old adult, probably female. The age of this individual was estimated based on several observations. Vertebrae display osteophytic lipping. All elements are porous. Teeth display severe attrition to the point where specific identification is difficult. The sex of this individual was estimated based on the overall gracility of the elements present in conjunction with measurements of the femoral and humeral heads. This individual may be Moratto' s Burial 12 which is described as a probable female, aged 36-55. This individual is not known to be associated with any funerary objects.	1	1
UNK 6	According to the burial bags, this burial was excavated from Unit P4, at a depth of 0-53 cm. Moratto does not indicate that any human remains were excavated from this unit. Osteological examination determined that these remains represent a minimum of one adult of indeterminate sex. Elements present include rib fragments, a nearly complete right ulna and left fibula, left calcaneus, and one left tarsal. The remains were too fragmentary to sex or specifically age, although all observable epiphyses were fused, indicating the individual was adult at the time of death. This individual is not known to be associated with any funerary objects.	1	1
UNK 7	This burial was found in unlabeled bags. Its unit of excavation is not known. Osteological examination determined that this burial represents a minimum of two individuals. One individual, Burial UNK. 7 A, is an adult of indeterminate sex, represented by a partial cranium and femora and tibiae shafts. The second individual, Burial UNK.7B, is a child of unknown sex, determined to be 4-8 years old at the time of death, based on dental development. The second skeleton may be Moratto 's Burial 4 which was	2	2; one adult one juvenile

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	determined to be a 5-7 year-old child. These individuals are not known to be associated with any funerary objects.		
UNK 8	The elements in a bag labeled "4-Tuo-208 M-2" and found at a depth of 80-100 cm includes a human cranial fragment and represents a minimum of one individual of indeterminate age. The cranial fragment measures approximately 26mm in length, 7mm wide at the smallest angle, and 18mm wide at the largest angle. This cranial fragment lacks any other diagnostic morphology to determine its specific location on the cranium. Additionally, due to the fragmentary nature of this bone, sex and specific age could not be determined. No funerary objects were associated with these remains.	1	1
UNK 9	The elements in a bag labeled "4-Tuo-208 N-3" and found at a depth of 55cm includes a human partial left mandible and represents a minimum of one adult individual. This partial mandible is from the left side, and measures approximately 81 mm in length, 32 mm anteriorly from the top of the alveoli to the bottom of the horizontal ramus, and 48 mm posteriorly at the tallest point of the ascending ramus. Sex estimation would be female due to the gracile appearance of the masseteric tuberosity, and the obtuse appearance of the gonial angle (Krogman and Iscan 1986). Age could not be estimated due to the fragmentary nature of this burial, although complete eruption of the third molar (with some attrition) is indicative of an adult individual. No funerary objects were associated with these remains.	1	1
UNK 10	The elements in a bag labeled "4-Tuo-208 N-4" and found at a depth of 20-40cm includes a human second molar from the upper right side. The molar represents a minimum of one individual of at least 12 years of age. The mediobuccal aspect of the molar measures 10 mm and the buccolingual aspect of the molar measures 11 mm. Due to the lack of context of this molar, sex and specific age could not be determined. No funerary objects were associated with these remains.	1	0
UNK 11	Right Side Frontal bone (including nasal bones and ethmoid). Temporal fragment temporal/occipital cranial fragment: The three elements in a bag labeled "4-Tuo-205 P-5" and found at a depth of 0-20cm represent a minimum of one individual. Elements included in this burial are a partial right frontal bone with partial nasal bones and partial ethmoid that measures approximately 65 x 65 mm; a temporal fragment that measures approximately 50 x 36 mm; and a temporal fragment including the mastoid process and a small portion of the occipital measuring approximately 65 x 38 x 40 mm. Due to the fragmentary nature of this burial, sex and age could not be estimated, although the large size of the mastoid process is indicative of an adult. No funerary objects were associated with these remains. In 2012, a re-evaluation was conducted on Burial UNK. 11 where a small error was found with the previous assessment. The temporal/occipital cranial fragment is actually part of the right frontal bone. Also, sex could be determined based on the prominent glabella and the rugose superciliary arches, both of which are indicative of a male individual.	1	1
UNK 12	The elements in a bag labeled "4-Tuo-205 P-5" and found at a depth of 120-140cm includes an intermediate hand phalanx and represents a minimum of one adult individual of indeterminate age. Also included in this bag were several fragmentary faunal remains, and two pieces of red chert debitage. The complete intermediate hand phalanx measures approximately 30 x 14 mm, 30 mm thick at the proximal end, and 6 mm thick at the distal end. Age	1	1

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	and sex could not be estimated due to the incomplete nature of the burial. No funerary objects were associated with these remains.		
UNK 13	The elements in a bag labeled "4-Tuo-208 R5" and found at a depth of 140-160 cm includes an upper right second premolar and represents a minimum of one individual aged 35-40 years. Also included in this bag were several fragmentary faunal remains. The upper right second premolar shows considerable wear, and was aged by using attrition stages. Sex could not be determined due to the incomplete nature of the burial. No funerary objects were associated with these remains. ***Lower Left First Molar (LLMI) the elements in a bag labeled "4-Tuo-208 R5" and found at a depth of 20-40cm include a lower left first molar and represents a minimum of one individual aged 15-20 years. Also included are several fragmentary faunal remains. The molar is complete with no root, and shows little to no wear. Age was estimated using attrition stages and sex could not be estimated due to the incomplete nature of the burial. No funerary objects were associated with these remains. ****Rib Fragment The elements in a bag labeled "4-Tuo-208 R5" and found at a depth of 100-120cm include a fragmentary middle rib including the head, neck, and tubercle. This represents a minimum of one individual of indeterminate sex and age. The rib fragment measures 56mm in length, and lacks any other identifiable morphology. Age and sex could not be estimated due to the fragmentary nature of this burial. No funerary objects were associated with these remains.	2	2*, second individual was returned (LLm1 cap [deciduous])
UNK 14	The elements in a level bag labeled "4-Tuo-208 S6" include a cranial fragment which represents a minimum of one individual. The cranial fragment is the right temporal, and includes the petrous pyramid; it measures approximately 45 x 40 x 30 mm. Sex and age could not be estimated due to the incomplete nature of this burial. No funerary objects were associated with these remains.	1	1
UNK 15	The elements in a bag labeled "4-Tuo-208 S6" and found at a depth of 140-160cm includes a fragmentary intermediate hand phalanx which represents a minimum of one individual. Also included in the bag were several fragmentary faunal remains. The phalanx measures approximately 25 x 12 mm and is missing the proximal articulation. It also exhibits a small peri-articulation of the right side when viewed from the dorsal aspect. Sex and age could not be estimated due to the fragmentary nature of this burial. No funerary objects were associated with these remains.	1	1
UNK 16	There is an MNI of three individuals found in a bag labeled "Non-human faunal remains; 4-Tuo- 300". The first individual is a juvenile represented by an epiphysis measuring 28 x 20 mm. Sex cannot be estimated for juvenile individuals and age could not be determined due to the fragmentary nature of this burial. The adult female individual consists of a fragmentary first metacarpal measuring 38 x 10 mm, with the head of the metacarpal missing. The other fragments that may also represent this individual are a fragmentary left fourth metatarsal, an occipital fragment, and a right parietal fragment. The metatarsal fragment measures approximately 37 x 16 mm, with only the base and part of the shaft present. The occipital fragment measures 45 x 41 mm and consists of the external occipital protuberance with some faint nuchal muscle markings, possibly indicating a female. The parietal fragment measures 28 x 25 mm. All of these bony elements had	3	3: M, F, Ind.

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
	similar coloration, which means it is possible they all are from the same individual. Sex was determined using discriminant function analysis for fragmentary metacarpals. Age could not be determined due to the fragmentary nature of this burial, however, all of the elements are from an adult. The adult male individual is represented by the right and left mastoid processes of the temporal, a right parietal fragment, a small parietal fragment, a right zygomatic and maxilla fragment, and a right ischiopubic ramus. The coloration of these bones are all similar, making it possible that they are all from the same individual. The left mastoid process measures 33 x 33 mm. The right mastoid process measures 35 x 34 mm. The right parietal fragment measures 50 x 43 mm. The other parietal fragment measures 28 x 16 mm. The zygomatic and maxilla fragment measures 48 x 45 mm and consists of the bottom portion of the eye orbit and part of the maxillary sinus. The ischiopubic ramus measures 42 x 32 mm. Sex was determined using the mastoid processes and the ischiopubic ramus. Both of the mastoid processes are relatively large, indicating a male individual. The ischiopubic ramus is large in size and slightly concave, also indicative of a male individual. Age was estimated using the parietal fragments and examining the diploe vascularity and the meningeal grooves. The deep meningeal grooves and the state of the diploe are consistent with an individual of approximately fifty years of age at death. Other identifiable bony elements included in this bag that could belong to either of the adult burials are a manubrium fragment, a right medial cuneiform, a left patella fragment, left and right parietal fragments, a left maxilla fragment, a humeral shaft fragment, a scapula fragment, a right rib fragment, a thoracic fragment, and a lower left molar (LLM 1 or 2). The manubrium fragment measures 70 x 31 mm and consists of the clavicular and jugular notches. The medial cuneiform measures 29 x 24 mm. The patella fragment measures 39 x 25 mm and consists of a partial articular facet. The maxilla fragment measures 25 x 18 mm and comprises of alveoli of ULP4 and ULM 1. The parietal fragment measures 34 x 31 mm. The right parietal fragment measures 28 x 25 mm and is burnt. The humeral shaft fragment measures 68 x 17 mm and is burnt. The scapula fragment measures 47 x 11 mm and is part of the lateral border. The rib fragment measures 49 x 10 mm and is either the 10th or 11 rib. The thoracic fragment measures 17 x 11 mm and consists of only one of the superior articular facets. The LLM 1 or 2 measures 28 mm from the crown to the root, and 11 mm both mesic-distally and bucco-lingually. Age was determined using occlusal attrition stages, and indicated that the individual was approximately 40 years old at death. There are also fifteen unidentifiable human remain fragments, two of which are human teeth, present within the un-provenanced faunal remains bag. The teeth fragments are both possibly lower unidentifiable teeth. One of them measures 15 mm from crown to root, however, the crown is split making it difficult to identify which tooth it is. The other tooth measures 15 x 7 mm and is missing most of the crown, also making it difficult to make a positive identification of which tooth it is. The remaining bony elements are too fragmented to distinguish what they are. Sex and age were not estimated for these bones due to the fragmentary nature of this burial. No funerary objects were associated with these remains.		

Burial	Burial Particulars TUO-300	NAGPRA MNI	Our MNI/Number of Individuals sampled
UNK 17	A partial distal hand phalanx was found in a bag labeled "4-Tuo-208 N-7" at a depth of 120-140 cm (bedrock) representing a minimum of one individual. The phalanx measures 16 x 10 mm and is missing the proximal portion. Sex and age could not be determined due to the fragmentary nature of this burial. No funerary objects were associated with these remains.	1	too small
UNK 18	A partial rib and distal radius fragment were found in a bag labeled "4-Tuo-208 P-5" at a depth of 80-100 cm representing a minimum of one individual. The rib measures 27 x 11 mm and consists of a tubercle. The radius fragment measures 28 x 14 mm and comprises of the distal radial articular surface portion. Sex and age could not be estimated for this individual due to the fragmentary nature of this burial, however, it appears to be an adult individual based on the fused epiphyses. No funerary objects were associated with these remains.	1	1
UNK 19	A humeral head fragment was found in a bag labeled "4-Tuo-208 R-13" at a depth of 60-80 cm representing a minimum of one individual. The humeral head fragment measures 36 x 31 mm. Sex and age could not be determined due to the fragmentary nature of this burial. No funerary objects were associated with these remains.	1	1
UNK 20	Two right temporal fragments were found in a bag labeled "4-Tuo-208 P-5; Identifiable Faunal Remains" at a depth of 60-80 cm. One measures 43 x 31 mm, and the other measures 41 x 35 mm. Sex and age-at-death could not be determined due to the fragmentary nature of this burial. No funerary objects were associated with these remains.	1	1

Part 3: Notes on burials from CA-TUO-314 (Moratto 1971a; SFSU 2014c; Slaymaker 1971)

Site Notes:

- Ca-Tuo-314 was located on the south bank of Moccasin Creek about one mile above its confluence with the Tuolumne River. In 1971, the site area was located inside a trailer park called the Golden Chain Campground. The trailer park was situated about 1700' southeast of the junction of State Highway 49 and State Highway 120. Moccasin Creek is a tributary of the Tuolumne River. Site area was estimated at 50 x 30 meters. A remnant housefloor, rock feature and rock cairn were noted. The site, however, had been severely disturbed by earthmoving equipment and stump removal.
- According to Slaymaker (1971), "The site was a mess. Only sparse patches of the original ground surface remained and these were difficult to locate."
- Local collectors had also disturbed the site; vandalism was ongoing at the time of Slaymaker's investigation. Local informants told SFSC that a mound about two meters high had stood on the site. Examination of pothunter holes indicated cultural deposits extended another three meters below ground surface. Due to the nature of disturbance no attempt was made to determine site function.

- The materials at SFSU from Ca-Tuo-314 were recovered during a data-recovery project led by M. Moratto of SFSC in 1970-71 in conjunction with the construction of the New Don Pedro Reservoir. Students and faculty from SFSC, Columbia Junior College, and Merced College participated in the project. The archaeological investigations were contracted by the National Park Service (NPS contract# 497-0P1 0605).
- No site dating was attempted by Slaymaker (1971). In his report, clam shell disc beads with callus remaining were noted. Split drilled olivella beads were also noted. Bennyhoff and Hughes (1987) state these are diagnostic markers for the "late Middle period" in the Delta, a cultural phase occurring around ca. AD 500. According to an article in the Stockton Record (1971), Moratto is quoted as saying the site could date to as early as A. D. 500. Thus, the site, which was evidently fairly large and regularly reoccupied, appears to have been occupied primarily during the later prehistoric period. This temporal assignment is consistent with the Mariposa Complex (ca. A. D. 1200-1800) which represents the protohistoric to contact period Sierra Miwok (Moratto 1984).
- Following the 1971 excavation, the artifacts and human remains recovered from Ca-Tuo-314 were brought to SFSC for cataloging and analysis. Human remains were not cataloged. No site catalog was found at SFSU. The box of Ca-Tuo-314 materials found in 2011-2012 contained artifacts labeled 156-.
- At the start of excavation, Slaymaker noted the remains of hundreds of human burials visible on the surface, including many disarticulated and shattered skeletons. After a week absence from excavation, the crew returned to find that vandals had stacked the bones of the prehistoric inhabitants "in a pile over three feet high, six feet long and four feet wide." This activity and previous damage to the site resulting from use of heavy earthmoving machinery made an accurate count of these remains impossible.
- Slaymaker provenanced recovery of human remains into two categories: "Human Burials Disturbed by Earthmoving Equipment" and "Burials Scattered on Surface". Slaymaker recorded that "five human burials, partially exposed by earthmoving activities were excavated in situ." (See TAM NO.9, p.129) However, Slaymaker goes on to describe seven human burials disturbed by earthmoving equipment a few pages later (1971:132-133). The description of scattered surface remains is broken down by the area in which they were found: Western half of the site (UNK. 2A, 2B, 2C) and Eastern half of the site. (UNK. 8A, 8B, 8C). Slaymaker noted that all burials from the site "were in various stages of disturbance, the best of the lot being only crushed and not pulverized." There is no record of who analyzed the human remains.
- The Ca-Tuo-314 human remains were inventoried by Michelle Kaye, graduate assistant to the SFSU NAGPRA program in November and December 1998. The remains were contained in nine paper bags. The remains in the paper bag labeled "Mocc Bur 2" were divided and rebagged into 3 separate bags: Bur. 2, UNK. 6A, 6B and UNK. 7A, 7B, 7C.

The reason for this is two-fold. Foremost, SFSU discovered that only one of the many sandwich-sized bags placed within the larger paper bag was actually labeled "Bur.2." The other remains in the bag that were bagged, were unlabeled. Several remains were not bagged at all. A decision was made to separate the remains accordingly: Bur. 2, UNK. 6A, 6B being the unbagged remains and UNK. 7 A, 7B, 7C being the bagged, but unlabeled remains. A second reason for separating the remains was accidental. The barely legible handwriting on the bag was not initially recognized as reading "Mocc Bur 2," it was instead misread as "Mocc Bones." This error was detected when comparing the rebagged Ca-Tuo-314 remains with a Ca-Tuo-279 box inventory compiled on 8/25/98 by Julie London, former NAGPRA Coordinator. In her inventory, London sought to separate those remains that may belong to Ca-Tuo-314, from those that were consistent with descriptions from site Ca-Tuo- 279. The remains described in this report are the ones London separated from the Ca-Tuo-279 collection.

- Prior to the inventory, the human remains collected from this site were stored in two burial boxes labeled "Tuo-279". These boxes contained 27 bags. Four of these bags were completely unlabeled. Most were labeled with site number, burial number, and/or unit of excavation. Several bags were labeled "Mocc" or "Moccasin", indicating they had been excavated from Ca-Tuo-314, the Moccasin Site. Bags were sorted according to site number when possible. As all human remains discussed by Brennan in his description of site Ca-Tuo-279 were accounted for in the bags labeled "TU0-279", all unlabeled bags were inventoried as the Ca-Tuo-314 collection. Human remains whose burial number could not be determined were designated with the prefix "UNK."

Burial	Burial Particulars	NAGPRA MNI	OUR MNI/# Individuals sampled
B2, A & B	According to Slaymaker, Burial 2 was found positioned in a tight flex on the right side in the Northeast area of the site "in power cut." This burial was disturbed by earthmoving equipment. The burial was that of an adult male. Sex was determined from general robust characters and the presence of a narrow sciatic notch. No pathologies or associated artifacts were noted. A description of individual remains was not provided. Osteological examination confirmed that Burial 2 represents a minimum of one adult, likely male. Sex estimation is based on a squared mental eminence and the general robusticity of the mandible. Elements present include: <i>a fragmented mandible</i> and a fragmented maxilla. The following teeth were found: Maxillary right I1, I2, M1, M2, M3. Maxillary left I1, I2, C, P2, M2, M3. Mandibular right P 1, M1, M2. Mandibular left I1, I2, P1, M1, M2, M3. Wear on the teeth is moderate to extensive with large dentin areas exposed to severe loss of crown height and breakdown of enamel rim. Tooth wear patterns suggests a middle aged individual, likely someone between the ages of 35 and 45, which correspond to Brothwell, (1965:69) and roughly to modal tooth wear patterns described by Lovejoy (1985, 68:47-56). In addition, left maxillary I2 had abscessed through the alveolar portion of the maxilla. Cranial fragment from the parietal and occipital regions were also noted, as was a left occipital condyle. Noncranial bones included the fragmented head of a femur, the proximal end of a metacarpal and unidentifiable splintered long bone fragments. <i>Both the left (B2B) and right (B2A) mandible fragments were sampled, along with LLM1 and LLM3, and LRM1 and LRM2.</i>	1	2; mandible halves do not match

Burial	Burial Particulars	NAGPRA MNI	OUR MNI/# Individuals sampled
B4, A & B	According to Slaymaker, Burial 4 is that of a child of indiscernible sex found in a flexed position on the left side and oriented northeast by southwest. These remains were recovered from Unit C, 45-60 cm. "B.S. under cairn." This burial was disturbed by earthmoving equipment. No pathologies or associated artifacts were noted for this site. A description of individual remains was not provided. *****Osteological examination determined that Burial4 represents a minimum of three individuals, one adult, one young adult (likely early 20's), and one infant/child (likely 1-3 years). All are of indeterminate sex. All remains recovered were fragmentary and several of the long bones showed signs of gnawing by rodents. Some bones are also charred and calcified from being burned for a fairly long time at a high temperature. The adult is represented by fragmented, but paired, femurs, fibula, tibia, humeri, and ulna. Additional remains include: the transverse processes of two thoracic vertebrae, six rib fragments, two patella, a fragmented right scapula, three sacral fragments (one anterior segment which is badly charred), a right hamate, the three partial proximal portions of metacarpals and one distal foot phalanx. *****Cranial remains, which may belong to the adult or young adult (it is difficult to tell whom they belong to due to their fragmentary nature) include: <i>a fragmented, but mostly complete mandible with teeth present</i>, a partial maxilla with teeth present, a fragment of superciliary arch of the frontal bone, a partial left zygomatic bone, occipital fragments (including a left partial occipital condyle), and a partial sphenoid bone (including the left hamulus and a fragment of the right greater wing). Teeth include: Right maxillary: M1, M2, M3. <i>Right Mandibular: C, P1, P2, M1. Left Mandibular: P 1, P2, M1.</i> It is possible that right maxillary <i>M3</i> and right mandibular C 1. both of which were found in isolation may belong to a different individual. Because the right maxillary M3 shows extensive wear and severe attrition, where the remainder of the teeth display only moderate wear, it is likely this is the case with at least this tooth. As for the teeth contained in the partial mandible and maxilla, the maxillary teeth fared better than the mandibular teeth. The maxillary teeth show only moderate dentin patches. In most of the mandibular teeth the pulp chambers were exposed. A mandibular abscess is present inferior to M 1. The mental eminence of the body of the mandible is more rounded than squared which is suggestive of a female; however, this alone is not definitive for purposes of sex identification. *****Remains corresponding to the young adult include: a fragmented right humerus shaft, a second humerus shaft and a separated and fragmentary partial epiphysis, a complete cervical vertebrae, and a fragmented left os coxae (small fragments from ischial tuberosity, pubis, ilium, auricular surface and ilium). Cranial remains likely from the young adult include a fragmented right zygomatic bone and the left partial greater wing of the sphenoid bone (not completely fused). *****Remains that cannot definitively be said to be adult or young adult include a fragmented right and left clavicle (epiphysis are missing and clavicles are small in size suggestive of a female or young adult), several undiagnostic long bone fragments, two os coxae fragments (one from the ischium, one from the pubis), fragmented left and right temporal bones including partial petrous portions and a squamous portion and several undiagnostic and very fragmented cranial remains.	3	2 sampled; young adult mandible and adult longbone fragment (possibly femur) see bolded note

Burial	Burial Particulars	NAGPRA MNI	OUR MNI/# Individuals sampled
	*****Remains attributable to the infant/child include: the immature spinous process of a lumbar vertebrae (recent union of the arches) and two partial rib body fragments (no secondary ossification centers). **** Also associated with this burial was a mandibular half from a rodent, complete with teeth. *** <i>the rodent mandible was sampled. Remains sampled: likely young adult = L. mandible frag, with M1, M2, and M3 extracted; age based on wear. Also sampled: one longbone fragment → adult.</i>		
UNK 1: Unk 1C	The human remains inventoried as Burial UNK. 1A, 1B were found in a paper bag labeled "Unit O4, depth 75 cm., South 155. West 100." No other information on these remains was available. Additionally, no map of the site was available to help place these remains. Osteological examination determined that these remains represent a minimum of two adults of indeterminate sex. Elements present include: two right and two left complete sets of auditory ossicles, a fragment of the left greater wing of a sphenoid bone, two fragments of the lesser wing of a sphenoid bone, six occipital fragments from the area of the cruciform eminence, one fragment of the frontal bone, one fragment of the temporal bone and several undiagnostic cranial fragments. None of these remains lend themselves to age and sex determination.***** <i>The adult remains could not be relocated in this bag with this provenience. However, in the bag labelled as UNK 1 were the remains of a juvenile with this provenience. We sampled rib fragments from this individual.</i>	2	1; only juvenile sampled (Unk 1C rib fragment)
UNK 2, A & B	According to Slaymaker, these remains are those of burials scattered on the surface. He describes them as belonging to the Western half of the site (1971: 134) and consisting of a minimum of four adults. The remains were weighed at 573.20 grams. No other information pertaining to these remains was available. *****The remains were found in a small paper bag labeled: "Western half of the site. Surface collection. 573.20 g." Osteological examination does not confirm Slaymaker's report. examination determined that Burial UNK. 2A. 2B, 2C represents a minimum of three individuals: one adult male of undetermined age, one adult, possibly female of undetermined age, and one child of indeterminate sex, aged seven years or less. *****The remains are consistent with cremation. They are very fragmented and some are burned. It was not always possible to side bones because of their condition. Due to their fragmentary state, the remains of the first two individuals cannot be clearly separated. Sex of the male was determined from an occipital fragment showing a large occipital protuberance and the presence of a large nuchal crest. The sex of the second individual is less certain. A right temporal fragment which shows a relatively small mastoid process and no extension of the posterior end of the zygomatic process past the external auditory meatus is suggestive of a female. Elements present from the adults include: a right fragmented femur shaft, fragments from the shaft of a tibia, fragments from the shaft of a fibula, fragments from the left proximal shaft of a humerus and proximal epiphysis, fragments of a right radius, including a separated and fragmented radial head, fragment of the body of a rib, four sacral fragments from around the median crest, 13 very fragmented pieces of an os coxae, two patella fragments from the lateral articular facet, a fragment of a 5th foot intermediate phalanx and the inferior articular facet of a left thoracic vertebrae. Cranial remains include: left maxillary fragments (alveolar portion), right and left mandibular fragments (ascending ramus and coronoid process) right temporal fragment (mastoid	3	2 sampled; juv rib and adult tibia fragment

Burial	Burial Particulars	NAGPRA MNI	OUR MNI/# Individuals sampled
	process and part of the petrous portion), occipital fragments (external occipital protuberance, cruciform eminence), parietal fragments, frontal fragments (frontal sinus), right fragment of the greater wing of the sphenoid bone. Adult teeth include: Right Maxillary: C, P2. Left Maxillary: I1, M2 . One canine with only a partial root remaining (could not side). All teeth were isolated. Teeth show moderate to extensive wear with dentin exposed. ***The second individual, the child, is represented by a right rib body fragment , fragments from a fibula, several unidentifiable long bone fragments, a right maxillary di2 (moderate wear), a mandibular di1 (side uncertain), a left mandibular di2. ***** <i>Elements sampled include deciduous incisor (returned) and the juvenile rib fragment (UNK 2A) and a tibial shaft fragment from one of the adults (UNK 2B).</i>		
UNK 3 not sampled	These remains were found in a small unlabeled paper bag, which has now been relabeled "Unlabeled bag #1.". No information is available on this burial. Osteological examination determined that Burial UNK. 3A represents a minimum of one adult, sex and age indeterminate. Elements present include one small left proximal ulna fragment and two small splintered fragments from the distal portion of an ulna. ***** <i>These remains were not sampled.</i>	1	0
UNK 4 not sampled	These remains were found in a small unlabeled paper bag, which has now been relabeled "Unlabeled bag #2." No information is available on this burial. Osteological examination determined that Burial UNK. 4A represents a minimum of one adult; sex indeterminate. Elements present include: one right fragment of the foramen spinosum of the sphenoid bone and 10 small ilium fragments from an os coxae. ***** <i>These remains were not sampled.</i>	1	0
UNK 5	These remains were found in a small unlabeled paper bag, which has now been relabeled "Unlabeled bag #3." No information is available on this burial. Osteological examination determined that Burial UNK. 5A represents a minimum of one adolescent (12-19 years) to Adult. The lower age bracket is suggested by the size of the fibula fragments when pieced together. Elements include: one left cuboid fragment, one left first cuneiform, one fragmented distal toe phalanx, the styloid process of a right fibula, three fibula fragments from the distal epiphysis and five undiagnostic fragments (likely tarsal fragments). ***** <i>The sample taken for UNK 5 consists of a fibula fragment.</i>	1	1
UNK6: Unk 6A	No Provenience is provided for these individuals, but the NAGPRA paperwork states that these individuals may be related to Burial 2 in terms of site location. The remains for TUO-314 were contained in nine paper bags. <u>The remains in the paper bag labeled "Mocc Bur 2" were divided and rebagged into 3 separate bags: Bur. 2, UNK. 6A, 6B and UNK. 7A, 7B, 7C. The reason for this is two-fold. Foremost, they discovered that only one of the many sandwich-sized bags placed within the larger paper bag was actually labeled "Bur.2." The other remains in the bag that were bagged, were unlabeled. Several remains were not bagged at all. A decision was made to separate the remains accordingly: Bur. 2, UNK. 6A, 6B being the unbagged remains and UNK. 7A, 7B, 7C being the bagged, but unlabeled remains. A second reason for separating the remains was accidental. The barely legible handwriting on the bag was not initially recognized as reading "Mocc Bur 2," it was instead misread as "Mocc Bones." This error was detected when comparing the rebagged Ca-Tuo-314 remains with a Ca-Tuo-279 box inventory compiled on 8/25/98 by Julie London, former</u>	2	1 (adult; two samples taken, both from same individual based on stable isotope results)

Burial	Burial Particulars	NAGPRA MNI	OUR MNI/# Individuals sampled
	<u>NAGPRA Coordinator. In her inventory, London sought to separate those remains that may belong to Ca-Tuo-314, from those that were consistent with descriptions from site Ca-Tuo- 279. The remains described in this report are the ones London separated from the Ca-Tuo-279 collection.</u> ***** Osteological examination determined that Burial UNK. 6A, 6B represents a minimum of two individuals, One adult of indeterminate sex and a fetus of indeterminate sex. The second individual is represented only by a fragmented tibia shaft and unidentifiable fetal long bone fragments. The first individual is represented by charred and fragmented remains. Some bones are calcined indicating that they were subject to high temperatures for a fairly long time. The condition of these remains is consistent with cremation. Long bone remains include a fragmented proximal femur, including a separated and fragmented femoral head, fragmented tibia, fibula, ulna, and humerus with a separated and fragmented head. There are several undiagnostic fragmentary pieces of long bones. Additional remains include a fragmented patella, four fragmented ribs, a fragmented thoracic vertebrae, a superior articular facet of a sacrum and several fragments from an os coxae. None of the pieces from the os coxae were indicative of sex due to its fragmentary state. *****<i>Only the adult was sampled as the fetal remains could not be relocated. Samples taken include a rib fragment and a longbone fragment. These were labelled as UNK 6AR and UNK 6LB and treated as individuals. After Isotopes analysis, these samples were determined to likely belong to one individual based on the closeness of the values.</i>		
UNK 7: Unk 7A & Unk 7B	No Provenience is provided for these individuals, but the NAGPRA paperwork states that these individuals may be related to Burial 2 in terms of site location. Originally, the remains for TUO-314 were contained in nine paper bags. The remains in the paper bag labeled "Mocc Bur 2" were divided and rebagged into 3 separate bags: Bur. 2, UNK. 6A, 6B and UNK. 7A, 7B, 7C. See reasoning stated above in italic. *****Osteological examination determined that Burial UNK. 7 A, 7B, 7C represents a minimum of three individuals: One adult-sex male, one child of indeterminate sex and one fetus of indeterminate sex. The second individual is represented only by a fragmented tibia shaft. The third individual, the fetus, is represented only by a partial tibia and fibula shaft. The first individual is incomplete and mostly fragmentary. Fragmented long bones remains include a femur shaft and separated and fragmented head, two tibia shafts, a fibula shaft, both humeri shafts and one separated and fragmented head, an ulna and a radius shaft. Additional remains present include: a fragmented patella, a partial sacrum, undiagnostic cranial fragments and several fragmentary pieces of os coxae from which sex was determined. Sex determination was based on acetabulum size and diameter, specifically the large size and lateral direction of the acetabulum, a narrow sciatic notch, and a flat sacro-iliac articulation, all of which correspond to Rogers and Saunders' (1994, 39:1 047-56) list of 17 individual morphological traits of the human pelvis. *****<i>A tibial fragment was taken from the adult male and labelled as UNK 7A, while UNK 7B is a tibial shaft fragment from the child. However, the Unk 7b was later identified as a tibial fragment from a deer. The remains of the fetus could not be relocated and were not sampled.</i>	3	2 one adult (tibia) and one juvenile that was later identified to be a deer tibia

Burial	Burial Particulars	NAGPRA MNI	OUR MNI/# Individuals sampled
UNK 8: Unk 8A - temporal, Unk 8B- LB & Unk 8C-juv	According to Slaymaker, these remains are those of burials scattered on the surface. He describes them as belonging to the Eastern half of the site (1971: 134) and consisting of one adult, one child-- 197.10 grams. and one adult cremation -13.60 grams. No other information pertaining to these remains was available. *****The remains were found in a small paper bag labeled: "Eastern half of the site. 210.0 g .. " Osteological examination does conform to Slaymaker's report. Examination determined that Burial UNK. 8A, 8B, 8C represents a minimum of three individuals: one adult- sex male; one adult- sex undetermined; one child/young adult, sex undetermined. The remains are very fragmented and some are burned. Some of the remains were covered in red ochre. These remains have since been rinsed to aid in osteological analysis. It was not always possible to side bones because of their condition. Due to their fragmentary state, the remains of the first two individuals cannot be clearly separated. Sex of the first individual was determined from the size of the mastoid process. *****The adults are represented by the following elements: one right femur shaft fragment, one right tibia shaft fragment, tibia fragments, shattered proximal epiphysis of humerus, humerus shaft fragments, and a fragmented distal portion of a metacarpal. Cranial bones include: a left temporal bone (likely male due to the size of the mastoid process), a right temporal bone (likely a different individual from the left one due to a substantial size difference), temporal fragments, a right zygomatic bone, two fragments from the basilar portion of the occipital bone and a left occipital condyle, occipital fragments, and four undiagnostic cranial fragments. The child is represented by only 11 unidentifiable subadult long bone fragments. ***** <i>Two samples were taken from the adult remains, a temporal bone fragment (Unk 8AT, from the male) and a longbone fragment (Unk 8BLB- indeterminate sex). Hull and Eerkens were able to identify a rib fragment within the juvenile remains, so this was sampled and labelled as Unk 8C.</i>	3	3 (8a -aduly male; 8b indt. Adult; 8c juve.)

Appendix C2. Chapter 6-All Collagen C, N, and S from Don Pedro Collection

Table below is for TUO-279.

Sample ID	Sex	Age at Death	Element	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	S (ug)	$\delta^{34}\text{S}$	% Col. Yield
TUO-279 B1	ind.	adult	thoracic vertebra spinous process	-17.7	344.81	6.4	115.06	3.50			5.4
TUO-279 B2 Indiv.1	m	adult (27-35y)	left fibula fragment	-18.6	290.02	7.2	99.38	3.40	16	4.0	3.1
TUO-279 B2 Indiv.1	m	adult (27-35y)	LLM1	-18.4 (av. of sect)		8.0 (av of sect)		3.10			
TUO-279 B2 Indiv.1	m	adult (27-35y)	LLM3	-18.6 (av. of sect)		7.9 (av of sect)		3.30			
TUO-279 B2 Indiv.1	m	adult (27-35y)	LLM1 root other half						38.8	4.7	13.1
TUO-279 B2 Indiv.2	ind.	adult	left occipital fragment	-18.4	303.91	7.0	105.91	3.35	13.3	4.9	4.4
TUO-279 B4	ind.	adult	tibial fragment	-18.6	345.74	7.1	114.41	3.53	13.3	4.9	2.3
TUO-279 Unk1	ind.	adult	spinous process	-18.9	425.40	5.9	162.86	3.05	17	12.2	10.7
TUO-279 Unk2	ind.	adult	rib fragment	-18.8	369.08	6.5	126.83	3.40			2.0
TUO-279 Unk3	ind.	adult	right third metacarpal	-18.6	482.15	6.9	167.46	3.36	17.8	4.1	27.7
TUO-279 Unk4 Indiv.1	ind.	adult	rib fragment	-17.6	485.95	8.1	165.49	3.43	20.8	5.0	13.1
TUO-279 Unk4 Indiv.2	ind.	juv.	spinous process fragment	-18.4	465.08	5.9	187.17	2.90	20	14.8	14.3

Note: n=9 (all radiocarbon dated); TUO-279 was once 4-TUO-106; “av of sect” means average of tooth sections.

Sample ID	Sex	Age at Death	Element	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	S (ug)	$\delta^{34}\text{S}$	% Col. Yield
TUO-300 B1	f	adult	fibula fragment	-19.1	412.71	6.6	148.83	3.24	22.0	10.5	2.9
TUO-300 B2	ind.	adult	L. zygomatic fragment	-19.9	414.76	7.2	150.77	3.21			2.8
TUO-300 B3	m	adult	tibial fragment	-18.3	451.69	9.2	157.53	3.35	17.0	10.7	1.5
TUO-300 B5	ind.	adult	tibial fragment	-19.1	408.62	7.5	147.86	3.22	28.0	8.1	3.2
TUO-300 B6	ind.	juv. (inf)	cranial fragment	-18.9	459.91	9.1	163.31	3.29	21.0	7.5	7.6
TUO-300 B8	f	adult (21-35yo)	mandible fragment	-18.3	407.60	7.8	146.89	3.24	20.0	9.2	3.4
TUO-300 B8	f	juv diet	LLM1	-18.3 (av. of sect)		9.3 (av sect)		3.30			
TUO-300 B8	f	juv diet	LLM1 other half						26.6	4.2	
TUO-300 B8	f	y.adult diet	LRM3	-19.2 (av. of sect)		8.8 (av sect)		3.30			
TUO-300 B9A	f	adult (old)	mandible fragment	-19.4	353.53	7.7	123.48	3.34		4.7	2.5
TUO-300 B9A	f	juv diet	ULM1	-20.0 (av of sect)		7.8 (av sect)		3.40			
TUO-300 B9A	f	juv diet	ULM1 root	-19.5	256.86	7.5	83.36	3.59			10.2
TUO-300 B9A	f	juv. diet	ULM2	-19.3 (av of sect)	274.30	8.3 (av sect)	84.78	3.77			4.1
TUO-300 B9B	ind.	adult	radius fragment	-19.2	461.97	6.6	160.42	3.36	21.0	8.1	2.3
TUO-300 B10A1	f	adult (21-35yo)	r. mandible	-19.2	303.80	7.8	108.71	3.26			3.3
TUO-300 B10A1	f	juv diet	LRM1	-19.1	165.80	8.9	56.03	3.45	33.9	5.5	0.8

Sample ID	Sex	Age at Death	Element	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	S (ug)	$\delta^{34}\text{S}$	% Col. Yield
TUO-300 B10A1	f	y. adult diet	LRM3						23.8	5.1	0.6
TUO-300 B10A2	ind	adult	rib fragment	-19.5	429.10	7.4	152.70	3.28			2.8
TUO-300 B11A	ind.	juv.	longbone fragment	-19.8	360.65	7.5	129.36	3.25	22.0	6.0	3.8
TUO-300 B11B	M	15-20yo	Premolar (P4)	-18.8	408.76	9.2	138.92	3.43	23.6	5.6	5.1
TUO-300 B13	ind.	juv.	rib fragment	-19.7	422.95	6.6	154.64	3.19			2.9
TUO-300 Unk1	ind.	juv.	longbone fragment	-19.8	366.74	7.9	117.05	3.66	25.0	8.2	2.3
TUO-300 Unk2 1.1	ind.	adult	longbone fragment	-19.2	215.11	6.9	72.88	3.44			0.4
TUO-300 Unk3	ind.	adult	femur fragment	-18.3	235.15	8.6	81.32	3.37			0.3
TUO-300 Unk4	m	adult	cranial fragment	-19.8	380.14	8.2	128.54	3.45			1.1
TUO-300 Unk5	f	adult (old)	left distal femur fragment	-20.0	357.00	9.5	102.73	4.05			1.9
TUO-300 Unk5		y.adult diet	LRM3	-19.1 (av sect)	228.62	8.7 (av sect)	78.21	3.41			5.5
TUO-300 Unk5		juv diet	M1root	-19.2	196.36	8.0	66.22	3.46			8.1
TUO-300 Unk6	ind.	adult	left fibula fragment	-18.1	356.32	8.4	128.65	3.23	21.0	4.1	21.5
TUO-300 Unk7A	ind.	adult	femur fragment	-18.0	356.32	9.2	124.48	3.34			1.6
TUO-300 Unk7A	ind	juv diet	ULM1	-19.1 (av sect)		8.6 (av sect)		3.30			
TUO-300 Unk7ATM		juv diet	ulm1 other half	-18.7	302.98	8.0	108.91	3.25			13.7
TUO-300 Unk7B	ind.	juv.	left humerus fragment	-19.1	362.61	8.4	126.57	3.34	22.0	5.4	2.6
TUO-300 Unk8	ind.	ind.	cranial fragment	-19.6	458.27	6.8	161.74	3.31			3.7

Sample ID	Sex	Age at Death	Element	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	S (ug)	$\delta^{34}\text{S}$	% Col. Yield
TUO-300 Unk9	f	adult	mandible fragment	-19.3	495.19	8.2	171.98	3.36	19.0	4.8	5.1
TUO-300 Unk9	f	adult	LLM3	-19.8 (av sect)		8.6 (av sect)		3.40			
TUO-300 Unk11	m	adult	cranial fragment	-18.6	340.61	8.1	121.35	3.27	16.0	2.9	3.2
TUO-300 Unk12	ind.	adult	hand phalanx fragment	-18.4	359.47	8.5	128.65	3.26			3.7
TUO-300 Unk13-rib	ind.	ind.	rib fragment	-18.8	490.97	8.4	168.91	3.39			4.3
TUO-300 Unk16A	f	adult	left 4th metatarsal	-18.5	456.16	8.5	149.39	3.56			2.3
TUO-300 Unk16A	f	adult	left 4th metatarsal trabecular bone	-18.1	184.20	8.2	65.76	3.27			2.5
TUO-300 Unk16B	m	adult	right zygomatic fragment	-19.6	443.52	8.7	153.51	3.37			1.9
TUO-300 Unk16C	ind.	adult	rib fragment	-18.9	390.94	7.2	135.93	3.36	15.6	4.8	3.9
TUO-300 Unk16Ct	ind	adult	LLM3	-19.8 (av of sect)		7.0 (av of sect)		3.40			
TUO-300 unk 16ct	ind	adult	LLM3 other half								5.3
TUO-300 Unk18	ind.	adult	rib fragment	-19.4	422.47	8.2	150.42	3.28			2.7
TUO-300 Unk20	ind.	ind.	right temporal fragment	-18.6	332.23	8.4	118.21	3.28			1.8

Note: TUO-300 was once 4-TUO-208; note that some individuals have provenience of 4-TUO-205; “av of sect” means average of tooth sections.

Sample ID	Sex	Age at Death	Element	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	S (ug)	$\delta^{34}\text{S}$	% Col. Yield
TUO-314 B2A	m	adult	R. mandible	-18.7	322.47	6.6	105.91	3.55			2.0
TUO-314 B2A	m	adult	lrm1	-19.1 (av of sect)	422.56	6.9 (av of sect)	141.20	3.49	21.7	3.8	4.2
TUO-314 B2B	ind.	adult	L. mandible	-18.9	433.89	6.5	145.82	3.47	20.0	4.3	3.6
TUO-314 B2B	ind.	adult	LLM1	-19.1 (av of sect)		7.4 (av of sect)		3.30			
TUO-314 B2B	ind.	adult	LLM1 other half						20.0	3.9	6.8
TUO-314 B2B	ind.	adult	LLM3	-18.9 (av of sect)		7.5 (av of sect)		3.30			
TUO-314 B4A	ind.	young adult	R. mandible	-19.3	421.64	6.4	144.50	3.40	20.0	3.7	2.0
TUO-314 B4A	ind.	juv diet	LRM1	-19.5 (av of sect)		7.2 (av of sect)		3.40			
TUO-314 B4A	ind.	juv diet	LRM2	-19.2 (av of sect)		7.3 (av of sect)		3.30			
TUO-314 B4A	ind.	juv diet	lrm1 + m2 combined						18.7	3.6	10.6
TUO-314 B4A	ind.	young adult diet	LRM3	-19.2 (av of sect)		7.3 (av of sect)		3.30			
TUO-314 B4B	ind.	ind. Adult	longbone fragment	-19.3	378.44	6.9	124.21	3.55	21.0	3.6	2.5
TUO-314 Unk1C	ind.	juv.	rib fragment	-18.7	399.42	6.9	144.95	3.21			9.9
TUO-314 Unk2A	ind.	juv.	rib fragment	-19.8	376.95	5.6	136.20	3.23			3.5
TUO-314 Unk2Bi1	ind.	adult	tibial fragment	-18.8	415.79	7.1	150.77	3.22	21.0	3.6	4.6
TUO314 Unk2Bi2	ind.	adult	maxilla	-19.2	379.44	7.6	126.78	3.49			
TUO-314 Unk2Bi2	ind.	juv diet	M2	-19.0 (av of sect)		7.4 (av of sect)		3.20			
TUO-314 Unk5A	ind.	adolesc ent (12-19 yo)	fibula fragment	-19.4	458.88	7.8	167.16	3.20	27.0	3.5	4.0
TUO-314 Unk6AR	ind.	adult	rib fragment	-18.9	446.55	6.8	163.31	3.19			5.7

Sample ID	Sex	Age at Death	Element	$\delta^{13}\text{C}$	C (ug)	$\delta^{15}\text{N}$	N (ug)	C/N	S (ug)	$\delta^{34}\text{S}$	% Col. Yield
TUO-314 Unk6AL	ind.	adult	longbone fragment	-18.6	479.47	6.7	172.91	3.24	20.0	5.0	2.9
TUO-314 Unk7A	m	adult	tibial fragment	-18.9	489.78	6.5	173.86	3.29	18.0	5.1	2.0
TUO-314 Unk8A	m	adult	Temporal fragment	-19.4	401.46	6.2	146.89	3.19			2.2
TUO-314 Unk8B	ind.	adult	longbone	-17.8	459.91	8.3	167.16	3.21	21.0	4.1	6.8
TUO-314 Unk8C	ind.	juv.	rib fragment	-20.6	287.57	5.8	107.83	3.11			5.4

Note: TUO-314 was once known as 4-TUO-308; “av of sect” means average of tooth sections.

Appendix C3. Chapter 6- $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ on Bone Apatite

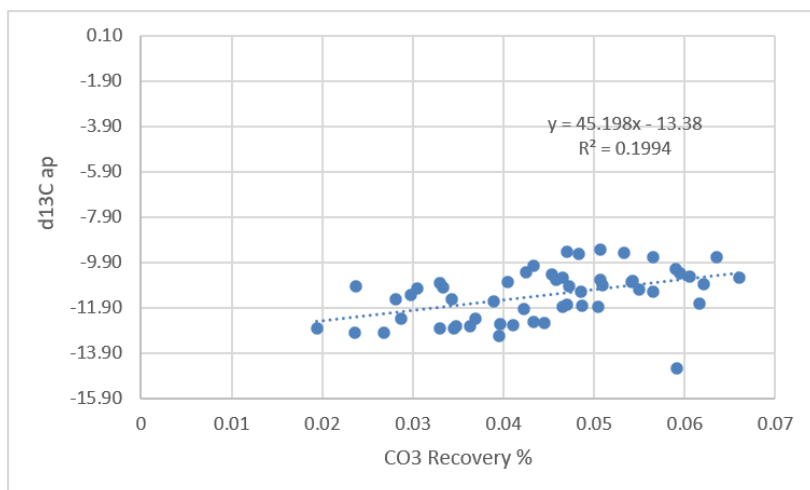
Apatite preparation: Bone apatite samples were prepared following standard lab protocol. After bone samples had been drilled, sonicated and dried, a small amount was taken for apatite. These samples were crushed into powder using an agate mortar and pestle. Approximately 0.04g of each sample was placed in a weighed centrifuge vial. Organics were removed by adding a 1.5% sodium hypochlorite solution (0.04ml/mg sample) and samples were left to soak for 24 hours. After the 24 hour soak, samples were centrifuged and the solution replaced. After a second 24 hours, the solution was discarded and the samples were washed three times with dH₂O. A diagenetic wash of 0.1M acetic acid solution (at the same ratio as sodium hypochlorite) was added and the samples were left to soak for 12 hours. The samples were then rinsed three times with dH₂O and any remaining water was pipetted off, and samples were left to dry with the caps off.

Once dry, samples were submitted to the UCD SIF. $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ were measured using a GasBench II system interfaced to a Delta V Plus IRMS (Thermo Scientific, Bremen, Germany).

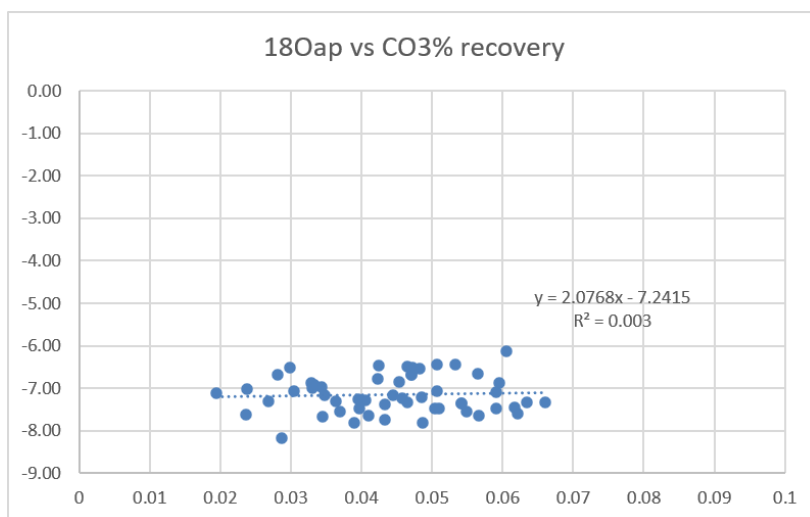
The issue with the samples is that there is a linear correlation between $\delta^{13}\text{C}$ and % CO₃ recovery. This may be due to a number of factors, including exchange with atmospheric carbon, that they are bone and the apatite was affected by diagenesis while the collagen remained viable; that the 0.1M acetic acid affected the values because they were left in solution for too long (hours instead of minutes); as well as possible issues during analysis. The graphs below the table show the issues. These values are being reported for completion and transparency.

Sample	Analysis#	Wt (mg)	d13CVPDB (‰)	d18OVPDB (‰)	% CO ₃	Comments
TUO-279 B1	10330	0.99	-10.7	-7.3	5.42	
TUO-279 B1	10331	1.018	-10.8	-7.3	5.42	duplicate
TUO-279 B2.1	10332	1.059	-11.0	-7.0	2.37	
TUO-279 B2.2	10333	1.03	-10.4	-6.9	5.95	
TUO-279 B4	10334	1.003	-11.0	-6.5	4.72	
TUO-279 U1	10335	0.976	-14.3	-7.2	3.84	
TUO-279 U2	10336	1.006	-10.9	-7.6	6.21	
TUO-279 U3	10337	1.02	-14.5	-6.6	1.03	
TUO-279 U4.1	10338	0.999	-12.0	-6.8	4.23	
TUO-279 U4.2	10339	1.088	-12.8	-7.0	3.30	
TUO-300 B1	10340	0.996	-11.2	-7.2	4.86	
TUO-300 B2	10341	0.994	-11.5	-7.0	3.43	
TUO-300 B3	10342	0.996	-10.6	-7.3	6.61	
TUO-300 B5	10343	0.987	-12.7	-7.2	3.48	
TUO-300 B6	10344	1.059	-14.1	-5.8	2.30	
TUO-300 B8	10349	0.98	-11.1	-7.1	3.05	
TUO-300 B8	10350	0.997	-11.0	-6.9	3.33	duplicate
TUO-300 B9A	10351	1.05	-11.4	-6.5	2.98	
TUO-300 B9B	10352	0.986	-11.8	-6.7	4.71	
TUO-300 B10A1	10353	1.068	-10.2	-7.1	5.90	

Sample	Analysis#	Wt (mg)	d13CVPDB (‰)	d18OVPDB (‰)	% CO3	Comments
TUO-300 B10A2	10354	1.012	-10.5	-6.8	4.54	
TUO-300 B11A	10355	1.064	-10.3	-6.5	4.25	
TUO-300 B13	10356	0.998	-9.7	-6.7	5.65	
TUO-300 U1	10357	1.044	-10.6	-6.5	4.65	
TUO-300 U2.1	10358	0.996	-12.8	-7.7	3.45	
TUO-300 U3	10359	1.006	-13.0	-7.6	2.36	
TUO-300 U4	10360	1.037	-12.8	-7.1	1.94	
TUO-300 U5	10361	1.073	-11.5	-6.7	2.81	
TUO-300 U6	10362	0.972	-14.4	-6.7	1.30	
TUO-300 U7A	10363	1.025	-10.8	-7.3	4.05	
TUO-300 U7B	10368	1.004	-9.5	-6.4	5.33	
TUO-300 U7B	10369	1.063	-9.3	-6.5	5.07	duplicate
TUO-300 U8	10370	0.982	-13.0	-7.3	2.68	
TUO-300 U9	10371	1.023	-11.7	-7.8	3.90	
TUO-300 U11	10372	0.99	-10.7	-7.1	5.07	
TUO-300 U12	10373	1.013	-10.9	-7.5	5.10	
TUO-300 U13	10374	1.08	-11.1	-7.6	5.49	
TUO-300 U14	10375	0.998	-14.6	-7.5	5.91	
TUO-300 U15	10376	0.995	-9.4	-6.7	4.70	
TUO-300 U16A	10377	1.002	-9.5	-6.5	4.83	
TUO-300 U16B	10378	1.007	-10.8	-6.9	3.29	
TUO-300 U16C	10379	1.037	-11.7	-7.5	6.17	
TUO-300 U18	10380	1.007	-9.7	-7.3	6.35	
TUO-300 U20	10381	1.012	-10.7	-7.2	4.58	
TUO-314 B2A	10382	0.987	-11.9	-7.5	5.04	
TUO-314 B2B	10387	0.975	-13.1	-7.3	3.95	
TUO-314 B4A	10388	1.063	-12.7	-7.6	4.10	
TUO-314 B4A	10389	1.006	-12.5	-7.7	4.33	duplicate
TUO-314 B4B	10390	0.997	-11.2	-7.6	5.66	
TUO-314 U2A	10391	1.004	-11.8	-7.8	4.87	
TUO-314 U2B	10392	1.023	-12.6	-7.5	3.97	
TUO-314 U5A	10393	1.009	-10.1	-7.4	4.33	
TUO-314 U6A1	10394	1.013	-12.7	-7.3	3.63	
TUO-314 U6A2	10395	1.021	-12.6	-7.2	4.45	
TUO-314 U7A	10396	0.993	-11.2	-7.6	9.64	
TUO-314 U7B	10397	0.988	-12.2	-5.6	3.95	
TUO-314 U8A1	10398	1.011	-12.4	-7.6	3.69	
TUO-314 U8A2	10399	1.005	-12.4	-8.2	2.87	
TUO-314 U8B	10400	1.035	-11.9	-7.3	4.65	
TUO-328 BU1	10401	0.992	-10.5	-6.1	6.05	



Linear Correlation



No Linear Correlation