# RESOURCE INTENSIFICATION IN PRE-CONTACT CENTRAL CALIFORNIA: A BIOARCHAEOLOGICAL PERSPECTIVE ON DIET AND HEALTH PATTERNS AMONG HUNTER-GATHERERS FROM THE LOWER SACRAMENTO VALLEY AND SAN FRANCISCO BAY

A Dissertation

by

ERIC JOHN BARTELINK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2006

Major Subject: Anthropology

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Chair of Committee: Lori E. Wright
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Ethan L. Grossman
Alston V. Thoms

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# ABSTRACT

Resource Intensification in Pre-Contact Central California: A Bioarchaeological
Perspective on Diet and Health Patterns Among Hunter-Gatherers from the Lower
Sacramento Valley and San Francisco Bay. (May 2006) Eric John Bartelink, B.S.,
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In this study, I use bioarchaeological data derived from human burials to evaluate subsistence change in mid-to-late Holocene central California (circa 4950-200 B.P.). Previous investigations in the region have proposed two competing models to account for changes in subsistence patterns. The *seasonal stress hypothesis* argues that the increased reliance on acorns and small seeds during the late Holocene led to improved health status, since these resources could be stored and used as a "buffer" against seasonal food shortages. In contrast, *resource intensification models* predict temporal declines in health during the late Holocene, as measured by a decline in dietary quality and health status, increased population crowding, and greater levels of sedentism. I test the hypothesis that health status, as measured by childhood stress and disease indicators, declined during the late Holocene in central California.

I analyzed 511 human skeletons from ten archaeological sites in the Sacramento Valley and San Francisco Bay area to investigate temporal and spatial variability in diet and health. I analyzed a subset (n = 111) of this sample to evaluate prehistoric dietary patterns using carbon and nitrogen stable isotope ratios. Indicators of health status show significant temporal and regional variation. In the Valley, tibial periosteal reactions, porotic hyperostosis, and enamel hypoplasias significantly increased through time, implying a decline in health status. In the Bay, health indicators show little temporal variability. However, inter-regional comparisons indicate a higher prevalence of stress and disease indicators among Bay Area skeletons than in the Valley skeletal series. The stable isotope data from human bone collagen and apatite also indicate significant inter-regional differences in prehistoric diets between the Bay and the Valley. In the Bay, diets shifted from high trophic level marine foods to a more terrestrially focused diet over time. In the Valley, there are no significant dietary trends observed in the data. Dental caries and antemortem tooth loss are significantly more prevalent in the Valley than in the Bay, and closely match the isotopic findings. The paleopathological findings provide support for late Holocene resource intensification models posited for the Valley, but not for the Bay Area.

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# CHAPTER I

# INTRODUCTION

> California prehistory has long been resistive to interpretation, and promises to remain so. Many factors contribute to this condition: absence of pottery and of permanent structures; a limited cultural inventory; quantitative meagerness of remains in most sites; paucity of ethnographic data where archaeological ones are most accessible, and vice versa; unusual sessility, from all indications, of population; and conservative stability, in the large, of culture. The nut will be hard to crack; this must be frankly admitted in advance. What the situation above all calls for is described by a phrase which I learned from Boas, as he from Virchow: "icy enthusiasm" [Kroeber 1936:115].
>
> — Alfred E. Kroeber

In the above passage Alfred Kroeber voiced a rather dismal view of California prehistory. His "icy enthusiasm" for California archaeology had much to do with his experience in other regions, such as the American Southwest, where "culture change" was evident in pottery styles and domestic architecture. Although Kroeber's colleague at University of California at Berkeley, Max Uhle, found evidence of cultural differences within the deeply stratified Emeryville shellmound site from San Francisco Bay, Kroeber discounted most of his findings (Bennyhoff 1986). Despite his pessimism, Kroeber did recognize some of the major challenges of hunter-gatherer archaeology, and aptly noted that scholars would have to work harder to find evidence of culture change in California than in many other places.

With an estimated population of 310,000 individuals, California was among the most densely settled landscapes in North America at the time of European contact (Cook

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[1] This dissertation follows the style and format of *American Antiquity*.

1976). It has been of the subject of considerable interest that such high population numbers could exist among non-agricultural societies. Early theorists attributed this demographic anomaly to California's natural resource abundance of large game, fish, shellfish, and plant foods (Bean and Lawton 1976; Kroeber 1939). The abundant food supply was cited as the reason why agriculture failed to develop; it was simply not needed. Others argued that the intensive focus on stored food staples by native groups, acorns in particular, could be considered a type of "proto-agriculture" (Bean and Lawton 1976). These perspectives advanced the notion that indigenous peoples had little impact on their natural environment, and produced an archaeological record that was essentially "static" (Jones and Raab 2004). Many ethnographers were influenced by early European accounts that described large game herds throughout San Francisco Bay and the Central Valley of California. It received little mention that the resource abundance observed during the contact period may have been due to a rebound in game populations, following significant declines in human population caused by the spread of introduced foreign diseases (Broughton 1999; Erlandson and Bartoy 1995; Erlandson et al. 2001; Preston 1996, 2002a, 2002b).

However, evidence for resource abundance in California's archaeological record has been seriously challenged by a number of recent studies (Basgall 1987; Beaton 1991; Broughton 1994a, 1994b, 1997, 1999, 2001; Hildebrandt and Jones 1992, 2002; Jones and Raab 2004a, 2004b). For instance, recent archaeofaunal studies have found evidence of *resource depression*, as measured by the temporal decline in low-cost, large game relative to higher-cost, smaller fauna during the late Holocene (Broughton 1994a, 1994b, 1997, 1999, 2001; Hildebrandt and Jones 1992, 2002; Simons 1992). Additionally, many archaeologists have linked the widespread abundance of mortar and pestle technology, beginning circa 4500 B.P., to the intensified use of high-cost vegetal resources, such as acorns (Basgall 1987).

These approaches fall under the rubric of *resource intensification models*, which predict temporal declines in foraging efficiency during the late Holocene. Resource intensification is defined as "a process by which the total productivity per areal unit of land is increased at the expense of overall decreases in foraging efficiency" (Broughton 1994b). Intensification theorists attribute the decline in high-ranked prey, and the increased focus on more costly, smaller fauna and plant staples, to resource imbalances caused by overpopulation during the late Holocene (Broughton 1994b). The prehistoric record in central California suggests that human populations were growing, and becoming more sedentary and culturally circumscribed throughout the late Holocene (Basgall 1987; Beaton 1991; Broughton 1999).

In central California, subsistence patterns have been reconstructed through the study of stone tool technology, archaeofaunal remains, and most recently, plant macrobotanical remains (Basgall 1987; Broughton 1999; Schulz 1981; Simons 1992; Wohlgemuth 2004). In this dissertation, I use data gleaned from human skeletal remains to investigate changes in diet and health during the middle and late Holocene in central California (circa 4950-200 B.P.). I draw on predictions from resource intensification theory to develop hypotheses aimed at understanding the health consequences of subsistence change in the prehistoric lower Sacramento Valley and San Francisco Bay of central California. Resource intensification models predict reduced foraging efficiency, associated with population-resource imbalances, territorial circumscription, and higher levels of sedentism during the late Holocene. As argued by Broughton and O'Connell (1999:156):

> …lower foraging efficiency implies greater foraging effort required to meet minimum caloric requirements and an increased risk of malnutrition. Undernourished foragers should experience higher levels of morbidity and mortality, slower growth rates, and reduced adult body size. The long-term decline in foraging efficiency documented in late Holocene California should be associated with higher levels of morbidity and mortality and smaller body size and stature among human consumers.

If resource intensification models accurately characterize subsistence change in California, then it follows that these patterns should be recognized in diet and health indicators observed on the bones and teeth of human skeletons.

### ***Research Design***

The archaeological chronology used for central California divides the middle to late Holocene into three discrete time periods: the Early period (circa 4500-2500 B.P.), the Middle period (circa 2500-1300 B.P.), and the Late period (circa 1300-200 B.P.). I use this framework to evaluate temporal changes in diet and health patterns in the lower Sacramento Valley and San Francisco Bay area.

In this study, I address the following research questions to investigate resource intensification models in prehistoric central California:

1. Were subsistence changes during the middle to late Holocene in central California characterized by the increased consumption of low trophic level fauna and plant resources, such as acorns, seeds, and root foods?
2. Were these subsistence changes associated with a decline in health status?

3. Did these changes result in greater inequality between the sexes, reflected in differences in both diet and the quality of health?

To test the predictions of resource intensification models, I use several independent lines of evidence. Stable carbon and nitrogen bone isotope values are commonly used in the reconstruction of prehistoric diets, and can be used to distinguish between marine and terrestrial diets in coastal settings (Schwarcz and Schoeninger 1991). To evaluate paleodietary change in central California, I examine human stable carbon and nitrogen isotopes of bone collagen, and stable carbon isotopes of bone apatite. I hypothesize that the shift toward greater consumption of lower-trophic level faunal resources and vegetal staples through time should be evident in the carbon and nitrogen stable isotope signatures. Although stable isotope values often cannot identify the specific food resources consumed, these data provide a means through which to evaluate the relative contribution of proteins and carbohydrates to diet, and also the respective contribution of different macronutrients that are derived from marine versus terrestrial ecosystems.

Dental disease provides an additional line of evidence that can be used to make inferences about prehistoric diet and oral health. I hypothesize that the prevalence of dental caries, antemortem tooth loss, and abscesses of the jaws should increase through time, concomitant with greater consumption of carbohydrate-rich foods, such as acorns, seeds, and root foods during the Middle and Late periods. Because San Francisco Bay populations had greater access to protein-rich marine foods that protect against caries development, I expect to find fewer carious lesions in these samples than in those from the lower Sacramento Valley.

To evaluate temporal changes in health status, I examine the following osteological indicators: 1) tibial periostoses; 2) mean femoral length, 3) porotic hyperostosis, and 4) linear enamel hypoplasia. I hypothesize that the prevalence of tibial periostoses (which are often used to infer general levels of infectious disease) should increase through time, associated with greater population crowding and sedentism during the late Holocene. I hypothesize that childhood health status, as measured by mean femoral length, porotic hyperostosis, and linear enamel hypoplasia, will decline through time. Because the purported changes in subsistence pattern originated between the Early and Middle periods, I expect to find greater declines in health associated with this transition than between the Middle and Late periods.

Sex differences in access to food resources may be the result of gendered status differences, or may simply be the unintended result of sexual division of labor practices (Grauer and Stuart-Macadam 1998). For instance, if males spent extended periods of time fishing and hunting away from the village, they would be expected to consume higher proportions of protein-rich foods. Similarly, females would be expected to consume higher proportions of plant foods, such as acorns, roots, seeds, and berries, since these foods are generally collected and processed by women. In central California, most lines of evidence suggest that sexual division of labor patterns became more demarcated through time, beginning with the Middle period, when acorns became a dietary mainstay (McGuire and Hildebrandt 1994). This is consistent with the predictions of intensification models, as greater sex segregation in labor organization may develop in response to population-resource imbalances (Cohen 1989a, 1989b). To evaluate evidence of sexual division of labor, I compare bone stable isotope values and the prevalence of dental disease between male and female skeletons.

### *Organization of the Dissertation*

In Chapter II, I describe the environmental and archaeological context of the project area, and provide descriptions of the archaeological sites used in the present study. Chapter III contains a critical review of resource intensification models that have been posited for prehistoric central California, as well as a summary of the bioarchaeological literature regarding subsistence transitions in southern and central California. In Chapter IV, I describe the demographic composition of the skeletal series, the methods used to estimate sex and age, and the justification for the dating scheme I used to place the skeletal series within a temporal framework. I address biases in the sex and age distribution of the samples, and also discuss taxonomic issues in California archaeology.

Chapter V provides a paleodietary reconstruction using stable carbon and nitrogen isotopes of bone collagen and carbon isotopes of bone apatite. I use archaeological and ethnographic evidence to first define the isotopic parameters of the prehistoric food resources, and then compare these expectations with the human bone isotope data. In Chapter VI, I examine the prevalence of dental caries, antemortem tooth loss, and alveolar abscessing to evaluate differences in diet and oral health through time, between regions, and between the sexes.

Chapter VII examines the prevalence of periosteal bone lesions of the tibia (lower leg). Although these lesions are considered non-specific indicators of health, they are commonly linked with general levels of infection; hence, the prevalence of tibial lesions through time is expected to change with demographically-influenced factors, such as population density and sedentism, as well as other indicators of declining health status.

Chapters VIII through X focus on non-specific indicators of nutritional stress and health status that occur during growth and development. In Chapter VIII, I use femoral length as a proxy measure for adult stature. Stature shows a strong correlation with morbidity and mortality in modern developing nations, and is a commonly used measure of overall health status. Chapter IX examines the prevalence of porotic hyperostosis in prehistoric crania from central California. Porotic hyperostosis manifests as lesions on the orbital roof and vault of the skull, and is most commonly linked with iron-deficiency anemia. However, lesions may result from iron-deficient diets, or from loss of absorbable iron due to chronic intestinal bleeding or diarrheal disease resulting from infection or parasitism. In Chapter X, I examine the prevalence and timing of dental enamel hypoplasias. Hypoplasias are defects in enamel tissue that are caused by nutritional stress or infection during dental development.

Finally, in Chapter XI, I evaluate the resource intensification models discussed in Chapter III in light of the dietary, nutritional, and paleopathological results. I compare these findings with published research from southern California to evaluate temporal and spatial variability in diet and health patterns. In addition to the specified goals of this research, my expectation is that this study will demonstrate the value of human skeletal data in testing the predictions of archaeological models.

# CHAPTER II

# CENTRAL CALIFORNIA ARCHAEOLOGY

In this chapter, I describe the environmental and cultural context for prehistoric cultures from the lower Sacramento Valley and San Francisco Bay. I then discuss the Central California Taxonomic System, which provides the framework from which I examine temporal and spatial variability in diet and health patterns. Finally, I provide an overview of the archaeological sites used in this study. For this study, I define central California as the region between Sacramento County to the north and Santa Clara County to the south, and between the Pacific Ocean to the west and the Sierra Nevada foothills to the east. This region falls within Kroeber's "California Culture Area", and includes physiographic provinces of the North and South Pacific Coastal Ranges, the Central Valley, and the Sierra Nevada foothills (Kroeber 1925; Moratto 1984). Although encompassing more than half a dozen tribelet territories and numerous language groups, the project area corresponds to the ethnographically-known Ohlone (Costanoan) peoples of San Francisco Bay and the Plains Miwok (Interior Miwok) of the lower Sacramento Valley (Moratto 1984). Linguistic reconstructions indicate that Miwok and Ohlone peoples belonged to the Utian language family, one of four families of the Penutian language stock.

## *Paleoenvironment and Physiography*

A number of methods are used to reconstruct past ecosystems, including pollen profiles, stable isotopes analysis, plant macrofossils, habitat-specific fauna, and geomorphology. Despite some limitations, these approaches generally provide sufficient detail for documenting environmental trends over broad time scales. However, attempts to directly link environmental change with patterns in the archaeological record are hindered by the coarse-grained nature of most proxy measures of climate change (Basgall 1999; Bettinger 1999; Byrne 1979). Despite these limitations, it is recognized that substantial changes in temperature and climate would have had an impact on the abundance of flora and fauna, and thus would have influenced the availability of food resources to prehistoric societies (Aikens 1983; Arnold 1992, Arnold et al. 1997; Glassow et al. 1994; Jones et al. 1999; Kennett and Kennett 2000). Additionally, climate change has played a major role in the visibility of the archaeological record, as observed by geomorphological records of sea level changes and floodplain development (see Atwater et al. 1977; Bickel 1978; Moss and Erlandson 1995; White 2003).

It is well known that significant changes in the earth's climate occurred during the late Pleistocene and early Holocene. Warmer ambient temperatures caused melting of glacial ice and resulted in a rapid rise in global sea level (Atwater et al. 1979; Bickel 1978). Between 8,000 and 10,000 years ago, rising sea level flooded the "Golden Gate" and submerged an interior river valley, creating the San Francisco Bay estuary (Atwater et al. 1977; Atwater et al. 1979; Axelrod 1981). By 6000 B.P., the rate of sea level rise subsided and was counterbalanced by sedimentation rates in the Sacramento-San Joaquin Delta (Atwater et al. 1979). Modern marshland communities were established by 6000 B.P. near the Delta and by 2000 B.P. in the southern reaches of San Francisco Bay. Pollen records from the North and South Coast Ranges indicate that late

Pleistocene-early Holocene transition (circa 12,800-7,000 B.P.) was a period marked by warmer and drier climate. The presence of drought-tolerant plants circa 8500 to 4500 B.P. also indicate warmer temperatures and drier climate, and marks the period known as the Altithermal or Hypsithermal (Anderson 1990:485; Antevs 1948; Barron et al. 2003; West 1993:231, 2002).

During the late Holocene, circa 3000 B.P., most modern vegetation communities were established and local environmental conditions became more stable (West 1993). The development of more maritime conditions between 5200 and 3500 years B.P. in northern California indicates a shift toward milder winters and cooler summers, and less extreme seasonality compared with the early Holocene (Barron et al. 2003:16). Pollen and stable isotope records indicate that the San Francisco Bay area experienced relatively stable climate throughout much of the late Holocene, although changes in pollen species and salinity suggest alternating periods of wet and dry conditions (Adam 1975; Byrne et al. 2001; Goman and Wells 2000; Ingram and DePaolo 1993; Ingram et al. 1996; Malamud-Roam and Ingram 2004).

Byrne et al. (2001) identified two major periods of reduced freshwater inflow into San Francisco Bay from the Sacramento-San Joaquin Delta, circa 3000 to 2500 cal yr B.P., and circa 1750 to 750 cal yr B.P. The second period is associated with a marked reduction in waterflow into the Delta, possibly by as much as 44 percent below modern levels (Byrne et al. 2001:75). This period (1200 and 600 B.P.) roughly corresponds to drought conditions identified in other areas of the world, known alternately as the Medieval Climatic Anomaly (MCA) or Medieval Warm period (Benson et al. 2002;

Hughes and Diaz 1994; Hughes and Graumlich 1995; Ingram et al. 1996; Jones et al. 1999; Meko et al. 2001:1035; Stine 1994). Evidence for multi-decadal drought conditions in California is based on radiocarbon dates of submerged and re-exposed tree stumps in Sierra Nevada lakes, bristlecone pine tree-ring sequences in the White Mountains, and by declines in freshwater inflow into San Francisco Bay from the Sacramento-San Joaquin drainage, as measured by changes in salinity and stable isotope ratios (e.g., Byrne et al. 2001; Hughes and Graumlich 1995; Ingram et al. 1996; Jones et al. 1999; LaMarche 1974; Stine 1994). Although there appears to be strong evidence of epic drought during the MCA, these conditions varied in periodicity and amplitude between regions. Recent debates among scholars have focused on the impact of the MCA on resource productivity in southern California, and specifically whether changes in social complexity during this period are the result of declining productivity of marine resources (Arnold 1992, Arnold et al. 1997; Colten and Arnold 1998) or severe drought conditions (Boxt et al. 1999; Jones et al. 1999; Raab and Larson 1997; Raab et al. 1995). Although the impact of the MCA on prehistoric settlement patterns in central California has not been systematically evaluated, there is some of evidence of population changes during this period. Ingram (1998) and Lightfoot and Luby (2002) note that the MCA coincides with the abandonment of several shell mound sites in the San Francisco Bay area, and may have marked a period of elevated resource stress. However, in the lower Sacramento Valley, Wohlgemuth (2005) notes a significant increase in the number of site components dating to the MCA (corresponding to Late period, phases 1 and 2). Using data from Schulz (1981), Wohlgemuth (2005) hypothesized that population increase during the MCA may have been the result of human migration into the Sacramento Valley from the nearby Sierra Nevada foothills. This hypothesis would account for the scarcity of Late period, phase 1 site components in the foothills, as well as the increase in dated site components in the Valley during this period.

### *Central Valley*

The dominant feature of interior California is the Central Valley, an elongated depression spanning 800 km in length and 30 to 80 km in width, and covering approximately 50,000 $km^2$ (see Figure 2.1; Schoenherr 1992). Valley floor elevation ranges from just below sea level east of San Francisco Bay to around 120 m along its northern and southern borders. The Central Valley is bisected at its center by the Mokelumne River, with the Sacramento Valley to the north and the San Joaquin Valley to the south. Meltwater from the Sierra and Cascade Mountains drains into the Sacramento-San Joaquin watershed through a series of smaller rivers. The main riverine systems include the Sacramento River, which flows from the north to the southeast for 260 km, and the San Joaquin River, which flows from the south to the northwest for 440 km. Both rivers swing westward near the Central Valley's center and merge at the Sacramento-San Joaquin Delta, which drains approximately 40 percent of California's landmass into the San Francisco Bay estuary (Jassby and Cloern 2000; Schoenherr 1992). The pristine Delta encompassed approximately 1900 $km^2$, although most of it has been drained for agricultural use over the past century.

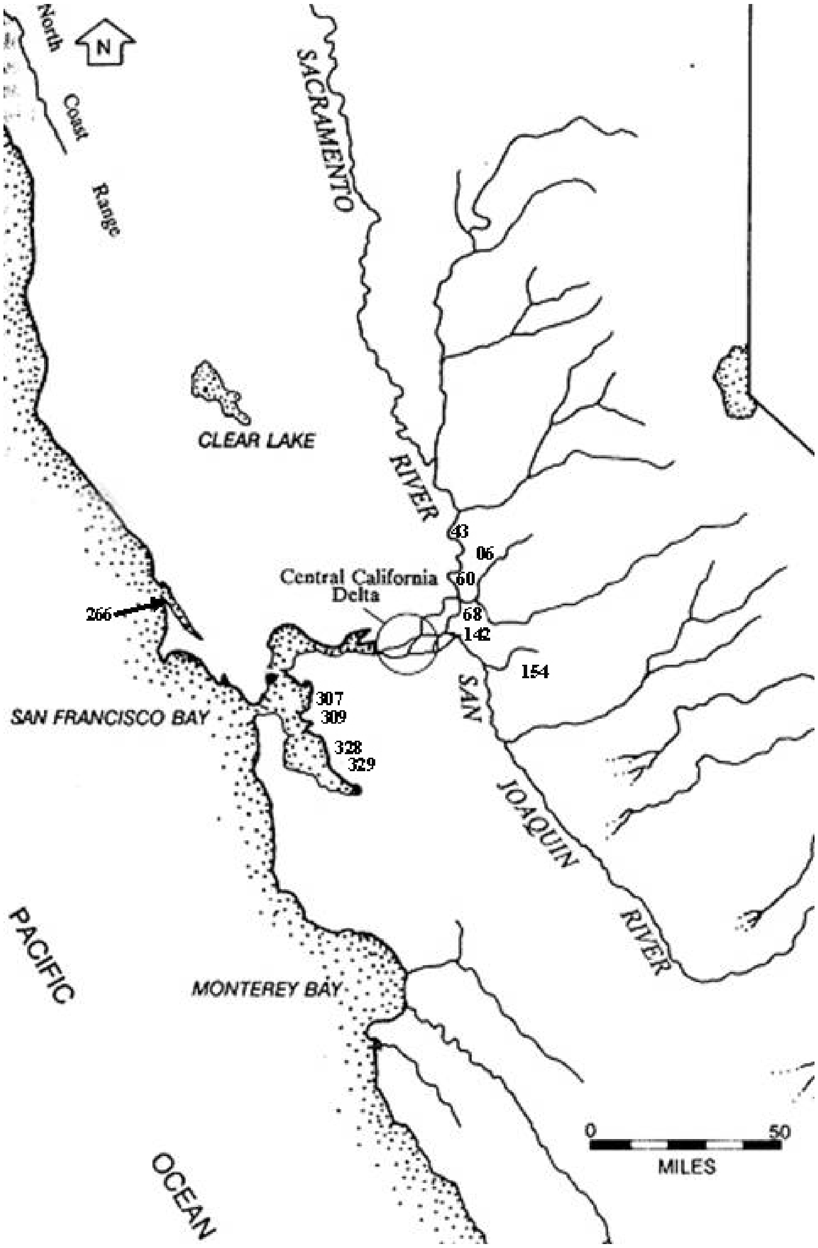

**Figure 2.1.** Map of central California showing the locations of archaeological sites from the lower Sacramento Valley and San Francisco Bay Area (adapted from Beaton 1991:947).

Despite the abundance of fresh water from the Sacramento and San Joaquin Rivers and their many tributaries, the Central Valley – with less than 25 cm of annual rainfall – is arid enough to be considered a desert (Roberts et al. 1980; Schoenherr 1992:16). Annual rainfall varies with latitude, with an average of 46 cm of precipitation in the lower Sacramento Valley and 25 cm in the San Joaquin Valley (Moratto 1984:171; Schoenherr 1992:518). Average temperatures range from 33.3 to 39°C in July and 4.4 to 10°C in January. Prior to recent anthropogenic disturbance, the Central Valley consisted of three overlapping biotic zones: valley grassland, freshwater marsh, and riparian woodland (Schoenherr 1992). Historic maps indicate that the lower Sacramento Valley was once dominated by perennial bunchgrasses, such as needlegrasses, triple-awned grasses, bluegrasses, and rye grasses. Annual grasses and herbs and perennial geophytes (e.g., *Liliaceae* and *Amaryllidaceae*) were also abundant in pristine plant communities (Schoenherr 1992).

Recent draining of the Sacramento-San Joaquin Delta for agricultural activities has resulted in the loss of nearly 94 percent of the freshwater marsh and 89 percent of the riparian woodland habitats of the Central Valley (Schoenherr 1992). Freshwater marsh communities are dominated by rushes, bulrushes (tules), sedges, and cattails (Külcher 1977; Schoenherr 1992). Riparian woodland communities existed along the major rivers and tributaries of the Valley, often extending up to 16 km in width (Roberts et al. 1980; Schoenherr 1992:533-534). These communities support several types of shrub as well as sycamore, willow, box elder, fremont cottonwood, and valley oak.

The Valley was home to a variety of mammals, including tule elk, black-tailed deer, pronghorn, grizzly bear, coyote, jackrabbit, mink, weasel, raccoon, river otter, and beaver. Avifauna included a variety of migratory waterfowl, such as ducks, geese, and swans, as well as resident birds, such as white pelicans, herons, ibis, cranes, cormorants, and eagles (Moratto 1984:170; Schoenherr 1992:532). Riverine resources included freshwater mussel, and anadromous (acipenserids, salmonids) and resident fishes (e.g., cyprinids and catostomids). Ethnohistoric accounts suggest that salmon were especially important dietary items for native peoples during the fall and spring spawning runs, as were smaller resident fishes, which were available throughout the year (Broughton 1994a; Gobalet et al. 2004; Moratto 1984:170; Schulz 1995; Yoshiyama 1999).

### *San Francisco Bay Area*

The Delta waters flow westward from the Central Valley into Suisun Bay, through the Carquinez Strait, and then enter San Pablo and San Francisco Bay, where freshwater mixes with saltwater from the Pacific Ocean. Collectively, these waters and their associated channels and marshland comprise California's largest estuarine system, which formed over the past 10,000 years (Moratto 1984:218). The San Francisco and Marin peninsulas meet at the Golden Gate along the western border of the Bay, and mark the division of the northern and southern coastal mountain ranges. The Berkeley Hills divide the San Ramon and Livermore Valleys and comprise the eastern reaches of the Bay Area (Moratto 1984:219). Although the San Francisco Bay estuary covers approximately 1100 km$^2$ today, heavy silting from dam and landfill projects has contributed to the loss of nearly 50 percent of pristine marshland habitats (Moratto 1984:219; Schoenherr 1992:687). Compared to the Central Valley, the Bay Area is much wetter and cooler, with an average of 56.8 cm of rainfall annually. Average temperatures along the Bay range from 16.4°C in July to 9.1°C in January (McBride 1974:317-318).

The Bay Area comprises a mosaic of biological communities, including saltwater and freshwater marshes, mudflats, sandy beaches, open waters, grasslands, and woodlands (Schoenherr 1992:672-687). Saltwater marsh communities along the east Bay are dominated by Pacific cordgrass, interspersed with annual pickleweed, salt grass, and salt-tolerant shrubs (Atwater et al. 1979; Schoenherr 1992). Inundated with salt water from tidal flushing, this habitat supports aquatic invertebrates, shorebirds, waterfowl, and several species of fish. In the more brackish areas of the estuary, cattails, bulrush, and tule infiltrate the tidal marsh and mudflats. Mudflats and sandy beaches support shellfish, shorebirds, waterfowl, and dungeness crab. Submerged mudflat habitats also support numerous species of anadromous (e.g., salmon, sturgeon) and estuarine fish (e.g., surf perch, jacksmelt, white seabass, bat ray, leopard sharks). The open waters of the Bay follow a typical aquatic food chain, with planktonic feeding fish at the bottom and predatory fish, birds, and marine mammals feeding at the top (Schoenherr 1992). The marshlands and mudflats provide the primary source of shellfish, such as clams, oysters, mussels, and abalone (Broughton 1997; Follett 1974, 1975; Lightfoot and Luby 2002).

Plant communities along the east Bay once consisted of blue oak-digger pine forest, valley oak savannah, and the California prairie, the latter of which was dominated by perennial and annual grasses, coast shrubs, and geophytes (Broughton 1999; Külcher 1977; McBride 1974:319). These communities were home to a number of mammals, including elk, black-tailed deer, pronghorn, jackrabbit, and brush rabbit (Lightfoot and Luby 2002).

Settlement pattern studies in central California indicate that prehistoric village sites were often situated in close proximity to freshwater rivers and streams in areas located above the floodplain (Moratto 1984). The riparian, riverine, marsh, and grassland communities of the lower Sacramento Valley and San Francisco Bay provided local access to key resources, such as wood for fuel, river cobbles for ground stone, tule and reeds for basketry, boats, and fishing equipment, and also a number of food resources, including acorns, berries, root foods, seeds, aquatic animals, and terrestrial game. However, ethnographic accounts indicate that many northern and central California societies set up temporary camps far away from the village during the month-long fall acorn harvest, which suggests that local stands of oak did not provide sufficient acorn supplies for some groups (McCarthy 1993).

Because the Central Valley is devoid of major rock formations, native peoples procured much of their raw stone materials through trade networks or through extended trips to obsidian and basalt quarries (Moratto 1984). Lithic sourcing studies suggest that most obsidian artifacts from the lower Sacramento Valley were acquired from the Clear Lake and Napa Valley region (Fagan 2003:163). Although cobble mortars and pestles are common in archaeological sites from the lower Sacramento Valley, wooden mortars and pestles are also known from ethnohistoric contexts (Moratto 1984). The presence of baked clay balls and fragments with basketry impressions suggests that these items may have been used as substitute “cooking stones” for boiling acorn mush and other foods

(Heizer and Beardsley 1943; Moratto 1984:171). In contrast to the Valley, rocky outcrops are abundant around San Francisco Bay and provided suitable raw materials for “cooking stones”, ground stone, and non-obsidian flaked-stone tools. Bedrock mortars are also known from some sites around the southern reaches of San Francisco Bay, as well as from inland sites in the nearby Livermore Valley to the east (Bocek 1991; Parkman 1994). Raw material for making obsidian stone tools was acquired either through trade or by extended trips to quarry sites to the north (Wilson 1993).

### ***Ethnographic Setting***

The basic political unit in California was the “tribelet”, a term coined by Alfred Kroeber to describe the distinct social organization of the California Indians (Kroeber 1925). The tribelet was a self-governing, politically autonomous entity, and “consisted of the aggregation of people living in two or more (often up to a dozen) separate villages, acknowledging the leadership of a chief who usually resided in the largest and most important of the several settlements” (Heizer 1978:5). Ethnohistoric records suggest that tribelets varied in size from as few as 20 members to several hundred.

Although Sir Francis Drake’s ship sailed passed the Golden Gate in 1578, dense fog obscured the inlet into San Francisco Bay (Moratto 1984). Gaspar de Portolá led the first land expedition to the Bay Area in 1769 and was among the first Europeans to come into contact with the Ohlone (Costanoan) Indians (Milliken 1995). Spanish accounts indicate that Indians living around San Francisco Bay subsisted on fish, shellfish, deer, acorns, geophytes, and a variety of other plants (Milliken 1995:18). Although the Spanish noted a number of Indian villages in the east Bay, these accounts do not depict settlements on top of large shell mound sites; instead, most villages are described as small settlements located along low lying marshland and woodland communities (Lightfoot and Luby 2002:276). However, abandonment of larger shell mound sites may have occurred in response to European presence, or may have been due to population decline resulting from the early spread of Old World diseases from the south prior to A.D. 1769 (Luby and Lightfoot; Preston 1996, 2002a, 2002b). Although studies of faunal remains from many shell mound sites of the Bay Area suggest year-round occupation (see Broughton 1994b; 1997, 1999; 2002a, 2002b; Howard 1929), some researchers have argued that the abandonment of some mounds during the late prehistoric period indicates a shift toward greater seasonal use of interior localities (Gould 1964; Lightfoot 1997; Lightfoot and Luby 2002:276-279). This hypothesis suggests that groups shifted toward a seasonal round pattern between the Bay and the interior, beginning with the Middle-Late period transition, circa A.D. 700 to 1000 (Parkman 1994; Lightfoot and Luby 2002:281). Ingram (1998) and Lightfoot and Luby (2002) note that the Middle-Late period transition roughly coincides with drought conditions of the Medieval Climatic Anomaly, which may have impacted local settlement patterns.

From 1770 to 1836, native groups from the Bay Area and interior central California were incorporated into the Spanish Mission system. In the immediate vicinity of San Francisco Bay, five missions were built, including Mission Dolores (San Francisco de Asís), Mission Santa Clara, Mission San Jose, Mission San Francisco Solano, and Mission San Rafael de Asís (Milliken 1995). Milliken (1994, 1995) reconstructed familial relationships using mission records and attempted to define tribelet boundaries throughout the Bay Area. His reconstructions suggest that the upper east Bay, near the Richmond-Oakland area, was occupied by the Huchiun and Saclan Ohlone tribelets, while the Tuibun Ohlone tribelet occupied areas along the southeastern reaches of the Bay near the city of Fremont. Although precise locations of villages are unknown, Milliken (1995) found that approximately 45 independent tribelets co-existed throughout the Bay Area during the contact period.

This Mission Period (A.D. 1770-1836) marked the rapid decline of the native population, as unsanitary conditions in mission settlements promoted the spread of infectious disease, such as tuberculosis, syphilis, and measles. By 1810, most indigenous groups from the southern and eastern reaches of San Francisco Bay had been incorporated into the Spanish Mission system. Although the Ohlone suffered the highest losses initially, interior groups (mostly Miwok and Yokuts) from the Central Valley were also heavily impacted by missionization, conflicts with white settlers, and epidemic disease (Cook 1976). In 1833, a measles epidemic decimated native populations throughout the Central Valley, including numerous Plains Miwok villages (Bennyhoff 1977).

Using ethnohistoric and ethnographic records, Cook (1978) estimated the pre-contact population of Alta California as 310,000, more than twice the number originally estimated by Kroeber (1925). Cook‘s (1955, 1976) estimate of the eighteenth century Central Valley population was 105,000, split nearly evenly between the Sacramento and San Joaquin Valleys. These numbers suggest a population density of approximately 93 individuals per 100 km$^2$, or roughly 20 times the average for precontact North America (Kroeber 1939:143). For the Ohlone (Costanoan), who occupied territories from northern San Francisco Bay to the southern Monterey coast, Kroeber (1925:464) estimated the eighteenth century population at 7,000; however, Levy's (1978) more recent estimates suggest population numbers of around 10,200 individuals.

### ***Central California Archaeology***

Between 1906 and 1908, Nels C. Nelson surveyed the shorelines of Marin, Alameda, and Contra Costa counties, and documented approximately 425 shell mounds in the San Francisco Bay area (Nelson 1909). Excavations were undertaken at several of these sites, including the massive Emeryville Shellmound located along the eastern shoreline of San Francisco Bay. In 1902, Max Uhle of U.C. Berkeley excavated a large trench 9.8 m deep at Emeryville, and identified ten discrete stratigraphic levels (Moratto 1984:227-229). In the lower levels Uhle found flexed burials that were stained with red ochre, bone tools, perforated "charmstones", non-obsidian flaked stone tools, and a high percentage of bay oyster shell. In the upper levels of the trench Uhle discovered cremated burials, polished stone artifacts, obsidian projectile points, and a high percentage of clam shell. Although Uhle interpreted these differences as evidence of temporal change at Emeryville, Alfred Kroeber – who held the notion that prehistoric California societies were essentially static – did not accept his findings (Moratto 1984).

Beginning in 1931, J.B. Lillard and W.K. Purves of Sacramento Junior College excavated three sites in the lower Sacramento Valley near the confluence of Deer Creek and the Cosumnes River (Lillard and Purves 1936). Using artifact seriation of grave lots, Lillard and Purves developed the first archaeological chronology for central California. Having found evidence for cultural differences between their Early, Intermediate, and Recent periods, they challenged Kroeber's notion that California cultures were static through time (Moratto 1984:179). Additional excavation in the area led to an extended report, in which the cultural sequence was renamed to the Early, Transitional, and Late periods (Lillard et al. 1939).

Lillard et al. (1939) noted that Early period burials were almost always fully extended and ventral (face down), with the head oriented toward the west (Moratto 1984:180). Grave goods accompanied the majority of the burials and often consisted of large projectile points made of chert or slate, *Haliotis* and *Olivella* shell beads and ornaments, quartz crystals, and perforated "charmstones". Lillard et al. (1939) also noted a few fragments of baked clay, which may have substituted for cooking stones, and a small number of mortars, pestles, and millingstones. During the Transitional period, a flexed burial position replaced the extended burial pattern and bodies were interred without regard to cardinal orientation; the use of red ochre on burials also became more common. Although grave goods were less abundant than in the Early period, some individuals were interred with large projectile points, non-perforated "charmstones", bone awls, fish spear tips, and a variety of shell bead ornaments (Moratto 1984:180). The abundance of cobble mortars and pestles, millingstones, and baked clay fragments in midden and burial contexts suggests greater importance of plant resources. In the Late period, the flexed burial pattern is maintained, although cremation and preinterment grave pit burning became common for the first time. Burials often contained obsidian points, incised bird bone tubes, *Haliotis* and *Olivella* shell ornaments and beads, and flat-bottom stone mortars.

The earliest known occupation along San Francisco Bay dates to circa 5000 B.P. and includes the eastern bayshore West Berkeley Village site (CA-ALA-307) and the southern bayshore University Village site (CA-SMA-77). Isolated skeletons discovered during various construction projects suggest an even earlier Bay Area occupation, although older settlements may have been inundated by rising sea level during the early Holocene (Atwater et al. 1977; Bickel 1978). R.K. Beardsley (1948, 1954a, 1954b) of U.C. Berkeley compared artifact and grave-lot assemblages from a number of sites throughout central California and concluded that the tripartite chronological sequence developed by Lillard et al. (1939) for the Sacramento Valley could also be extended to the San Francisco Bay area. Beardsley failed to recognize Early period occupation at the West Berkeley Village and University Village sites, although radiocarbon dating later confirmed that the Bay Area and lower Sacramento Valley were occupied contemporaneously as early as 5000 B.P. Beardsley (1948) also renamed the Early, Transitional, and Late periods identified by Lillard et al. (1939) as the Early (3000-200 BC), Middle (200 BC-AD 700), and Late Horizons (AD 700-1800). Since "horizons" represent cultural traditions that lasted for different lengths of time, central California archaeologists generally prefer the term "period" to denote chronological time, while "pattern" is used to describe continuity of cultural traditions independent of time (Bennyhoff and Fredrickson 1994; Bennyhoff 1994a, 1994b).

Over the past several decades, J.A. Bennyhoff, D.A. Fredrickson, and R.E. Hughes have attempted to construct a cultural chronology for central California and have worked out much of the taxonomic system in detail through a series of publications (Bennyhoff and Fredrickson 1994; Bennyhoff and Hughes 1987). Using the grave lot as the primary unit of analysis, Bennyhoff and Hughes (1987) devised scheme B1, which divides archaeological time into a series of cultural phases bracketed chronologically within three major time periods. Similar to Beardsley, they defined an Early period (circa 3000-500 B.C.), a Middle period (circa 200 B.C.-A.D. 700), and a Late period (circa A.D. 900-1800). In addition, they defined an Early-Middle period transition (circa 500-200 B.C.) and a Middle-Late period transition (circa A.D. 700-900). The justification for scheme B1 over earlier chronologies was made primarily on the basis of time-diagnostic *Olivella* shell bead types derived from burial contexts in conjunction with a large series of radiocarbon dates. Although scheme B1 has received much criticism, most archaeologists working in central California continue to use this chronology – despite its limitations – for lack of a better framework. In Chapter IV, I provide a more detailed discussion of scheme B1 and my justification for its use in the present study.

Bennyhoff and Fredrickson (1994) proposed that the early Bay Area culture be called the “Lower Berkeley pattern”, contemporaneous with the “Windmiller pattern” in the lower Sacramento Valley. Archaeologists have argued that cultural differences were greater between the Bay and the lower Sacramento Valley at an early date, and that the two cultures converged to a greater degree during the Middle and Late periods (Gerow and Force 1968). For example, while the mortuary complexes were distinctly different, groups from the Bay and Valley shared similarities in perforated “charmstones”, heavy flaked stone points made of non-obsidian material, notched and grooved net sinkers, and various *Olivella* and *Haliotis* beads and ornaments (Moratto 1984). The main differences relate to subsistence practices, with a greater abundance of portable mortars, pestles, bone tools, net sinkers, and shell refuse found in Bay Area sites than in sites of the lower Sacramento Valley (W. Wallace 1978:34).

Early period Valley (Windmiller) groups had a unique mortuary complex, in which the corpse was buried in a fully extended position and placed on its ventral surface, with the head oriented toward the west (Heizer 1949; Lillard et al. 1939). Eighty-five percent of interments contained grave goods compared with 33 percent of burials from the Bay (Wallace and Lathrap 1975). The dearth of midden refuse, abundance of grave goods, and presence of more organized cemeteries in Windmiller sites contrasts with Bay Area sites, where mounds served a dual purpose as cemeteries and villages and contained an abundance of faunal remains and artifacts. Some researchers have argued that Windmiller groups used mounds primarily as specialized mortuary sites, and that the habitation sites are now buried under meters of alluvium from seasonal flooding of the Mokelumne and Cosumnes Rivers (Meighan 1987; Schulz 1981; W. Wallace 1978). Because large, chipped-stone points are common Windmiller sites, Heizer (1949) originally suggested that Early period economies were focused primarily on hunting; however, the presence of ground stone fragments led him to later conclude that seeds and acorns might also have been important resources (Heizer 1974; Ragir 1972).

During the Middle period (Upper Berkeley pattern), Bay Area groups appear to have exerted greater influence on cultures from the Valley. In sites from the lower Valley, interment patterns were similar to the Bay, in that there were fewer grave offerings and corpses were buried in a flexed position with little consistency for cardinal direction (Bennyhoff and Fredrickson 1994). New types of *Olivella* and *Haliotis* shell beads and ornaments were also introduced during this period (Moratto 1984:209). A bone tool industry that developed in the Bay Area appears to have spread into the Valley and may be linked to the early use of coiled basketry. The presence of grave goods among a smaller percentage of the burial population and the increased practice of cremation suggests a higher degree social differentiation during this period (Moratto 1984). Mortars and pestles also became widespread throughout much of California during the Middle period, which suggests more intensified use of plant resources, such as acorns, seeds, and root foods (Basgall 1987; Wohlgemuth 2004).

Late period (Augustine pattern) life ways focused on intensive acorn exploitation, fishing, and hunting (Moratto 1984:211-213). Archaeological evidence from this period shows cultural continuity with ethnographically known Plains Miwok and Ohlone tribelets of the lower Sacramento Valley and San Francisco Bay, respectively (Bennyhoff 1977; Fredrickson 1973). Preinterment grave pit burning, cremation, and the presence of rare and ornate items associated with a small segment of the burial population suggest greater levels of social differentiation (Lightfoot and Luby

2002; Luby 1992, 2004; Luby and Gruber 1999). New technologies, including the bow and arrow and harpoon, were introduced during this period and may be linked with southward intrusion of Wintuan groups into the lower Sacramento Valley (Bennyhoff and Fredrickson 1994; Moratto 1984).

### *Archaeological Site Background*

Skeletal samples were selected primarily from sites that had suitable sample sizes, available chronological information (e.g., radiocarbon dates, burial seriation information), and published site reports. Although many of the sites were excavated under less than ideal circumstances, they are among the most intensively studied from central California, and all played a major role in defining the Central California Taxonomic System, or CCTS (Bennyhoff and Hughes 1987). I also selected sites that spanned the known archaeological sequence in the lower Sacramento Valley and San Francisco Bay, representing the period from 4950 to 200 B.P. These sites have well-preserved skeletal samples that are suitable for detailed osteological data collection and for dietary reconstruction using stable isotope analysis. Archaeological sites in California use a trinomial system that designates the state, the county, and site number. For example, CA-SJO-68 is located in San Joaquin County and is the 68th site to have been recorded for that county. I provide site descriptions and chronological information below. A map that shows the locations of the archaeological sites used in this study is presented in Figure 2.1.

*Lower Sacramento Valley Sites (San Joaquin and Sacramento Counties)*

*Blossom Mound.* The Blossom Mound (CA-SJO-68) is a Windmiller site located 1.9 km south of the big bend in the Mokelumne River and 2.4 km northwest of the town of Thornton (Heizer 1949; Ragir 1972). Located on an alluvial plain, the earthen mound is situated within a swampy marsh containing tule and brushy vegetation (Ragir 1972). E.J. Dawson excavated the mound in the early 1920s and reported its dimensions as 20 by 40 m with an elevation of 1 m above the valley floor; however, auger samples indicate that much of the mound was buried under alluvial sediments (Schenck and Dawson 1929). From 1938 to 1956, U.C. Berkeley archaeologists excavated the site under the direction of R.F. Heizer (Ragir 1972). The site was 1.5 to 1.8 m deep, with burials located between 15 and 168 cm from the mound's surface (Ragir 1972). At least four strata were present, consisting of loose topsoil underlain by a calcareous hardpan layer, a thick layer of brown midden material, and sterile red-yellow clay at the base of the mound. Over the course of several field seasons, approximately 177 burials were removed from the site. Although most burials represented primary inhumations, five cremations and several skull caches were discovered, the latter of which were interpreted as possible war trophies or sacrifices (Heizer 1949:26). The vast majority of the burials were fully extended, with the corpse placed on its ventral surface and the head oriented toward the west (Ragir 1972:47). Fifty-three percent of the burials had grave accompaniments, usually consisting of shell beads and ornaments, "charmstones", quartz crystals, and large projectile points. Based on the concentration of ash and the presence of faunal remains, projectile points, and baked clay fragments, archaeologists originally interpreted the mound as both a village site midden and cemetery (Heizer 1949; Ragir 1972).

More recently, archaeologists have questioned the mound as a village site because artifacts, hearth features, and faunal remains were not recovered in any great quantity (Meighan 1987; Schulz 1981). Meighan (1987) argued that the mound consisted of redeposited midden material since it contained less than one artifact was per cubic yard of soil. Radiocarbon dates and time-sensitive artifacts indicate that the site was occupied from 4350 to 3000 B.P., placing it firmly within the Early period (Ragir 1972). Of the six main sites with Windmiller components, the Blossom Mound appears to be the oldest known burial mound in the lower Sacramento Valley.

*McGillivray 1 Mound.* The McGillivray 1 Mound (CA-SJO-142) is a Windmiller site located 915 m south of the Mokelumne River and lies within the periphery of a swampy depression of tules and sedges known as Fog Lake (Heizer 1949; Lillard et al. 1939). Geological evidence suggests that – at the time of its use – the site was located directly along the banks of the Mokelumne River. This site is one of three burial mounds in the vicinity and is located 1 km away from the Blossom Mound (Lillard et al. 1939). Although the site dimensions are unknown, the mound was elevated 30 cm above the ground surface at the time of its excavation; similar to other mounds in the vicinity, much of the site was buried under alluvial sediments. Since there was little midden refuse in the mound, Heizer (1949) suggested that the village settlement was located nearby but was buried under several meters of alluvium from seasonal flooding of the Mokelumne River. From 1937 to 1938, U.C. Berkeley archaeologists excavated the site and removed 44 burials. Similar to other Windmiller sites, the majority of burials were fully extended with the corpse placed on its ventral surface and with the head oriented to the west; 82 percent of the burials had grave accompaniments (Heizer 1949). The cemetery dates to the late phase of the Early period through the Early-Middle period transition (circa 2800 to 2200 B.P.).

*Brazil Mound.* The Brazil Mound (CA-SAC-43) is located near a major bend in the Sacramento River, approximately 16 km south of downtown Sacramento and 2.4 km northwest of Freeport. F. Fenenga and students of Sacramento Junior College excavated the mound in 1939 and reported its dimensions as 61 m (east to west) by 30.5 m (north to south), with an elevation of 30.5 cm from the ground surface (Bouey 1995:5-7). Seventy burials were removed in 1939, although the landowner removed an additional six the following year. In 1968, P. Johnson, J. Nance, and students from the University of California at Davis continued excavation at the site. Smaller scale excavations were undertaken by Peaks and Associates in the 1980s, but were primarily concerned with identifying the spatial boundaries of the site (Bouey 1995). During the early 1990s, the U.S. Army Core of Engineers covered up the mound during a levee reconstruction project along the Sacramento River. As part of a mitigation project, archaeologists have recently reexamined all existing collections from the site and have produced a comprehensive site report (Bouey 1995).

Since the mound contained an abundance of projectile points, ground stone, baked clay fragments, faunal remains, hearths, ash lenses, and burials, the site is interpreted as both a cemetery and as a village site (Bouey 1995:57-63). Burials were interred in a flexed position, on either the left or right side, and about one-half contained grave goods (Ravesloot 1995). Although several individuals were interred with *Olivella* and *Haliotis* ornaments, most burials contained common utilitarian items, such as projectile points, bifaces, and pestles.

Archaeobotanical remains recovered from the site are representative of local grassland, riparian woodland, and marshland communities, and are dominated by acorn, berry, brodiaea, clover, fescue, goosefoot, grasses, maygrass, tule, and wild cucumber (Wohlgemuth 1995:285-288). The faunal assemblage consisted primarily of artiodactyls, medium-sized terrestrial carnivores, waterfowl, and a number of freshwater resident fish species (Schulz 1995; Simons 1995). Based on the floral and faunal evidence, Bouey (1995:348) suggested that the site was most likely occupied year-round rather than seasonally. A series of radiocarbon dates place the site between 2350 and 600 B.P., which includes both Middle and Late period occupation (Bouey 1995:84-85).

*Hicks 1 Mound.* The Hicks 1 Mound (CA-SAC-60) is located near the west bank of the Sacramento River, 1.6 km to the northeast of the town of Hood. Lillard et al. (1939:49-53) described the site as an ovate mound, measuring 23 by 43 m, with the long axis oriented from north to south. Although the mound had a maximum depth of 1.63 m, it rose only 50 cm from ground surface at the time of its excavation, due to deposition of alluvial sediments from the Sacramento River. During the 1930s and 1940s, Sacramento Junior College excavated the site and removed approximately 92 burials. Seventy-three burials were assigned to the Middle period and 12 were assigned to phase 2 of the Late period. Middle period burials were tightly flexed and showed no consistent pattern with respect to orientation or cardinal direction. Artifacts were associated with 41 percent of the burials and two cremations. Twelve Late period burials were oriented in a westerly direction, and many showed evidence of preinterment grave pit burning. Time-sensitive artifacts and radiocarbon dates suggest that the mound was used beginning around 1550 B.P., placing the site firmly within the Middle period, with brief reoccupation during phase 2 of the Late period.

*Cardinal Mound.* The Cardinal Mound (CA-SJO-154) is located in the northern San Joaquin Valley, in proximity to the Calaveras and San Joaquin Rivers. J.A. Bennyhoff and R.E. Hughes excavated the site in 1976, as it was being disturbed during a construction project. Since only burial records are available for the site, the precise location and dimensions of the mound are unknown. Despite the salvage nature of the excavation, archaeologists managed to recover approximately 36 burials and numerous artifacts from a portion of the site (Hoffman 1987). Common grave goods included *Haliotis* ornaments, *Olivella* beads, pestles, awls, bone harpoons, fish spears, flaked stone tools, and baked clay fragments (Hoffman 1987). Seventy percent of the burials had grave-good associations, and most were interred in a flexed position. Bennyhoff identified two periods of occupation, the first dating to the terminal phase of the Middle period, circa 1500 to 1300 B.P., and the second dating to phase 1a of the Late period, circa 1100 to 900 B.P. (Bennyhoff 1994a, Figure 6.4; Hoffman 1987:4).

*Johnson Mound.* Despite intensive excavation during the 1920s and 1930s, a site report was not published for the Johnson Mound (CA-SAC-06). Unpublished site records indicate that mound measured 11 m in length, with a maximum depth of 1.37 m.

Lillard et al. (1939) provide brief mention of the site and described its location as along the west bank of the Cosumnes River north of its confluence with the Mokelumne River. Late period villages from the lower Sacramento Valley are described as “circular mounds comprised of unstratified black, ashy dirt with accumulation refuse such as animal bones, shell and stone fragments scattered throughout” (Heizer and Fenenga 1939:382). Bennyhoff (1977) provides historical and archaeological evidence that suggests affiliation with the Cosumnes Tribelet, an ethnohistorically known group of Plains Miwok. Bennyhoff’s (1977) analysis of artifacts suggests that the site was used year-round rather than on seasonal basis. The presence of glass “trade beads” in some grave lots indicates that the site continued to be used into the contact period (Heizer and Fenenga 1939:383).

The Johnson Mound appears to have been a major center of the baked-clay industry of the lower Sacramento Valley, and produced hundreds of baked clay artifacts that were probably used in place of “cooking stones” (Heizer 1937; Schenck and Dawson 1929:350-360). Shell beads were found in all of the excavated burials, although other artifacts such as shell ornaments, arrow points, charred acorns, and bone awls were also common. Individuals were buried in a flexed position with the head oriented to the north or south, but consistently in a westerly direction. Time-sensitive artifacts and radiocarbon dates indicate that the site was occupied between the phase 1b of the Late period and the historic period, circa 900 to 100 B.P. Ethnohistoric accounts suggest that the Cosumnes Tribelet suffered high mortality due to violent altercations with the

Europeans and a measles epidemic that swept through the Central Valley in 1833 (Bennyhoff 1977; Cook 1976).

### *San Francisco Bay Sites, Upper East Bay (Alameda County)*

*West Berkeley Village.* The West Berkeley Village (CA-ALA-307) is a shell mound located on the northeastern shore of San Francisco Bay in the city of Berkeley. Located on a broad, sloping plain, the site lies adjacent to Strawberry Creek, which provided a year round supply of freshwater to the site's inhabitants (Wallace and Lathrap 1975:1-3). The mound measured 14 by 31 m at the time of excavation, although its original dimensions were estimated as 107 by 183 m prior to the leveling of the northern portion of the mound. The mound rose 6.1 m above ground surface with a subsurface deposit of approximately one meter.

The first scientific investigation of the site began in 1902 by E.L. Furlong under the direction of J.C. Merriam of U.C. Berkeley. In 1904, J. Peterson conducted a limited excavation at the site's northeast corner. Archaeologists at U.C. Berkeley excavated the remaining portions of the site in the 1950s before the mound was leveled (Wallace and Lathrap 1975). Analyses of the mound's composition indicate that it was composed of 50 percent shell, 45 percent ash, and 5 percent stone. Of the 95 burials recovered, 33 percent were associated with grave goods. The most common burial position was a loose flexure with the hands toward the face, although burial orientations were highly variable. Recently, archaeologists have detected intact subsurface deposits in sediment core samples, supporting the original spatial boundaries of the site reported by Nelson (1909) in his survey of Bay Area shell mounds (Dore et al. 2004).

Although Beardsley (1948) incorporated West Berkeley into his “Middle Horizon”, radiocarbon dates later demonstrated that the lower 3.7 m (12 feet) of the site date to the Early period, and the upper 1.8 m (6 feet) date to the Middle period. Initial radiocarbon dates placed the site between 3860 and 2700 B.P., representing the earliest occupation along San Francisco Bay (Breschini et al. 1996; Wallace and Lathrap 1975). However, recent AMS dating of charcoal-shell pairs taken from 15 stratigraphic levels of the mound indicate that the site was occupied from 5700 to 1200 cal yr B.P. (Ingram 1998). The original dates provided by Wallace and Lathrap (1975) were from mixed charcoal and shell lens deposits, and apparently did not encompass the entire occupational history of the mound. Ingram (1998) reports that the abandonment of West Berkeley Village and at least four other shell mounds in the vicinity (1300 to 1100 cal yr B.P.) coincides with MCA drought conditions and low freshwater inflow into San Francisco Bay, which may have negatively impacted the Bay Area ecosystem.

*Emeryville Shellmound.* The Emeryville Shellmound (CA-ALA-309) is perhaps the best-known archaeological site from San Francisco Bay. Located along the eastern bayshore in the city of Emeryville, the site lies within a diverse ecosystem of open estuary, saltwater marsh, tidal mudflats, riparian and oak woodland, and grassland (Broughton 1994b). Temescal Creek, located approximately 60 m from the site, provided the nearest supply of fresh water (Uhle 1907:3). Schenck (1926:156) reported that the creek had active salmon runs into the late 1800s, before it was diverted from its course to form Temescal Lake.

In 1902, M. Uhle and J.C. Merriam of U.C. Berkeley conducted the first scientific investigation of the Emeryville Mound. Uhle reported the site dimensions as 100 by 300 m, with a height of 9.8 m above ground surface. However, large portions of the site were destroyed in the late 1800s for the construction of a railway system and racetrack. Schenck's (1926) study of survey maps and oral accounts suggests that the mound may have been interconnected with at least three other large mounds in the immediate vicinity. Uhle's stratigraphically controlled excavation revealed evidence of culture change between the upper and lower levels of the site, represented by distinct differences in artifact types, dietary refuse, and mortuary practices. In 1906, N.C. Nelson conducted a second investigation on the opposite side of the mound from where Uhle excavated (Broughton 1996). This excavation provided support for most of Uhle's interpretations of temporal change, although Nelson failed to find evidence of cremation in the upper levels of the mound.

Between 1876 and 1924, the mound was the site of Shellmound Park, a tourist attraction that included a holiday resort and dance pavilion. In 1924, W.E. Schenck and colleagues at U.C. Berkeley salvaged artifacts and human remains from the site as it was being leveled to build a factory. Although nearly 700 burials were noted during the salvage operation, less than 400 were recovered. The highest concentration of burials occurred within the central portion of the mound, with a smaller number of burials located along the periphery (Schenck 1926). Several burials appear to have been interred below house floors in close proximity to hearth features. Although many infant burials may have been missed by the steam shovel, Schenck (1926:204) hypothesized that infants and children may often have been buried separately from adults. Analyses of mound constituents indicate that the site contained more than 50 percent shell (e.g., clams, mussels, oysters, and cockleshells), with the remainder comprising soil, ash lenses, fire-cracked rock, and worked artifacts (Schenck 1926). Like Kroeber, Schenck minimized evidence of culture change at the site, and attributed any differences to changes in the seasonal use of the site or to sampling bias (Bennyhoff 1986). However, Howard's (1929) detailed analysis of the avifauna from Emeryville suggests that the mound was occupied year-round rather than on a seasonal basis. Radiocarbon dates indicate that the site was occupied from 2600 to 700 $^{14}$C year B.P., spanning the entire Middle period through phase 1 of the Late period (Broughton 2002b:76).

### *San Francisco Bay Sites, Lower East Bay (Coyote Hills Area, Alameda County)*

The Patterson Mound (CA-ALA-328) and Ryan Mound (CA-ALA-329) are located approximately 3.2 km from the eastern shore of San Francisco Bay, near the cities of Newark and Union City (Bickel 1981). Located on an alluvial plain 1.2 to 1.8 m above sea level, the sites lie to the northeast of the Coyote Hills and to the south of Alameda Creek and Coyote Slough. With the addition of CA-ALA-12 and CA-ALA-13, these sites collectively form a distinct cluster of mounds often referred to as the "Coyote Hills sites", all located within 1.6 km of one another. Although currently situated a few kilometers from the Bay, at the time of their use, the mounds were adjacent to the shore and would have been inundated periodically by seasonal flooding (Bickel 1981; Wilson 1999). The nearest major freshwater source was Alameda Creek, located 4.8 km away, although freshwater springs were noted historically in the immediate vicinity (Bickel

1981). Unlike Bay Area sites to the north, the Coyote Hills sites are mostly earthen mounds that contain about 15 percent shell (Wilson 1999:3). Bickel (1981) and Wilson (1999) have suggested that these mounds were used as both village sites and cemeteries, although Leventhal (1993) has argued that the mounds served as specialized mortuary sites for elite individuals. Although faunal studies suggest year-round residence of the Coyote Hills (see Broughton 1994b), Parkman (1994) proposes that groups may have set up seasonal camps in the interior during the fall and spring. Wilson's (1999:51) obsidian hydration profiles suggest that, during the Late period, as many as seven or eight sites may have been occupied contemporaneously within the Coyote Hills area.

*Patterson Mound.* Nelson (1909) documented the Patterson Mound (ALA-328) in his survey of San Francisco Bay shellmounds, although the site was not excavated until several years later. The mound measured 107 m north-to-south by 76 m east-to-west, with a maximum depth of 4 m at the center (Davis and Treganza 1959). In 1935, W.R. Wedel of U.C. Berkeley carried out the first excavation of the mound and removed a small number of burials and artifacts (Wilson 1999:6). From 1949 to 1968, A.E. Treganza and students from San Francisco State University excavated the site as part of a field school. C.E. Smith of Hayward State University completed the last major excavation of site from 1966 to 1968. Between the numerous excavation projects, approximately 517 burials were removed from the site.

Bickel (1981) found that 33 percent of the burials had grave accompaniments. Most burials were in flexed or semi-flexed position on the left or right side, with a slight preference for westerly orientation (Bickel 1981; Luby 2004). Although the vast majority of the burials were primary interments, a small number of cremations were found throughout all levels of the mound. Luby's (1992) multivariate analysis of burial attributes from the basal cemetery (Component C) indicates that a tightly flexed burial position corresponds to the presence of burial goods, while a loosely flexed position indicates the lack of burial goods. *Haliotis* shell beads were only found in association with *Olivella* beads and are interpreted as markers of status. Expanding upon his earlier study, Luby (2004) also found a greater number of ornate, non-local items among the basal cemetery group than among burials deposited in the mound matrix, suggesting a change in social inequality through time. Luby (2004) hypothesized that funerary objects may have been increasingly exchanged or redistributed during mortuary feasts and funerals instead of being interred with the dead.

Davis and Treganza (1959:61) identified three cultural levels within the site, designated Components A (0-30 inches), B (31-79 inches), and C (80-156 inches). Component C, identified as a "basal cemetery" by Bickel (1981), dates to the end of the Early period (3000-2500 B.P.), and is coeval with the lower levels of the West Berkeley Village site (Davis and Treganza 1959). Component B demarcates the beginning of the mounded portion of the site and spans from about 2500 to 500 B.P. The final occupation of the mound, designated as Component A, dates from about 500 to 200 B.P. (Wilson 1999). The site may have been abandoned during phase 1 of the Late period, but appears to have been briefly reoccupied during phase 2 (Bickel 1981; Coberly 1973). European trade items have not been found in the Coyote Hills sites, so it is unclear whether the Patterson Mound was in use when the Spanish arrived in 1769 (Bickel

1981). Wilson's (1999) obsidian hydration profiles suggest that the entire occupation of the mound spans from about 2800 to 600 B.P. Original radiocarbon dates on mixed shell from base of the mound suggest the site was first settled by 2558±200 B.P. (Bickel 1981).

*Ryan Mound.* The Ryan Mound (ALA-329) is as an ovate mound, measuring 91 by 122 m at its base and 31 by 61 m at its precipice, with a height of approximately 3 m (Wilson 1993). The mound was partially disturbed by the landowners, who built a house and reservoir on a portion of the site (Coberly 1973). W.R. Wedel of U.C. Berkeley excavated the mound in 1935 and 1948, and removed several burials and artifacts. From 1959 through 1968, B. Gerow of Stanford University, and from 1962 through 1968, D. Pritchard of San Jose State University, removed approximately 500 burials from the site (Wilson 1999). C.E. Smith of Hayward State University completed the final excavation in 1972. The large number of abalone "banjo" pendants recovered from the mound has attracted significant interest, as these items may be associated with the Kuksu religious cult documented in ethnographic accounts.

Leventhal (1993:86-91) divides the mound into three components based on radiocarbon dates, obsidian hydration profiles, and time sensitive artifacts. Middle period occupation includes depths below 1.7 m and dates from about 2400 to 1800 B.P. Phase 2 of the Late period corresponds to depths from .79 to 1.75 m (1800 to 500 B.P.), and Late period phase 1 occupation from 0 to .79 m (500 to 200 B.P.). The earliest radiocarbon date suggests that the mound was occupied by 2080±90 B.P. Wilson (1993) found a high degree of correspondence between radiocarbon dates, obsidian hydration dates, and seriated *Olivella* beads derived from the same grave lot. Since the burials excavated by Stanford University have been repatriated, I used skeletal collections from the Wedel and Smith excavations for this study.

### ***Summary***

Central California prehistory is represented by a diverse archaeological record spanning more than five millennia. Although early anthropologists viewed prehistoric central California cultures as essentially “static”, the archaeological record has provided convincing evidence of culture change in the lower Sacramento Valley and San Francisco Bay during the Holocene. The development of the Central California Taxonomic System (CCTS) provided a key first step for examining change in culture and subsistence across different environmental zones. Many of the archaeological sites included in this study were pivotal to defining the CCTS, and provide the most appropriate skeletal samples for examining diet and health patterns in prehistoric central California.

# CHAPTER III

# THEORETICAL ORIENTATION

In this chapter, I discuss the theoretical orientation I use to evaluate diet and health patterns in prehistoric central California. I begin by discussing applications of human behavioral ecology, including the diet breadth, prey rank, and central place foraging models, and then review recent literature that addresses the relationship between population pressure, sedentism, and territoriality. Next, I link these approaches with resource intensification models posited for California and address some of the criticisms of these approaches. With these models in mind, I then review pertinent bioarchaeological literature on subsistence change and draw parallels between the transition to agriculture in North America and the emergence of acorn storage economies in California. Finally, I present my hypotheses and predictions regarding changes in diet and health during the late Holocene in central California.

## ***Archaeological Applications of Human Behavioral Ecology***

Since the 1980s, human behavioral ecology (HBE) approaches have gained favor by many anthropologists and have been successful in evaluating dietary preferences among human societies in both modern and archaeological contexts (Broughton and O’Connell 1999; Ugan 2005). HBE is grounded in neo-evolutionary principles, which link predictions of human behavior to natural selection theory (Winterhalder and Smith 2000). HBE further offers a number of models that can be empirically tested with ethnographic and archaeological data, providing a means with which to evaluate economic decision-making behavior in different ecological settings. One productive avenue of research is the use of resource intensification models in archaeology, which derive predictions from optimal foraging theory.

Optimal foraging theory (OFT) predicts that, with respect to foraging behavior, individuals will attempt to maximize the amount of calories extracted from the environment relative to the amount of energy expended in acquiring them (Broughton and O'Connell 1999; Kelly 1995; Winterhalder 1987; Winterhalder and Smith 2000). The model assumes that natural selection has designed organisms to "maximize average net rate of energy gain while foraging", which can be evaluated through proxy measures such as foraging efficiency (Broughton 1999:9). Foraging efficiency is determined by the net-acquisition rate (NAR), or simply the energy gained in kcal during foraging minus labor input, divided by the total residence time spent foraging within a resource patch (Smith 1991). In general, this requires an estimate of prey encounter rates (search costs) and handling costs, which may vary between different patches and prey species (Kelly 1995:78). The advantage of using NAR as a proxy for foraging efficiency is that it can be directly measured among living hunter-gatherer societies and can be approximated for archaeological contexts. Post-encounter return rates have been calculated from a number of recent ethnographic and experimental studies, and provide the basis for archaeological applications of optimal foraging models (see Table 3.1).

OFT models most commonly used in ethnographic and archaeological research include the diet breadth model and the patch use model. The diet breadth model,

Table 3.1. Post-Encounter Return Rates for Various Terrestrial Plant and Animal Resources from the Western United States.

| Resource | Scientific Name | Cal/Person/Hour |
|---|---|---|
| mule deer | *Odocoileus hemionus* | 17,971-31,450 |
| mountain sheep | *Ovis canadensis* | 17,971-31,450 |
| antelope | *Antilocapra americana* | 15,725-31,450 |
| bearded seal | *Erignathus barbatus* | 15,000-25,680 |
| jackrabbit | *Lepus sp.* | 13,475-15,400 |
| gopher | *Thomomys sp.* | 8,983-10,780 |
| rabbit | *Sylvilagus sp.* | 8,983-9,800 |
| pollen, cattail | *Typha latifolia* | 2,750-9,360 |
| large ground squirrel | *Spermophilus sp.* | 5,390-6,341 |
| elder duck | *Somateria mollissima* | 3,180-5,160 |
| small ground squirrel | *Spermophilus citellus* | 2,837-3,593 |
| Canada goose | *Branta canadensis* | 1,720-3460 |
| waterbird, ducks | *Anas sp.* | 1,975-2,709 |
| springparsley/biscuitroot | *Cymopterus bulbosas* | 1,867-1626 |
| seeds, gambel oak | *Quercus gambelli* | 1,488 |
| Seeds, oak | *Quercus* | 1,073 |
| seeds, pinyon pine | *Pinus monophylla* | 841-1,408 |
| seeds, tansymustard | *Descurainia pinnata* | 1,307 |
| seeds, salina wild rye | *Elymus salinas* | 921-1,238 |
| roots, bitterroot | *Lewisia rediviva* | 1,237 |
| seeds, bulrush | *Scirpus sp.* | 301-1,699 |
| seeds, shadscale | *Atriplex nuttalli* | 1,200 |
| seeds, shadscale | *Atriplex confertifolia* | 1,033 |
| seeds, barnyard grass | *Echinochloa crusgalli* | 702 |
| seeds, peppergrass | *Lepidium fremontii* | 537 |
| seeds, sunflower | *Helianthus annuus* | 467-504 |
| seeds, bluegrass | *Poa sp.* | 91-418 |
| seeds, wild rye | *Elymus cinereus* | 266-473 |
| seeds, ricegrass | *Oryzopsis hymenoides* | 92-301 |
| seeds, reed canary grass | *Phalaris arundinacea* | 261-321 |
| seeds, scratchgrass | *Muhlenbergia asperifolia* | 162-294 |
| seeds, foxtail barley | *Hordeum jubatum* | 138-273 |
| seeds, sedge | *Carex sp.* | 202 |
| roots, cattail | *Typha latifolia* | 128-267 |
| roots, bulrush | *Scirpus sp.* | 160-257 |
| seeds, saltgrass | *Distichlis stricta* | 60-146 |
| seeds, pickleweed | *Allenrolfa occidentalis* | 90-150 |

*Note:* (Data compiled from Simms 1987; Smith 1991; Smith and McNees 2005).

originally used to describe the prey selection behavior of insects (Charnov 1976), predicts that predators will select prey based on net-acquisition rate. The model predicts that post-encounter return rates will be most closely scaled with prey body size for large prey captured within relatively homogenous resource patches (Alvard 1993; Simms 1987; Winterhalder 1981). All other things equal, low cost, high return packages (e.g., large game) should always be taken when encountered, regardless of the relative abundance of other higher cost, lower return resources. Since smaller packages (e.g., small fauna, many types of plants) are generally more costly to acquire and have lower caloric return rates relative to energy expenditure, they should be taken only when the abundance of higher-ranked resources are significantly depleted.

According to the diet breadth model, lower-ranked resources should be incorporated sequentially in order of decreasing rank when encounter rates with the next highest-ranked taxon become depleted (Broughton 2002b; Stephens and Krebs 1986:17-24). As human foragers consume high-ranked prey over time, *resource depression* may result, defined as a “reduction in the densities and/or capturability of prey resources within patches” (Broughton 2002a:47). Resource depression should be most evident for patches in the vicinity of densely settled village communities (Broughton 1999; Winterhalder and Smith 2000). Thus, the increased use of higher-cost, lower-ranked resources signifies an increase in diet breadth and a reduction in foraging efficiency as predicted by OFT models.

Although prey size is often considered a good proxy measure for faunal resource ranking, it may be misleading in some cases. For example, some marine mammals have high handling costs, which may offset return rates despite prey body size. Smaller prey encountered in aggregate, such as small fishes and grasshoppers, may also have higher return rates if acquired through mass capture (e.g., fishing weirs, seines, and nets; see Lindström 1996; Ugan 2005:79-82), although return rates for small mammals and waterfowl remain low regardless of procurement method. However, Ugan (2005:83) notes that the high return rates reported for many small prey items captured *en masse* are offset by high processing costs. Under some circumstances, shellfish may be within the optimal diet since they require relatively little technology and labor investment, provide a good source of protein, and can be collected by different segments of society (e.g., women, men, children and elderly; Erlandson 1988, 1991, 2001; Yesner 1980). Sexual division of labor may further alter the ranking of some food resources, since foraging goals between men and women may conflict (Jochim 1988:134; Zeanah 2004). Despite these challenges, OFT models should be suitable in many archaeological settings for testing predictions of the diet breadth model.

Recent criticisms of HBE approaches have also highlighted issues with optimality models, especially in instances where human behavior appears contradictory. For example, recent ethnographic research on hunter-gatherer societies suggests that males often pass over easily exploited, high-return plant foods for more costly-to-acquire game, despite the lower return rates (Bird 1999; Hawkes and Bird 2002; Hawkes and O'Connell 1992). These studies suggest that, in many cases, foraging goals may also be directed toward prestige and access to mating partners in addition to caloric benefits. Despite these challenges, HBE models are founded on widely demonstrated principles of evolutionary and economic theory that can be empirically tested in ethnographic, experimental, and archaeological contexts. The degree to which the model and data fit should be a reasonable measure of the variation explained by the model. Careful applications of OFT consider the effects of technology, sexual division of labor, and the behavior of prey-species on measures of foraging efficiency.

The patch use model, as described by Charnov (1976:129), assumes that food resources are encountered in homogenous patches across the landscape. According to the model, the return rates for the selected prey species will decline with foraging time as the abundance of optimal resources decline due to harvest pressure. The marginal value theorem (MVT) further adds that the "predator should leave the patch it is presently in when the *marginal capture rate of the patch drops to the average capture rate for the habitat*" (Charnov 1976:132, emphasis in original). The importance of the MVT is that it makes explicit when a resource patch will suffer from diminishing returns, and when it is more profitable to move to a new patch (Charnov et al. 1976). In archaeology, the patch use model and MVT can be used to measure different aspects of foraging behavior, including foraging time, travel distance, and changing use of resource patches. As low cost, high-ranked resources are consumed and decline significantly in patches surrounding the residential base, greater foraging effort should be invested in the acquisition of high-ranked resources from more distant patches (Broughton 1999). Taken together, evidence of resource depression and the increased use of distant patches can both be indicators of declining foraging efficiency. Patch use will also vary between groups that practice different mobility and food procurement strategies, as explained below.

Binford (1980) introduced the *forager-collector* dichotomy as a conceptual tool for investigating variability in the archaeological record caused by different mobility strategies. *Foragers* follow a residential mobility strategy that involves moving between resource patches according to seasonal availability in key resources. *Collectors*, on the other hand, reside at a central place and use logistical task groups to procure specific resources, which are transported back to the residence. In general, collector societies that transport resources to a central place tend to be more sedentary, are more reliant on food storage, and have higher population densities (Bettinger et al. 1997). Although not intended as a strict classification scheme, Binford's (1980) dichotomy can be integrated with central place foraging models to predict optimal traveling distance, search and handling costs for different resources, and the use of distant resource patches (Bettinger et al. 1997).

### ***Population Pressure, Sedentism, and Territoriality***

Population pressure has frequently been invoked as "prime mover" for explaining changes in subsistence patterns and social organization, such as the transition to agriculture and the origins of social inequality (Boserup 1965; Carneiro 1970; Cohen 1977, 1989). Boserup (1965) was among the first to suggest that population pressure was the driving force behind technological change, and used this to explain why societies adopted agriculture in different areas of the world. Boserup (1965) argued that, as populations grow and put pressure on their food supply, individuals are forced to increase labor inputs to produce more food per areal unit of land. Population pressure was first discussed in the writings of Thomas Malthus, who used the concept to describe the tendency for animal populations to outgrow available food supply, leading to resource imbalances. The model provided an important component of natural selection theory, in that it described how the resource base regulates mortality and fertility rates. Cohen (1977) has been a leading proponent of "push" models that view population-resource imbalances as a causal mechanism for the development of agriculture. For instance, he argued:

> …human population has been growing throughout its history, and that such a growth is the cause, rather than simply the result, of much human "progress" or technological change, particularly in the subsistence sphere. While hunting and gathering is an extremely successful mode of adaptation for small human groups, it is not well adapted to the support of large or dense human populations. I suggest therefore that the development of agriculture was an adjustment which human populations were forced to make in response to their own increasing numbers [Cohen 1977:14].

Developing his argument further for the archaeological record, Cohen stated:

> I called attention in particular to combinations of the following events: the enlargement of the territory exploited by individual groups or by the population of a region as a whole, including expansion into biologically stressful environments; the exploitation of new ecological zones or microniches; the broadening of the range or "spectrum" of food resources exploited; the increased use of aquatic resources; the shift toward low trophic-level (vegetable) consumption, and particularly toward consumption of calorically prolific vegetable starches which are often poor in other nutrients; the decline in the exploitation of big game; the shift toward the consumption of small animals; the decline or extinction of exploited species; and the increased prevalence of sub-climax vegetation resulting from human interference [Cohen 1981:278].

Despite initial excitement, population pressure models have fallen out of favor in recent years, and have been admittedly hard to test using archaeological data (Hayden

1992; Keeley 1988:374; Richerson et al. 2001). Critics of these approaches contend that population growth is a poor causal mechanism for explaining subsistence change, and cite examples where populations failed to adopt agriculture in areas with high population numbers (Hayden 1995). Richerson et al. (2001:396) have recently argued that the lag in the timing of population growth and evidence for intensified subsistence economies is far too great to be considered a viable explanation for the adoption of agriculture in different areas of the world during the Holocene. Renewed interest in population pressure models, however, has provided a more unified theoretical perspective, linking population-resource imbalances with changes in residence patterns, territoriality, and the development of social inequality in hunter-gatherer societies (Binford 2001; Hammel and Howell 1987; Keeley 1988, 1995, 1999; Larson 1996; Lightfoot 1993; Wood 1998). Recent approaches have also become more cognizant of the critical distinction between population pressure and population growth:

> Population-pressure is *not* population growth; rather it is the *latent* potential for growth that is thwarted by some set of environmental or socio-demographic conditions (i.e., Malthusian penalties or their imminent threat) or cultural behavior (e.g., infanticide). Thus, population-pressure is simply the latent unfavorable ratio of humans to resources that is inherent in humans' reproductive capacity [Rosenberg 1998:658, emphasis in original].

Because population pressure stems from resource imbalance, it can result from in situ population growth, immigration, or a reduction in available food supply due to environmental and social factors (e.g., drought, failed trade relations between neighboring groups, loss of access rights to resources in an adjacent territory; Rosenberg 1998; Wood 1998). Rosenberg (1998:658-659) has proposed a model that links population-resource imbalances with conditions that lead to greater sedentarism, particularly the increased investment in maintaining territorial resource defense. The model predicts that societies will invest greater labor effort in the defense of predictable resource patches, especially under conditions of increased competition between neighboring groups (Cashdan 1983; Dyson-Hudson and Smith 1978; Rosenberg 1998). Rosenberg (1998) frames this hypothesis as follows:

> Specifically, what is being proposed here is that fully sedentary lifeways will evolve when (1) the risk of local resource depletion due to continuous use is outweighed by the risk of physical displacement from the most productive locales by competitors and (2) the cost of intensified exploitation (where feasible) is less than the cost of intensified defense [Rosenberg 1998:663].

Sedentism has been a major issue of interest to archaeologists over past several decades, and has important implications for understanding the development of food storage economies, inter-group trade, territorial defense, sexual division of labor, and social inequality (Binford 2001; Kelly 1991, 1992, 1995; King 1974; Testart 1982, 1988). Hitchcock (1987:374) defines sedentism as a process "whereby human groups reduce their mobility to the point where they remain residentially stationary year-round". Since mobility patterns are complex among human societies, many researchers have opted to view sedentism along a continuum rather than as a categorical variable (Eder 1984; Kelly 1992:49, 1995). Although population growth *per se* does not necessarily define conditions associated with sedentism, once sedentary, populations heavily reliant on stored foods may relax Malthusian checks to some degree and grow at a faster rate (Kelly 1992:58-59).

In a large ethnographic survey of hunter-gatherer societies, Keeley (1988, 1995, 1999) identified robust correlations between population density, reliance on food storage, and evidence of wealth differentiation among groups that occupied a central residence for greater than five months of the year. Population pressure was positively correlated with intensive seed and nut use, while reliance on large game was inversely correlated with intensified use of plant foods (especially seeds and nuts; Keeley 1999). Societies with high population density also stored more food and stayed in winter villages longer than societies with low population density (Keeley 1988:393-394). Testart (1982) argues that a specific set of conditions is needed in order for intensive storage economies to develop:

> Where some natural food resources are *bountiful* but *seasonal*, they can be gathered en masse while available and stored *on a large scale* once transformed through appropriate food preservation techniques, thus becoming the staple food year-round. This possibility lies at the intersection of four conditions, two ecological (abundance and seasonality of resources) and two technical (efficient food-getting and food-storage techniques). The presence of these four conditions determines an economy in which storage provides the bulk of food during the season of scarcity [Testart 1982:523-524, emphasis in original].

Testart (1982:524-525) found that food storing hunter-gatherer societies tend to be more sedentary, to have higher population densities, and to show greater evidence of social inequality than non-storing societies. For native Californians, reliance on food storage would have been a necessity for sustaining sedentary village communities during winter and early spring, when many key food resources would have been scarce (Baumhoff 1963; Bettinger 1987; Testart 1982:524, 1988:173). Ethnographic research among some native California societies indicates that reliance on stored foods (e.g., acorns, salmon) turned the season of scarcity into a time of leisure, and marked a time of important festivals and ceremonies (Testart 1988:171). Once dependent on food storage, however, villages would have also been increasingly at risk for resource stress, as natural disasters (e.g., floods, fire) or intercommunity conflict could have resulted in the loss of critical stored food surpluses such as acorn caches.

Reconstructions of pre-contact California suggest population numbers among the highest in North America (Baumhoff 1963; Cook 1955; Kroeber 1939). Researchers have attributed this demographic phenomenon, maintained in the absence of agriculture, to the adoption of intensive acorn storage economies during the late Holocene (Bean and Lawton 1977; Heizer 1958; Kroeber 1925; Meighan 1959). Baumhoff (1963) was the first to seriously consider the relationship between carrying capacity and available food resources in California, and proposed a unique acorn-game-fish adaptation for groups that lived along the Sacramento River and its tributaries within the north-central areas of the state. For the Sacramento Valley, Baumhoff (1963:230) linked high population densities to the abundance of food staples, and suggested that populations had reached their maximum level of resource productivity, representing the upper limits of carrying capacity without the development of agriculture.

Estimates of prehistoric population size generally incorporate settlement pattern data and the number of site components and phases per period, as measured by relative frequencies of radiocarbon and obsidian hydration dates (Basgall 1987; Bouey 1987:67; Broughton 1999; Cook and Heizer 1968; Glassow 1999; Schulz 1981:181-186). While many indices provide support for substantial population growth during the late Holocene in areas of California, population estimates need to be evaluated against a backdrop of geomorphologic perturbations that have biased the early to middle Holocene record (Bickel 1978; White 2003). The loss of this record may have been substantial, since coastal sites have been subject to significant deterioration through wave action and sea level rise, and sites along the major waterways of the Central Valley have been affected by changes in floodplain development (Atwater et al. 1977; Bickel 1981; Erlandson 1994a, 1994b; White 2003).

### ***Resource Intensification Models and Central California Prehistory***

Since the earliest historic descriptions, California has been perceived as a land of unlimited resource abundance. Eighteenth century accounts by Spanish explorers described large herds of elk and deer that virtually blanketed the landscape throughout the San Francisco Bay area (Raab and Jones, ed. 2004). The abundance of game and the vast array of plants used by native peoples impressed many of the first Europeans, and perpetuated the notion that aboriginal societies had little detrimental effect on the natural environment. Alfred Kroeber, the so-called father of California anthropology, also maintained that the state's rich and diverse resources provided an unlimited food supply to native peoples. "The food resources of California were bountiful in their variety rather than in their overwhelming abundance…If one supply failed, there were a hundred others to fall back upon" (Kroeber 1925:524). However, evidence for resource abundance in the prehistoric record has been seriously challenged by a number of recent archaeological investigations (Basgall 1987; Beaton 1991; Broughton 1994a, 1994b, 1997, 1999, 2001; Hildebrandt and Jones 1992, 2002; Jones et al. 2004). For example, many archaeofaunal studies have found evidence of resource depression, as measured by the decline in large game relative to more costly, smaller fauna during the middle and late Holocene (Broughton 1994a, 1994b, 1997, 1999, 2001; Hildebrandt and Jones 1992, 2002). These studies have also identified similar patterns in the faunal record from different environmental contexts (e.g., Sacramento Valley, San Francisco Bay, and Pacific Coast of North America), perhaps influenced by similar demographic conditions, albeit, operating on different time scales. Many researchers attribute the abundance of fauna observed during the contact period to a rebound in game populations, following significant declines in human population caused by the spread of introduced foreign diseases (Broughton 1999; Erlandson and Bartoy 1995; Erlandson et al. 2001; Preston 1996, 2002a, 2002b). If this is accurate, then human population may have been decimated by waves of introduced infectious disease beginning in the mid-to-late 1500s.

The archaeological applications discussed above fall under the rubric of resource intensification models, which predict declines in foraging efficiency during the late Holocene in California. As originally described by Esther Boserup (1965) and adopted by others, resource intensification is defined as “the sum of additional labour and material devoted to increasing the yield of currently exploited resources within the residential estate” (Beaton 1991:951). Stated another way, intensification models predict an increase in overall productivity from a given patch of land, but “individuals must expend more energy, per unit time, in the process” (Broughton 1994b:372).

### *Archaeofaunal Studies*

Since the 1980s, archaeological applications of the diet breadth model in California have primarily focused on temporal changes in the relative abundance of different types of floral and faunal remains, projectile points, and ground stone assemblages (Basgall 1987; Beaton 1991; Broughton 1994a, 1994b; 1997, 1999; Hildebrandt and Jones 1992; Raab 1996; Wohlgemuth 1996, 2004). Bayham (1979) provided the first quantitative application of the diet breadth model for evaluating long-term faunal exploitation patterns throughout the Archaic period of North America. Following OFT principles, Bayham (1979, 1982) argued that prey rank should be most closely scaled with body size. Following this logic, the ratio of large to small ranked taxa recovered from faunal assemblages can be used as a proxy measure for levels of foraging efficiency. The simplicity of the diet breadth and patch use models has broad appeal and practical utility for archaeologists interested in foraging efficiency, as measured through analyses of faunal assemblages.

Over the past few decades, HBE-based archaeological models have had measurable success in demonstrating examples of resource depression in different regions, including California (Botkin 1980; Broughton 1994a; 1994b, 1997,1999, 2001, 2002a; Chatters 1987; Glassow 1992; Jones and Richman 1995; Kennett 2005; Porcasi et al. 2000; Raab 1992; Simons 1992), the Pacific Coast of North America (Butler 2000; Hildebrandt and Jones 1992, 2002; Jones et al. 2004), the Great Basin (Broughton and Grayson 1993; Grayson 1991; Janetski 1997), north-central Nevada (Ugan and Bright 2001), the southwestern United States (Bayham 1982; Speth and Scott 1989), southern

New Zealand (Nagaoka 2002), and the Cook Islands of south-central Polynesia (Butler 2001). The vast majority of this research has provided support for late Holocene resource intensification models, and at a minimum, suggest that foraging societies have had significant impacts on animal populations in prehistory. Many of these studies have also seriously questioned the notion of native resource conservation practices, at least with respect to the impact that prehistoric societies had on game populations (see Broughton 1999, 2002b; Raab and Jones, ed. 2004).

*Central California.* Faunal assemblages from sites within the lower Sacramento Valley and San Francisco Bay have recently been the focus of much research, and have important implications for evaluating diet and health trends in prehistoric central California (Broughton 1994a, 1994b, 1997, 1999, 2001, 2002a; Hildebrandt and Jones 1992; Rogers and Broughton 2001; Schulz 1995; Simons 1992, 1995). These studies have provided a more synthetic and hypothesis driven approach for evaluating temporal trends in animal exploitation patterns in California, and most have embraced HBE models.

Broughton (1994a) analyzed vertebrate fauna from nine late Holocene sites in the north-central Sacramento Valley and found that the abundance of medium and large mammals declined through time relative to small, resident fish species. After controlling for latitude and seasonal variability, Broughton (1994a) also found that large anadromous fish (e.g., salmon and sturgeon) declined in abundance relative to smaller, resident fish species (e.g., cyprinids and catostomids). The effects of latitude were pronounced for anadromous fish, as high river discharge may have greatly reduced their capturability for groups living in the Delta south of 39°N latitude (Broughton 1994a:509-510). Although most indices were consistent with declining foraging efficiency, the ratio of large to medium-sized mammals (e.g., artiodactyl/lagomorph index) failed to show a clear temporal trend.

Simons (1992) examined prehistoric patterns of vertebrate exploitation in 11 late Holocene sites from the San Francisco Bay area, spanning the late Holocene (circa 3000-200 B.P.). He found an unexpectedly high marine mammal-to-artiodactyl ratio in the Early period assemblages, indicating greater importance of marine mammals at an earlier date than was found in previous Bay Area faunal studies. During the Middle period, marine mammals declined in abundance relative to artiodactyls, although this trend was reversed during the Late period. This Late period spike in marine mammal hunting, however, was the result of an increase in the hunting of sea otters. While recognizing that these patterns were consistent with the predictions of the diet breadth model, Simons (1992) broadly interpreted this as evidence of resource intensification, but also factored in the effects of interannual environmental fluxes, seasonal exploitation of different habitats, and co-harvesting strategies that emphasized both pinnipeds and sea otters.

Broughton (1994b) tested the diet breadth model using vertebrate fauna from 14 late Holocene archaeological sites from San Francisco Bay, expanding upon the earlier research by Simons (1992). Documenting similar trends, Broughton found dramatic declines in the ratio of artiodactyls (elk, black-tailed deer, pronghorn) to sea otters throughout the occupational histories of different regions of the Bay, and found little correlation between the observed trends and changes in environment, technology, or seasonal availability of prey species. Since artiodactyls and sea otters comprised 81.3 percent of the mammalian vertebrate assemblage, Broughton (1994b:378) argued that the relative abundance of each prey type through time should be a good measure of foraging efficiency, since artiodactyls, on average, weigh at least twice as much as sea otters. Broughton's (1994b:391) analysis of resident and migratory fauna also suggested multi-season occupation for the shell mound sites used in his study. The presence of certain species of migratory waterfowl suggested winter-spring occupation. Furthermore, the high number of bat rays and smoothhound sharks suggested spring and summer occupation, the seasons in which these fish species move from deeper areas of the estuary to more shallow waters closer to the shoreline (Gobalet et al. 2004:820).

More recently, Broughton (1997, 1999, 2001, 2002a, 2002b) has produced a fine-grained analysis of archaeofaunal remains from the enormous Emeryville Shellmound site, located along the eastern shore of San Francisco Bay (circa 2600-700 B.P.). Since predictions of the diet breadth model are based on post-encounter return rates with prey species from more-or-less homogenous patches, Broughton (1999) compared the abundance of different faunal species by habitat type (e.g., aquatic versus terrestrial). Bracketing the faunal assemblage into stratigraphically controlled temporal units, he found significant declines in the abundance of low cost, high-ranked prey species relative to smaller, more costly fauna throughout the occupational history of the mound.

Ninety-nine percent of the eight fish species represented at Emeryville comprised requiem shark, bat ray, salmon, and sturgeon, although smaller fishes were nearly absent from the assemblage due to the screen recovery methods used in the original excavations (Broughton 1997:851, 1999:42). Sturgeon, the largest fish taxon identified in the assemblage, declined significantly in abundance through time relative to all other identified fish species; mean dentary widths of sturgeon also showed significant declines through time, suggesting that predation pressure resulted in a lower mean age-at-death. Since sturgeon would have been available year-round (unlike requiem sharks, bat rays, and salmon) and are slow moving, benthic browsers, they would have been highly susceptible to resource depression (Broughton 1997, 1999).

Examining the avifaunal record, Broughton (1999, 2001:265) found that 83.5 percent of birds at Emeryville comprised ducks, geese, and cormorants. Cormorants breed on offshore rookeries and could only have been exploited using watercraft, while ducks and geese could have been captured from near shore habitats. Broughton (1999, 2001) hypothesized that the abundance of cormorants relative to ducks and geese could be used as a proxy for resource depression. Following the predictions of the diet breadth model, both ducks and geese in the assemblage declined in abundance through time relative to cormorants, suggesting greater investment in exploiting the latter from distant rookeries.

The mammalian vertebrate fauna at Emeryville produced the most interesting trends through time. Four taxonomic groups dominated this assemblage, and include sea otters, pinnipeds, artiodactyls, and small and medium-sized carnivores. For sea mammals, the abundance of large migratory pinnipeds (e.g., Steller sea lion, California sea lion, fur seal) declined relative to smaller sea otters through time. Since large pinniped species aggregate on mainland haul outs and offshore rookeries during the breeding and birthing season, they would have been highly susceptible to resource depression (Broughton 2002b; Hildebrandt and Jones 1992). The terrestrial faunal assemblage was dominated by artiodactyls, such as elk and black-tailed deer, and nine species of small and medium-sized carnivores (e.g., coyote, gray fox, raccoon, long-tailed weasel, badger, spotted skunk, striped skunk, river otter, and bobcat; Broughton 1999:51-52). In general, the abundance of artiodactyls declined relative to terrestrial carnivores through time, although the number of deer elements significantly increased in the upper-most strata of the mound (circa 2000 to 700 B.P.). After ruling out environmental causes, Broughton (1999:55-64) hypothesized that the dramatic increase in deer remains was due to the greater use of distant resource patches following the depression of local patches. To test this hypothesis, he examined temporal differences in butchery patterns and anatomical part representation. Since ethnographic and experimental data show that transport costs increase with distance from the home base, he argued that low-utility elements would have been removed more frequently in conjunction with a greater amount of field processing during the later occupation of the site (Broughton 1999:58; Rogers and Broughton 2001). When compared by strata, butchery patterns and anatomical part representation data suggested higher levels of selective transport and field processing of artiodactyl remains, corresponding to the late spike in deer elements (Broughton 1999; Rogers and Broughton 2001). Since sea otters and artiodactyls dominate the Emeryville vertebrate assemblages, but differ with respect to body size, Broughton (1999) calculated an index to compare the relative profitability of each prey group. The abundance of large artiodactyls significantly declined relative to lower-ranked sea otters, suggesting localized resource depression induced by human foragers.

In a final test of the diet breadth model, Broughton (1999:70-71) calculated shellfish indices from data tabulated by Gifford (1916). As noted by Gifford, larger shellfish species, such as oysters and mussels, were abundant in the lower levels of Emeryville, but later decreased through time relative to bent-nose clams. Since oysters and mussels can be extracted with relatively little effort from the intertidal zone, they should have been preferred species over the clams, which would have required the use of a digging stick. This shift in shellfish species has also been identified in a number of other Bay Area sites, although additional research is needed to determine whether overexploitation of larger shellfish species or environmental factors, such as changes in siltation levels in the Bay, are the primary cause (see discussions in Bickel 1981; Broughton 1999:71; Gould 1964; Greengo 1951, 1978; Ingram 1998).

*Pacific Coast of North America.* A number of studies have also applied HBE models to examine prehistoric exploitation patterns on marine mammal populations along the Pacific coast of North America during the Holocene (Hildebrandt and Jones 1992, 2002; Jones and Hildebrandt 1995; Jones et al. 2004; Porcasi et al. 2000; Walker et al. 1999). Archaeologists have long since noted the presence of marine mammal remains in areas where they no longer live today. Researchers have commonly attributed this to overexploitation by Europeans during the historic period (Lyman 1989, 1995), or to changes in sea surface temperature during the late Holocene (Colten 2002;

Colten and Arnold 1998). Hildebrandt and Jones (1992, 2002) challenged these notions by suggesting that prehistoric human foragers had significant impacts on marine mammal populations in the past, which has affected their present distribution along the Pacific Coast.

Based on faunal assemblages from archaeological sites between southern Oregon and southern California, Hildebrandt and Jones (1992, 2002) argued that early coastal populations overexploited migratory breeding marine mammals from mainland haul outs and near shore rookeries, and later intensified their efforts to hunt these species from more distant, offshore rookeries and islands. Unlike the smaller resident species, such as the sea otter and harbor seal, migratory breeders (e.g., Steller sea lion, California sea lion, northern fur seal) cannot mate or give birth to young in open waters and instead must establish birthing and breeding colonies on mainland haul outs and rookeries (Hildebrandt and Jones 1992:366-367). Males establish breeding territories in the late spring and form harems; these groups also include pregnant females and juveniles. About one month following birth, newborn pups are able to swim on their own, and the groups again disperse on their annual migration. During this mating and birthing season, fur seal and sea lion colonies are highly susceptible to predation pressure, and respond behaviorally by moving their colonies farther from the shore. Hildebrandt and Jones (1992, 2002) argue that as haul outs and near shore rookeries became increasingly depleted, more investment would have been placed in the development of technology needed to exploit marine mammals at these distant rookeries. In particular, they link the development of the oceangoing canoe and composite harpoon during the late Holocene to the greater use of offshore rookeries and islands for marine mammal hunting. Although the effects of environmental change and over-hunting during the contact period have not been fully resolved (see discussions in Colten 2002; Colten and Arnold 1998; Lyman 1989, 1995) several studies of marine mammal exploitation patterns are consistent with predictions of intensification models (Broughton 1999; Hildebrandt and Jones 1992, 2002; Jones and Hildebrandt 1995; Jones et al. 2004; Porcasi et al. 2000; Walker et al. 1999).

### *Criticisms of Resource Intensification Theory*

Despite recent interest in resource intensification theory, many researchers have taken issue with the ability of the model to explain socio-economic changes in prehistoric California, and also its failure to address the role of social factors on driving culture change (Arnold 1992, 1995a, 1995b, 1997; Arnold et al. 1997; Hildebrandt and McGuire 2002; White 1998a, 1998b, 2003, 2005). Most recently, the factors that influenced the rise of chiefdom-level social complexity among the prehistoric Chumash of southern California has been the focus of contentious debate among archaeologists (Arnold 1992, 1995a, 1997; Arnold et al. 1997; Colten and Arnold 1998; Jones et al. 1999; Lambert and Walker 1991; Raab 1996, 2004; Raab and Bradford 1997; Raab and Larson 1997; Raab et al. 1995; Walker and Lambert 1989).

Although the archaeofaunal and bioarchaeological evidence is consistent with the predictions of intensification models in the southern California (Lambert and Walker 1991; Raab 1996, 2004; Walker and Lambert 1989), the influence of climate change has also factored into the debate, and is focused primarily on whether the circumstances that led to socioeconomic change in southern California were brought on by drought conditions of the Medieval Climatic Anomaly (MCA), circa A.D. 800 to 1350 (Jones et al. 1999), or by El Niño Southern Oscillation (ENSO) events that caused warmer sea surface temperatures and decimated the marine ecosystem (Arnold 1992, 1993, 1995a, 1996, 2000; Arnold and Tissot 1993; Arnold et al. 1997; Colten and Arnold 1998). Arnold (1992, 1995a) and Colten and Arnold (1998) argue that warming sea surface temperatures during the MCA interval had detrimental effects on the availability of marine resources, which provided the impetus for the development of more complex social systems. Under this model, elite "big men" acted as the primary medium for access to food resources between the Santa Barbara mainland and the Channel Islands, the latter of which exchanged shell beads and ornaments (made by craft specialists) for food resources (Arnold 1992, 1993, 1995a, 1995b, 1997, 2000; Arnold and Munns 1994; Arnold et al. 1997). These "big men" were able to gain prestige and elite status through the manipulation of labor organization during periods of environment stress, stimulating the development of complex levels of social stratification Arnold's model further links the evolution of the Chumash political economy with the development of the plank canoe. This new technology would have been critical for intensified fishing and marine mammal hunting, and also for transporting resources between the mainland and islands. While recognizing the late Holocene as period of resource stress, Arnold (1992, 1995a, 1997) has argued that warming sea surface temperatures rather than drought conditions were primarily responsible for the development of social complexity in the Channel Island area of southern California. This perspective contrasts with the intensification models, which link these changes to population-resource imbalances, brought on by the over-exploitation of fauna by densely-packed foragers, and further exacerbated by drought conditions of the MCA (Jones et al. 1999; Raab 1996, 2004). Kennett and Kennett (2000) have recently compiled a high-resolution oxygen isotope record on marine shell from the Santa Barbara Channel Island area, and found evidence for colder sea surface conditions during the MCA, contradicting the record upon which Arnold's model is based. Although these debates are far from resolved, the broad picture from the late Holocene Santa Barbara area is consistent with population pressure and economic intensification models; however, environmental factors appear to have greatly exacerbated already stressful conditions between the eighth and fourteenth centuries.

Other recent studies from California have also found archaeofaunal evidence that appears inconsistent with the expectations of resource intensification models (Hildebrandt and McGuire 2002; White 1998a, 1998b, 2003, 2005). For example, Hildebrandt and McGuire (2002) found evidence for a significant increase in deer exploitation during the middle to late Holocene (Middle Archaic) in California, and argue that intensification models cannot explain the patterns observed in the archaeofaunal record. Drawing parallels with ethnographic research on modern foraging societies, they suggest that an increase in artiodactyl hunting was an expression of gender-differentiated fitness goals directed toward male prestige. According to their model, as gender organization became increasingly differentiated during the Middle Archaic, males directed foraging efforts toward hunting large game as a means to gain prestige and greater access to mating partners. Recent ethnographic research on forager societies indicates that men often pass up low cost food resources (e.g., plant foods, shellfish) for large game, suggesting that social prestige may contribute to diet choice, in addition to simply providing calories (Bird 1999; Hawkes 1990, 1991; Hawkes and Bird 2002). Broughton and Bayham (2003) take issue with Hildebrandt and McGuire's (2002) model, and instead argue that the increase in artiodactyls is more likely due to higher levels of terrestrial productivity, associated with the cooler and wetter conditions following the Altithermal. Broughton and Bayham (2003) also contend that the trends identified by Hildebrandt and McGuire (2002) may be obfuscated by regional differences in environment, spatial variability in the settlement patterns, and through the increased use of distant resource patches.

White (1998a, 1988b, 2003) has also recently challenged the logic of intensification models in explaining socio-economic change in central and northern California. He argues that social competition was a more critical factor influencing intensification, and manifested under conditions of resource abundance rather than population-resource imbalances. From this perspective, population growth and intensification were the outcome of competitive social relationships that were influenced, but not caused, by environmental change. This model further links these competitive social relationships to increased social differentiation, inter-group resource exchange, and also multi-regional population movements during the late prehistoric period. White (2005:28) extends this argument further to explain how changing sociopolitical organization could have resulted from the coordinated efforts of mass capture of game in the Clear Lake Basin of northern California: "intensification in

California was best understood as a product of technology and organization enabling mass capture via coordinated group harvest or employing technologies designed and built via capital." White's (2003:187) analysis of archaeofaunal remains from the Colusa Basin of northern California indicates that small fauna were the focus of intensive exploitation during the Middle Archaic, but diets shifted toward artiodactyls later in time, suggesting increased foraging efficiency through time, contra the predictions of intensification models.

### *Archaeobotanical Studies*

In addition to the faunal trends described above, resource intensification models have also been advanced to explain the development of intensive acorn economies during the late Holocene in California (Basgall 1987; Beaton 1991; Bouey 1987; Wohlgemuth 1996, 2004). Although archaeological evidence of early acorn use in California is mounting (Schulz and Johnson 1980; White 2003; Wohlgemuth 2004:144), methods used to remove poisonous tannins appear to have differed from the ethnographically known leaching basin method. Ethnographic accounts indicate that while acorns were sometimes buried in the mud for several weeks or months, or were mixed with clay to leach out tannins, these strategies most likely predate the use of the leaching basin (Driver 1952; Fredrickson 2003; Gifford 1936; Merriam 1918, 1965; White 2003; Wohlgemuth 2004). Wohlgemuth (1997, 2004:144) has recently identified pits of unburned acorn caches in archaeological sites within the Los Vaqueros reservoir area east of San Francisco Bay and at CA-SOL-391, to the north of the Bay Area. Radiocarbon dates for acorn shell from SOL-391 suggest that earlier leaching methods were in use 3740-4450 cal B.P. (Wohlgemuth 2004:144). Fredrickson (2003) states that the leaching basin method probably developed alongside storage granaries and mortar and pestle technology, associated with more sedentary life ways of the late Holocene. Although many food items were processed using mortars and pestles, including nuts, seeds, berries, bulbs, meat, and fish (see Barrett and Gifford 1933:144-145), this toolkit was the most efficient method for processing acorns into a palatable food resource (Basgall 1987).

Basgall (1987) has provided one of the most influential discussions of resource intensification models for explaining the emergence of late Holocene acorn storage economies in prehistoric California. In many areas of the world, acorns have historically been viewed as famine food (see Mason 1995). California scholars, however, have conventionally viewed acorns as a high-ranked, reliable resource that had obvious benefits as a buffer food, particularly during the lean winter and spring months (Heizer and Elsasser 1980; Schulz 1981). Explanations for the lack of intensive acorn economies prior to the late Holocene have ranged from environmental factors that restricted oak tree distribution in the past, to technological ignorance of the leaching process, and to the time required for populations to “settle in” and become familiar with new ecological niches (Basgall 1987:39; Mayer 1976:16, 29; Schulz 1981). Basgall (1987:39) rejected these explanations, in part, because of the implication that some societies are inherently less sophisticated than others. Since ethnographic research indicates that mortars and pestles were used primarily for acorn processing, the relative abundance of these implements in archaeological sites has often been used as a crude index of acorn reliance (Basgall 1987; Bouey 1987; Jones 1996; McCarthy 1993; Schulz 1981). Following this logic, Basgall (1987) noted that evidence for the acorn toolkit was scarce during the Early period (4500-2800 B.P.), but became more abundant in sites dating to the Middle (2800-1200 B.P.) and Late (1200-100 B.P.) periods. He further noted a high degree of temporal and spatial disparity in the distribution and appearance of mortar and pestle technology throughout California. This incongruity suggests that acorns were unlikely to have been considered a superior food resource in the past, since the efficient technology (i.e., mortars and pestles) used to process them failed to rapidly diffuse across different regions.

Basgall (1987) calculated return rate estimates for acorn harvesting and processing using ethnographic and experimental data (see Dubois 1935; Gayton 1948). These estimates produced return rates of 1.0 kg/4.2 hr (1073 cal/hr), which included the costs of gathering, transport, shelling, pounding, leaching, and cooking of 2.72 kg (6 lbs) of acorns. Based on these findings, Basgall (1987) concluded that acorns have substantially higher labor costs relative to many other food resources (cf. McCorriston 1994:102). In summarizing the archaeological and ethnographic evidence for acorn use, Basgall argued that the late introduction of mortar and pestle technology is best explained by food stress resulting from population-resource imbalances, “not because of some inherent quality of the resource itself” (Basgall 1987:40-41).

Relatively little is known about prehistoric uses of different plant foods among California societies. Ethnographic research by J.P. Harrington suggested that the Ohlone (Costanoan) Indians of central California gathered at least 157 different plant types, 63 of which were used as food (Bocek 1984). Since few archaeobotanical samples were collected until the 1980s, researchers are only just beginning to understand trends in plant food intensification during the Holocene (Wohlgemuth 2004). Wohlgemuth (1996) examined archaeobotanical data from 11 Holocene sites in the North Coast Ranges and Central Valley of California, and reported a shift between the Early and Middle period in the ratio of small seeds to acorns, suggesting that acorns became economically important during the Middle period (circa 2800 B.P.). The Late period trend, however, was marked by an increase in small seed use, suggesting a greater diversification of plant foodstuffs. Expanding upon this study, Wohlgemuth (2004) has recently examined 940 macrobotanical samples from dozens of archaeological sites throughout California. Using Keeley's (1999) ethnographic model, Wohlgemuth (2004:13) predicted that intensive plant use should have been less among groups that had direct access to aquatic resources, such as populations from San Francisco Bay and the interior Sacramento Valley. Based on macrobotanical evidence from 48 sites in interior central California, Wohlgemuth (2004:72-83) found that acorn was the most ubiquitous taxa represented, regardless of time period. Wild cucumber was the second most ubiquitous taxon during the Lower and Upper Archaic periods, but remained prominent into the protohistoric period. Between the Middle (7000-2500 B.P.), Upper Archaic (2500-1200 B.P.) and Emergent periods (1200-200 B.P.), the abundance of acorn shell increased dramatically, providing support for the assertion that intensified acorn exploitation was primarily a late Holocene phenomenon (Wohlgemuth 2004:145). When compared by region, Wohlgemuth (2004:148-49) found some evidence for lower diversity indices and fewer macrobotanical remains in sites from the San Francisco Bay area and the lower Sacramento Valley than areas that lacked significant aquatic resources, providing partial support for Keeley's (1999) model. Small seed assemblages were dominated primarily by farewell to spring, goosefoot, and maygrass, but were abundant only in sites from interior central California (Wohlgemuth 2004:135). The dearth of small seeds during the Lower Archaic relative to later periods also supports Keeley's hypothesis (also see Binford 2001) that seed intensification is correlated with significant population pressure (Wohlgemuth 2004:144). The most dramatic temporal trend in small seed use occurred between the Upper Archaic (1500-1200 B.P.) and Lower Emergent (1200-500 B.P.) period, concomitant with other archaeological evidence for population increase (Basgall 1987). Although small seed use declined between the Lower and Upper Emergent, seed use remained prominent into the protohistoric period (Wohlgemuth 2004:140).

The Middle Archaic record was poorly represented in the eastern San Francisco Bay area, compared with the Upper Archaic and Emergent periods (Wohlgemuth 2004:114). Archaeobotanical samples showed a low ubiquity of nutshell, but were primarily represented by acorn and bay nut, followed by hazel and buckeye (Wohlgemuth 2004:114). Interestingly, evidence of acorn use declined during the Lower Emergent period, while wild cucumber became the most ubiquitous taxon represented (Wohlgemuth 2004:114-117). Berries appear to have been a more important food resource in the Bay Area than in the interior of central California, although they were not found in high frequency during any time period. Wohlgemuth (2004:120) argues that the changes in plant food exploitation in the Bay Area could reflect a shift toward greater seasonal site use during the late prehistoric period, as suggested by Lightfoot and Luby (2002:276-277).

Todt (1997) notes that the broad usage by early ethnographers of the terms "Indian potatoes", "Indian carrots", or "wild onions" for the different edible root foods (i.e., geophytes, underground storage organs) used by native Californians has hindered the species identification of these plants. Wohlgemuth reports that native groups in California used at least 58 different species of geophytes, primarily from the Liliaceae, Apiaceae, and Cyperaceae genera.

> Bulbs and corms were locally important but did not loom nearly so large as in the Northwest and Plateau. …The most important Liliaceae include the *Brodiaea* group, the "Indian potatoes" of ethnography, comprising the related genera *Brodiaea*, *Dichelostemma*, *Triteleia*; mariposa lilies (*Calochortus sp.*); and onions (*Allium sp.*). All were dug from April to July with a digging stick and cooked in earth ovens, and some were stored for winter (in houses rather than outdoor granaries; Barrett and Gifford 1933; Duncan 1963). The most important of the Apiaceae was yampah (*Perideridia sp*), roots of which were gathered in the late spring (Barrett and Gifford 1933; Chestnut 1902) or fall (Goodrich et al. 1980), and eaten raw or stone-boiled. The most important Cyperaceae, especially in wetland areas, were nut sedge (*Cyperus esculentus*) and tule (*Scirpus sp.*) [Wohlgemuth 2004:29].

Wohlgemuth (2004:82) found that geophyte use in interior central California peaked during the Middle Archaic (7000-2500 B.P), marked by the increased ubiquity of *Brodiaea sp.* bulbs. The decline in geophytes between the Middle and Upper Archaic period corresponded with an increase in acorn shell, suggesting that intensive use of root foods may have preceded large-scale acorn economies (Wohlgemuth 2004:82). Unlike sites from interior central California, archaeobotanical assemblages from the San Francisco Bay area show little evidence of geophyte use (Wohlgemuth 2004:117).

Wohlgemuth's (2004) study provides some of the first direct evidence for the prehistoric use of geophytes in central California, and indicates that several types of root foods were more significant to the native diet than was previously recognized. It is of interest that the mortar and pestle—the tool kit used to process geophytes on the Columbia Plateau in the northwestern United States—may have played an important role in geophyte processing in central California (see Thoms 1989, 2006:13). Another important contribution of Wohlgemuth's (2004:140-141) pioneering study is that it demonstrates some major discrepancies between archaeological and ethnographic data regarding plant use, which may be due to a combination of factors, including sample preservation, and incomplete accounting of native plant use reported in early ethnographic accounts. In summary, Wohlgemuth (2004:149-160) argues that the trends observed in the macrobotanical assemblages generally support predictions of late Holocene population pressure and resource intensification, although technological diffusion, population movements, and environmental change also played a significant role.

A final point that should be considered with respect to prehistoric plant exploitation patterns in central California focuses on native land management practices, most notably the burning of grasslands described in early European accounts (Anderson 2005). Lewis (1973) was one of the first to suggest that the native burning practices would have increased herb and grass productivity. Burning not only would have increased the abundance of roots and berries in particular, but also would have attracted game to predictable resource patches. Bean and Lawton (1976:39) have gone so far to call the burning of the grassbelt a form of "proto-agriculture", and possibly even constituting a type of game management. Anderson (1993:158, 1996, 2005; Anderson and Rowney 1999) has advanced the idea of native California societies as natural conservation managers, who used burning and soil tilling to enhance the productivity of grasses, forbs, and other economically important plants. Grassland burning would have provided additional benefits, such as opening corridors to facilitate travel between regions (Anderson 1993:165; Keeley 2002; Lewis and Ferguson 1988). Although substantial data has been generated in support of complex indigenous land management practices (e.g., Anderson 1992, 1996, 1999, 2005; Anderson and Rowney 1999), extensive grassland burning is consistent with the predictions of intensification models, in that increased effort is expended in the extraction of more resources from the same unit of land (Beaton 1991; Boserup 1965; Cohen 1977:80-81).

The archaeobotanical research discussed above provides strong support for resource intensification models for late Holocene central California. The high labor costs of acorns suggest that they were resorted to initially during times of food stress, but were later selected as a dietary staple since they were capable of sustaining large population numbers during the winter and spring when other resources were scarce. The intensified use of acorns and other plant foods, such as small seeds and geophytes, also coincides with periods when large game populations suffered from high levels of resource depression in many areas of central California.

### *Sexual Division of Labor*

Although the use of ethnographic analogy based on specific case studies can be misleading, the richly documented ethnographic database from California and elsewhere can be used to generate hypotheses regarding sexual division of labor divisions in prehistory. Ethnographic research on modern foraging societies also provides a rich data source for modeling sexual division of labor practices in the past (Bird 1999; Hawkes and Bird 2002; Zeanah 2004). Among modern foraging societies, the sexual division of labor plays an important role in dictating mobility patterns, gender equality, and diet choice (Jochim 1988; Zeanah 2004). During the ethnohistoric period in California, subsistence activities were well demarcated according to gender, with women's subsistence activities focused on intensive processing of plant foods, such as acorns (Willoughby 1963). Women were also primarily responsible for basket making and plant gathering, although all members of the community assisted in the gathering and transport of acorns during the fall harvest (Jackson 1991; Willoughby 1963:26). Men's subsistence activities focused primarily on large game hunting and fishing activities (E. Wallace 1978:683), and by all accounts, did so exclusively among Ohlone (Costanoan) and Miwok societies (Willoughby 1963:18-25). For groups reliant on aquatic resources, men were most often responsible for making fishing nets, weirs, and hunting snares (Willoughby 1963:64). In modern coastal foraging societies, women are the primary shellfish gatherers (Claassen 1991, 1998:223), an observation that has contributed to the notion that shellfish are unequivocally low-ranked resources (Osborn 1977). Ethnographic and ethnohistoric reports from southern California indicate that women exploited shellfish from intertidal zones using pry bars and digging sticks, which could have been extracted with relatively low labor costs (Walker and Hollimon 1989:172; E. Wallace 1978:683). Although there were some deviations, E. Wallace (1978:683) notes that the “pattern of sex dichotomy reveals a remarkable similarity from one end of the state to the other.” Gender roles were not inflexible, however, and men and women did participate in one another’s work (E. Wallace 1978; Willoughby 1963).

The most important staple food throughout most areas of California during the ethnohistoric period was undoubtedly the acorn (Kroeber 1925; Moratto 1984; Schulz 1981). Ethnographic descriptions indicate that acorns were collected between late October and early November by the entire community, and were transported back to the village site using burden baskets (E. Wallace 1978:683; Willoughby 1963). Acorns were generally laid out to dry at the village site and then were stored in large granaries made of willow, deer brush, white fir, and pine needles (Bates 1984; Jackson 1991). Ethnographic research indicates that women were usually responsible for constructing and maintaining acorn granaries (Jackson 1991). Granaries were large, often capable of storing more than 500 lbs of acorns, and were commonly raised above the ground to prevent insect infestation (Bates 1984). The sides of the granary were tied together to prevent insects, animals, and mold from developing, but could easily be separated to access acorns when needed.

Preparing acorns for consumption was entirely within the domain of women and involved the labor-intensive process of shelling, winnowing, pounding, leaching, and cooking to make a variety of breads and soups (Jackson 1991). Acorns were shelled with using a hammer stone and the skin was separated from the nutmeat using a winnowing basket. The nutmeat was then pounded into fine flour using a stone mortar and pestle, a process that took several hours (Jackson 1991:305; Merriam 1918). Portable wooden mortars and pestles were also used in stone-poor areas, such as the Central Valley, while bedrock mortars were the primary toolkit in the Sierras (Hunt 2004; Jackson 1991). Once pounded into flour, the poisonous tannins were leached out using either hot or cold water poured into a sandy depression, known as a leaching basin. Among some northern groups, acorn dough was also mixed with clay to aid in the leaching process (Merriam 1918:130-131). Experimental research indicates that clays can reduce tannic acid content of acorns up to 77 percent, via adsorption, catalysis, and cooking (Johns and Duquette 1991). Leached acorn meal was cooked in watertight baskets using hot rocks (i.e., stone boiling), making a thick porridge (Driver 1952; Merriam 1918). For bread making, acorn mush was baked on top of hot rocks, which were sometimes covered with earth.

Although sexual division of labor practices have been documented for many native California societies, researchers generally rely on other evidence with respect to the archaeological record. For instance, some archaeologists view the widespread increase in mortar and pestle technology, circa 2800-1200 B.P., as strong evidence for increased gender differentiation in subsistence activities (Hildebrandt and McGuire 2002; Jones 1996; McGuire and Hildebrandt 1994). In sites dated from about 6000 to 4000 B.P., assemblages are dominated by milling stone tools used for seed processing (Erlandson 1994a). It would be erroneous, however, to suggest that males did not contribute in the acquisition of food resources based on the lack of flaked stone tools (McGuire and Hildebrandt 1994). McGuire and Hildebrandt (1994) examined evidence of gender-specific items from 44 middle Holocene and 104 late Holocene burials from southern California. They expected to find a higher frequency of projectile points and bifaces associated with male burials and a higher frequency of ground stone associated with female burials. For the middle Holocene sample, 93.6 percent of the burials contained milling tools; the remaining eight burials were associated with projectile points and bifaces, two of which included female burials (McGuire and Hildebrandt 1994:50). Late Holocene males were also much more likely to be associated with projectile points and bifaces than females, while females were much more likely than males to be interred with milling equipment. Based on these findings, McGuire and Hildebrandt (1994) linked the increase in gender-specific artifacts and grave goods after 2500 B.P. to greater circumscription in sexual division of labor practices. This is consistent with Hollimon's (1991) study of southern California Chumash burials, which found that "gendered" grave items corresponded with biological sex to greater degree during the Late period than the Early and Middle periods. These studies suggest that ethnographic analogy may not always provide an accurate representation of sexual division of labor in prehistory, since sex or gender-based subsistence practices in the past may have differed substantially from their ethnographic period counterparts.

### *Resource Intensification and Skeletal Health in Prehistoric California*

A central research question in archaeology over the past twenty-five years has been the health consequences of the transition from hunting and gathering to agriculture in many regions of the world (Larsen 1995). Early theorists attributed the adoption of agriculture and a more sedentary life way to an improvement in the human condition, brought on by technological change and increased social complexity. From this perspective, agriculture is believed to have provided a more reliable subsistence base that could better "buffer" societies against food shortages (Cohen 1977). However, ethnographic data collected on hunter-gatherers during the 1970s and 1980s suggests that low population densities and high levels of mobility protect individuals from long-term exposure to pathogens that cause infectious disease (Cohen 1977, Cohen 1989a; Hurtado and Hill 1990). Studies of labor costs also indicate that foragers work fewer hours per day than agriculturalists and yet maintain relatively stable population numbers (Cohen 1989a).

During the 1980s and 1990s, bioarchaeologists became increasingly interested in collecting data from human skeletons to examine the health consequences of the transition to agriculture in different areas of the world (Cohen 1981; Cohen and Armelagos 1984; Armelagos et al. 1991; Larsen 1995, 1997). In the influential volume, *Paleopathology at the Origins of Agriculture* (Cohen and Armelagos 1984), studies in the Americas and elsewhere suggested that health conditions declined with the transition from foraging to farming. More recent studies suggest that while health conditions declined for many prehistoric agriculturalists when compared to earlier hunter-gatherers from the same region, this was not a universal phenomenon (Larsen 1995,1997; Steckel et al. 2002a, 2000b). In general, prehistoric hunter-gatherers tended to show lower frequencies of dental pathology (e.g., carious lesions, antemortem tooth loss, periodontitis), non-specific indicators of stress (e.g., porotic hyperostosis; enamel hypoplasia, Harris lines), and periosteal reactions than prehistoric agriculturalists, and also attained a taller mean stature (Cohen and Armelagos 1984; Steckel et al. 2000a, 2000b). Although these trends are mirrored in many New World contexts, patterns reported for agricultural transitions in some parts of the Old World have been more variable (e.g., Kennedy 1984; Meiklejohn et al. 1984).

Recently, some researchers have questioned conventional interpretations of health changes with agriculture. For example, Wood et al. (1992) have argued that skeletons with lesions may actually represent healthier individuals than those without lesions, since many acute illnesses can cause death before an osseous response had time to develop (Wood et al. 1992). Thus, skeletons with lesions may represent healthier individuals that survived bouts of stress or illness, while those without lesions may have been the non-survivors with more compromised health status. Although the implications of this “osteological paradox” call into question aspects of traditional bioarchaeological inferences, recent studies are providing novel ways for addressing many of these issues (Usher 2000; Walker 1996; Wright and Yoder 2003). Nonetheless, the bulk of the data provide strong support for bioarchaeological interpretations of health transitions for many archaeological contexts.

Despite the successes of bioarchaeological research in understanding the health consequences of agricultural intensification, few studies have investigated health patterns among nonagricultural sedentary societies, such as prehistoric California. During the late Holocene, sedentary communities developed throughout many areas of

California, some of which formed complex levels of social organization comparable to that of agricultural societies (Arnold 1992, 1995a). Recent studies have examined the biological consequences of sedentism, subsistence change, and population-resource imbalances in southern California, which has provided data on health and dietary patterns that can serve as a basis for comparison with prehistoric agricultural societies (Lambert and Walker 1991; Schulz 1981; Walker and DeNiro 1986).

Bioarchaeological studies conducted in California have focused mainly on the Santa Barbara Channel Island area of southern California (Goldberg 1993; Lambert 1994; Lambert and Walker 1991; Walker 1986, 1989; Walker and DeNiro 1986; Walker and Erlandson 1986; Walker and Hollimon 1989; Walker and Thornton 2002), the Central Valley (Brabender 1965; Dickel et al. 1984; Doran 1980; Hoffman 1987; Ivanhoe 1995; Ivanhoe et al. 1998; Kennedy 1960; McHenry 1968; McHenry et al. 1978; Newman 1957; Schulz 1981; Wall 1991; Weiss 1998, 2002), and the San Francisco Bay area (Andrushko et al. 2005; Brabender 1965; Brooks 1975; Ivanhoe and Chu 1996; Jurmain 1990a, 1990b, 2001; Jurmain and Bellifemine 1997). In this section, I review a number of studies from California, but focus primarily on those that have examined temporal changes in diet and health patterns.

### *Southern California*

In southern California, bioarchaeologists have explored diet and health trends in prehistoric Chumash skeletons from the Santa Barbara Channel Islands and mainland (Lambert 1993, 1994; Lambert and Walker 1991; Titus and Walker 2000; Walker 1986, 1989; Walker and Erlandson 1986). One of the most striking patterns identified in the region is evidence of interpersonal violence, recognized by the high frequency of healed, depressed cranial vault fractures and projectile points embedded in bones (Lambert 1994, 1997; Lambert and Walker 1991; Walker 1989, 1997, 2001). Walker (1989) examined 744 crania from the Channel Islands area and found abundant healed cranial trauma. The prevalence of nonlethal injuries was significantly higher in crania from the northern Channel Islands (18.6 percent) than in mainland groups (7.5 percent). The injuries are most often circular or ellipsoidal in shape, and are most common on the frontal and parietal bones (Walker 1989:316-317). When compared by sex, males had a significantly higher prevalence of healed lesions than females (males, 24 percent; females, 10 percent). The frequency of cranial injuries also increased through time, suggesting elevated levels of interpersonal violence.

Lambert (1993, 1997) extended Walker's study to include injuries to both cranial and postcranial remains. Documenting similar trends, Lambert (1993, 1997) found that the prevalence of healed, depressed cranial trauma increased throughout the prehistoric period, with the highest levels in the early phase of the Middle period (circa 1490 B.C. to A.D. 580). Sex differences in the distribution of vault lesions suggested that the behaviors that led to these injuries differed between males and females (Lambert 1997:88). The frequency of embedded projectile points in skeletal elements also showed interesting patterns. Unlike nonlethal cranial vault trauma, projectile point injuries provide unambiguous evidence of interpersonal violence that was clearly aimed at causing death (Lambert 1997:90). Lambert (1997:94-97) found that projectile point injuries were most often found in the thorax, followed by the pelvic region and the cranium. Seventy percent of the cases lacked evidence of healing, suggesting that these individuals had died as a result of their injuries. Similar to the pattern identified for healed vault injuries, males showed a significantly higher frequency of projectile point injuries than females. Although the frequency of projectile point injuries increased through time, the highest frequency occurred during the late phase of Middle period (A.D. 300-1150). The different "peaks" in interpersonal conflict recorded by nonlethal cranial trauma versus lethal projectile point injuries suggest that the level of violence increased through time, since traumatic injuries became more lethal in nature (Lambert 1993, 1997; Lambert and Walker 1991). This unprecedented level of violence in southern California is consistent with resource intensification models, and indicates that the late Holocene was a time of significant sociopolitical stress. Archaeological evidence and paleoclimatic records also suggest that this was a period marked by increasing population density, when sedentary village communities were experiencing drought conditions that would have negatively affected resource productivity and sources of potable drinking water (Jones et al. 1999; Lambert and Walker 1991; Walker 1986). The introduction of the bow and arrow to the region during the period may also have enabled the development of more complex patterns of warfare (Blitz 1988; Lambert 1997).

Several studies show that health conditions declined during the late prehistoric period in the Channel Islands area (Lambert 1993, 1994; Lambert and Walker 1991; Walker and Hollimon 1989; Walker and Lambert 1989). Walker (1986) examined 432 crania for evidence of cribra orbitalia, a condition expressed in the superior roof of the eye orbit and commonly attributed to childhood iron-deficiency anemia. Walker (1986) found that the prevalence of cribra orbitalia was similar to that of maize-dependent agriculturalists, despite the fact that groups were heavily dependent on iron-rich marine foods, such as fish and marine mammals. The occurrence of orbital lesions increased through time and peaked during the late phase of the Middle period (Lambert and Walker 1991:969; Walker 1991-1992:102). Cribra orbitalia also differed significantly between regions, with islanders affected to a greater degree than mainlanders. Among islanders, the number of lesions increased with distance from the mainland, with the highest rate at San Miguel Island and the lowest at Santa Cruz Island (Lambert and Walker 1991:969). Resource productivity and the number of freshwater sources also differed between islands, suggesting that contaminated drinking water was a probable source of infection. Since cribra orbitalia is commonly found among prehistoric agriculturalists, these lesions have been generally attributed to a heavy consumption of iron-deficient foods, such as maize, during early childhood (Stuart-Macadam 1985). The high prevalence among southern California Channel Islanders suggests that bacterial infection from contaminated water sources may also have been a major cause of anemia in prehistory (Lambert and Walker 1991; Walker 1986). Although diet would have influenced the frequency of cribra orbitalia, bacterial infection was probably a more important factor in southern California, as weanling diarrheal disease can cause significant loss of dietary iron in young children. Helminth infestation, acquired through the consumption raw fish and marine mammals infested with parasites, may also have been a primary source of anemia in these groups (Walker 1986:351-352).

Tibial periosteal reactions were also relatively common in the Channel Islands area (Hollimon 1991; Lambert 1993, 1994). Periosteal reactions are often the result of streptococcal and staphylococcal infection, but may also be caused by treponemal infection or localized trauma (Ortner 2003). These lesions are often caused by infection through unsanitary living conditions, such as contaminated water sources, and can easily be spread through person-to-person contact (Cohen 1989; Lambert 1993). Similar to the patterns identified for anemia and interpersonal violence, the prevalence of tibial periosteal reactions increased through time, and peaked between the early and late phases of the Middle period (Lambert 1993:515). The trend was the same for both sexes, although males were slightly more affected than females. Lambert (1993:517) also notes that periosteal reactions were few and small in the Early period skeletons, and may primarily reflect localized bone trauma; however, lesions from the Middle period sample were significantly larger and more numerous, suggesting that they may be due to unsanitary health conditions associated with densely populated village communities. Walker et al. (2005) have recently confirmed the earliest documented evidence of treponemal disease in the western United States in individuals from the Santa Barbara mainland. Skeletons recovered from CA-SBA-52, an Early period site from the coast, show an unusually high prevalence of periosteal reactions (39 percent of 44 individuals affected; Walker et al. 2005:285). Since the lesions are confined to the limb bones, the diagnosis is more consistent with endemic syphilis or yaws than with venereal syphilis; debate is ongoing whether the Europeans introduced the latter form of the disease during the contact period (Walker et al. 2005:286). The identification of treponemal disease was confirmed through detailed histological analysis of a sub-sample of the affected individuals, which showed evidence of chronic inflammation (Walker et al. 2005:287-290). This study further suggests that periosteal reactions identified in the long bones of southern California groups are most likely due to infection rather than to trauma-induced bone reactions. Of particular interest is that burials from the post-contact period (circa A.D. 1542-1769) show caries sicca, a pathognomic lesion more often associated with venereal forms of treponemal disease (Walker et al. 2005:295-299).

Lambert (1993, 1994) has also examined temporal changes in stature in skeletal samples from the Channel Island area. Growth and development studies indicate that health status and diet contribute the most to stature, although genetic differences between populations account for some variation in height (Bogin 2005; Czerwinski and Towne 2004). Since femur length is highly correlated with stature, Lambert (1993) used this to approximate changes in body height for the skeletal samples. When compared, femur length showed significant declines in both sexes, between the early and late phases of the Early period, and between the late Middle and Late periods (Lambert 1993:516-517). The total loss in stature was approximately 10 cm between the earliest and latest periods, consistent with other evidence of declining health conditions during the late prehistoric period. Lambert and Walker's (1991) study of linear enamel hypoplasia (LEH) provides additional evidence for stressful conditions in the Channel Islands area. LEH lesions are bands of defective enamel, generally attributed to malnutrition or infection, which develop during dental development in childhood (Larsen 1997). Since these lesions are retained in adulthood but form in childhood, they can be used as a measure of childhood health status. The prevalence of LEH increased through time, with the highest levels associated with the Late period (Lambert and Walker 1991:968; Walker and Lambert 1989).

Walker and Hollimon (1989) and Hollimon (1988) have also examined changes in osteoarthritis (OA) patterns as a proxy for functional stress levels among prehistoric populations from the Channel Islands area. Using summed joint scores, Walker and Hollimon (1989) found a significant increase in OA between the Early and Late periods. The greatest increases were for joints of the lower limb, a trend that was more dramatic in males than females. Early period females had a higher prevalence of OA of the knee and vertebral column, while males had greater involvement at the shoulder, elbow, and hand (Walker and Hollimon 1989:176). These differences declined through time, as vertebral OA decreased in females and increased in males. Walker and Hollimon (1989) attributed the increase in OA to higher functional demands associated with the intensified exploitation of marine resources during the Middle and Late periods, and the minimization of sex differences to a shift toward a more similar sexual division of labor. The increase in OA of the elbow and wrist in males may reflect the greater use of canoes, nets, and harpoons associated with intensive fishing during the Late period (Walker and Hollimon 1989:180). For Early period females, the high degree of vertebral involvement may reflect the use of digging sticks for extracting tubers and shellfish, plant processing, and stresses encumbered from carrying burden baskets (Lambert and Walker 1991:967; Walker and Hollimon 1989:180).

Dietary change in the Channel Islands area has been examined through studies of dental wear, dental caries, and stable isotope analyses (Goldberg 1993; Harrison and Katzenberg 2003; Walker 1978; Walker and Deniro 1986; Walker and Erlandson 1986). These studies have provided the dietary context from which paleopathological trends have been examined, and have allowed researchers to evaluate the economic significance of carbohydrate and protein resources through time. Walker's (1978) study of dental wear in the Santa Barbara area found significant declines in attrition rates through time. He attributed the higher attrition rates in the Early period samples to the consumption of marine foods, such as shellfish and dried fish, foods that would have introduced grit and sand in the diet. Lambert and Walker (1991:966) later suggested that the consumption of abrasive roots and tubers may have been more important factors that contributed to the high attrition rates observed during the Early period. Walker and Erlandson's (1986) study of dental caries supports this interpretation since the prevalence of carious lesions declined through time, suggesting greater carbohydrate consumption (e.g., roots, tubers) during the Early period, and greater consumption of protein and fluorine-rich marine foods during the Late period. Compared by sex, carious lesions were more abundant in females than males during the Early period, although these differences declined during the Late period (Walker and Erlandson 1986:380). Sex differences in the Early period samples suggests differential access to protein between males and females, possibly due to more marked sexual division of labor practices (Walker 1988; Walker and Erlandson 1986). This evidence is consistent with the osteoarthritis patterns, which show that labor practices may have been become less sex-specific through time (Walker and Hollimon 1989).

The application of stable isotope analysis has provided unambiguous evidence of paleodietary change in the Channel Islands area of southern California (Goldberg 1993; Harrison and Katzenberg 2003; Walker and DeNiro 1986). Comparisons have been facilitated by the lack of C4 plants in the region, which produce carbon isotope signatures that overlap with marine resources. In a classic study, Walker and DeNiro (1986) analyzed carbon and nitrogen isotopes in bone collagen from 40 Chumash burials from the Santa Barbara mainland coast and Channel Islands. Temporal comparisons indicate that the marine component of the diet increased through time, a trend that was most dramatic among northern Channel Island populations. The contribution of terrestrial proteins to the diet also increased with proximity to the mainland. This suggests that geographical location (e.g., mainland interior, mainland coast, island) is strongly correlated with dietary signatures, and that trade networks were ineffective in redistributing food resources between regions (Walker and DeNiro 1986). The low diversity of terrestrial plant and animal resources on the islands is consistent with the heavier emphasis on marine foods. While sample sizes did not permit comparisons by sex, some of the isotopic variation may have been due to changes in post-marital residence patterns between the interior and coast or to sex differences in access to marine resources (Walker and DeNiro 1986:60).

Goldberg's (1993) doctoral dissertation examined carbon and nitrogen isotopes in bone collagen from burials from the Channel Islands and the southern California mainland coast and interior. Goldberg (1993) found significant regional differences (mainland interior, mainland coast, northern Channel Islands, southern Channel Islands) for both the time periods examined (< 3000 B.P. vs. >3000 B.P.). Similar to Walker and DeNiro's (1986) study, Goldberg (1993:149-150) found an increase in marine protein consumption with distance from the mainland. The high degree of variability observed among males from the coast may be the result of intermarriage patterns between the mainland coast and interior, as described in Mission records from the region. The southern Channel Island groups were also more reliant on marine foods than those from the northern islands, which Goldberg (1993:150) attributed to a less productive terrestrial resource base and the greater distance from the mainland. Goldberg (1993:150-151) also found evidence that indicated greater consumption of marine protein through time, although the pattern varied by region. For example, carbon isotope values showed significant differences through time for sites in the mainland interior, although nitrogen isotope values did not. Coastal sites showed no significant differences. Among sites from the northern Channel Islands, carbon and nitrogen isotope values increased significantly through time; however, for the southern Channel Islands, carbon isotope values significantly declined through time. When only San Clemente Island is considered, both carbon and nitrogen isotope values significantly declined through time, suggesting significant decreases in marine protein consumption. Goldberg (1993:151) attributed the latter trend to the increased consumption of terrestrial foods acquired through trade with the mainland. In general, males tended to have higher carbon and nitrogen isotope values than females, suggesting unequal access to marine foods between the sexes. Harrison and Katzenberg (2003) analyzed carbon and nitrogen isotopes from bone collagen and carbon isotope values from bone apatite in 33 samples from San Nicolas Island (southern Channel Islands). Two sites dated to an early period (< 3000 B.P.) and one site to a later period (>3000 B.P.). Since carbon isotope values from bone apatite provide a record of the composition of the whole diet, these values can be compared with carbon isotopes values from bone collagen to better understand the relative contribution of proteins and carbohydrates to the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993). Harrison and Katzenberg (2003:238) found that the protein component of the diet was more enriched than that of the whole diet, suggesting heavy marine protein consumption, but found no temporal or spatial variation.

Two isotopic studies have also examined paleodietary change in the Monterey Bay area, located in-between Santa Barbara to the south and San Francisco Bay to the north (Jones 1996; Newsome et al. 2004). Jones (1996) reported bone collagen carbon and nitrogen isotope values for six burials from four sites at Monterey Bay. Of particular interest was the C3 dominated terrestrial signature, since the burials were excavated from shell midden contexts. This may suggest that the dietary importance of shellfish has been overemphasized based on dietary reconstructions from shell midden accumulations (see Claassen 1998). Newsome et al. (2004) have recently examined carbon and nitrogen isotope values in nine human burials from a site near Monterey Bay. Using a source-partitioning mixing model (Iso-Source), Newsome et al. (2004) compared dietary values between bone collagen samples dated to the early and middle

Holocene. Based on the statistical constraints developed in their model, Newsome et al. (2004) concluded that the early Holocene group consumed approximately 75 percent marine proteins, while the middle Holocene group consumed around 55 percent marine proteins. They suggested that the decline in the marine protein component was due to the reduced consumption of fish, but that marine mammal consumption remained important for both groups. Although sample sizes are small, this study provides a novel attempt to model paleodiets that derive from multiple food sources that differ with respect to macronutrients.

### *Central California—Sacramento and San Joaquin Valleys*

Despite ongoing interest in central California bioarchaeology (e.g., Andrushko et al. 2005; Bartelink 2001; Cordero 2001; Grady et al. 2001; Hollimon 1995; Ivanhoe 1995; Ivanhoe and Chu 1996; Jurmain 2001; Jurmain and Bellifemine 1997; Richards 1995; Weiss 1998, 2002), few studies have examined temporal changes in diet and health in the region. In comparison with southern California, research in central California has produced somewhat conflicting results. McHenry's (1968) classic study of Harris lines in human femora from the lower Sacramento Valley was the first attempt to understand the effects of acorn subsistence on prehistoric health patterns. Harris lines (i.e., transverse lines) develop in the long bone diaphyses of children in response to growth disruption, and signify a rebound from nutritional or disease-related stress (Larsen 1997). McHenry (1968) found a significant decline in Harris line frequency between the Early, Middle, and Late periods, which he attributed to the benefits provided by more reliable acorn storage economies. Schulz's (1981) dissertation study later confirmed the trend identified by McHenry, although some discrepancies occurred between the two studies, likely due to differences in the x-ray method, sample representation, and interobserver error. For example, Schulz (1981) found an average of 2.82 lines per bone compared to 8.01 found by McHenry. Although the Harris line data suggests that health conditions improved through time in the lower Sacramento Valley, contradictory results were found in the enamel hypoplasia data from the same samples (McHenry and Schulz 1976, 1978; Schulz 1981). The frequency of hypoplastic defects in canines decreased from 14 to 10 percent between the Early and Middle period, but increased to 18.5 percent with the Late period (Schulz 1981:121). The latter trend was unexpected since enamel hypoplasias and Harris lines are both measures of developmental stress resulting from nutritional deficiencies or disease-related illness (McHenry and Schulz 1976:508). Schulz (1981:121-122) hypothesized that this trend may have been the result of the spread of Old World infectious diseases by Europeans during phase 2 of the Late period. One explanation for the divergent trends between the Harris line and LEH data is that the former may be recording acute growth interruptions caused by nutritional stress, while the latter may be the result of more severe and chronic childhood illness, such as infection (McHenry and Schulz 1978:45; Schulz 1981:124).

Doran (1980) examined paleodemographic profiles in skeletal samples from the lower Sacramento Valley dated to the Early, Middle, and Late periods, and found an increase in population growth rates through time (i.e., lower mean age-at-death), with the most significant demographic changes occurring between the Early to Middle periods. Doran suggested that the increased growth rates could have resulted from a reduction in birth spacing and the age of first pregnancy. He further hypothesized that elevated levels of infection may have caused the increased mortality rates through time in the 0 to 4 year old age-category. For ages four to twelve years, however, mortality rates declined, suggesting an overall reduction in childhood stress (Doran 1980:94-97). The decline in mortality rates in four-year olds also suggested that transition from breast milk to solid foods became less disruptive through time.

The aforementioned studies have been used in support of the *seasonal-stress hypothesis*, which predicts that the acorn and salmon-dependent populations of the Middle and Late periods were healthier than Early period populations from the lower Sacramento Valley (Dickel et al. 1984). According to this model, the intensive acorn-storage economies of the Middle and Late period provided a more reliable subsistence base that could buffer populations against seasonal food shortages. Early period populations, in comparison, were subject to more episodic bouts of starvation, particularly during the late winter and early spring, when critical food resources would have been scarce (Dickel et al. 1984; Schulz 1981). Schulz's (1970, 1981) study of Early period (Windmiller) burial orientations found that nearly 80 percent fell between 223 and 282 degrees (magnetic), corresponding to the position of the setting sun at the winter and summer solstices, respectively. Based on this evidence, he argued that the vast majority of interments occurred between late spring and early winter, when Sacramento Valley populations would have experienced episodes of starvation.

Although several studies indicate that health conditions actually improved through time in the Central Valley, other studies suggest that health declined in the region (Ivanhoe 1995; Newman 1957; Weiss 2002). For example, Ivanhoe (1995:239) examined cranial and postcranial changes in an extensive sample from the lower Sacramento Valley, and reported a significant decrease in body size, with a total stature reduction of 2.5 percent between the Early and Late period. Ivanhoe (1995) attributed this reduction in stature to the increased consumption of protein-deficient acorns during the Middle and Late periods, with may have contributed to stunted growth. Newman (1957) also reported a reduction in postcranial size and robusticity through time, although he attributed these changes to sequential population replacements. Furthermore, osteometric analyses of postcranial remains indicate larger humeral and femoral dimensions for the Early period samples compared with those from the Middle and Late periods (Dickinson-McDonald 1988; Dittrick and Suchey 1986). A recent study by Weiss (2002) also reported a significant decline in mean femoral cortical thickness and an increase in skeletal lesions (unspecified) in two temporally distinct cemeteries from CA-SJO-91, located in the northern San Joaquin Valley. Weiss (2002) suggested that the decline in health was due to increased nutritional stress and disease associated with the drought conditions of the Medieval Climatic Anomaly (circa 1100±90 to 1220±200 years B.P.).

Paleodietary studies in the Central Valley have been primarily limited to analyses of dental attrition and dental pathology (e.g., Kennedy 1960; Leigh 1928; Newman 1957; Schulz 1981; Schmucker 1985). Newman (1957) reported an increase in the prevalence of carious teeth between the Early, Middle, and Late periods. In a later study, Kennedy (1960) compared the rate of dental disease between Early and Late period samples, and also found that carious lesions were more prevalent in Late period groups. Early period groups, in contrast, had higher levels of antemortem tooth loss, alveolar abscesses, and dental attrition. These studies suggest that Middle and Late period diets were more cariogenic than those of the Early period, consistent with a diet that became more focused on carbohydrate rich foods, such as acorns. However, Schulz's (1981) more comprehensive examination of dental caries in samples from the lower Sacramento Valley found no temporal differences. Females had a significantly higher caries rate than males, suggesting that they consumed greater amounts of carbohydrates-rich foods (Schulz 1981:148). Males, in contrast, had higher rates of pulp exposure, particularly for the Middle and Late periods. Schulz (1981:161) hypothesized that the lower prevalence of caries in males would have made non-carious teeth more susceptible to pulp exposure through attrition, while antemortem tooth loss due to caries would have reduced the number of observable teeth affected by pulp exposure in females. Based on these findings, Schulz (1981) concluded that, while acorns probably became more important in the Middle and Late periods, the contribution of carbohydrates and proteins to the diet remained essentially unchanged through time.

### *Central California—San Francisco Bay Area*

Bioarchaeological research in the San Francisco Bay Area has largely been synchronic in nature. To date, only a few studies have investigated temporal variation in diet and health patterns (e.g., Bartelink 2001; Brooks 1975; Ivanhoe and Chu 1996). Ivanhoe and Chu (1996) examined cranial and postcranial measurements in skeletal samples from the San Francisco Bay area. Although the trend was not as marked as that identified for the lower Sacramento Valley, Ivanhoe and Chu (1996) found a significant reduction in stature through time. The greatest differences occurred between the Early and Early-Middle period transition, and between phase 1 and 2 of the Late period. Ivanhoe and Chu (1996:369-370) also found that San Francisco Bay populations are metrically smaller than their Sacramento Valley counterparts, and may have represented a morphologically distinct population. These findings are consistent with previous osteometric studies on central California samples (e.g., Brooks 1975; Gerow 1993).

Bartelink (2001) examined temporal patterns in the expression of elbow OA in skeletons from five sites along the eastern shore of San Francisco Bay (e.g., CA-ALA-13, 307, -309, -328, -329). Research over the past few decades has demonstrated a relationship between joint degeneration and functional stress, with the strongest correlation at the elbow joint (Jurmain 1991a, 1999). Bartelink (2001) hypothesized that the prevalence of elbow OA in females would increase through time, due to greater functional demands associated with acorn processing with mortars and pestles. For males, a change from unilateral to bilateral OA involvement was expected, marking the shift from the atlatl to the bow and arrow between the Middle and Late period. Although the greatest differences occurred between the Early and Middle period, the prevalence of elbow OA involvement actually declined through time. Males showed greater OA involvement than females during the Middle and Late period. Bartelink (2001) argued that the greater sex difference through time reflected a change in the sexual division of labor.

Similar to reports from the Santa Barbara Channel, evidence of interpersonal violence in central California is relatively common (Andrushko et al. 2005; Grady et al. 2001; Jurmain 1991b, 2001; Jurmain and Bellifemine 1997; Pastron et al. 1973; Tenney 1986), although temporal patterns have yet to be systematically explored. While evidence of interpersonal violence in the San Francisco Bay area is less prevalent than southern California, the prevalence of "parry fractures," healed cranial trauma, and projectile point injuries is substantially higher than that reported for most other North American prehistoric contexts (see Jurmain 1991b, 1999, 2001; Jurmain and Bellifemine 1997). Jurmain (2001) found that 4.4 percent of adults from the Yukisma site (CA-SCL-638, circa 240 B.C. to A.D. 1770) showed healed cranio-facial fractures, a rate slightly higher than the 2.7 percent reported for the Ryan Mound site (CA-ALA-329) located 14 miles away (Jurmain and Bellifemine 1997). Similarly, Newman (1957) found that 2.1 percent of male crania from the lower Sacramento Valley showed healed cranial trauma. Jurmain (2001) reported that 70 percent of all long bone fractures from the Yukisma site were to the forearm, injuries that may be linked to interpersonal violence. The overall rate of forearm injuries was 2.3 percent, comparable to the 1.8 percent observed in samples from the Ryan Mound (Jurmain 1991b, 2001). For both the Yukisma and Ryan Mound samples, at least 2.5 percent of skeletons had embedded projectile points, slightly higher than the ~1.9 percent reported for nearby Rubino site (CA-SCL-674; Grady et al. 2001), and the 2.2 percent identified in sites from southern California (Lambert 1994, 1997). Recent examinations of skeletal samples from the Rubino site have also documented an unusual pattern of "trophy taking", which included the targeting of forearm bones and crania for removal (Andrushko et al. 2005; Grady et al. 2001). Andrushko et al. (2005) found that for individuals missing forearms, cut marks were nearly always present on associated distal humeri. In areas adjacent to the primary interments, they identified caches of drilled and polished radii and ulnae, further supporting the "trophy taking" hypothesis. Of particular interest is that most of the evidence of interpersonal violence in central California is found on the skeletons of adult males (Andrushko et al. 2005; Grady et al. 2001; Jurmain and Bellifemine 1997). This is consistent with ethnographic and ethnohistoric evidence of warfare practices, which primarily involved young and middle-aged males.

### ***Theoretical Expectations***

In this study, I use bioarchaeological evidence to investigate changes in diet and health associated with late Holocene resource intensification in central California. I draw on predictions from human behavioral ecology to develop a series of hypotheses aimed at understanding the biological consequences of subsistence change throughout the prehistoric record of the lower Sacramento Valley and the San Francisco Bay area. Resource intensification models posited for central California predict temporal declines in foraging efficiency during the late Holocene, marked by population-resource imbalances, territorial circumscription, and higher levels of sedentism. If intensification models accurately characterize subsistence change in California, then it follows that these patterns should be recognized in diet and health indicators observed on bones and teeth of human skeletons. These expectations closely match the mid-to-late Holocene human skeletal record from the Santa Barbara Mainland and Coast of southern

California (Lambert 1993, 1994; Walker 1996; Walker and Erlandson 1986; Walker and Lambert 1991).

I address three primary research questions in this study to investigate temporal and spatial variability in diet and health: 1) *were subsistence changes during the late Holocene in central California marked by the increased consumption of low trophic level fauna and vegetal foods, such as acorns, seeds, and root foods?;* 2) *were these subsistence changes associated with a decline in health status?;* and 3) *did these changes result in greater inequality between the sexes, reflected in differences in both diet and the quality of health?*

Resource intensification models predict late Holocene declines in foraging efficiency, measured by the increased focus on lower-ranked food resources through time. I hypothesize that the shift toward intensified acorn use, smaller fauna, and lower-trophic level marine resources through time should be evident in the carbon and nitrogen stable isotope values from human bone. Although stable isotope values often cannot identify the specific food resources consumed, the data provide a means through which to measure the differential contribution of protein and carbohydrate resources to diet, and also the contribution of different macronutrients that are derived from marine versus terrestrial ecosystems.

Temporal comparison of dental caries rates provides an additional line of evidence regarding the importance of protein and carbohydrate food resources through time. I hypothesize that the dental caries rate will increase through time, due to the greater consumption of carbohydrate-rich plant foods, such as acorns, seeds, and root foods. Since San Francisco Bay area populations had direct access to a greater diversity of protein-rich marine foods that protect against caries development, I expect to find fewer carious lesions in these samples than in those from the lower Sacramento Valley.

To evaluate temporal changes in health, I examine the following four indicators of health status: 1) tibial periostoses; 2) mean femoral length; 3) porotic hyperostosis; and 4) linear enamel hypoplasia. Resource intensification models predict temporal declines in foraging efficiency, and by extension, temporal declines in health status during the late Holocene (Broughton and O'Connell 1999). I hypothesize that the prevalence of tibial periostoses (as a general measure of infectious disease) should increase through time, associated with greater population crowding and sedentism during the late Holocene. I hypothesize that nutritional status, as measured by mean femoral length, porotic hyperostosis, and linear enamel hypoplasia, will decline through time with the economic transition between the Early and Late period. Since the hypothesized subsistence changes originated between the Early and Middle periods, I expect to find greater declines in health during this transition than between the Middle and Late periods.

To evaluate possible changes in the sexual division of labor, I compare male and female health status and stable isotope dietary signatures through time. Although males and females are at different levels of risk for disease due a variety of biological factors, sexual inequality in access to food resources plays an important role in sex differences in health in many societies (Ortner 2003:114-117). Sex differences in access to food resources may be the result of gendered status differences, or may simply be an unintended consequence of sexual division of labor practices (Grauer and Stuart-Macadam 1998). In central California, available evidence suggests that sexual division of labor patterns became more demarcated through time (McGuire and Hildebrandt 1994). This is consistent with the expectations of resource intensification, since greater sex segregation in labor organization may result from population-resource imbalances (Cohen 1989a, 1989b).

### *Summary*

Resource intensification models provide a robust and testable framework from which to evaluate temporal changes in diet and health patterns in prehistoric central California. While debate continues among archaeologists regarding the importance of environmental factors, population pressure, and social complexity in driving subsistence change, the results of this study should help to clarify whether the purported changes resulted in poorer or improved health conditions through time. The seasonal-stress hypothesis advanced by Schulz (1981), McHenry (1968), and Dickel et al. (1984) argues that the development of intensified acorn strategies resulted in improved nutrition and health, contra the predictions of resource intensification models. Since the bioarchaeological component of the seasonal-stress hypothesis is primarily based on three lines of evidence (i.e., Harris lines, linear enamel hypoplasias, dental caries), it is possible that these data did not fully encompass the biological changes in health and diet experienced by populations from the lower Sacramento Valley. Resource intensification models, on the other hand, predict temporal declines in health in the lower Sacramento Valley and the San Francisco Bay area, as measured by a reduction in dietary quality, increased population crowding, and greater levels of sedentism. Although temporal trends in interpersonal violence have not been examined in central California, the comparatively high levels of trauma observed in the Bay Area suggest that populations may have been experiencing high levels of resource stress during the late Holocene.

# CHAPTER IV

# SAMPLE DEMOGRAPHY AND CHRONOLOGY

Sex and age are key variables that influence disease processes that affect skeletal and dental tissues (Ortner 2003). Since various sex and age cohorts may be at differential risk of morbidity and mortality, it is important to control for these variables in paleopathological analyses (Jurmain 1999). Age and sex-controlled comparisons also provide a more meaningful framework for interpreting health and diet information. In this chapter, I describe the criteria used to estimate sex and age of the skeletal samples and then evaluate potential biases in the samples. Finally, I describe the seriation method that I used to place burials within their respective time periods, as well as some of the criticisms of the dating scheme (i.e., Scheme B1, Bennyhoff and Hughes 1987). I provide examples of the data collection forms used in this study in Appendix A. These forms were designed to collect data following guidelines in *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker 1994), and were provided by Lori Wright of Texas A&M University.

The skeletal samples used in this study are curated at the Phoebe Apperson Hearst Museum of Anthropology (PAHMA) located on the campus of the University of California at Berkeley. Permission to complete paleopathological and isotopic analyses of human skeletal remains was granted by the curator and museum staff in full compliance with the Native American Graves and Repatriation Act (NAGPRA). I completed all osteological analyses between May 2004 and January 2005. The skeletal samples from the lower Sacramento Valley sites fall within the ethnographic boundaries of the Plains Miwok tribe, while skeletal samples from San Francisco Bay fall within the ethnographic boundaries of the Ohlone Tribe.

## ***Sex and Age Estimation***

### *Sex Estimation*

For the purposes of this study, I examined a total of 511 skeletons, the majority of which were adults (85.3 percent; n = 436). Of the adult sample, 93.1 percent (406/436) could be sexed using standard osteological criteria. Males comprised 44.1 percent (179/406) and females 55.9 percent (227/406) of the sexed sample. Thirty skeletons (7.4 percent of the adult sample) were assigned an indeterminate sex since they either lacked diagnostic criteria or showed intermediate expressions of sexually dimorphic features.

I estimated the sex of the adult sample using several methods outlined in *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker 1994). *Standards*, as this document came to be known, was developed for NAGPRA compliance and represents a culmination of the efforts of several bioarchaeologists to establish minimum criteria for recording osteological data, especially for collections subject to repatriation. For the vast majority of the adult sample, I relied on sexually dimorphic features of the pelvis (e.g., ventral arc, subpubic concavity, ischiopubic ramus ridge, preauricular sulcus, sciatic notch), which provide correct classification approximately 95 percent of the time (e.g., France 1998; Phenice 1969; Rogers and Saunders 1994; Steele and Bramblett 1988; Sutherland and Suchey 1991; Walker 2005; White 2000).

For the cranium, I scored five sexually dimorphic features (e.g., nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge, and mental eminence) using a five-point ordinal scale ranging from the most gracile to the most robust (see Ascadi and Nemeskeri 1970; Buikstra and Ubelaker 1994). In general, non-metric criteria of the skull produce an accuracy rate of 80 to 90 percent (White 2000:362).

When pelvic and cranial indicators were unavailable, I sexed adults using long bone measurements. In a previous study, Dittrick and Suchey (1986) measured a large sample of femora and humeri from prehistoric central California and reported sectioning points for males and females. In their study, accuracy for humeral and femoral dimensions was comparable to that of cranial indicators, and ranged from about 80 to 90 percent. Dittrick and Suchey (1986) also examined temporal variation and reported different sectioning points for the Early period and the combined Middle and Late period samples. For approximately ten percent of the adult sample, I estimated sex metrically using Dittrick and Suchey's (1986) sectioning points.

### *Adult Age Estimation*

I used a number of criteria to estimate the age-at-death of the adult sample. In general, the pelvis provides the most reliable criteria for estimating age. I evaluated pubic symphysis age estimates separately for males and females using the Suchey-Brooks aging casts and following procedures outlined in Brooks and Suchey (1990), Buikstra and Ubelaker (1994), and Katz and Suchey (1986). Similarly, I evaluated age-related changes in the auricular surface of the ilium following the protocol described in Buikstra and Ubelaker (1994) and Lovejoy et al. (1985). In general, these pelvic indicators have proved to be effective in aging forensic and modern anatomical collections with a reasonable degree of accuracy, although age ranges and standard deviation increase appreciably for older individuals (Brooks and Suchey 1990; Buckberry and Chamberlain 2002; Buikstra and Ubelaker, ed. 1994; Klepinger et al. 1992; Lovejoy et al. 1985). In cases that lacked pelves, ectocranial suture closure was used to estimate age following Buikstra and Ubelaker (1994) and Meindl and Lovejoy (1985). Other aging methods, such as the degree of dental attrition and vertebral osteophytosis were also assessed, although these criteria were only used to clarify discrepancies between more reliable aging criteria.

In conjunction with the methods outlined above, I also used the *transition analysis* aging method, recently developed by Boldsen (1997) and Boldsen et al. (2002). Unlike most skeletal aging methods that categorize general changes in anatomical features into a series of sequential phases, transition analysis uses multiple aging criteria and provides point-age estimates based on maximum likelihood ratios. This approach attempts to counter the limitations of most traditional aging methods by independently evaluating age-related changes in a series of different components. For example, five separate components of the pubic symphysis (e.g., symphyseal relief, symphyseal texture, superior apex, dorsal symphyseal margin, dorsal symphyseal margin) are independently evaluated, followed by six features of the auricular surface and posterior iliac region, and five cranial sutures (see descriptions in Boldsen et al. 2002:96-104). A central problem in paleodemographic research is that the age-at-death distribution of the study sample tends to “mimic” the distribution of the reference sample following the age criteria upon which the latter age estimates are based (Bocquet-Appel and Masset 1982; Hoppa and Vaupel 2002). The transition analysis method attempts to overcome this problem by first estimating the age-at-death distribution of the entire sample and then estimating the age-at-death for specific individuals in the sample (Boldsen et al. 2002:73). An additional advantage is that the method can be applied to incomplete or fragmentary skeletons. Although transition analysis is still considered in the testing stage, it represents a statistically robust approach for skeletal aging that can complement more traditional methods. For the purposes of this study, I calculated age estimates for adults and compared point age estimates and ranges with other aging criteria. In most cases, the transition analysis error ranges overlapped with pubic symphysis and auricular surface ages, and confirmed the general age interval in which each skeleton was placed. The ADBOU (Archaeological Database Odense University) computer software program– developed by Jesper Boldsen– was used to calculate the age-at-death distribution and point age estimates.

### *Subadult Age Estimation*

For estimating the age of the subadult sample, I used dental eruption sequences, dental maturation stages, long bone lengths, and epiphyseal union stages. I estimated dental ages using figures and descriptions presented in Buikstra and Ubelaker (1994). Similarly, I recorded long bone measurements following Buikstra and Ubelaker (1994) and compared these values with standardized tables reported in Scheuer and Black (2000). Finally, I recorded epiphyseal union stages for the major long bones and compared these values with aging charts compiled in Scheuer and Black (2000).

### ***Skeletal Samples***

Table 4.1 presents the sample distribution by age category: subadult (0-16 years); young adult (18-29 years); middle adult (30-39 years); late adult (40+ years); and adult, age indeterminate (18+ years). For some of the analyses, I divide the subadult sample into the following age categories: 0-5 years, 6-10 years, 11-16, and 17-19 years. I also combined age categories to increase the sample size for some statistical comparisons and in instances when significant age or sex differences did not exist. For the adult sample, 82.6 percent (360/436) could be assigned an age category; the remaining 17.4 percent (76/436) of the adult sample are classified as adult, age indeterminate (20+ years). The remaining 75 individuals (14.7 percent of sample) are classified as subadults, and included individuals that ranged from infancy to age 16 years, although most (67 percent) were between 6 and 16 years of age.

The Sacramento Valley skeletal sample consists of 290 individuals (Table 4.1). When partitioned by time period, the Early period (n=137) sample has the largest sample size, followed by the Middle (n=90) and Late (n=63) periods, respectively. For the Early period sample, males outnumber females 2 to 1 in the young adult age category, while females outnumber males 1.4 to 1 in the late adult category. Females also outnumber males 4.5 to 1 in the Middle period sample and 4 to 1 in the Late period sample for the late adult category. In general, comparisons of the total sex ratios by time period indicate that the Early period sample is well balanced, while the Middle and Late period samples are skewed toward a higher number of females. For subadults, the Early period sample has the highest number of individuals represented (n=28), followed by the Middle (n=13) and Late Period (n=11) samples.

Table 4.1. Age and Sex Distribution of the Skeletal Samples by Region and Time Period.

| | **Sacramento Valley** | | | | | | | | **San Francisco Bay** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Males** | | **Females** | | **Indeter-minate** | | **Subadults** | | **Males** | | **Females** | | **Indeter-minate** | | **Subadults** | |
| **Age** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** |
| **Early Period (4950-2150 B.P.)** | | | | | | | | | | | | | | | | |
| 0-17 | | | | | | | 28 | 20.4 | | | | | | | 11 | 20.4 |
| 18-29 | 21 | 15.3 | 10 | 7.3 | | | | | 5 | 9.3 | 9 | 16.7 | | | | |
| 30-39 | 10 | 7.3 | 11 | 8.0 | 3 | 2.2 | | | 4 | 7.4 | 5 | 9.3 | | | | |
| 40+ | 14 | 10.2 | 20 | 14.6 | 1 | .7 | | | 5 | 9.3 | 16 | 29.6 | | | | |
| 20+ | 7 | 5.1 | 9 | 6.6 | 3 | 2.2 | | | 2 | 3.7 | 3 | 5.6 | | | | |
| Total | 52 | 38.0 | 50 | 36.5 | 7 | 5.1 | 28 | 20.4 | 16 | 29.6 | 27 | 50.0 | | | 11 | 20.4 |
| **Middle Period (2150-1050 B.P.)** | | | | | | | | | | | | | | | | |
| 0-17 | | | | | | | 13 | 14.4 | | | | | | | 7 | 7.1 |
| 18-29 | 17 | 18.9 | 13 | 14.4 | 1 | 1.1 | | | 15 | 15.3 | 15 | 15.3 | 3 | 3.1 | | |
| 30-39 | 9 | 10.0 | 7 | 7.8 | | | | | 10 | 10.2 | 6 | 6.1 | 1 | 1 | | |
| 40+ | 4 | 4.4 | 18 | 20.0 | 1 | 1.1 | | | 4 | 4.1 | 17 | 17.3 | 1 | 1 | | |
| 20+ | 3 | 3.3 | 3 | 3.3 | 1 | 1.1 | | | 5 | 5.1 | 8 | 8.2 | 6 | 6.1 | | |
| Total | 33 | 36.7 | 41 | 45.6 | 3 | 3.3 | 13 | 14.4 | 34 | 34.7 | 46 | 46.9 | 11 | 11.2 | 7 | 7.1 |
| **Late Period (1050-200 B.P.)** | | | | | | | | | | | | | | | | |
| 0-17 | | | | | | | 11 | 17.5 | | | | | | | 5 | 7.2 |
| 18-29 | 7 | 11.1 | 11 | 17.5 | | | | | 6 | 8.7 | 14 | 20.3 | 1 | 1.4 | | |
| 30-39 | 5 | 7.9 | 4 | 6.3 | | | | | 6 | 8.7 | 1 | 1.4 | | | | |
| 40+ | 4 | 6.3 | 16 | 25.4 | 1 | 1.6 | | | 9 | 13.0 | 5 | 7.2 | | | | |
| 20+ | | | 2 | 3.2 | 2 | 3.2 | | | 7 | 10.1 | 10 | 14.5 | 5 | 7.2 | | |
| Total | 16 | 25.4 | 33 | 52.4 | 3 | 4.8 | 11 | 17.5 | 28 | 40.6 | 30 | 43.5 | 6 | 8.7 | 5 | 7.2 |

The San Francisco Bay sample consists of 221 individuals (Table 4.1). The Middle period (n=98) sample has the largest sample size, followed by the Late (n=69) and Early (n=54) period samples. The small size of the Early period sample is due to the paucity of archaeological phases dating to this period in the Bay Area. For the Early period sample, females outnumber males 3.3 to 1 in the young adult category and 3.2 to 1 in the late adult category. For the Middle period sample, males outnumber females 1.7 to 1 in the middle adult category, while females outnumber males in the late adult category 4.3 to 1. Finally, for the Late period, females outnumber males 2.3 to 1 in the young adult category and 1.4 to 1 in the late adult category; males outnumber females only in the middle adult category. The Early period also has the highest representation of subadults (n=11), followed by the Middle (n=7) and Late period (n=5) samples. Overall, the San Francisco Bay sample has a balanced sex distribution for the Late period sample, with a more skewed representation for the Early and Middle period.

### *Burial Seriation*

The skeletal remains used in the present study were excavated between the early 1900s and the 1970s. The conditions under which many archaeological investigations were undertaken varied dramatically, ranging from careful excavations by professional archaeologists to salvage recovery efforts undertaken during construction projects. Fortunately, professional archaeologists excavated the majority of sites selected for the present study, many of whom were affiliated with the University of California Archaeological Survey at U.C. Berkeley. Between the 1950s and 1990s, the late James A. Bennyhoff seriated hundreds of burials into the Central California Taxonomic System, using the grave lot as the primary unit of analysis. Although Bennyhoff never published his burial seriations, he “phased” skeletons from dozens of archaeological sites throughout central California for several osteological research projects. I obtained burial seriation information through a detailed review of the Bennyhoff note collection curated by Randy Milliken of Far Western Anthropological Research Group, Inc. Bennyhoff’s notes are organized by archaeological site and contain detailed descriptions and charts that illustrate how each burial was phased. For each burial, Bennyhoff listed the corresponding museum catalogue and/or burial numbers by site, phase, and time period. Although Bennyhoff relied heavily on time-diagnostic shell bead types from grave lots, his notes indicate that he evaluated a number of independent lines of evidence, including radiocarbon dates, obsidian hydration profiles, burial orientation, “charm stone” types, projectile point types, and grave depth in making his assessments.

As discussed in Chapter II, the chronological framework used in the present study follows Bennyhoff and Hughes’ scheme B1 (Bennyhoff 1994a; Bennyhoff and Hughes 1987). This chronological sequence was developed as an alternate to previous dating schemes (e.g., Beardsley 1948, 1954a, 1954b; Gifford 1947; Heizer 1949) and is based primarily on time-diagnostic *Olivella* shell bead types. Bennyhoff and Hughes (1987:147) argued that most previous dating schemes were based on only a few radiocarbon dates that failed to identify significant periods of culture change. Scheme B1 is based on 180 uncorrected radiocarbon dates, many of which were derived directly from shell beads (Bennyhoff and Hughes 1987). In general, while archaeologists recognize the time-diagnostic value of many *Olivella* bead types, several problems have come to light over the past two decades with respect to the dating scheme (see Groza 2002). First, the radiocarbon dates used to construct scheme B1 were based on different sample materials, including charcoal, bone collagen, and shell, and were derived from both burial and midden contexts (Bennyhoff and Hughes 1987; Groza 2002:27-39).

Second, the use of mixed charcoal and shell samples may have provided imprecise dates, since materials of different ages may have been combined. Third, some of the radiocarbon analyses used to construct scheme B1 were performed before $\delta^{13}C$ correction was systematically applied, before humic acids and diagenetic carbonates were routinely removed from bone collagen and charcoal samples, and before routine correction for the marine reservoir effect for dating shell.

In a recent study, Groza (2002) recalibrated 162 of the 180 dates that were used to construct scheme B1, and AMS-dated 103 additional time-sensitive *Olivella* beads to test the scheme's validity. Groza (2002) found support for most of the time-sensitive bead types defined by Bennyhoff and Hughes (1987), although the new AMS dates altered the calendrical dates for some of the phases. In particular, Groza (2002) found that Bennyhoff had reversed the "Late Middle" and "Terminal Middle" phases, and that the Late Period began later than originally thought. Groza (2002) introduced scheme D as an alternative to scheme B1, which should be a more reliable chronology since it based on a single material (*Olivella* shell beads), and corrects for both $\delta^{13}C$ and the reservoir effect. Despite inconsistencies between these two dating schemes, I follow convention in using the general chronological framework presented in scheme B1, but recognize that scheme D may gain in acceptance after further validation. Table 4.2 and Figure 4.1 provide a comparison of dating scheme B1 and scheme D.

Table 4.2. Central California Chronology.

| | **Approximate Dates (Scheme B1) (Bennyhoff and Hughes 1987)** | | **Calibrated Dates (Scheme D) (Groza 2002)** | |
|---|---|---|---|---|
| **Period** | **B.P.** | **B.C./A.D.** | **B.P.** | **B.C./A.D.** |
| Late Period | 1050-200 B.P. | A.D. 900-1800 | 740-230 B.P. | A.D. 1210-1720 |
| Middle/Late Transition | 1250-1050 B.P. | A.D. 700-900 | 940-740 B.P. | A.D. 1010-1210 |
| Middle Period | 2150-1250 B.P. | 200 B.C.-A.D. 700 | 2160-940 B.P. | 210 B.C.-A.D. 1010 |
| Early/Middle Transition | 2450-2150 B.P. | 500-200 B.C. | 2450-2160 B.P. | 500-210 B.C. |
| Early Period | 4950-2450 B.P. | 3000-500 B.C. | >3450-2450 B.P. | >1500-500 B.C. |

Due to potential biases associated with individual burial seriations, I combined all skeletons from each region into three broad chronological periods for the purposes of this study: Early period (circa 4950-2150 B.P.), Middle period (circa 2150-1050 B.P.), and Late period (circa 1050-200 B.P.). I also include skeletons dated to the Early-Middle period transition with the Early period sample and skeletons dated to the Middle-Late period transition with the Middle period sample. Although this sacrifices more detailed chronological resolution, it also avoids the problem of grouping burials into unrealistic time increments that have been difficult to validate (see Bouey 1995; Groza 2002). In conjunction with Bennyhoff's seriations, I also crosschecked burial numbers with available radiocarbon dates to evaluate any major discrepancies between absolute and relative dating methods. Fortunately, some of the sites were only occupied during one time period, and some of the others showed relatively clear stratigraphic demarcations between periods.

Table 4.3 presents the skeletal sample by time period, site, and region. For the Sacramento Valley, the Early period is represented by SJO-68 (Blossom Mound) and SJO-142 (McGillivray Mound). The Middle period is represented primarily by SAC-43

(Brazil Mound) and SAC-60 (Hicks Mound), although a few individuals from SJO-154 (Cardinal Mound) are included in the sample. Four sites represent the Late period sample: SJO-154, SAC-43, SAC-60, and SAC-06 (Johnson Mound). The majority of burials are from SJO-154 and SAC-06, the latter of which was occupied from the Late period into the Mission period.

For the San Francisco Bay, the Early period is represented primarily by ALA-307 (West Berkeley Village), although a few individuals from the "basal cemetery" (Component C) at ALA-328 (Patterson Mound) are included in the sample. The Middle period is represented by four sites: ALA-307, ALA-309 (Emeryville Shellmound), ALA-328, and ALA-329 (Ryan Mound). The Late period is primarily represented by ALA-309 and ALA-329, but also includes two individuals from ALA-328. Compared with the Early period, the Middle and Late period samples are more representative of the two sub-regions of the Bay Area included in this study (i.e., upper east Bay and lower east Bay).

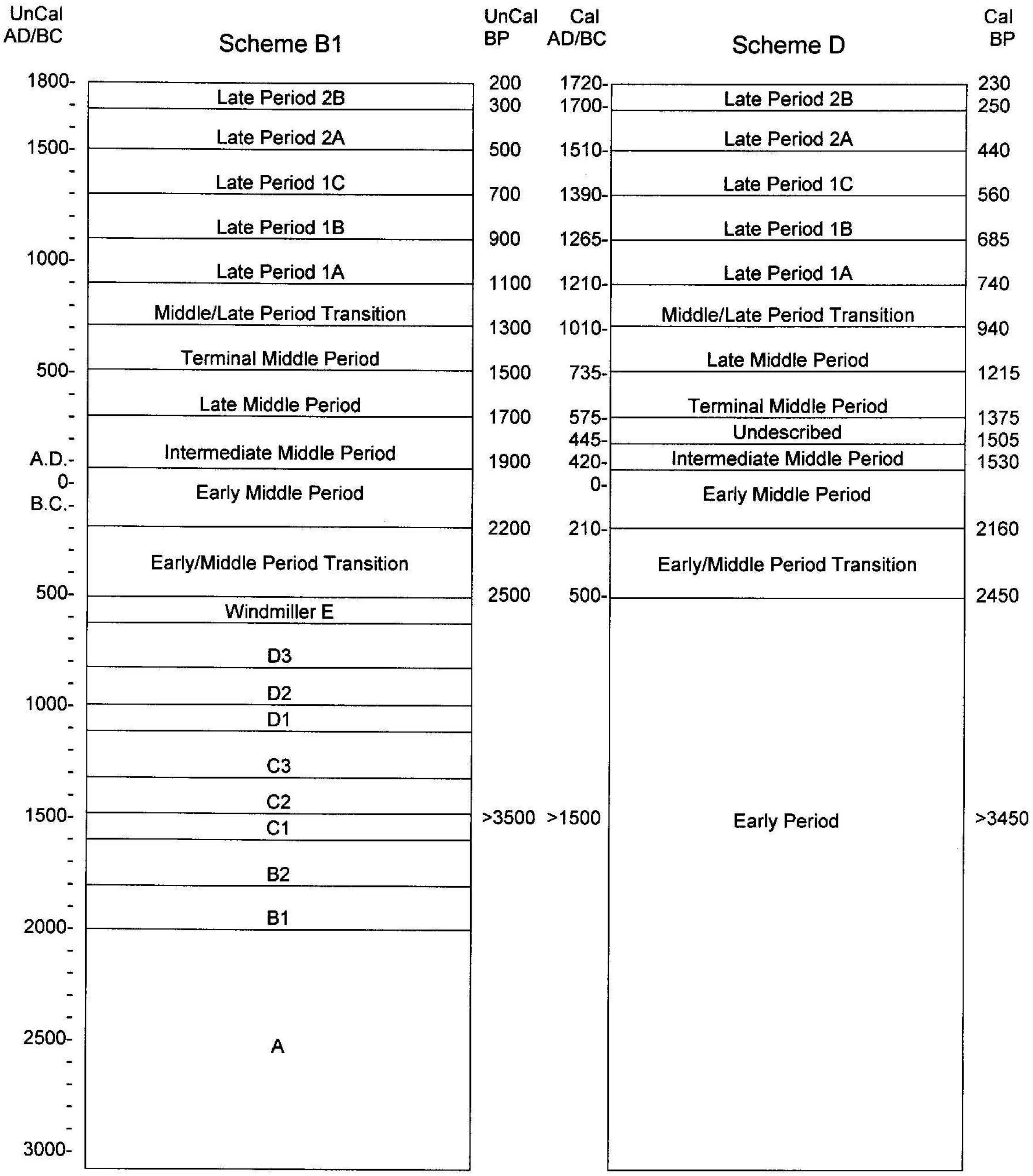

**Figure 4.1** Scheme B1 and Scheme D.
(Redrawn after Bennyhoff and Hughes 1987:149, Figure 10; Groza 2002:95, Figure 6).

Table 4.3. Distribution of Skeletal Samples by Region and Time Period.

| | **Sacramento Valley** | | | | | | **San Francisco Bay** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Males** | **Females** | **Indeterminate** | **Subadult <17 years** | **Totals** | | **Males** | **Females** | **Indeterminate** | **Subadult <17 years** | **Totals** |
| **Early Period** | | | | | | **Early Period** | | | | | |
| CA-SJO-68 | 33 | 35 | 5 | 27 | 100 | CA-ALA-307 | 14 | 22 | | 9 | 45 |
| CA-SJO-142 | 19 | 15 | 2 | 1 | 37 | CA-ALA-328 | 2 | 5 | | 2 | 9 |
| Total | 52 | 50 | 7 | 28 | 137 | Total | 16 | 27 | | 11 | 54 |
| **Middle Period** | | | | | | **Middle Period** | | | | | |
| CA-SJO-154 | 2 | 3 | | 3 | 8 | CA-ALA-307 | 2 | 3 | 3 | 2 | 10 |
| CA-SAC-43 | 20 | 22 | 2 | 6 | 50 | CA-ALA-309 | 17 | 16 | 6 | 3 | 42 |
| CA-SAC-60 | 11 | 16 | 1 | 4 | 32 | CA-ALA-329 | 6 | 15 | | 1 | 22 |
| Total | 33 | 41 | 3 | 13 | 90 | CA-ALA-328 | 9 | 12 | 2 | 1 | 24 |
| | | | | | | Total | 34 | 46 | 11 | 7 | 98 |
| **Late Period** | | | | | | **Late Period** | | | | | |
| CA-SJO-154 | 3 | 12 | | 3 | 18 | CA-ALA-309 | 20 | 21 | 5 | | 46 |
| CA-SAC-43 | 3 | 2 | | 2 | 7 | CA-ALA-328 | | 2 | | | 2 |
| CA-SAC-60 | 1 | 2 | | 1 | 4 | CA-ALA-329 | 8 | 7 | 1 | 5 | 21 |
| CA-SAC-06 | 9 | 17 | 3 | 5 | 34 | Total | 28 | 30 | 6 | 5 | 69 |
| Total | 16 | 33 | 3 | 11 | 63 | | | | | | |

### *Summary*

The accurate determination of sex and age is a critical component in paleopathological investigations. As Walker et al. (1988) have noted, age and sex biases can be influenced by a number of factors including the gender of the investigator, differential preservation of skeletal samples, and cultural rules regarding burial practices of the dead. In this study, I minimized some of these biases by relying on multiple criteria for estimating sex and age from the skeletal sample. Although the demographic composition of the sample is biased towards a higher number of females, especially in late adult age category, the overall sample sizes should be adequate for comparing the prevalence of pathological lesions between groups.

The skeletal samples demonstrate age and sex biases, but should still provide adequate sample sizes for most statistical comparisons. The skewing of the sample towards adults is due, in part, to the primacy that adults have been given in burial seriation studies, and also due to the fact that subadults were less commonly interred with time-diagnostic grave goods. In general, females are over-represented for both regions, particularly in the late adult category. For statistical comparisons of disease or stress indicators that are influenced by age and sex (e.g., dental caries), I address the effects of biases in the age-sex distribution.

Using Bennyhoff's note collection, I was able to seriate a relatively large sample of burials into three major time periods for the purposes of comparison. While debate continues with respect to the reliability of various dating schemes among California archaeologists, I deemed it necessary to use scheme B1 to provide meaningful temporal assignments for the skeletal samples. To minimize burial phasing problems, I assigned each skeleton to a broader time interval, which should be sufficient to identify major diet and health trends.

# CHAPTER V

# PALEODIETARY RECONSTRUCTION

The reconstruction of prehistoric diets has been a central focus of bioarchaeological research over the past several decades and has provided important insights regarding food exploitation patterns of earlier human societies. The emergence of ecologically oriented approaches during the 1960s laid the groundwork for the study of archaeofaunal and archaeobotanical remains – the food items consumed by prehistoric societies – as well as the study of the material remains used to extract and process those food resources. However, the archaeological record may be inherently biased, because of differential preservation of biological remains, varied sampling methods during excavation, and misinterpretation of the uses of food processing implements.

Since the 1970s, applications of stable isotope analysis in archaeology have provided a new tool that can aid in the reconstruction of prehistoric diets. The statement "you are what eat" is the basis for applications using stable isotopes for reconstructing past diets and refers to the relationship between the isotopic composition of an animal's tissues and its diet (Ambrose et al., 2003). In this chapter, I first review the theoretical basis of stable isotope analysis and then define the parameters of prehistoric diets in central California based on evidence derived from the archaeological and ethnographic record. With these parameters defined, I provide a reconstruction of late Holocene paleodiets in the Sacramento Valley and San Francisco Bay using stable isotope analyses of carbon and nitrogen in bone collagen, and stable isotopes of carbon in bone apatite.

### *Stable Isotope Analysis*

Isotopes are atoms of the same element that have the same number of protons but a different number of neutrons. Unlike unstable forms of isotopes, stable isotopes do not undergo radioactive decay over time, and thus record chemical signatures of biological and geological processes in nature. Although chemically similar, isotopes of the same element react at different rates in chemical reactions due to slight differences in atomic mass (i.e., due to the difference in the number of neutrons). This results in the disproportionate incorporation (enrichment) of one isotope over another if the chemical reaction does not go to completion. Alternatively, isotopes are fractionated during equilibrium processes due to thermodynamic differences between compounds. The enrichment of one isotope relative to another is known as “isotopic fractionation”, and accounts for differences in stable isotope ratios in nature. Stable isotopes are expressed by the ratio of the “rare” isotope to the “abundant” isotope (e.g., $^{13}C/^{12}C$) relative to an international standard.

Stable isotope ratios are calculated relative to a standard of known isotopic composition, and are expressed in parts per thousand, or “permil”, relative to the standard (Schoeller 1999:668-669). International laboratory standards for stable isotope research are provided by the National Bureau of Standards and the International Atomic Energy Agency, Vienna. The delta notation symbol (δ) is used to express the isotopic ratio of a sample relative to the standard. Isotopic composition is calculated as follows:

$$\delta = (R_{\text{sample}} - R_{\text{standard}}) / R_{(\text{standard})} \times 1000$$

Where R is equal to the ratio of the rare to the abundant isotope in the sample compared with that of the standard.

The most common stable isotope ratios used to reconstruct diet of living organisms are $^{13}C/^{12}C$ ($\delta^{13}C$) and $^{15}N/^{14}N$ ($\delta^{15}N$). Stable isotopes of carbon are expressed relative to the PDB standard, a Cretaceous belemnite fossil from the Peedee formation in South Carolina. PDB, by definition, has a value of 0‰, and is enriched in $^{13}C$ relative to organic carbon and most terrestrial carbonate materials. Hence, $\delta^{13}C$ values for the materials in this study are negative relative to the standard. Since the actual source of PDB has been exhausted, secondary standards (e.g., NBS-19) are used and calibrated to PDB. Stable isotopes of nitrogen are expressed by the ratio of $^{15}N/^{14}N$ relative to the standard, which is atmospheric $N_2$ (AIR). Because atmospheric $N_2$ is more depleted in $^{15}N$ than most living things, $\delta^{15}N$ values in nature are almost always positive relative to the standard, which is set at 0‰. Substances that are enriched in the "heavy" isotope of carbon or nitrogen have higher delta ($\delta$) values than substances that are depleted in the "heavy" isotope. I discuss the distribution of stable isotopes of carbon and nitrogen isotopes in ecosystems below.

### *Carbon*

Carbon has two stable isotopes, $^{13}C$ and $^{12}C$, that occur in nature at abundances of 1.1 and 98.9 percent, respectively (Schwarcz and Schoeninger 1991). Hence, the heavy isotope is less abundant than the light isotope. Natural variations in carbon isotopes ratios reflect fractionation processes and variation in dissolved marine bicarbonate and atmospheric $CO_2$. The atmosphere transfers carbon to terrestrial organisms through plant photosynthesis, while natural waters derive carbon from multiple sources, including dissolved inorganic carbon ($HCO_3$), atmospheric $CO_2$, and $CO_2$ from decomposed organic matter introduced by rivers (Tan 1989). In marine ecosystems, organisms obtain carbon primarily from the photosynthetic activity of phytoplankton (Schwarcz and Schoeninger 1991:304).

The photosynthetic pathway a plant uses to fix atmospheric $CO_2$ is the main factor that determines carbon isotope variation in living organisms. During photosynthesis, the carboxylating enzyme, ribulose bisphosphate carboxylase, incorporates smaller amounts of $^{13}C$ than $^{12}C$, which results in $^{13}C$-depleted plant tissues relative to atmospheric $CO_2$ (O'Leary 1981, 1988). C3, C4, and CAM plants follow unique photosynthetic pathways and differ in isotopic composition due to differences in reaction rates when incorporating atmospheric $CO_2$. These pathways relate to adaptive mechanisms that different plants use to maximize efficiency of photosynthesis in different environments (Heaton 1999).

C3 plants follow the Calvin-Benson photosynthetic pathway and utilize a 3-carbon molecule that discriminates against the isotopically heavier $^{13}C$ when incorporating atmospheric $CO_2$. C3 plants show a large isotopic discrimination relative to atmospheric $CO_2$ and this fractionation results in plant tissues with $\delta^{13}C$ values that that typically range from –34 to –22‰, with an average of –27.1 ± 2.0‰ (O'Leary 1988:329, 334). C3 plants account for the vast majority of the earth's vegetation, and include trees, shrubs, legumes, and most types of grasses and tubers that are found in temperate regions (O'Leary 1981, 1988).

C4 plants include maize, millet, amaranth, sugarcane, and some tropical grasses that are typical of hot and arid climates. These plants follow the Hatch-Slack photosynthetic pathway and utilize a 4-carbon molecule that discriminates less against the isotopically heavier $^{13}$C than do C3 plants when incorporating atmospheric $CO_2$. Because of these differences in photosynthesis, C4 plants are more enriched in the "heavy" isotope than are C3 plants and have an average isotopic value of –13.1 ± 1.2‰ (O'Leary 1988:334). The non-overlapping ranges of C3 plants C4 plants permit discrimination between dietary signatures for organisms that consume these resources in different amounts.

CAM (Crassulacean Acid Metabolism) plants include desert-adapted flora such as succulents and cactus, and have isotopic signatures that overlap with C3 and C4 plants. CAM plants open their stomates at night and selectively incorporate $CO_2$ using a process similar to that used by C4 plants (O'Leary 1988:331). During the daytime, some CAM plants reopen their stomates and incorporate $CO_2$ into their tissues similar to C3 plant photosynthesis. For CAM plants that only photosynthesize in the dark, $\delta^{13}$C values average around -11‰. However, CAM plants can range isotopically from –10 to –20‰, depending on the degree of daytime photosythesis.

Other factors can contribute $\delta^{13}$C variation in plants, although these differences are small relative to the differences caused by different photosynthetic pathways. Genetic differences within a single plant species can result in $\delta^{13}$C values that vary by as much as 3.0‰, although variability will be more restricted within a given ecosystem (Tieszen 1991:236). Different plant parts (e.g., seeds, roots, leaves) may also differ slightly in isotopic composition, due to variation in $\delta^{13}C$ values of different biochemical components (Codron et al. 2005). The environment also influences variation in $\delta^{13}C$ values in plants. For example, increases in irradiance and temperature and decreases in precipitation cause $\delta^{13}C$ enrichment in plant tissues (Heaton 1999; Tieszen 1991). In dense forests in particular, $\delta^{13}C$ values can vary by 3-4‰ due the "canopy effect" (coined by van der Merwe and Medina 1989), with the most depleted values near the ground surface and the most enriched values in the upper layers of the canopy. Differences in available sunlight and reassimilation of $^{13}C$ depleted $CO_2$ near the ground surface appears to account for much of the $\delta^{13}C$ variability in forested environments (Heaton 1999:640-641; van der Merwe and Medina 1989, 1991; Tieszen 1991).

Aquatic freshwater plants obtain carbon from dissolved inorganic carbon in natural waters and show $\delta^{13}C$ values that overlap with terrestrial plants; however, most are C3 plants and have average values of approximately -25‰ (Schwarcz and Schoeninger 1991:304). In contrast, marine plants typically are more enriched in $^{13}C$ than terrestrial plants by about 7‰, and these differences are passed up the food chain to animal consumers. Marine plankton vary isotopically and generally show intermediate values between the ranges of C3 and C4 plants; however, sea grasses and some algae (e.g., seaweed) may have $\delta^{13}C$ values that are close to the average values for C4 plants (Ambrose 2000; Schwarcz and Schoeninger 1991:304). Animals that feed within marine ecosystems tend to have $\delta^{13}C$ values that are enriched by ~7‰ relative to those that feed within terrestrial ecosystems.

The isotopic composition of plants is recorded in the tissues of animal consumers (Schoeninger and DeNiro 1984). However, controlled feeding studies indicate that an animal's tissues are slightly enriched in $^{13}C$ relative to the diet (Ambrose 2000; Ambrose and Norr 1993; DeNiro and Epstein 1978; Krueger and Sullivan 1984). DeNiro and Epstein (1978) found tissues to be enriched by 1-2‰ for small animals, although the range for controlled feeding studies of both small and large mammals varies from .5 to 4.6‰ (Ambrose 2000:101; Ambrose and Norr 1993:5, Table 1). Diets of prehistoric humans and mammals in nature suggest larger isotopic differences between bone collagen and diet, and have values that range from 4.7 to 6.1‰. Collagen-diet spacing varies between tissues, with little isotopic fractionation between an animal's diet and muscle, and greater fractionation between diet and bone collagen (DeNiro and Epstein 1978). Recent controlled feedings experiments on rats and mice indicate an average collagen-diet spacing of 5.0‰ for bone collagen (Ambrose and Norr 1993; Tieszen and Fagre 1993).

The use of carbon isotopes from bone mineral (carbonates in bioapatite) for paleodietary construction has been the subject of considerable debate. Sullivan and Krueger (1981) were the first to argue that apatite from bone and enamel could be used for paleodietary reconstruction, thus extending the period of time to studies of older fossils that no longer preserve the organic collagen fraction. However, Schoeninger and DeNiro (1982) argued that diagenetic exchange between sediments and fossils would produce erroneous carbon isotope values. Although new sample treatment methods are now used to remove the more soluble and isotopically lighter diagenetic carbonates from the mineral fraction of bone and enamel tissue (Lee-Thorp et al. 1989; Sullivan and Krueger 1983), this has not always been successful. However, bioapatite samples can be examined spectroscopically using Fourier transform infrared spectroscopy (FTIR), which can help identify samples that are diagenetically altered (Nielsen-Marsh and Hedges 2000a; Wright and Schwarcz 1996).

Krueger and Sullivan (1984) argued that the $\delta^{13}C$ value of bioapatite reflects the isotopic composition of all dietary macronutrients (proteins, carbohydrates, and lipids), while the $\delta^{13}C$ value of bone collagen primarily reflects the protein component of the diet. Two controlled feedings studies using rats and mice fed a pure C3, C4, and mixed diet indicate that some carbon molecules from dietary protein are preferentially routed to bone collagen and record a signature biased toward the protein component of the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993). These studies also support the hypothesis that the $\delta^{13}C$ value of apatite is derived from dissolved bicarbonate in the blood and accurately reflects the isotopic composition of the whole diet. This suggests that carbon atoms used to form collagen follow a protein “routing” model, while carbon atoms used to form the carbonate in bioapatite follow a “linear mixing model” (Ambrose and Norr 1993; Tieszen and Fagre 1993).

The use of carbon isotopes from bone collagen in conjunction with bioapatite can provide additional information regarding the contribution of different macronutrients to the diet. These applications use differences in carbon isotope values between diet and bone collagen, and diet and bone apatite, to determine potential sources of dietary macronutrients. Ambrose and Norr (1993) found a consistent spacing of 9.4 ± .6‰ between diet and apatite, which was 4.4‰ larger than the average spacing of 5.0‰ between diet and collagen. However, collagen-diet spacing varies depending on whether dietary protein is isotopically heavier or lighter than that of the whole diet. For example, terrestrial animals that feed from C3 food webs show a collagen-apatite spacing of approximately 4.4‰, since the $\delta^{13}$C value of the protein component of the diet is the same as that of the whole diet (9.4-5.0 = 4.4‰). However, a diet that consisted of $^{13}$C-enriched marine animal proteins and C3 carbohydrates would result in a collagen-apatite spacing value that is less than 4.4‰, since the $\delta^{13}$C value of the dietary protein would be heavier than that of the whole diet (Ambrose et al. 1997; Harrison and Katzenberg 2003). Alternately, a diet that consisted of C4 plants and C3 animal proteins would result in a collagen-apatite spacing value that is greater than 4.4‰, since the $\delta^{13}$C value of dietary protein would be lighter than that of the whole diet. However, Harrison and Katzenberg (2003:241) found relatively high collagen-apatite spacings (~10‰) in some individuals from sites from Southern Ontario that predated the introduction of maize, a C4 plant. The authors suggest that these high values reflect a diet that consisted almost entirely of C3 plant foods, which provided the main source of dietary protein.

### *Nitrogen*

Stable nitrogen isotopes have also been successfully applied in the reconstruction of prehistoric diets, and can be used to distinguish between marine and terrestrial diets. Nitrogen has two stable isotopes, $^{15}$N and $^{14}$N, that occur in nature at abundances of .36

and 99.64 percent, respectively. More than 99 percent of exchangeable nitrogen is bound as $N_2$ in the atmosphere and ocean, and is incorporated into most plants from inorganic ammonium and nitrates in soils (Ambrose 1991; Schwarcz and Schoeninger 1991). Terrestrial plants that obtain $N_2$ from the soil generally have $\delta^{15}N$ values that are higher than the standard (AIR), which is 0‰ (Heaton 1987; Virginia and Delwiche 1982). Nitrogen in soils is incorporated into the tissues of vascular plants, and derives from complex nitrification and denitrification processes associated with the bacterial decomposition of organic matter. However, some plants (e.g., legumes) share a symbiotic relationship with bacteria and fix most of their nitrogen from atmospheric $N_2$. These plants have significantly lower $\delta^{15}N$ values than non-fixing plants that obtain nitrogen from the soil. In aquatic ecosystems, blue-green algae (cynobacteria) act as nitrogen-fixers, and thus also have low $\delta^{15}N$ values (Schoenhherr 1992).

Terrestrial plants that obtain nitrogen through bacterial degradation in soils also show significant variation in $\delta^{15}N$ values due to differences in environment and climate (Ambrose 1986, 1991; Heaton 1987). For instance, soils in saline and arid climates are more enriched in $^{15}N$ than are cool, moist forest soils. Terrestrial plants located within coastal and estuarine settings are also isotopically enriched, due to sea spray and fixation with nitrogen-enriched saline soils (Heaton 1987; Sealy et al. 1987). Marine plants have $\delta^{15}N$ values that are ~4‰ heavier than terrestrial plants, and these differences are reflected in animal consumers.

Since all nitrogen incorporated into bone collagen derives from dietary protein, $\delta^{15}N$ values of an animal's tissues accurately reflect the $\delta^{15}N$ value of the whole diet.

Since plants contain only 10 to 25 percent protein, and meat is 85 to 90 percent protein, meat consumption will dominate $\delta^{15}N$ signatures (Ambrose et al. 2003:220-221). Unlike carbon isotopes, nitrogen isotopes show a "trophic effect", with a 3-4‰ step-wise increase over food values at each level in the food web (DeNiro and Epstein 1981). Herbivore tissues are enriched by 3-4‰ over the plants that they eat, and carnivores show a similar enrichment over herbivore tissues. Due to this step-wise enrichment, it is often possible to reconstruct food webs of primary producers, herbivores, and carnivores within a given ecosystem (Ambrose 1986). Marine animals are more enriched in $^{15}N$ than terrestrial animals, due to longer food chains in marine environments. Additionally, phytoplankton at the base of marine food webs are enriched in $^{15}N$ due to the incorporation of dissolved nitrates from seawater, and this higher $\delta^{15}N$ value is transferred to secondary consumers (Schwarcz and Schoeninger 1991).

Although stable nitrogen isotopes have been useful for reconstructing animal diets, researchers have recognized that other factors also contribute to high $\delta^{15}N$ values in animals (Ambrose 1986, 1991; Sealy et al. 1987). For instance, large herbivores from arid regions show anomalously high $\delta^{15}N$ values, which suggests that metabolic processes also contribute to isotopic variation (Ambrose and DeNiro 1986; Ambrose 1986, 1991). Research in this area suggests that two different metabolic processes may account for this variation. Ambrose and DeNiro (1986) and Ambrose (1986, 1991) argued that water-stressed animals selectively retain greater amounts of $^{15}N$ for tissue synthesis, whereas the lighter $^{14}N$ will be excreted in urea. In contrast, Sealy et al. (1987) argued that nitrogen recycling within the digestive system in protein-stressed ruminants could produce trophic-like effects and result in high $\delta^{15}$N values. Schwarcz et al.'s (1999) study of prehistoric humans and archaeofauna from the Sahara Desert suggests a relationship between high $\delta^{15}$N values and both arid climate and excretion of $^{15}$N-depleted urea due to water-stress. These studies indicate that both metabolic factors and climate should be carefully considered in human paleodietary studies, since each may produce high $\delta^{15}$N values that could be misinterpreted as trophic level effects relating to diet.

### *Archaeological Applications*

Applications of stable isotope analyses for reconstructing prehistoric diets began in the late 1970s with Vogel and van der Merwe's (1977) classic study of prehistoric populations from eastern North America. This study was the first to document the introduction and increased reliance on maize, a C4 cultigen, by prehistoric societies in the Americas. Later research demonstrated that the adoption of maize agriculture varied dramatically between regions, and that maize was not eaten in some areas until very late in prehistory (Larsen 1997). The spatial and temporal variability in these trends appears to reflect environmental differences, responses to climate change, the availability of other food resources, and also cultural factors. More recent applications have used carbonate from bone apatite to track the introduction of C4 cultigens in the diet (Ambrose et al. 2003; Harrison and Katzenberg 2003).

Schoeninger et al. (1983) found that the combination of carbon and nitrogen isotopes could be used to distinguish between marine and terrestrial C3 diets in coastal settings. Since marine food webs tend to be enriched in both $\delta^{13}$C and $\delta^{15}$N, the importance of marine foods can be assessed using bivariate plots of carbon and nitrogen (Keegan and DeNiro 1988). Larsen et al. (1992) found that carbon and nitrogen isotopes could also help distinguish between maize and marine food consumption for Georgia coast groups that exploited both resources.

Paleodietary studies using carbon and nitrogen isotopes suggest that Mesolithic populations from the Atlantic coast of Europe were more reliant on marine resources than were later Neolithic populations (Lubell et al. 1994; Richards et al. 2003). Along the Pacific Coast of North America, a number of studies have also documented spatial and temporal variation in marine food consumption (Chisholm et al. 1983; Goldberg 1993; Harrison and Katzenberg 2003; King 1997; Molto and Kennedy 1991; Walker and DeNiro 1986). For instance, Walker and DeNiro (1986) found evidence for the increased use of marine resources (e.g., marine fish, sea mammals) through time among forager societies from the southern California coast. Goldberg's (1993) study of coastal groups from southern California found that marine animal consumption increased through time for the Northern Channel islanders, but decreased through time for Southern Channel islanders. Chisholm et al. (1983) and Schwarcz (1991) found that groups that lived along the British Columbia coast were heavily dependent on salmon, but found little variation in $\delta^{13}C$ and $\delta^{15}N$ through time. Coltrain et al. (2004) found that arctic foragers of eastern Canada relied heavily on marine foods, and may have derived some of their dietary protein from whaling. These studies document substantial regional and temporal variation in the consumption of marine resources in different coastal settings, and demonstrate the wide applicability of stable carbon and nitrogen analysis in the discrimination between marine versus terrestrial food consumption.

### *Materials and Methods*

I obtained bone samples for stable carbon and nitrogen isotope analysis (n=111). I sampled approximately 2-3 grams of bone from adult individuals, and attempted to include an equal number of males and females from each time period and region to obtain a representative sample. In following the PAHMA guidelines for destructive analysis, I preferentially selected rib fragments (n=56) for isotopic analysis. In cases where rib fragments were unavailable or showed evidence of poor bone preservation, I selected long bone shaft fragments (n=37). For eighteen individuals, I used bone powder samples that came from femora and tibiae shafts. These samples were used in previous bone dating research and had been carefully cleaned prior to grinding (Cook and Heizer 1953, 1959; Heizer and Cook 1947, 1949). To verify that these samples had not been chemically altered, I compared the $\delta^{13}C$ and $\delta^{15}N$ values of bone fragments and bone powder samples from four individuals. In this study, I also include four samples from CA-MRN-266, a Late period site located along Tomales Bay to the north of San Francisco. I use preliminary results from this site to compare coastal forager diets with diets from San Francisco Bay and the lower Sacramento Valley.

To provide baseline data for key animal resources, I sampled archaeological fauna (n=19) from two sites used in this study (ALA-309, SAC-06). Ala-309 is located along eastern shore of San Francisco Bay, and SAC-06 is located along the Cosumnes River in the lower Sacramento Valley. Faunal specimens are housed at the PAHMA and were sampled according to the museum's destructive analysis policy. To supplement the archaeofauna data, I collected bone samples of modern fauna from central California and also used published isotope results from the literature. I evaluate all dietary differences between periods and regions using the Mann-Whitney U test, which is a commonly used non-parametric alternative to the Student's T-test. Because I expect data to be non-normally distributed, this statistic is especially suited to the data since comparisons are based on average rank rather than on sample means. I consider results to be statistically significant at $p<.05$.

### *Collagen*

A diamond-studded dremel drill was used to clean the external bone cortex and to remove any adhering cancellous bone from the samples. I cleaned bone samples ultrasonically in 50 mm centrifuge tubes through washes of Barnstead filtered-$dH_20$, 95 percent ethanol, 100 percent ethanol, and acetone to remove any surface contaminants. The "collagen" fraction was extracted by soaking bone samples in a .25 M HCl solution until completely demineralized (Ambrose 1993; Schoeninger et al. 1989; Schwarcz and Schoeninger 1991). Collagen was extracted from bone powder samples by soaking the sample in a 1.0 M HCl solution until demineralized (~45 min to 1 hr), following a modified protocol of Ambrose (1990) and Bell et al. (2001). Collagen pseudomorphs were soaked in a .125 M solution of NaOH for 24 hrs to remove humic contaminants, and the "collagen" residue was gelatinized, frozen overnight, and lyophilized (freeze-dried). I measured collagen yields by subtracting the collagen sample weight after processing from the pretreatment sample weight. Fresh bone provides good collagen yields of around 20 percent, while yields between 1 and 5 percent may produce anomalous results (Ambrose 2000; van Klinken 1999). Carbon and nitrogen isotope ratios in collagen were measured by continuous-flow mass spectrometry by Thomas Boutton, Department of Rangeland Ecology and Management, at Texas A&M University. Collagen was combusted in a Carbo Erba EA-1108 elemental analyzer, which feeds sample gases to the Finnigan Delta Plus isotope ratio mass spectrometer. Precision of duplicate measurements was ± .1‰ for $\delta^{13}C$ and ± .15‰ for $\delta^{15}N$. I calculated atomic C/N ratios to identify diagenetically altered samples. Previous research suggests that samples with a C/N ratio outside the range of 2.9-3.6 may be diagenetically altered (DeNiro 1985).

### *Apatite*

For bioapatite, bone samples were mechanically ground into a powder using a steel mortar and pestle and sieved through a fine-mesh screen (<70 μm). The collagen fraction was removed through treatment with a 1.5 percent sodium hypochlorite solution (.04 ml solution/mg sample) for 48 hr, replaced once at 24 hr (Koch et al. 1997). The samples were agitated several times a day to ensure even contact between the bone powder and solution. At 48 hr, the solution was centrifuged, decanted, and rinsed three times through Barnstead filtered-$dH_20$. Diagenetic contaminants were removed using a 1 M solution (.04 ml solution/mg sample) of dilute acetic acid, buffered with NaOH to a pH of 4.5 (Koch et al. 1997). The samples were treated for 24 hr, with a solution change at 12 hr. At 24 hr, the solution was centrifuged, decanted, and rinsed three times. The samples were placed in an oven to dry overnight at 90°C. Ethan Grossman, of the

Department of Geology and Geophysics, Texas A&M University, measured stable carbon and oxygen isotope ratios using a Thermo Finnigan Delta Plus isotope ratio mass spectrometer with a Gas Bench II on-line gas preparation system. Stable isotope ratios were measured relative to PDB and the data were corrected for an internal laboratory carbonate standard (B2; -0.509‰ for $\delta^{13}$C, –0.14‰ for $\delta^{18}$O). Instrument precision is ~± .1‰ for $\delta^{13}$C and ± .2‰ for $\delta^{18}$O.

### *FTIR Analysis*

To evaluate diagenesis, I performed Fourier transform infrared spectroscopy (FTIR) on a subset of apatite samples (n=30) from ten archaeological sites. Since there may be a relationship between collagen and apatite preservation, I selected samples that primarily had high C/N ratios and/or low collagen yields. I prepared FTIR samples by mechanically grinding 2 mg of fine bone powder with 200 mg of spectroscopic grade KBr (potassium bromide). The KBr/bone mixture was placed on a 12 mm disc and pressed into a pellet using a hydraulic press at ~10,000 psi. FTIR uses a light source, which passes an infrared beam through the KBr pellet. As photons of infrared light interact with molecules within the bone, certain wavelengths of light are absorbed that identify bands associated with the $PO_4$, $CO_3$, OH, and $H_2O$ groups (Surovell and Stiner 2001:633). The relative abundance of light measured across these wavelengths is used to evaluate chemical alterations due to diagenesis. I collected spectra between wave numbers 2500 and 400 $cm^{-1}$, and scanned each sample 100 times using a Nicolet Magna 560 FTIR spectrometer. I corrected the baseline of each scan and measured spectra heights at 565, 590, 605, 1035, and 1415 $cm^{-1}$ using the OMNIC (Version 3.0) computer software program (Wright and Schwarcz 1996; Garvie-Lok *et al.* 2004).

The most commonly used measures of diagenesis in bone apatite include the C/P ($CO_3/PO_4$) ratio and the crystallinity index (CI), or splitting factor (SF). The C/P ratio is used to measure carbonate content and is calculated by dividing the 1415 cm-1 by the 1035 cm-1 peak height (Wright and Schwarcz 1996). Low C/P values (~.15) indicate low carbonate content, while high values (>.25) indicate higher than modern bone carbonate content. I calculated the CI by adding the 565 and 605 cm-1 peaks, and dividing by the 590 cm-1 trough in between them (Termine and Posner 1966; Shemesh 1990; Surovell and Stiner 2001). The CI evaluates the crystalline structure of bioapatite, and high values (> 4.25) can indicate either post-burial increase in crystal size or the dissolution of more soluble crystals due to diagenesis or sample treatment (Nielsen-Marsh and Hedges 2000b). FTIR preparation and analysis were performed under the supervision of Dr. Andreas Kronenberg, Department of Geology and Geophysics, at Texas A&M University. FTIR data was repeatable (n=4) at .04 ± .01 for C/P and .12 ± .13 for CI.

### *Parameters of Prehistoric Diet in Central California*

Reconstructions of prehistoric diet in central California have focused on the analysis of artifact assemblages, archaeobotanical remains, and archaeofaunal remains. Although each of these sources of dietary information are subject to biases, such as differential preservation and potential misinterpretation of artifact function, these data – in conjunction with the ethnohistoric record – can be used to define the parameters of the prehistoric diet. Archaeological research in central California suggests a subsistence economy focused on intensive game hunting, fishing, and seed and nut exploitation. However, the relative importance of these different subsistence strategies throughout the Holocene has been the focus of much debate.

The "menu" for central California theoretically includes any plant or animal resource that could have been consumed prehistorically. Strike's (1994) ethnobotanical volume indicates that the California Indians exploited hundreds of different plant resources during the ethnohistoric period. However, many of these plant resources were harvested solely for medicinal properties or for the construction of housing, boats, and basketry. Although the ethnohistoric and ethnographic record provide valuable information regarding "menu" choices, these dietary reconstructions may not directly reflect prehistoric uses of plant and animal resources.

### *Plant Resources*

The natural landscape in central California has been substantially altered by human activity over the past two hundred and fifty years. The arrival of Europeans and their cattle in the late eighteenth century resulted in the introduction of foreign grasses that quickly replaced much of the indigenous vegetation of the Central Valley and San Francisco Bay area. Since the late 1800s, land reclamation projects, mining, farming, and dam construction all dramatically altered ecosystems of the lower Sacramento Valley and San Francisco Bay estuary. These changes are expected to affect $\delta^{13}C$ and $\delta^{15}N$ in food webs, which may inhibit paleodietary interpretations of key plant resources.

Since stable isotope data are not available for archaeobotanical remains from the region, I rely on published data on modern plants, recognizing these constraints.

Table 5.1 lists several economically important plant food resources in central California and their isotopic composition. Figure 5.1 plots the $\delta^{13}$C and $\delta^{15}$N values of these plants reported in the literature. These plants are described in the ethnographic literature of central California groups (see Strike 1994), and many of the taxa are also abundant in archaeobotanical assemblages (Wohlgemuth 2004). The data are from modern plants from San Francisco Bay and the southern California coast. I corrected for the anthropogenic burning of fossils fuels (“Suess Effect”) that has lowered modern atmospheric $CO_2$ $\delta^{13}$C values, by adding +1.5‰ to modern plant values (Ambrose et al. 1997). This correction is necessary to bring these values in line with expectations of the prehistoric diet.

Table 5.1. Names and Stable Isotope Values of Economically Important Plants Resources in Central California.

| Common Name | Species | n[2] | $\delta^{13}$C | $\delta^{13}$C Corrected[1] | $\delta^{15}$N | Location | Citation | Sample |
|---|---|---|---|---|---|---|---|---|
| **Nuts** | | | | | | | | |
| Valley oak | *Quercus lobata* | 1 | -27.47 | -25.97 | 3.00 | SC | Goldberg 1993:180, Table 8 | acorns |
| Scrub oak | *Quercus dumosa* | 1 | -23.95 | -22.45 | -.76 | SC | Goldberg 1993:180, Table 8 | acorns |
| Coast live oak | *Quercus agrifolia* | 1 | -24.80 | -23.30 | 2.82 | SC | Goldberg 1993:180, Table 8 | acorns |
| Coast live oak | *Quercus agrifolia* | 1 | -27.37 | -25.87 | -1.24 | SC | Goldberg 1993:180, Table 8 | leaves |
| Walnut | *Juglans californica* | 1 | -26.79 | -25.29 | 1.16 | SC | Goldberg 1993:180, Table 8 | nut meat |
| Holly-leaved cherry | *Prunus ilicifolia* | 1 | -24.19 | -22.69 | 6.01 | SC | Goldberg 1993:180, Table 8 | nuts |
| Holly-leaved cherry | *Prunus ilicifolia* | 1 | -28.00 | -26.50 | 5.95 | SC | Goldberg 1993:180, Table 8 | leaves, stems |
| Holly-leaved cherry | *Prunus ilicifolia* | 1 | -27.21 | -25.71 | 2.90 | SC | Goldberg 1993:180, Table 8 | leaves |
| **Seeds** | | | | | | | | |
| Wild cucumber | *Marah sp.* | 1 | -26.10 | -24.60 | 8.61 | SC | Goldberg 1993:180, Table 8 | nut |
| **Fruits** | | | | | | | | |
| California blackberry | *Rubus vitifolius* | 7 | -24.70 | -23.20 | 6.50 | SFB | Cloern et al. 2002:720, Table 2 | various |
| Elderberry | *Sambucus mexicana* | 1 | -26.73 | -25.23 | 3.95 | SC | Goldberg 1993:180, Table 8 | berries |
| Manzanita | *Arctostaphylos spp.* | 1 | -26.35 | -24.85 | -3.05 | SC | Goldberg 1993:180, Table 8 | berries |
| Manzanita | *Arctostaphylos spp.* | 1 | -27.17 | -25.67 | -.07 | SC | Goldberg 1993:180, Table 8 | leaves, stems |
| **Sedges, Rushes, Seeds** | | | | | | | | |
| Tule | *Scirpus acutus* | 80 | -27.70 | -26.20 | 8.70 | SFB | Cloern et al. 2002:720, Table 2 | various |
| Alkalai bulrush | *Scirpus maritimus* | 13 | -26.40 | -24.90 | 9.20 | SFB | Cloern et al. 2002:720, Table 2 | various |
| California bulrush | *Scirpus californicus* | 34 | -27.40 | -25.90 | 8.30 | SFB | Cloern et al. 2002:720, Table 2 | various |
| Common cattail | *Typha latifolia* | 79 | -25.50 | -24.00 | 7.00 | SFB | Cloern et al. 2002:720, Table 2 | various |

[1] +1.5‰ added to published modern plant values to correct for "Suess Effect".

[2] n >1 are mean values (SD not provided).

**Location:** SC = Southern California, SFB = San Francisco Bay.

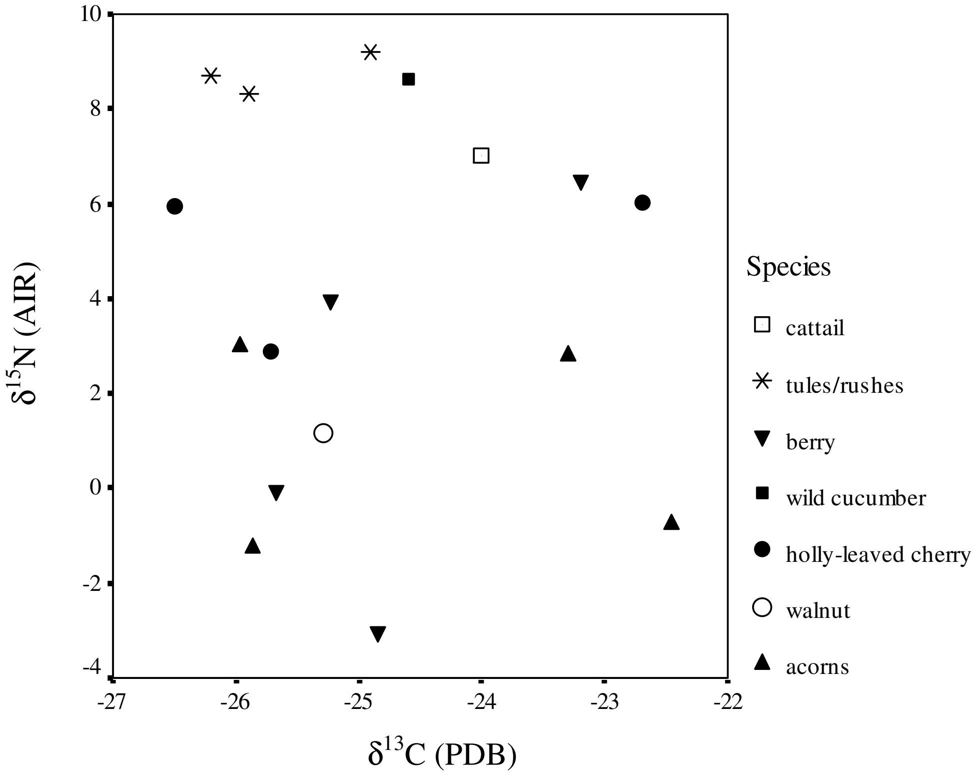

**Figure 5.1.** $\delta^{13}C$ and $\delta^{15}N$ values for economically important plants in central California. ***Note:*** +1.5‰ was added to the published $\delta^{13}C$ values to correct for the "Suess Effect". Sources of data are listed in Table 5.1.

I calculated mean $\delta^{13}C$ and $\delta^{15}N$ values for six different plant species (n=12), including oak (*Quercus sp.*), walnut (*Juglans californica*), holly-leaved cherry (*Prunus ilicifolia*), wild cucumber (*Marah sp.*), elderberry (*Sambucus mexicana*), and manzanita (*Arctostaphylos spp.*). $\delta^{13}C$ values for these plants range from –22.45 to –26.5‰, with an average value of –24.8 ± 1.3‰. $\delta^{15}N$ values are more variable, and range from –.07 to 8.6‰, with an average value of 2.44 ± 3.4‰. For other plants listed in Table 5.1, $\delta^{13}C$ and $\delta^{15}N$ signatures represent published mean values based on more representative samples. These plants include California blackberry (*Rubus vitifolius*), tule (*Scirpus* *acutus*), alkalai bulrush (*Scirpus maritimus*), California bulrush (*Scirpus californicus*), and cattail (*Typha latifolia*). The mean values for these plants fall within the range of the calculated means for other plants.

Acorns (Q*uercus spp.*) have an average isotopic composition of –24.1 ± 1.8‰ for $\delta^{13}$C and .96 ± 2.3‰ for $\delta^{15}$N. Manzanita and acorns from some oak trees show unusually low $\delta^{15}$N values that are close to the standard value for AIR, which may be influenced by chemical fertilzers that lower $\delta^{15}$N values of soils (Keegan 1989). In contrast, wild cucumber, cattail, holly-leaved cherry, tule, and bulrush all have high $\delta^{15}$N values. Many of these plants are associated with nitrogen-enriched saltwater marsh environments, which may explain their high $\delta^{15}$N values (Cloern et al. 2002). However, nitrates from animal fertilizers and pollution may also be contributing to these high isotopic signatures. Ethnographic and archaeological data indicate that the seeds of these plants were important food resources to native California societies, and were often roasted or boiled into porridge (Strike 1994).

### *Animal Resources*

In addition to the diverse array of plant foods exploited in native California, the diet also consisted of a number of terrestrial, freshwater, and marine animal resources. Archaeofaunal studies indicate that a variety of terrestrial mammals were exploited prehistorically in central California, including black-tailed deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), coyote (*Canis latrans*), and raccoon (*Procyon lotor*).

Prehistoric fish remains from sites in the Sacramento River drainage are dominated by freshwater species, such as Sacramento perch (*Archoplites interruptus*), Sacramento sucker (*Catostomus occidentalis),* Sacramento blackfish (*Orthodon microlepidotus*), hitch (*Lavinia exilicauda*), and tule perch (*Hysterocarpus traski*), among others (Gobalet et al. 2004:823-824).

In contrast, bones of salmon (*Oncorhynchus spp.*) and sturgeon (*Acipenser spp.*) are poorly represented in many sites within the Sacramento River drainage (Gobalet et al. 2004). However, salmon were a major dietary food resource during the ethnohistoric period, and may be under-represented in archaeofaunal assemblages (Yoshiyama 1999). For instance, Kroeber (1932) noted that salmon were often filleted at the weir, so fish bones may rarely have been deposited in village middens. Shell remains of *Margaritifera falcata* have also been identified in archaeological sites along the Sacramento River, although freshwater mussels probably were a minor component of the diet (Bouey and Richman 1995).

In the greater San Francisco Bay area, prehistoric peoples exploited a variety of anadromous, marine, and freshwater fish species. Anadromous fish are abundant in most Bay Area shell mounds, which suggests that salmon and sturgeon were key dietary items at these sites. Marine fish were also important and included bat rays (*Myliobatis californica*), Pacific herring (*Clupea pallasi*), northern anchovy (*Engraulis mordax*), topsmelt (*Atherinopsis affinis*), jacksmelt (*Atherinopsis californiensis*), and leopard shark (*Triakis semifasciata*). Although freshwater fish were probably less important, Gobalet et al. (2004) have identified fish bones of Sacramento sucker, Sacramento blackfish, Sacramento pikeminow, Sacramento perch, thicktail chub, hitch, and threespine stickleback in a number of archaeological sites from the east Bay. Freshwater fish could have easily been exploited from creeks and sloughs in close proximity to village sites.

Archaeofaunal studies indicate that marine mammals were an important food resource to the prehistoric groups of San Francisco Bay. Bones of large marine mammals, such as Steller sea lion (*Eumetopias jubatus*), California sea lion (*Zalophus californianus*), and Northern fur seal (*Callorhinus ursinus*) are abundant in many archaeological sites, as are remains of smaller resident species, such as sea otter (*Enhydra lutris*) and harbor seal (*Phoca vitulina*).

Shellfish also represented a key dietary resource to prehistoric San Francisco Bay populations. Shell mound sites contain an abundance of California oyster (*Ostrea lurida*), bay mussel (*Mytilus spp.*), and bent-nosed clam (*Macoma nasuta*), which could have been exploited throughout most of the year. However, many researchers have argued that the abundance of shellfish in village middens may be a poor determinant of their dietary importance, since shellfish provide small amounts of meat relative to shell detritus (Claassen 1998).

Table 5.2 lists isotope ratios of economically important fauna from central California. I include data from the published literature in order to expand the breadth of faunal dietary signatures. For all modern fauna, I converted modern values to prehistoric values by adding +1.5‰ to $\delta^{13}$C values to correct for anthropogenic burning of fossil fuels. To reconstruct isotopic values of dietary meat, I corrected bone collagen isotope values for the "offset" between collagen and muscle tissue caused by inter-tissue differences in isotopic fractionation. For mammals, I added –2.4‰ to $\delta^{13}C$ values to correct for the offset between bone collagen and muscle (DeNiro and Epstein 1978). This offset is similar to the –2.25‰ value reported by Tieszen and Fagre (1993) in controlled diet experiments on mice. For fish, I corrected for the offset between bone-collagen and muscle by adding –3.7‰ to $\delta^{13}C$ values (Keegan and DeNiro 1988). This correction was not necessary for many of the marine fauna, since published $\delta^{13}C$ values were taken directly from muscle tissue. Although some studies on animals have found a small bone collagen-to-muscle offset for $\delta^{15}N$ values (~1.7±.7‰), there is a high degree of variation reported between researchers (Keegan and DeNiro 1988). For the purposes of this study, I assume that $\delta^{15}N$ values for bone collagen and muscle are the same.

For the samples I processed, C/N ratios calculated for modern and archaeological fauna fall within the acceptable range of well-preserved collagen (2.9-3.6). A sea otter sample has a C/N ratio of 3.56, but shows adequate collagen yield (6.5 percent) and has $\delta^{13}C$ and $\delta^{15}N$ values within the range of other specimens. An archaeological salmon bone shows a low collagen yield (.91 percent), but has an acceptable C/N ratio (3.46). $\delta^{13}C$ and $\delta^{15}N$ values for this specimen are within the expected range for anadromous fish, c although the $\delta^{15}N$ value is higher than the values for other salmon. Given the degree of isotopic variability in fish, it is uncertain whether this sample is diagenetically altered. Collagen yields for faunal specimens ranged from .91 to 22.7 percent, with an average of 9.1 percent (n=19). There was no relationship between C/N ratio and collagen yields in

Table 5.2. Names and Stable Isotope Values of Economically Important Animal Resources in Central California.

| Common Name | Species | | n[1] | Tissue[2] | Original $\delta^{13}$C[3] | Fossil Fuel $\delta^{13}$C Corrected[4] | Corrected $\delta^{13}$C Meat[5] | Apatite $\delta^{13}$C[6] | Collagen-Apatite Spacing | $\delta^{15}$N | % C | % N | C/N | %Collagen Yield | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Terrestrial mammals** | | | | | | | | | | | | | | | |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -19.89 | | -22.29 | | | 4.57 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -19.87 | | -22.27 | | | 5.62 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -20.68 | | -23.08 | | | 2.90 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -18.37 | | -20.77 | | | 6.18 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -19.70 | | -22.10 | | | 4.29 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -18.9 | | -21.30 | | | 3.88 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | a | 1 | AB | -19.33 | | -21.73 | | | 5.31 | | | | | SC |
| Black tailed deer | *Odocoileus hemionus* | b | 1 | MB | -22.87 | | -23.77 | -16.01 | 5.36 | 5.82 | 44.6 | 15.3 | 3.39 | 17.40 | SV |
| Black tailed deer | *Odocoileus hemionus* | b | 1 | AB | -20.18 | | -22.58 | -11.33 | 8.85 | 5.56 | 35.9 | 12.7 | 3.3 | 3.22 | SFB |
| Black tailed deer | *Odocoileus hemionus* | b | 1 | AB | -20.55 | | -22.95 | -13.61 | 6.94 | 7.04 | 46.1 | 16.5 | 3.26 | 15.20 | SFB |
| Black tailed deer | *Odocoileus hemionus* | b | 1 | AB | -20.88 | | -23.28 | -10.99 | 9.89 | 5.74 | 41.1 | 14.3 | 3.35 | 1.22 | SV |
| Pronghorn | *Antilocapra Americana* | b | 1 | AB | -20.78 | | -23.18 | -12.78 | 8.00 | 7.83 | 45.9 | 16.6 | 3.24 | 6.79 | SV |
| Elk | *Cervus elaphus* | b | 1 | AB | -20.21 | | -22.61 | -11.55 | 8.66 | 5.77 | 43.9 | 15.8 | 3.24 | 8.37 | SFB |
| Elk | *Cervus elaphus* | b | 1 | AB | -21.01 | | -23.41 | -12.80 | 8.21 | 5.39 | 45.3 | 16.3 | 3.25 | 11.10 | SV |
| Raccoon | *Procyon lotor* | b | 1 | MB | -20.98 | -19.48 | -21.88 | -15.73 | 3.75 | 8.62 | 45.9 | 16.5 | 3.24 | 22.60 | SV |
| Raccoon | *Procyon lotor* | b | 1 | AB | -12.20 | | -14.60 | -9.55 | 2.65 | 8.66 | 43.0 | 14.6 | 3.43 | 9.49 | SFB |
| Coyote | *Canis latrans* | b | 1 | MB | -19.87 | -18.37 | -20.77 | -13.63 | 4.74 | 7.73 | 45.9 | 16.3 | 3.29 | 14.70 | SV |
| Coyote | *Canis latrans* | b | 1 | AB | -18.76 | | -21.16 | -12.08 | 6.68 | 8.19 | 37.4 | 13.6 | 3.22 | 6.03 | SFB |
| Jackrabbit | *Lepus californicus* | c | 1 | MB | -22.00 | -20.50 | -22.90 | | | 1.90 | | | | | SC |

Table 5.2 Continued

| **Common Name** | **Species** | | **n**[1] | **Tissue**[2] | **Original $\delta^{13}C$**[3] | **Fossil Fuel $\delta^{13}C$ Corrected**[4] | **Corrected $\delta^{13}C$ Meat**[5] | **Apatite $\delta^{13}C$**[6] | **Collagen-Apatite Spacing** | **$\delta^{15}N$** | **% C** | **% N** | **C/N** | **% Collagen Yield** | **Location** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Squirrel | *Sciurus sp.* | c | 1 | MB | -19.90 | -18.40 | -20.80 | | | 2.10 | | | | | SC |
| Mountain lion | *Felis concolor* | c | 1 | MB | -17.60 | -16.10 | -18.50 | | | 7.60 | | | | | SC |
| Bobcat | *Lynx rufus* | c | 1 | MB | -15.80 | -14.30 | -16.70 | | | 10.00 | | | | | SC |
| **Marine mammals** | | | | | | | | | | | | | | | |
| Sea Otter | *Enhydra lutris* | b | 1 | AB | -11.37 | | -13.77 | -8.38 | 2.99 | 16.30 | 44.9 | 16.2 | 3.22 | 14.50 | SFB |
| Sea Otter | *Enhydra lutris* | b | 1 | AB | -10.57 | | -12.97 | -7.34 | 3.23 | 14.89 | 41.9 | 13.7 | 3.56 | 6.48 | SFB |
| Sea Otter | *Enhydra lutris* | c | 1 | MB | -10.00 | -8.50 | -10.90 | | | 13.90 | | | | | NC |
| Sea Otter | *Enhydra lutris* | c | 1 | MB | -9.70 | -8.20 | -10.60 | | | 13.30 | | | | | NC |
| Sea Otter | *Enhydra lutris* | c | 1 | MB | -9.60 | -8.10 | -10.50 | | | 15.40 | | | | | NC |
| Harbor seal | *Phoca vitulina* | b | 1 | AB | -11.13 | | -13.53 | -9.78 | 1.35 | 18.58 | 43.6 | 14.5 | 3.51 | 6.05 | SFB |
| Harbor seal | *Phoca vitulina* | c | 1 | MB | -11.70 | -10.20 | -12.60 | | | 16.00 | | | | | SC |
| Harbor seal | *Phoca vitulina* | c | 1 | MB | -13.90 | -12.40 | -14.80 | | | 19.30 | | | | | NC |
| Harbor seal | *Phoca vitulina* | c | 1 | MB | -11.20 | -9.70 | -12.10 | | | 17.50 | | | | | |
| Steller sea lion | *Eumetopias jubatus* | b | 1 | AB | -11.90 | | -14.30 | -10.11 | 1.79 | 19.05 | 39.2 | 14.2 | 3.23 | 10.20 | SFB |
| California sea lion | *Zalophus californianus* | c | 1 | MB | -12.90 | -10.40 | -12.80 | | | 17.60 | | | | | SC |
| California sea lion | *Zalophus californianus* | c | 1 | MB | -13.30 | -11.80 | -14.20 | | | 17.20 | | | | | SC |
| California sea lion | *Zalophus californianus* | c | 1 | MB | -11.00 | -9.50 | -11.90 | | | 19.30 | | | | | NC |
| California sea lion | *Zalophus californianus* | c | 1 | MB | -13.30 | -11.80 | -14.20 | | | 23.00 | | | | | NC |

Table 5.2 Continued

| Common Name | Species | | n[1] | Tissue[2] | Original $\delta^{13}$C[3] | Fossil Fuel $\delta^{13}$C Corrected[4] | Corrected $\delta^{13}$C Meat[5] | Apatite $\delta^{13}$C[6] | Collagen-Apatite Spacing | $\delta^{15}$N | % C | % N | C/N | % Collagen Yield | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Marine fish** | | | | | | | | | | | | | | | |
| Marine fish | Marine fish | c | 10 | MB | -12.50±1.4 | -11.00±1.4 | -11.00±1.4 | | | 13.80±1.6 | | | | | SC |
| Rockfish, surfperch | Marine fish | d | 24 | MB | | -16.10±.7 | -16.10±.7 | | | 14.30±1.3 | | | | | CCC |
| Leopard shark | *Triakis semifasciata* | e | 31 | MT | -17.20±.9 | -15.70±.9 | -15.70±.9 | | | 17.20±1.6 | | | | | SFB |
| Jacksmelt | *Atherinopsis californiensis* | e | 15 | MT | -17.30±1.4 | 15.80±1.4 | 15.80±1.4 | | | 14.30±1.4 | | | | | SFB |
| Northern anchovy | *Engraulis mordax* | f | 4 | MT | -16.80±.4 | -15.30±.4 | -15.30±.4 | | | 13.90±.8 | | | | | GF |
| Pacific sardine | *Sardinops sajax* | f | 3 | MT | -17.00±.3 | -15.50±.3 | -15.50±.3 | | | 12.90±.1 | | | | | GF |
| Shortbelly rockfish | *Sebastes jordanii* | f | 5 | MT | -17.10±.3 | -15.60±.3 | -15.60±.3 | | | 13.80±.2 | | | | | GF |
| Lingcod | *Ophiodon elongates* | f | 6 | MT | -18.30±.5 | -16.80±.5 | -16.80±.5 | | | 12.50±.3 | | | | | GF |
| Shiner surfperch | *Cymatogaster aggregate* | e | 18 | MT | -17.40±.8 | -15.90 | -15.90 | | | 15.90±1.5 | | | | | SFB |
| **Anadromous fish** | | | | | | | | | | | | | | | |
| Salmon | *Oncorhynchus spp.* | b | 1 | AB | -12.12 | | -15.82 | -8.46 | 3.66 | 17.29 | 16.5 | 5.57 | 3.46 | .912 | SFB |
| Salmon | *Oncorhynchus spp.* | b | 1 | MB | -13.00 | -11.50 | -15.20 | -8.74 | 4.26 | 13.87 | 40.4 | 13.7 | 3.44 | 4.88 | CCC |
| Sturgeon | *Acipenser spp.* | b | 1 | AB | -7.94 | | -11.64 | -8.46 | -.52 | 16.57 | 44.4 | 16.3 | 3.18 | 9.70 | SFB |
| Sturgeon | *Acipenser spp.* | b | 1 | AB | -13.17 | | -16.87 | -7.86 | 5.31 | 15.25 | 30.4 | 11.0 | 3.20 | 3.79 | SFB |
| White sturgeon | *Acipenser transmontanus* | e | 13 | MT | -19.70±1.1 | -18.20±1.1 | -18.20±1.1 | | | 17.50±1.8 | | | | | SFB |
| Chinook salmon | *Oncorhynchus tshawytscha* | f | 4 | MT | -17.50±.2 | -16.00±.2 | -16.00±.2 | | | 13.80±.2 | | | | | GF |

Table 5.2 Continued

| Common Name | Species | | n[1] | Tissue[2] | Original $\delta^{13}$C[3] | Fossil Fuel $\delta^{13}$C Corrected[4] | Corrected $\delta^{13}$C Meat[5] | Apatite $\delta^{13}$C[6] | Collagen-Apatite Spacing | $\delta^{15}$N | % C | % N | C/N | % Collagen Yield | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Freshwater fish** | | | | | | | | | | | | | | | |
| Sacramento sucker | *Catostomus occidentalis* | g | | MB | -28.00 | -26.50 | -26.50 | | | 9.50 | | | | | CV |
| **Shellfish and crab** | | | | | | | | | | | | | | | |
| Bay mussel | *Mytilus sp.* | e | 21 | MT | -20.60±1.7 | -19.10±1.7 | -19.10±1.7 | | | 10.40±1.7 | | | | | SFB |
| Freshwater mussel | *Margaritifera falcate* | h | 34 | MT | -22.89 | -21.39 | -21.39 | | | 2.50 | | | | | NC |
| Crab | *Cancer magister* | i | | MT | ~-22.00 | ~-20.50 | ~-20.50 | | | ~14.50 | | | | | SUB |

[1] Number of samples (S.D. provided for n>1 if available), [2]sample (AB = archaeological bone, MB = modern bone, MT = muscle tissue), [3]uncorrected $\delta^{13}$C value for bone collagen or muscle tissue, [4]+1.5‰ added to $\delta^{13}$C values to correct for "Suess Effect", [5]-2.4‰ and –3.7‰ added to $\delta^{13}$C bone collagen values for mammals and fish, respectively, to correct for fractionation between bone collagen and muscle tissue (DeNiro and Epstein 1978), [6]apatite $\delta^{13}$C value, +1.5‰ added to modern bone samples to correct for "Suess Effect".

[2] **Bold-faced** values in table indicate low collagen yield (<1%).

**Data Sources**: [a]Goldberg (1993:181, Table 9), [b]present study, [c]Schoeninger and DeNiro (1984:627, Table 1), [d]Newsome et al. (2004:6, Table 2), [e]Greenfield et al. 2005, [f]Sydeman et al. (1997:330, Table 1), [g]Sarakinos et al. (2002:384), [h]Howard et al. (2005:223-234); [i]Stewart et al. (2004:4524, approximated from Figure 3).

**Sample locations in California:** (SC = southern California; SV = Sacramento Valley; SFB = San Francisco Bay; NC = northern California; CCC = central coast; Gulf of the Farallones; SUB = Suisun Bay).

the archaeological samples (r = .364, p = .09, n=15), so I assume that bone collagen signatures reflect actual dietary values.

Figure 5.2 plots the $\delta^{13}$C and $\delta^{15}$N values of the faunal specimens. The individual data points represent dietary values for single mammalian specimens; however, isotopic values for marine fish and shellfish represent mean values from the literature based on marine ecology studies (see Table 5.2). The data conform well to reconstructed food webs from other terrestrial and marine ecosystems: $\delta^{13}$C values separate most terrestrial mammals from marine fauna, while $\delta^{15}$N values show the expected step-wise enrichment between trophic levels. Collagen-apatite spacing values are also greatest for terrestrial herbivores, followed by terrestrial carnivores, anadromous fish, and marine mammals, which conforms to expectations regarding the different sources of dietary macronutrients between animals feeding at different levels of the food web.

Terrestrial herbivore meat has a mean $\delta^{13}$C value of –22.4 ±.9‰ and mean $\delta^{15}$N of 5±1.6‰. Slightly higher $\delta^{15}$N values in some of these samples may be due to the excretion of $^{15}$N-depleted urea in water-stressed herbivores. More likely, these values reflect consumption of $^{15}$N-enriched plants that are typical of coastal and estuarine environments (Heaton 1987; see Figure 5.1).

Terrestrial carnivore meat has an average $\delta^{13}$C and $\delta^{15}$N value of –18.9 ±2.9‰ and 8.5 ±.9‰, respectively. Although raccoons are omnivorous, I include these fauna with terrestrial carnivores since isotopic signatures overlap. The mountain lion, bobcat, and a single raccoon sample show higher $\delta^{13}$C values than the other carnivores, which suggests greater consumption of $^{13}$C-enriched resources (marine foods, or C4 plants) in these samples.

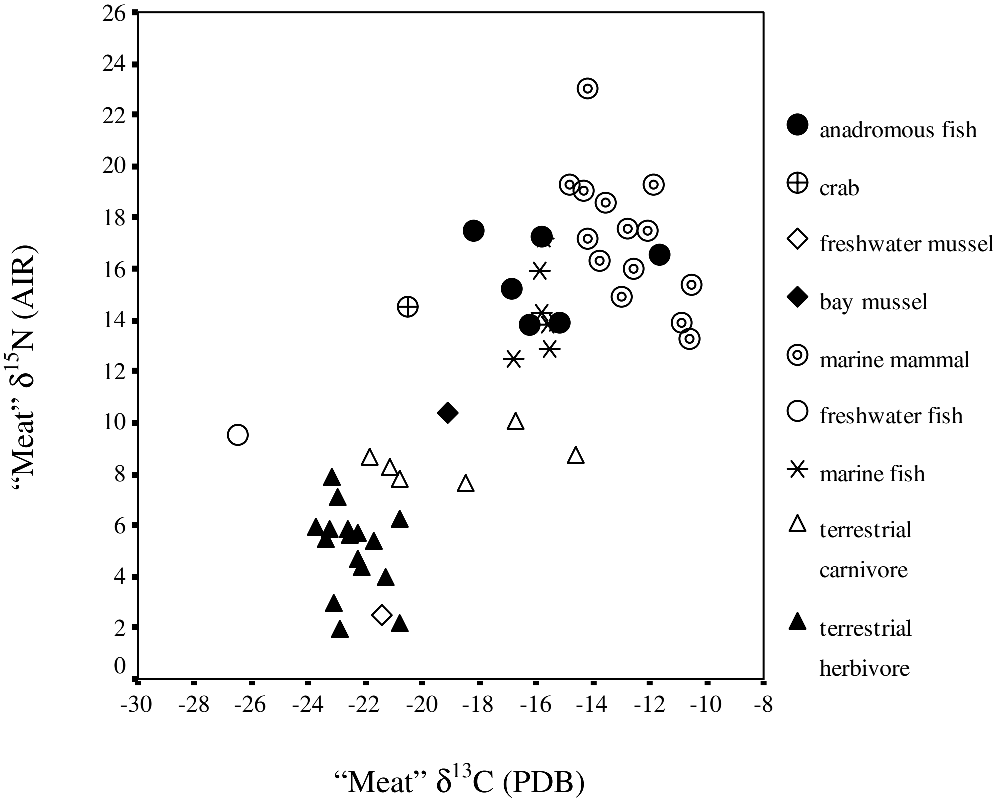

**Figure 5.2.** $\delta^{13}$C and $\delta^{15}$N “meat” values for economically important animal resources in central California. Note: +1.5‰ was added to the published values to correct for the “Suess Effect”, and –2.4‰ was added to correct for collagen-muscle tissue fractionation in terrestrial animals and –3.7‰ in fish. Marine fish and shellfish are represented by published mean values. Sources of data are listed in Table 5.2.

Marine mammals and marine fish eat at high trophic levels within longer food chains, and have higher $\delta^{13}$C and $\delta^{15}$N values than terrestrial animals. Marine mammals are at the top of the food web, with an average $\delta^{13}$C value of –12.8±1.4‰ and $\delta^{15}$N value of 17.2±2.6‰. Pinniped carnivores (e.g., Steller sea lion, California sea lion, harbor seal) consume a diet consisting of marine fish and invertebrates, and have an average $\delta^{13}$C value of -13.5±1.0‰ and $\delta^{15}$N value of 18.7 ±1.9‰ . In contrast, sea otters mainly consume invertebrates and lower trophic level fish, and have an average $\delta^{13}$C value of –11.7±1.5‰ and $\delta^{15}$N value of 14.8±1.2‰ (n=5). Pinnipeds and sea otters differ by ~2.0‰ in $\delta^{13}$C and ~4.0‰ in $\delta^{15}$N.

Table 5.2 contains mean $\delta^{13}$C and $\delta^{15}$N values for marine fish reported in the literature. Mean $\delta^{13}$C values for individual fish species range from –15.3 ±.4‰ for northern anchovy to –16.8 ±0.5‰ for lingcod. $\delta^{15}$N values range from 12.5±.3‰ for lingcod to 17.2 ±1.6‰ for leopard shark. Although many of the species that inhabit San Francisco Bay are classified as estuarine fish and are adapted to brackish waters, isotopic signatures of these fish clearly reflect a high trophic level signature.

In contrast, freshwater fish have more variable isotopic signatures, and range from about –16.0 to –27.0‰ for $\delta^{13}$C and 5.0 to 14‰ for $\delta^{15}$N (France 1995; Katzenberg 1999; Katzenberg and Weber 1999; Schoeninger and DeNiro 1984; Yoneda et al. 2004). Sacramento sucker, an indigenous fish from central California, has a $\delta^{13}$C value of approximately –26.5‰ and a $\delta^{15}$N value of 9.5‰, which is clearly distinct from marine fish (Sarakinos et al. 2002:384).

Anadromous fish (salmon and sturgeon) are also variable because these fish spend their life cycle in both marine and fresh waters (Moyle 2002). For instance, salmon are born in freshwater rivers and streams, migrate to the sea to mature, and again return to fresh waters to spawn. However, most of the life cycle and feeding for these fish occurs in the ocean; thus, $\delta^{13}$C and $\delta^{15}$N values are similar to marine fish. Anadromous fish have a mean $\delta^{13}$C value of –15.6±2.2‰ and a mean $\delta^{15}$N value of 15.7±1.7‰ (Table 5.2), which is within the range of values reported for marine fish.

Economically important invertebrates are not well characterized for the study area, but the available data are consistent with previous research of similar ecosystems. Bay mussel (*Mytilus sp.*) has a mean $\delta^{13}$C value of –19.1±1.7‰ and a mean $\delta^{15}$N value of 10.4±1.7‰ (n=21; Table 5.2). Newsome et al. (2004:6, Table 2) report a higher mean $\delta^{13}$C value for California mussels (-14.7±.3‰, n=8) collected in Santa Cruz, California; however, this reflects differences in the sources of carbon between coastal and estuarine environments. Freshwater mussels collected from the Yolo River Basin from northern California have an average $\delta^{13}$C value of –21.4‰, and an average $\delta^{15}$N value of 2.5‰, which is distinctly different from shellfish from saltwater enivornments (Howard et al. 2005:223-224). Crab mussel tissue (*Cancer magister*) has an approximate $\delta^{13}$C value of –20.5‰ and $\delta^{15}$N value of 14.5‰ for samples collected in the northern San Francisco Bay (Stewart et al. 2004).

Although water birds (cormorants, ducks, and geese) were economically important resources in central California, avifauna dietary signatures are poorly characterized for the region. $\delta^{13}$C values of egg albumen from piscivorous birds from the Farallones Islands area range from –15.9 to –17.7‰, while $\delta^{15}$N values range from 16.7 to 17.3‰ (Sydeman et al. 1997:330, Table 1, n=15). Schoeninger and DeNiro (1984) report much lower values for aquatic migratory birds from southern California

($\delta^{13}C$ = -21.9 ±3.9‰; $\delta^{15}N$ = 11.1 ±2.7‰, n=3), but this may reflect interspecific differences in diet or the tissues sampled. Piscivorous bird flesh should be similar to marine fish values for $\delta^{13}C$, and enriched by 3-4‰ for $\delta^{15}N$ values.

Figure 5.3 provides a reconstruction of the theoretical food web for prehistoric central California, and the isotopic values reflect the food portions actually consumed (e.g., meat, acorns). The boxes represent the range of carbon and nitrogen isotope values as defined by the floral and faunal data presented in Tables 5.1 and 5.2. The range represented by freshwater fish reflects the degree of isotopic variability described in studies from other regions. This range could be narrowed with future research on isotopic variability of modern and archaeological fish from central California.

### *Evaluation of Sample Quality*

Preparation of bone collagen for isotopic analysis involved mechanical, ultrasonic, and chemical cleaning to remove diagenetic contaminants from bone samples. These steps are usually effective for well-preserved collagen, although sample quality must be carefully evaluated prior to data analysis. To evaluate samples for diagenetic alteration, I examined atomic C/N ratios and percent collagen yields. Table 5.3 presents isotopic data and measures of sample quality for the human bone samples. Nine samples produced C/N ratios that were outside normal ranges for well-preserved collagen (2.9-3.6). Five of these samples also had low collagen yields, and all are from Early period sites from the Sacramento Valley. The remaining four samples had C/N ratios that were between 3.61 and 3.65, but showed high collagen yield (between 7.24

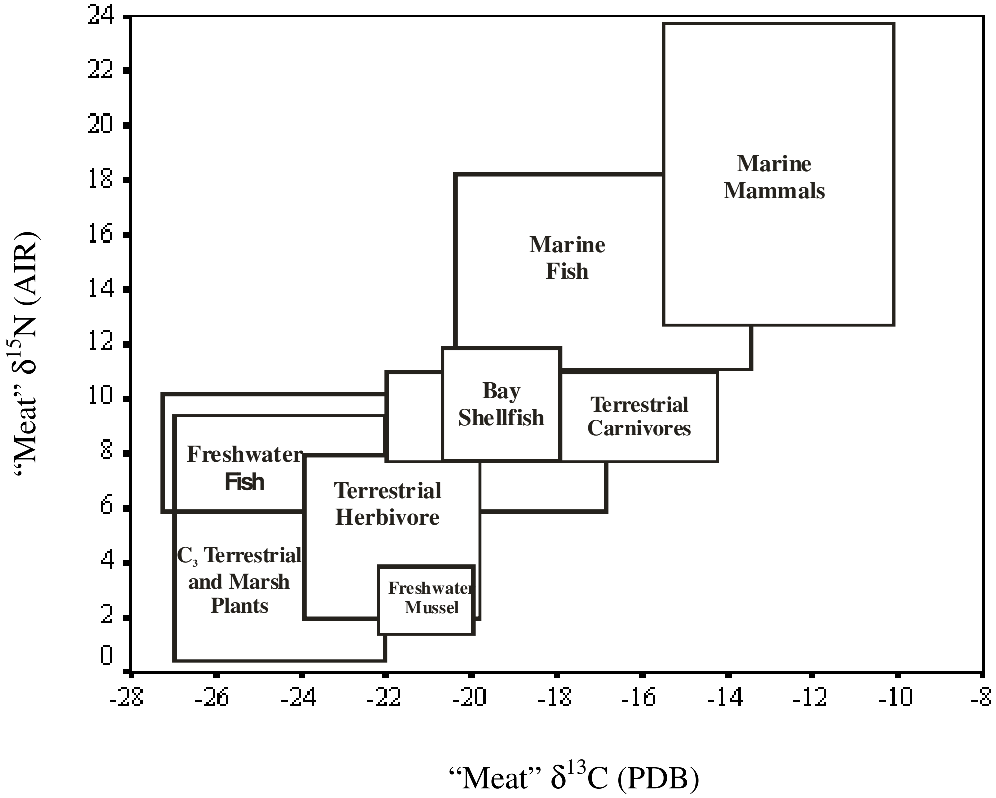

**Figure 5.3.** Reconstructed carbon and nitrogen dietary signatures for economically important food resources in prehistoric central California.

and 21.44 percent), and had $\delta^{13}$C and $\delta^{15}$N signatures similar to other samples from the same region and time period (Table 5.3). Four additional samples had a C/N ratio of 3.6, but also produced good collagen yields (13-30 percent) and had similar $\delta^{13}$C and $\delta^{15}$N values to other samples from the same region and time period. I exclude the five samples with both high C/N ratios and low collagen yields from the analyses, but include the other eight samples with C/N ratios that were between 3.6 and 3.65.

Table 5.3. Stable Isotope Values and Preservation Indicators for Human Bone Samples from Central California.

| Period | Sample No. | Sample | Sex | Collagen $\delta^{13}C$ | Apatite $\delta^{13}C$ | Collagen-Apatite Spacing | $\delta^{15}N$ | %C | %N | C/N ratio[1] | % Collagen Yield | $\delta^{18}O$ | C/P ratio | CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sacramento Valley | | | | | | | | | | | | | | |
| Early | 5661 | powder | M | -20.56 | -10.57 | 9.99 | 9.42 | 33.21 | 11.03 | 3.51 | 2.40 | -5.59 | | |
| Early | 5664 | powder | M | -21.21 | -13.00 | 8.21 | 9.46 | 32.49 | 11.14 | 3.40 | 2.20 | -6.85 | | |
| Early | 5667 | powder | M | -23.09 | -12.27 | 10.82 | 2.90 | 7.38 | .98 | **8.79** | **.14** | -7.44 | | |
| Early | 5668 | powder | M | -19.97 | -12.24 | 7.73 | 10.02 | 32.33 | 10.17 | **3.71** | 1.60 | -6.92 | | |
| Early | 5677 | Rib | M | -19.33 | -12.92 | 6.41 | 11.78 | 43.34 | 15.77 | 3.21 | 6.49 | -8.90 | .18 | 3.83 |
| Early | 5806 | long bone | M | -20.21 | -11.3 | 8.91 | 10.44 | 39.74 | 13.17 | 3.58 | 1.40 | -7.63 | | |
| Early | 5824 | long bone | M | -19.70 | -14.47 | 5.23 | 11.03 | 41.16 | 13.78 | 3.49 | 14.0 | -9.50 | | |
| Early | 5827 | long bone | M | -19.61 | -13.00 | 6.61 | 11.91 | 43.71 | 14.46 | 3.53 | 5.63 | -8.67 | | |
| Early | 6470 | long bone | M | -20.78 | -15.57 | 5.21 | 9.29 | 23.57 | 6.64 | **4.14** | **.90** | -8.68 | .23 | 3.25 |
| Early | 7015 | Rib | M | -20.20 | -14.45 | 5.75 | 10.36 | 45.50 | 15.35 | 3.46 | 16.35 | -10.04 | .23 | 3.31 |
| Early | 7597 | Rib | M | -20.07 | -14.81 | 5.26 | 11.02 | 45.25 | 16.19 | 3.26 | 7.86 | -8.31 | | |
| Early | 7603 | Rib | M | -19.12 | -12.87 | 6.25 | 12.87 | 44.55 | 16.32 | 3.19 | 8.65 | -9.35 | | |
| Early | 7613 | Rib | M | -20.46 | -13.58 | 6.88 | 10.65 | 46.17 | 16.58 | 3.25 | 10.24 | -8.13 | | |
| Early | 7632 | long bone | M | -19.33 | -14.23 | 5.10 | 11.58 | 45.42 | 15.25 | 3.48 | 8.59 | -8.66 | | |
| Early | 5666 | long bone | F | -21.34 | -12.02 | 9.32 | 9.72 | 21.26 | 7.67 | 3.23 | 3.25 | -8.21 | | |
| Early | 5670 | powder | F | -19.69 | -11.44 | 8.25 | 10.68 | 26.61 | 8.53 | **3.64** | 1.05 | -8.63 | | |
| Early | 5676 | long bone | F | -20.01 | -12.34 | 7.67 | 9.92 | 15.73 | 4.79 | **3.83** | 1.40 | -8.44 | | |
| Early | 5678 | long bone | F | -19.39 | -12.18 | 7.21 | 11.71 | 40.79 | 14.54 | 3.27 | 5.27 | -8.14 | .19 | 3.54 |
| Early | 5801 | long bone | F | -19.57 | -12.44 | 7.13 | 11.67 | 40.35 | 14.52 | 3.46 | 5.83 | -8.16 | | |
| Early | 6472 | long bone | F | -20.05 | -15.86 | 4.19 | 10.13 | 44.18 | 15.42 | 3.34 | 14.82 | -7.31 | | |
| Early | 7567 | Rib | F | -20.72 | -15.43 | 5.29 | 9.66 | 43.20 | 15.77 | 3.20 | 18.38 | -8.13 | | |
| Early | 7575 | Rib | F | -18.28 | -12.54 | 5.74 | 12.42 | 31.80 | 10.72 | 3.46 | 3.69 | -9.14 | .23 | 3.24 |
| Early | 7578 | Rib | F | -19.86 | -13.32 | 6.54 | 9.72 | 42.16 | 15.29 | 3.22 | 9.47 | -7.71 | | |
| Early | 7579 | Rib | F | -19.28 | -14.06 | 5.22 | 10.39 | 44.20 | 16.12 | 3.20 | 12.93 | -8.41 | | |
| Early | 7637 | long bone | F | -19.90 | -12.86 | 7.04 | 10.72 | 42.42 | 15.35 | 3.22 | 8.89 | -7.84 | | |
| Middle | 6718 | Rib | M | -20.38 | -14.47 | 5.91 | 11.80 | 44.01 | 15.90 | 3.23 | 21.38 | -8.44 | | |
| Middle | 6727 | Rib | M | -19.74 | -12.52 | 7.22 | 12.20 | 39.45 | 13.15 | 3.50 | 3.41 | -9.22 | .18 | 3.72 |
| Middle | 6728 | Rib | M | -19.90 | -12.07 | 7.83 | 12.19 | 38.40 | 12.98 | 3.45 | 11.59 | -9.01 | | |
| Middle | 6785 | long bone | M | -19.99 | -11.88 | 8.11 | 11.16 | 35.71 | 12.05 | 3.46 | 4.71 | -5.64 | .18 | 3.72 |
| Middle | 11289 | rib | M | -20.36 | -11.17 | 9.19 | 10.71 | 41.70 | 14.50 | 3.36 | 19.26 | -7.83 | | |
| Middle | 6698 | long bone | F | -19.06 | -12.99 | 6.07 | 12.17 | 43.62 | 15.79 | 3.22 | 10.49 | -8.37 | | |
| Middle | 6700 | long bone | F | -19.83 | -12.70 | 7.13 | 10.53 | 41.47 | 15.02 | 3.22 | 9.38 | -7.29 | .20 | 3.21 |
| Middle | 6702 | long bone | F | -19.70 | -12.75 | 6.95 | 10.8 | 40.67 | 14.49 | 3.28 | 5.92 | -7.49 | | |
| Middle | 6703 | long bone | F | -19.93 | -13.62 | 6.31 | 10.99 | 42.52 | 15.29 | 3.24 | 12.44 | -6.97 | | |
| Middle | 6714 | long bone | F | -19.78 | -13.39 | 6.39 | 11.08 | 44.81 | 16.13 | 3.24 | 8.42 | -5.33 | .21 | 2.9 |
| Middle | 6774 | long bone | F | -19.82 | -14.58 | 5.24 | 11.53 | 44.09 | 15.22 | 3.38 | 18.07 | -5.97 | .23 | 3.23 |

Table 5.3 Continued.

| Period | Sample No. | Sample | Sex | Collagen $\delta^{13}C$ | Apatite $\delta^{13}C$ | Collagen-Apatite Spacing | $\delta^{15}N$ | %C | %N | C/N ratio[1] | % Collagen Yield | $\delta^{18}O$ | C/P ratio | CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Middle | 11276 | rib | F | -20.24 | -14.54 | 5.70 | 10.51 | 46.74 | 15.91 | 3.43 | 18.25 | -7.27 | | |
| Middle | 11296 | rib | F | -20.13 | -14.57 | 5.56 | 10.58 | 43.17 | 14.72 | 3.42 | 19.21 | -7.39 | .15 | 3.37 |
| Late | 6734 | long bone | M | -20.08 | -14.42 | 5.66 | 11.12 | 40.92 | 13.73 | 3.48 | 14.70 | -9.62 | | |
| Late | 6779 | long bone | M | -19.98 | -12.95 | 7.03 | 11.36 | 44.74 | 14.64 | 3.57 | 7.76 | -9.14 | | |
| Late | 6792 | rib | M | -19.53 | -13.11 | 6.42 | 12.71 | 39.75 | 13.45 | 3.45 | 2.75 | -8.76 | | |
| Late | 6805 | long bone | M | -19.43 | -13.13 | 6.30 | 10.33 | 44.02 | 15.62 | 3.29 | 7.35 | -7.29 | | |
| Late | 7117 | powder | M | -20.17 | -13.36 | 6.81 | 10.40 | 41.71 | 14.59 | 3.34 | 5.79 | -6.81 | | |
| Late | 7126 | rib | M | -20.23 | -13.17 | 7.06 | 11.8 | 42.35 | 15.37 | 3.31 | 5.50 | -7.91 | .12 | 4.1 |
| Late | 7130 | powder | M | -20.12 | -13.57 | 6.55 | 10.02 | 37.69 | 13.53 | 3.25 | 9.40 | -8.26 | | |
| Late | 7150 | powder | M | -20.18 | -12.79 | 7.39 | 11.53 | 37.54 | 12.39 | 3.54 | 2.57 | -6.85 | | |
| Late | 7151 | powder | M | -19.89 | -12.59 | 7.30 | 11.46 | 35.29 | 11.87 | 3.47 | 2.17 | -7.15 | | |
| Late | 7152 | rib | M | -20.19 | -13.93 | 6.26 | 11.17 | 43.98 | 14.55 | 3.53 | 7.00 | -7.15 | | |
| Late | 6733 | long bone | F | -20.11 | -12.27 | 7.84 | 11.76 | 32.73 | 11.13 | 3.43 | 9.68 | -2.74 | | |
| Late | 6796 | long bone | F | -20.47 | -12.24 | 8.23 | 10.53 | 35.60 | 12.72 | 3.27 | 4.87 | -6.30 | | |
| Late | 6800 | long bone | F | -20.10 | -14.09 | 6.01 | 10.12 | 43.84 | 15.72 | 3.25 | 13.33 | -7.18 | | |
| Late | 7127 | powder | F | -19.56 | -14.48 | 5.08 | 10.49 | 42.18 | 14.87 | 3.31 | 12.48 | -7.02 | | |
| Late | 7129 | powder | F | -19.81 | -15.05 | 4.76 | 10.34 | 42.97 | 15.48 | 3.24 | 8.50 | -7.72 | | |
| Late | 7132 | powder | F | -19.95 | -12.31 | 7.64 | 9.79 | 40.16 | 13.54 | 3.46 | 3.53 | -6.47 | | |
| Late | 7146 | powder | F | -19.61 | -13.39 | 6.22 | 10.36 | 41.82 | 14.29 | 3.41 | 6.69 | -6.47 | | |
| Late | 7147 | powder | F | -20.18 | -12.95 | 7.23 | 10.02 | 43.64 | 15.05 | 3.38 | 6.96 | -7.47 | | |
| San Francisco Bay | | | | | | | | | | | | | | |
| Early | 556 | rib | M | -14.98 | -11.56 | 3.42 | 15.45 | 44.14 | 15.97 | 3.23 | 7.46 | -6.82 | 0.2 | 3.44 |
| Early | 8257 | long bone | M | -14.29 | -10.87 | 3.42 | 16.86 | 43.06 | 15.67 | 3.21 | 6.74 | -6.74 | | |
| Early | 8260 | rib | M | -12.89 | -10.92 | 1.97 | 17.73 | 44.82 | 15.35 | 3.41 | 12.35 | -6.96 | | |
| Early | 8291 | long bone | M | -16.07 | -12.19 | 3.88 | 12.62 | 39.52 | 13.33 | 3.46 | 5.57 | -6.90 | | |
| Early | 8292 | rib | M | -13.65 | -11.55 | 2.10 | 17.57 | 32.76 | 11.78 | 3.24 | 2.78 | -7.55 | | |
| Early | 8301 | rib | M | -14.33 | -9.75 | 4.58 | 16.30 | 43.48 | 15.77 | 3.22 | 10.63 | -8.63 | | |
| Early | 8303 | long bone | M | -13.31 | -11.02 | 2.29 | 17.30 | 42.65 | 15.30 | 3.25 | 7.55 | -7.07 | .16 | 3.75 |
| Early | 8320 | long bone | M | -14.14 | -10.53 | 3.61 | 15.28 | 41.05 | 14.27 | 3.36 | 4.94 | -5.71 | | |
| Early | 8345 | rib | M | -13.18 | -10.84 | 2.34 | 18.44 | 44.19 | 15.92 | 3.24 | 5.13 | -9.08 | | |
| Early | 557 | powder | F | -14.49 | -10.57 | 3.92 | 15.93 | 44.13 | 15.90 | 3.24 | 6.25 | -5.59 | .21 | 3.47 |
| Early | 8258 | long bone | F | -14.56 | -10.95 | 3.61 | 16.17 | 44.22 | 15.99 | 3.23 | 9.07 | -6.07 | .13 | 3.63 |
| Early | 8261 | long bone | F | -13.44 | -12.04 | 1.40 | 17.32 | 40.28 | 14.47 | 3.25 | 3.86 | -7.47 | .13 | 4.28 |
| Early | 8274 | rib | F | -13.80 | -10.96 | 2.84 | 16.35 | 46.18 | 16.45 | 3.28 | 14.80 | -5.99 | | |
| Early | 8283 | rib | F | -16.32 | -12.86 | 3.46 | 11.95 | 43.88 | 15.00 | 3.41 | 14.16 | -6.72 | | |
| Early | 8287 | long bone | F | -14.50 | -11.49 | 3.01 | 15.67 | 43.60 | 15.83 | 3.21 | 8.67 | -5.77 | | |
| Early | 8300 | long bone | F | -15.34 | -9.84 | 5.50 | 13.27 | 42.24 | 14.33 | 3.44 | 4.04 | -6.04 | | |
| Early | 8302 | rib | F | -14.20 | -10.59 | 3.61 | 16.05 | 44.58 | 14.37 | **3.62** | 7.24 | -6.62 | | |
| Early | 8310 | rib | F | -13.56 | -11.29 | 2.27 | 17.31 | 41.16 | 14.85 | 3.23 | 5.90 | -7.46 | | |
| Middle | 1392 | rib | M | -17.87 | -13.27 | 4.60 | 9.10 | 43.25 | 15.81 | 3.19 | 4.61 | -4.03 | .21 | 2.88 |

Table 5.3 Continued.

| Period | Sample No. | Sample | Sex | Collagen $\delta^{13}C$ | Apatite $\delta^{13}C$ | Collagen-Apatite Spacing | $\delta^{15}N$ | %C | %N | C/N ratio[1] | % Collagen Yield | $\delta^{18}O$ | C/P ratio | CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Middle | 2688 | long bone | M | -18.91 | -12.60 | 6.31 | 7.74 | 42.42 | 15.4 | 3.21 | 7.37 | -4.96 | | |
| Middle | 3762 | long bone | M | -15.29 | -10.73 | 4.56 | 13.25 | 42.52 | 14.37 | 3.45 | 12.45 | -6.40 | | |
| Middle | 3782 | rib | M | -18.95 | -11.88 | 7.07 | 8.27 | 43.92 | 14.76 | 3.47 | 8.29 | -6.36 | | |
| Middle | 3795 | rib | M | -16.09 | -12.24 | 3.85 | 12.06 | 45.14 | 16.25 | 3.24 | 6.74 | -5.74 | | |
| Middle | 3815 | rib | M | -15.73 | -12.45 | 3.28 | 13.03 | 46.21 | 16.79 | 3.21 | 13.34 | -3.74 | .20 | 3.01 |
| Middle | 7094 | rib | M | -17.25 | -13.99 | 3.26 | 10.79 | 45.78 | 16.49 | 3.24 | 24.69 | -6.44 | | |
| Middle | 8792 | rib | M | -17.83 | -12.97 | 4.86 | 10.10 | 46.05 | 14.73 | **3.65** | 15.03 | -7.91 | | |
| Middle | 8822 | rib | M | -17.84 | -13.42 | 4.42 | 10.27 | 44.51 | 16.08 | 3.23 | 14.75 | -8.54 | | |
| Middle | 10292 | rib | M | -17.57 | -13.91 | 3.66 | 10.23 | 45.57 | 16.44 | 3.23 | 20.04 | -7.96 | | |
| Middle | 1365 | rib | F | -17.95 | -13.59 | 4.36 | 8.51 | 46.93 | 16.84 | 3.25 | 19.41 | -5.90 | | |
| Middle | 3784 | rib | F | -16.62 | -12.59 | 4.03 | 11.16 | 44.90 | 14.54 | 3.60 | 13.44 | -6.68 | .23 | 3.27 |
| Middle | 3787 | rib | F | -16.48 | -13.35 | 3.13 | 11.36 | 46.20 | 16.74 | 3.22 | 13.81 | -6.05 | | |
| Middle | 3816 | rib | F | -16.31 | -12.34 | 3.97 | 12.01 | 44.67 | 16.17 | 3.22 | 12.24 | -6.60 | | |
| Middle | 7075 | rib | F | -18.65 | -13.89 | 4.76 | 8.58 | 46.64 | 16.75 | 3.25 | 17.18 | -6.23 | | |
| Middle | 7077 | rib | F | -18.97 | -14.44 | 4.53 | 8.43 | 46.57 | 15.09 | 3.60 | 20.18 | -7.30 | .23 | 3.17 |
| Middle | 7082 | rib | F | -17.12 | -14.48 | 2.64 | 11.86 | 44.19 | 14.34 | 3.60 | 29.67 | -6.49 | .18 | 3.38 |
| Middle | 8763 | rib | F | -18.39 | -13.71 | 4.68 | 8.93 | 20.76 | 7.52 | 3.22 | 20.05 | -7.97 | | |
| Middle | 8778 | rib | F | -19.02 | -15.05 | 3.97 | 8.59 | 45.37 | 16.44 | 3.22 | 20.60 | -7.71 | | |
| Middle | 8797 | rib | F | -17.97 | -13.63 | 4.34 | 9.63 | 43.16 | 15.70 | 3.21 | 17.52 | -7.98 | .18 | 3.72 |
| Middle | 8827 | rib | F | -18.18 | -13.41 | 4.77 | 9.76 | 44.72 | 15.72 | 3.32 | 18.86 | -8.92 | .22 | 3.51 |
| Late | 10372 | rib | F | -20.28 | -15.26 | 5.02 | 6.62 | 43.99 | 15.98 | 3.21 | 22.65 | -6.36 | | |
| Late | 2685 | rib | M | -16.52 | -12.32 | 4.20 | 12.51 | 45.20 | 16.30 | 3.24 | 16.15 | -6.44 | | |
| Late | 2687 | rib | M | -14.24 | -10.44 | 3.80 | 13.94 | 41.78 | 15.03 | 3.24 | 2.31 | -4.07 | .18 | 3.42 |
| Late | 3755 | long bone | M | -15.73 | -12.07 | 3.66 | 13.04 | 42.85 | 14.82 | 3.37 | 12.20 | -6.49 | | |
| Late | 7071 | rib | M | -16.4 | -13.27 | 3.13 | 11.18 | 46.84 | 15.20 | 3.60 | 21.23 | -6.79 | .18 | 3.5 |
| Late | 7076 | rib | M | -17.89 | -14.27 | 3.62 | 9.53 | 44.14 | 16.01 | 3.22 | 19.22 | -7.23 | .24 | 3.15 |
| Late | 7095 | rib | M | -18.41 | -15.04 | 3.37 | 9.58 | 46.77 | 15.10 | **3.61** | 21.44 | -6.93 | .21 | 3.33 |
| Late | 7098 | rib | M | -17.34 | -14.58 | 2.76 | 10.69 | 46.98 | 16.32 | 3.36 | 20.57 | -6.21 | | |
| Late | 7100 | long bone | M | -17.75 | -13.37 | 4.38 | 10.01 | 43.32 | 14.92 | 3.39 | 10.99 | -6.00 | | |
| Late | 5329 | rib | F | -18.47 | -13.96 | 4.51 | 8.77 | 44.09 | 15.97 | 3.22 | 21.82 | -6.41 | | |
| Late | 7073 | rib | F | -18.32 | -13.59 | 4.73 | 8.96 | 46.59 | 14.98 | **3.63** | 14.02 | -6.71 | .17 | 3.43 |
| Late | 7108 | rib | F | -18.61 | -12.95 | 5.66 | 9.00 | 42.53 | 14.35 | 3.46 | 4.69 | -5.83 | .17 | 3.67 |
| Central Coast (Tomales Bay) | | | | | | | | | | | | | | |
| Late | 6366 | powder | M | -12.86 | -9.68 | 3.18 | 16.43 | 40.64 | 14.53 | 3.26 | 3.21 | -4.56 | | |
| Late | 6368 | powder | M | -13.32 | -10.46 | 2.86 | 16.03 | 40.72 | 14.57 | 3.26 | 3.78 | -5.45 | | |
| Late | 6483 | powder | M | -13.77 | -9.94 | 3.83 | 15.58 | 38.85 | 14.06 | 3.22 | 4.75 | -4.59 | | |
| Late | 6375 | powder | F | -13.64 | -10.35 | 3.29 | 16.11 | 39.77 | 14.14 | 3.28 | 4.18 | -4.76 | | |

1 Samples with C/N ratios outside of normal ranges and low collagen yields (<1%) are indicated in bold-faced type.

2 The high collagen yields (>20 percent) for a few samples may be due to problems with the balance.

Figure 5.4 plots C/N ratios on the *x*-axis and the collagen yields on the *y*-axis. With the five diagenetically altered samples removed, there is no significant relationship between C/N ratio and collagen yields (r = -.014, p = .884, n=106). There is also no significant relationship between C/N ratios and $\delta^{13}$C and $\delta^{15}$N values ($\delta^{13}$C, r = -.174, p = .075; $\delta^{15}$N, r = -.146, p = .134), or between $\delta^{13}$C values and collagen yields (r = .119, p = .226). However, $\delta^{15}$N values show a significant negative correlation with collagen yield for the San Francisco Bay samples (r = -.379, p = .001), but not for the Sacramento Valley samples (r = -.092, p = .519). The negative correlation in the Bay samples is due to the lower collagen yields and higher $\delta^{15}$N values at ALA-307 (n=18; Table 5.2). However, when plotted together, $\delta^{13}$C and $\delta^{15}$N values are strongly correlated (r = .95, p = .001), which indicates that the samples are preserving a biogenic signal. Since all other measures indicate good sample quality, I assume that these samples are not diagenetically altered.

Thus, for the vast majority of samples (106/111 = 95.5 percent), bone quality indicators indicate reasonably good collagen preservation. The average collagen yield for the 106 useable samples is 10.66±6.1 percent. Average collagen yields are highest for ribs (13.5±6.9 percent, n=56), second highest for long bones (8.5±8.5 percent, n=37), and lowest for powder samples (5.3±3.0 percent, n=18). The paired bone and powder samples from four individuals also showed a high degree of replicability, with mean differences of .03±05‰, .3±14‰, and .04±.03 for $\delta^{13}$C, $\delta^{15}$N, and C/N ratio, respectively. Based on these findings, I consider the bone powder samples sufficient for dietary analysis.

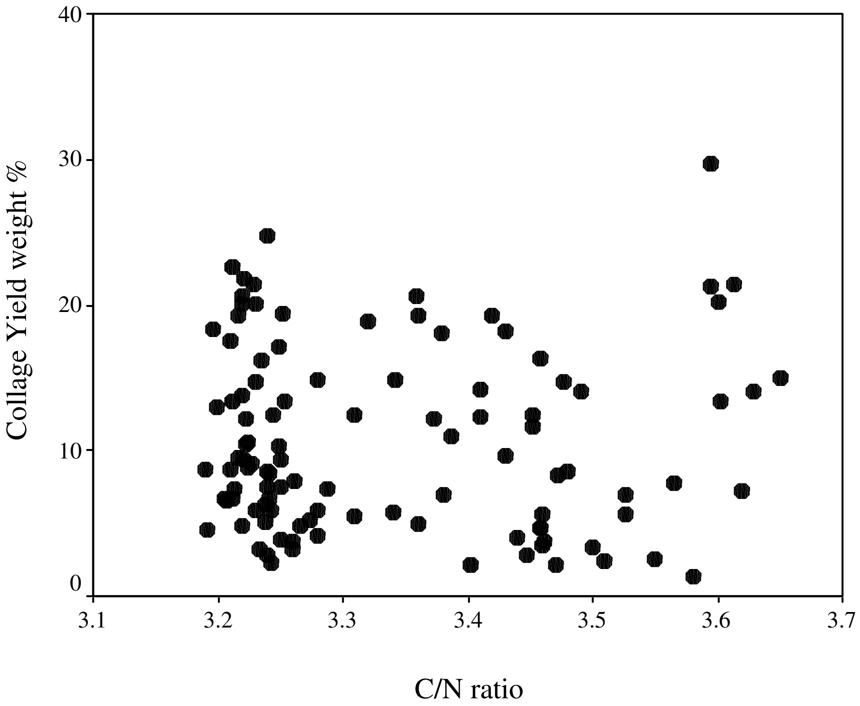

**Figure 5.4.** Plot of the relationship between the C/N ratio and % collagen yield in prehistoric human bone samples from central California.

Diagenesis of bone apatite can be a significant problem for prehistoric bone samples, regardless of the length of time since burial. Soils and groundwater from the burial environment can exchange $CO_3$ with bioapatite in tooth enamel and bone, and may also result in carbonate dissolution and recrystallization (Nielsen-Marsh and Hedges 2000b). Since these diagenetic processes alter the mineral phase of apatite, stable isotope ratios may not accurately reflect dietary signatures. Dilute acetic acid is commonly used to remove the more labile carbonates that are adsorbed onto the surfaces of apatite crystals, as well as exogenous calcite and dolomite (Garvie-Lok et al. 2004; Kohn and Cerling 2002). Labile carbonates are more easily dissolved by acetic acid treatment than are structural carbonates that substitute into crystal lattice positions during diagenesis. Although pretreatment with dilute acetic acid may be effective in removing diagenetic carbonates, samples should be screened for signs of recrystallization and carbonate content.

Figure 5.5 presents the relationship between C/P ratio and CI in the samples (see Table 5.3). There is a significant negative correlation between the C/P ratio and CI (r = -.733, p = .001, n=30), which suggests that recrystallization and excessive carbonate loss have occurred in some of the samples. Three samples with high CI values also have low C/P ratios (<.15), suggesting significant loss of carbonate content.

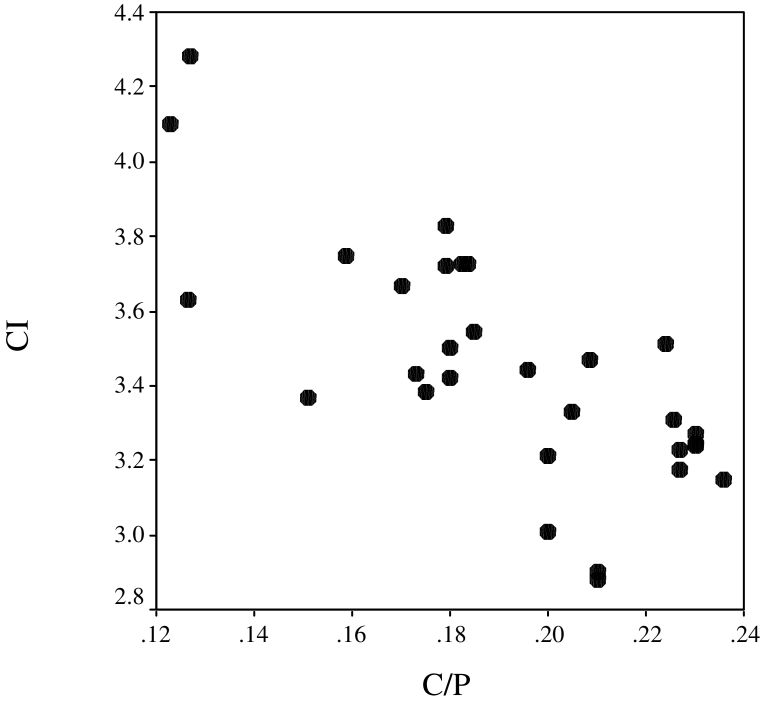

**Figure 5.5.** Plot of the relationship between the C/P and CI in prehistoric human bone apatite samples from central California.

Figures 5.6 and 5.7 plot the relationship between $\delta^{13}C$ and CI and $\delta^{13}C$ and C/P of apatite, respectively. $\delta^{13}C$ values show a significant negative correlation with C/P ratio (r = -.374, p = .042, n=30), but not CI (r = .341, p = .066). However, when the five samples with low C/P ratios (<.17) are removed, there is no correlation between C/P ratio and $\delta^{13}C$ (r = -.289, p = .161, n=25), or between CI and $\delta^{13}C$ (r = .233, p = .233, n=25). Although it was not possible to examine all samples with FTIR, the sample prescreening suggests that the vast majority of samples appear to be suitable for stable isotope analysis. I exclude the five samples that showed low C/P ratios (<.17) from statistical analyses, but assume the remaining samples preserve a biogenic signal.

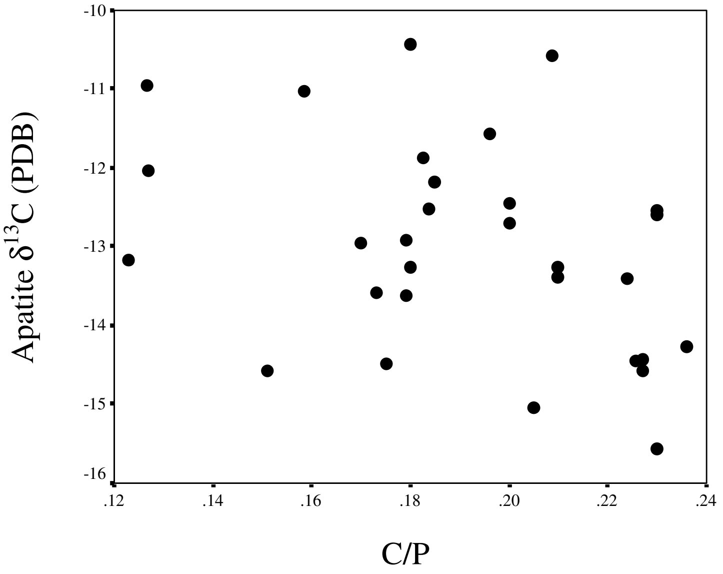

**Figure 5.6.** Plot of the relationship between the C/P and apatite $\delta^{13}C$ in prehistoric human bone samples from central California.

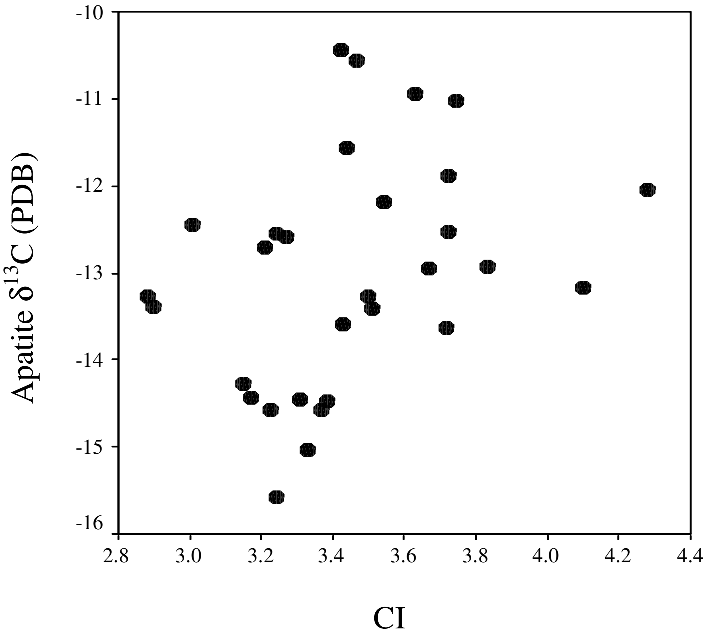

**Figure 5.7.** Plot of the relationship between the CI and apatite $\delta^{13}$C in prehistoric human bone samples from central California.

### *Paleodietary Interpretation*

#### *Regional and Temporal Trends*

Table 5.4 presents mean stable isotope values from human bone collagen and apatite. I also include the four skeletons from Tomales Bay (central coast) in the plot for comparison with the main study samples. Table 5.5 presents Mann-Whitney U test results for inter-regional sample comparisons. Sacramento Valley skeletons have an average $\delta^{13}$C value of –19.9±.5‰ and $\delta^{15}$N of 10.9±.9‰, whereas San Francisco Bay skeletons have an average $\delta^{13}$C value of –16.4±2.0‰ and $\delta^{15}$N of 12.3±3.3‰. When the data are partitoned by time period, Early period Valley skeletons average –19.9‰ for $\delta^{13}$C and 10.8‰ for $\delta^{15}$N, while Bay skeletons average –14.3‰ for $\delta^{13}$C and 16.0‰ for

$\delta^{15}$N. These values are significantly different ($\delta^{13}$C, z = -5.263, p = .001; $\delta^{15}$N, z = -5.175, p = .001). Middle period Valley skeletons average –19.9‰ for $\delta^{13}$C and 11.3‰ for $\delta^{15}$N, whereas Bay skeletons average –17.7‰ for $\delta^{13}$C and 10.0‰ for $\delta^{15}$N, also significantly different ($\delta^{13}$C, = -4.506, p = .001; $\delta^{15}$N, -2.305, p = .021). Late period Valley skeletons average –20.0‰ for $\delta^{13}$C and 10.9‰ for $\delta^{15}$N, while Bay skeletons average –17.2‰ for $\delta^{13}$C and 10.7‰ for $\delta^{15}$N; these values are significantly different for $\delta^{13}$C but not for $\delta^{15}$N ($\delta^{13}$C, z = -4.45, p = .001).

Table 5.4. Comparison of Stable Isotope Values in
Bone Collagen and Apatite in Prehistoric Central California.

| | **Collagen $\delta^{13}$C** | | | **Apatite $\delta^{13}$C** | | | **Collagen-apatite spacing** | | | **$\delta^{15}$N** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **n** | **Mean** | **SD** | **n** | **Mean** | **SD** | **n** | **Mean** | **SD** | **n** | **Mean** | **SD** |
| **Sacramento Valley** | | | | | | | | | | | | |
| Early Period | 20 | -19.9 | .7 | 24 | -13.2 | 1.4 | 20 | 6.7 | 1.5 | 20 | 10.8 | 1.0 |
| Middle Period | 13 | -19.9 | .3 | 12 | -13.1 | 1.1 | 12 | 6.8 | 1.1 | 13 | 11.3 | .7 |
| Late Period | 18 | -20.0 | .3 | 17 | -13.3 | .8 | 17 | 6.6 | 1.0 | 18 | 10.9 | .8 |
| **San Francisco Bay** | | | | | | | | | | | | |
| Early Period | 18 | -14.3 | .9 | 15 | -11.1 | .8 | 15 | 3.3 | 1.0 | 18 | 16.0 | 1.8 |
| Middle Period | 22 | -17.7 | 1.2 | 22 | -13.3 | 1.1 | 22 | 4.4 | 1.0 | 22 | 10.0 | 1.8 |
| Late Period | 11 | -17.2 | 1.4 | 11 | -13.3 | 1.3 | 11 | 4.0 | .8 | 11 | 10.7 | 1.8 |
| **Central Coast** | | | | | | | | | | | | |
| Late Period | 4 | -13.4 | .4 | 4 | -10.1 | .4 | 4 | 3.3 | .4 | 4 | 16.0 | .4 |

Carbon and nitrogen bone isotope ratios show the greatest differences between regions in the Early period (mean differences of 5.6‰ for $\delta^{13}$C, 5.2‰ for $\delta^{15}$N). In contrast, Middle and Late period samples show a ~2.0‰ difference between regions for carbon isotopes only. Although $\delta^{15}$N values are significantly higher in Valley skeletons than in Bay skeletons for the Middle period, this difference is relatively small (1.3‰).

Table 5.5. Mann-Whitney U Results for
Inter-regional Comparisons of Stable Isotope Values.

| | n | z | p value[1] | Trend[2] |
|---|---|---|---|---|
| **Early Period** | | | | |
| $\delta^{13}$C collagen | 38 | -5.263 | **.001** | SFB>SV |
| $\delta^{15}$N collagen | 38 | -5.175 | **.001** | SFB>SV |
| $\delta^{13}$C apatite | 39 | -4.331 | **.001** | SFB>SV |
| Coll-apatite spacing | 39 | -4.966 | **.001** | SFB>SV |
| **Middle Period** | | | | |
| $\delta^{13}$C collagen | 35 | -4.506 | **.001** | SFB>SV |
| $\delta^{15}$N collagen | 35 | -2.305 | **.021** | SV>SFB |
| $\delta^{13}$C apatite | 34 | -.667 | .505 | |
| Coll-apatite spacing | 34 | -4.343 | **.001** | SV>SFB |
| **Late Period** | | | | |
| $\delta^{13}$C collagen | 29 | -4.450 | **.001** | SFB>SV |
| $\delta^{15}$N collagen | 29 | -1.034 | .301 | |
| $\delta^{13}$C apatite | 28 | -.259 | .796 | |
| Coll-apatite spacing | 28 | -4.281 | **.001** | SV>SFB |

[1] Statistically significant results (p<.05) are indicated by bold-faced type in the table.
[2] Direction of trend indicates which skeletal sample has a higher $\delta^{13}$C or $\delta^{15}$N value, or larger collagen-apatite spacing.

Figure 5.8 shows that $\delta^{13}$C and $\delta^{15}$N values for individual skeletons do not overlap between the Sacramento Valley and San Francisco Bay, indicating distinct food consumption patterns in the two regions. Figure 5.9 plots carbon and nitrogen isotope values for the Sacramento Valley sample. $\delta^{13}$C values in Valley skeletons cluster together and show a small spread of values, ranging from –18.3‰ to –21.3‰ in individual skeletons. The spread of $\delta^{15}$N values is somewhat larger, and ranges from 9.4‰ to 12.9‰ in individual skeletons. The low variability in isotopic signatures and small standard deviations suggest that diets were relatively homogenous within the Valley during all time periods. However, the higher standard deviations for $\delta^{13}$C and

$\delta^{15}N$ values in Early period skeletons indicate greater isotopic variability during this period than was found for the Middle and Late period samples (Table 5.4).

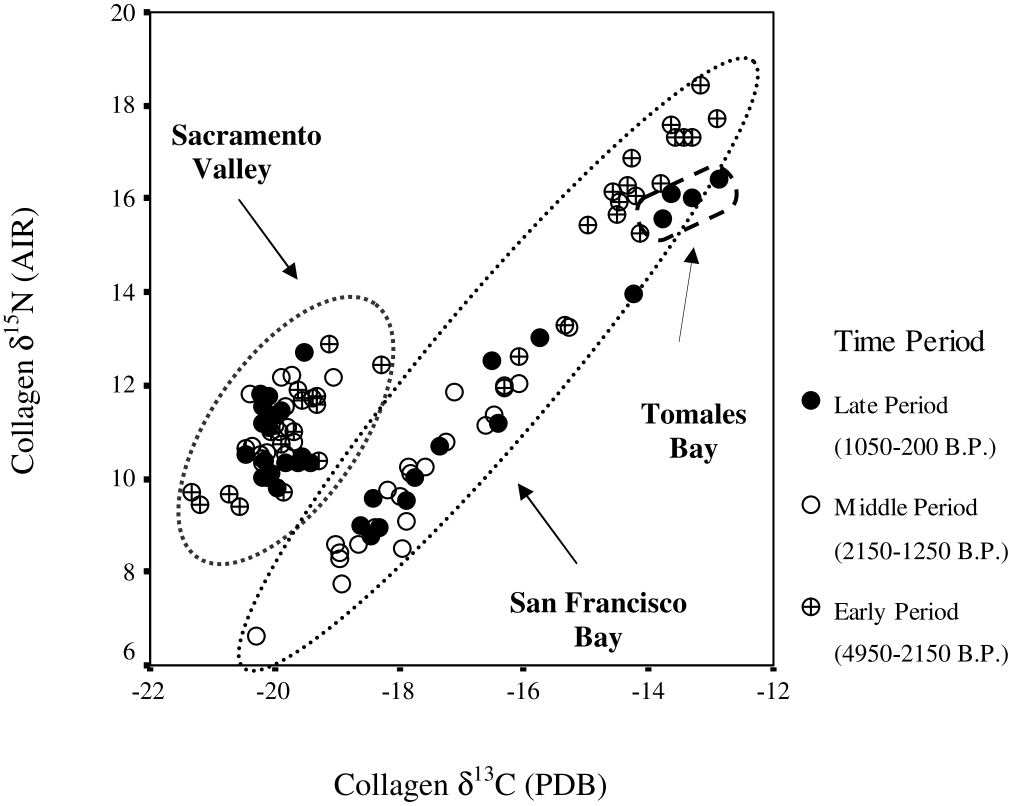

**Figure 5.8.** Plot of the relationship between the $\delta^{13}C$ and $\delta^{15}N$ in prehistoric human bone collagen samples from prehistoric central California.

Statistical results presented in Table 5.6 indicate no significant temporal differences in $\delta^{13}C$ and $\delta^{15}N$ values for Sacramento Valley skeletons. Comparison with the theoretical food web presented in Figure 5.3 indicates that that mean $\delta^{13}C$ and $\delta^{15}N$ values for Valley skeletons fall entirely within the expected ranges of terrestrial C3 resources and freshwater fish. The low $\delta^{15}N$ values in these samples suggests that dietary protein from anadromous fish (salmon, sturgeon) was not a major component of the diet, contrary to what has been in the ethnographic literature and ethnohistoric accounts (see Yoshiyama 1999).

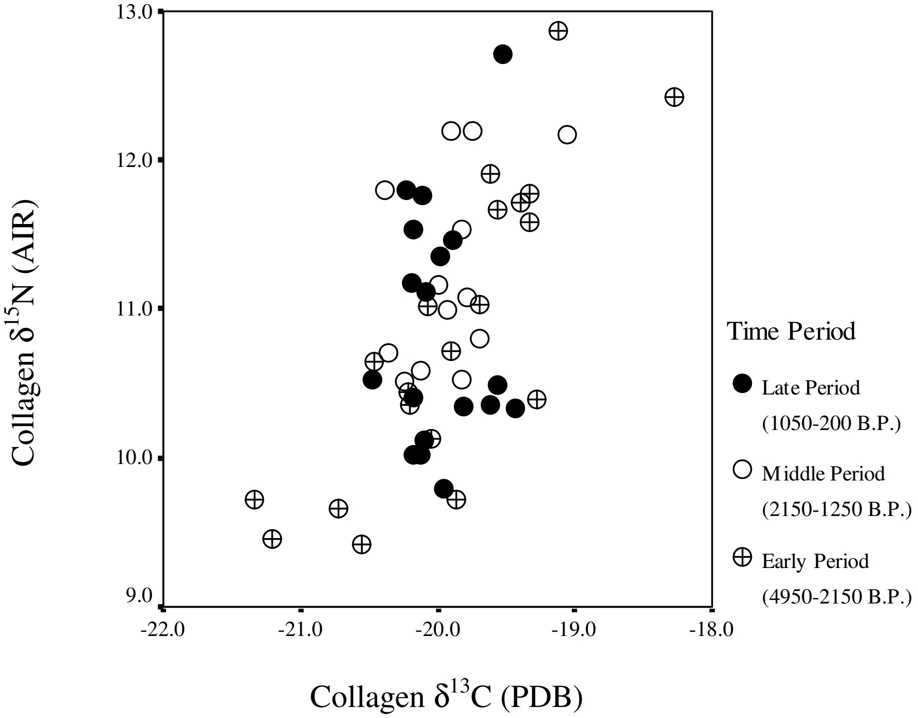

**Figure 5.9.** Plot of the relationship between the $\delta^{13}C$ and $\delta^{15}N$ in prehistoric human bone collagen from the Sacramento Valley.

In contrast to the Valley, San Francisco Bay skeletons show a strong linear relationship between $\delta^{13}C$ and $\delta^{15}N$ values (r = .98, p = .001; Figure 5.10). This suggests that two isotopically distinct food sources are primarily contributing to the dietary signatures: $^{13}C$-enriched marine proteins and terrestrial C3 resources. Early period skeletons have average values of –14.3‰ for $\delta^{13}C$ and 16.0‰ for $\delta^{15}N$; Middle period skeletons have average values of -17.7‰ for $\delta^{13}C$ and 10.0‰ for $\delta^{15}N$; and Late period skeletons have average values of –17.2‰ for $\delta^{13}$C and 10.7‰ for $\delta^{15}$N. Carbon and nitrogen isotope signatures are significantly different between the Early and Middle ($\delta^{13}$C, z = -5.193, p = .001; $\delta^{15}$N, z = -5.22, p = .001) and the Early and Late ($\delta^{13}$C, z = -3.955, p = .001; $\delta^{15}$N, z = -4.18, p = .001) periods (Table 5.6). Isotope signatures are not significantly different between the Middle and Late period samples.

Table 5.6. Mann-Whitney U Results for
Temporal Comparisons of Stable Isotope Values.

| | | **Sacramento Valley** | | | | **San Francisco Bay** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **n** | **z** | **p value**$^1$ | **Trend**$^2$ | **n** | **z** | **p value**$^1$ | **Trend**$^2$ |
| EP vs. MP | $\delta^{13}$C collagen | 33 | -.221 | .825 | | 40 | -5.193 | **.001** | EP>MP |
| | $\delta^{15}$N collagen | 33 | -1.437 | .151 | | 40 | -5.220 | **.001** | EP>MP |
| | $\delta^{13}$C apatite | 36 | -.252 | .801 | | 37 | -4.578 | **.001** | EP>MP |
| | Coll-apatite spacing | 36 | -.419 | .675 | | 37 | -3.001 | **.003** | EP<MP |
| EP vs. LP | $\delta^{13}$C collagen | 38 | -.629 | .530 | | 29 | -3.955 | **.001** | EP>LP |
| | $\delta^{15}$N collagen | 38 | -.044 | .965 | | 29 | -4.180 | **.001** | EP>LP |
| | $\delta^{13}$C apatite | 41 | -.543 | .587 | | 26 | -3.451 | **.001** | EP>LP |
| | Coll-apatite spacing | 41 | .000 | 1.000 | | 26 | -1.791 | .073 | EP<LP |
| MP vs. LP | $\delta^{13}$C collagen | 31 | -.480 | .631 | | 33 | -.707 | .480 | |
| | $\delta^{15}$N collagen | 31 | -1.782 | .075 | | 33 | -.917 | .359 | |
| | $\delta^{13}$C apatite | 29 | -.642 | .521 | | 33 | -.115 | .902 | |
| | Coll-apatite spacing | 29 | -.117 | .859 | | 33 | -1.261 | .207 | |

[1] Statistically significant results ($p<.05$) are indicated by bold-faced type in the table.

[2] Direction of trend indicates which skeletal sample has a higher $\delta^{13}$C or $\delta^{15}$N value, or larger collagen-apatite spacing.

Comparison with the theoretical food web presented in Figure 5.3 indicates that that mean $\delta^{13}$C and $\delta^{15}$N values for Bay skeletons fall within the range of marine and terrestrial C3 resources. Early period skeletons fall within the expected dietary "meat" values of high trophic level marine resources, including both marine and anadromous fish, and marine mammals. Middle and Late period skeletons show a high level of variability and overlap, and also significantly lower δ$^{13}$C and δ$^{15}$N values, which indicate greater consumption of lower trophic level marine resources (e.g., shellfish) and a significant contribution of C3 plants.

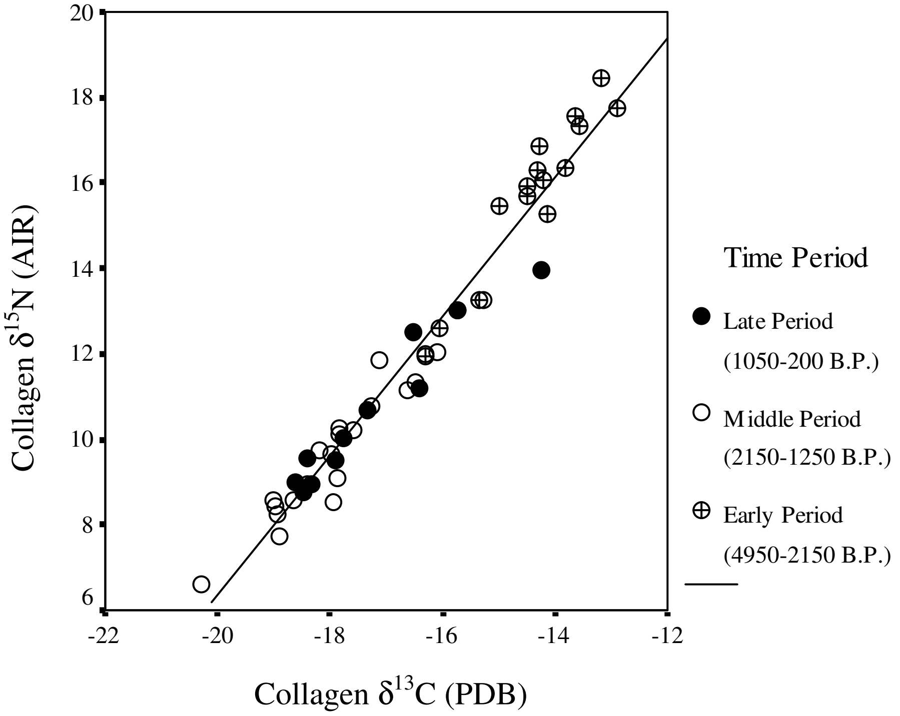

**Figure 5.10.** Plot of the relationship between the δ$^{13}$C and δ$^{15}$N in prehistoric human bone collagen from San Francisco Bay. The linear relationship indicates that two isotopically distinct food resources are contributing to dietary signatures (Pearson's r = .98, p = .001).

Bay and Valley bone apatite δ$^{13}$C values are nearly identical in the Middle and Late periods (~-13.3‰; Table 5.4). In contrast, Early period Bay values are enriched in $^{13}$C by 2.1‰ over Valley skeletons, a statistically sigificant difference (z = -4.331, p = .001; Table 5.5).

Valley skeletons have a collagen-apatite spacing of 6.7‰, 6.8‰, and 6.6‰ for the Early, Middle, and Late periods, respectively (Table 5.4). In contrast, collagen-apatite spacing in Bay skeletons is 3.3‰, 4.4‰, and 4.0‰ for the Early, Middle, and Late periods, respectively.

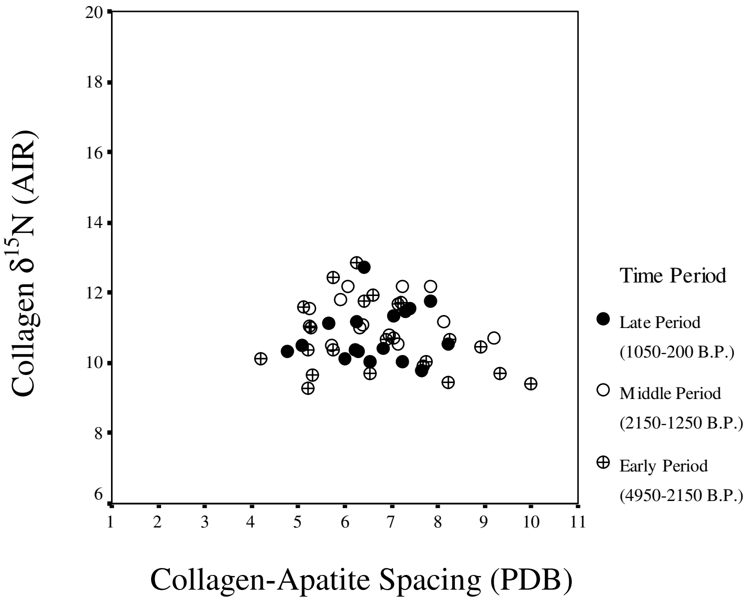

**Figure 5.11.** Plot of the relationship between the $\delta^{13}C$ and collagen-apatite spacing $\delta^{13}C$ in prehistoric human bone samples from the Sacramento Valley.

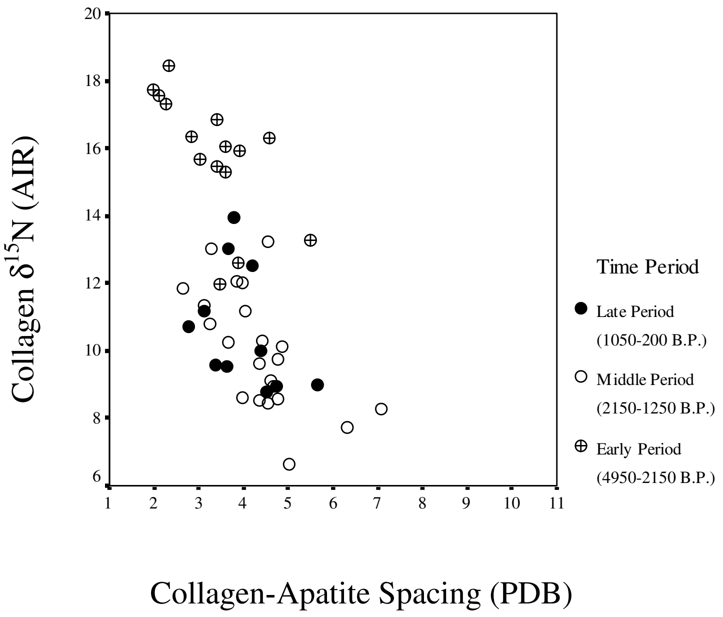

**Figure 5.12.** Plot of the relationship between the $\delta^{13}$C and collagen-apatite spacing $\delta^{13}$C in prehistoric human bone in San Francisco Bay.

Figures 5.11 and 5.12 plot the relationship between collagen-apatite spacing and $\delta^{15}$N for the Sacramento Valley and San Francisco Bay samples, respectively. As discussed previously, a collagen-apatite spacing value of 4.4‰ indicates that the $\delta^{13}$C of protein component of the diet is equal to that of the whole diet. Values higher than 4.4‰ indicate that dietary protein is depleted in $^{13}$C relative to the whole diet, and values less than 4.4‰ indicate that the $\delta^{13}$C of dietary protein is enriched in $^{13}$C relative to that of the whole diet. The large collagen-apatite spacing value of ~6.7‰ in Valley skeletons indicates that the diet was significantly depleted in $^{13}$C relative to the whole diet, which indicates a diet that consisted primarily of C3 terrestrial resources (plants and mammals) and freshwater fish. However, the smaller values (<4.4‰) in Early and Late period Bay skeletons indicate that the $\delta^{13}$C of dietary protein was more enriched in $^{13}$C than that of the whole diet, which indicates a diet that consisted of marine proteins and terrestrial plant resources. The average 4.4‰ collagen-apatite spacing in Middle period Bay Area skeletons indicates that the $\delta^{13}C$ of dietary protein was equal to that of the whole diet.

Bone apatite $\delta^{13}C$ values are significantly higher in Early period Bay skeletons than in Middle and Late period Bay skeletons (EP vs. MP, $z = -4.578$, $p = .001$; EP vs. LP, $z = -3.451$, $p = .001$). Collagen-apatite spacing values are also smallest for Early period skeletons, and then increase through time, suggesting a temporal shift toward greater consumption of C3 plants. Early and Middle period collagen-apatite spacing values are significantly different ($z = -3.001$, $p = .003$), and differences approach statistical significance ($p = .073$) for comparisons between Early and Late period Bay skeletons.

Carbon and nitrogen stable isotope ratios from Tomales Bay (central California coast) are featured in Figure 5.8 (also see Table 5.4). These skeletons have average values of –13.4‰ for $\delta^{13}C$ and 16.0‰ for $\delta^{15}N$, and plot in the upper right hand corner of Figure 5.8 alongside Early period Bay skeletons. The Tomales Bay region, to the north of San Francisco Bay, is thought to have been occupied relatively late in prehistory, and it is of particular interest that these skeletons are isotopically similar to Early period Bay Area groups. The mean collagen-apatite spacing value of 3.3‰ is also identical to Early period Bay skeletons. Although larger sample sizes are needed, stable isotope bone values from Tomales Bay are consistent with a $^{13}C$-enriched diet, comprising high trophic level marine proteins and terrestrial C3 carbohydrates. The similarities between the Early period Bay and Late period coast are interesting in light of the large time difference represented by the two samples, which is approximately 2000 years.

### *Sex Comparisons*

Although samples sizes are relatively small when male and female skeletons are examined separately, sex differences in food consumption patterns may be reflected in stable isotope signatures. Table 5.7 presents carbon and nitrogen stable isotope data for males and females by region, and statistical results are provided in Table 5.8. In the Sacramento Valley samples, male and female skeletons have nearly identical $\delta^{13}C$ signatures, whereas $\delta^{15}N$ values in males are slightly enriched by ~.5‰. This suggests greater meat consumption in males, but the difference in $\delta^{15}N$ is small and only approaches statistical significance for the Middle ($z = - 1.757$, $p = .079$) and Late ($z = -1.822$, $p = .068$) period samples. For bone apatite, Middle period male skeletons also have significantly higher $\delta^{13}C$ values than female skeletons (1.2‰ difference; $z = -2.03$, $p = .042$). However, collagen-apatite spacing differences indicate that dietary protein is less enriched in $^{13}C$ in Middle period males than in females ($z = -2.03$, $p = .042$). These differences could be due to greater consumption of $^{13}C$-depleted freshwater fish and C3 plants by males, which would account for the higher $\delta^{15}N$ and collagen-apatite spacing values. In contrast, the lower $\delta^{15}N$ values and smaller collagen-apatite spacing in females relative to males could be due to their greater consumption of terrestrial herbivores and lesser consumption of C3 plants.

Table 5.7. Sex Comparison of Stable Isotope Values in Prehistoric Central California.

| | | Collagen $\delta^{13}C$ | | | Apatite $\delta^{13}C$ | | | Collagen-apatite spacing | | | $\delta^{15}N$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **Sex** | **n** | **Mean** | **SD** | **n** | **Mean** | **SD** | **n** | **Mean** | **SD** | **n** | **Mean** | **SD** |
| **Sacramento Valley** | | | | | | | | | | | | | |
| Early Period | Males | 11 | -20.0 | .6 | 13 | -13.3 | 1.4 | 13 | 6.7 | 1.6 | 11 | 11.0 | 1.1 |
| | Females | 9 | -19.8 | .9 | 11 | -13.1 | 1.4 | 11 | 6.7 | 1.5 | 9 | 10.7 | 1.0 |
| Middle Period | Males | 5 | -20.1 | .3 | 5 | -12.4 | 1.2 | 5 | 7.7 | 1.2 | 5 | 11.6 | .7 |
| | Females | 8 | -20.0 | .4 | 8 | -13.6 | .8 | 7 | 6.3 | .7 | 8 | 11.0 | .6 |
| Late Period | Males | 10 | -20.0 | .3 | 10 | -13.3 | .6 | 9 | 6.6 | .6 | 10 | 11.2 | .8 |
| | Females | 8 | -20.0 | .3 | 8 | -13.4 | 1.1 | 8 | 6.6 | 1.3 | 8 | 10.4 | .6 |
| **San Francisco Bay** | | | | | | | | | | | | | |
| Early Period | Males | 9 | -14.1 | 1.0 | 9 | -11.0 | .7 | 8 | 3.2 | .9 | 9 | 16.4 | 1.8 |
| | Females | 9 | -14.5 | .9 | 9 | -11.2 | .9 | 7 | 3.5 | 1.0 | 9 | 15.6 | 1.8 |
| Middle Period | Males | 10 | -17.3 | 1.3 | 10 | -12.8 | 1.0 | 10 | 4.6 | 1.3 | 10 | 10.5 | 1.9 |
| | Females | 12 | -18.0 | 1.2 | 12 | -13.8 | .9 | 12 | 4.2 | .7 | 12 | 9.6 | 1.7 |
| Late Period | Males | 8 | -16.8 | 1.4 | 8 | -13.2 | 1.5 | 8 | 3.6 | .5 | 8 | 11.3 | 1.7 |
| | Females | 3 | -18.5 | .2 | 3 | -13.5 | .5 | 3 | 5.0 | .6 | 3 | 8.9 | .1 |
| **Central Coast** | | | | | | | | | | | | | |
| Late Period | Males | 3 | -13.3 | .5 | 3 | -10.0 | .4 | 3 | 3.3 | .5 | 3 | 16.0 | .4 |
| | Females | 1 | -13.6 | - | - | -10.4 | - | 1 | 3.3 | - | 1 | 16.1 | - |

Table 5.8. Mann-Whitney U Result Sex Comparisons of Stable Isotope Values.

| | | Sacramento Valley | | | | San Francisco Bay | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Period** | | **n** | **z** | **p value[1]** | **Trend[2]** | **n** | **z** | **p value[1]** | **Trend[2]** |
| Early Period | $\delta^{13}C$ collagen | 20 | -.494 | .621 | | 18 | -1.104 | .270 | |
| | $\delta^{15}N$ collagen | 20 | -.570 | .569 | | 18 | -1.015 | .310 | |
| | $\delta^{13}C$ apatite | 24 | -.782 | .434 | | 15 | .000 | 1.000 | |
| | Coll-apatite spacing | 24 | -.261 | .794 | | 15 | -.638 | .524 | |
| Middle Period | $\delta^{13}C$ collagen | 13 | -1.317 | .188 | | 22 | -1.451 | .147 | |
| | $\delta^{15}N$ collagen | 13 | -1.757 | .079 | | 22 | -1.055 | .291 | |
| | $\delta^{13}C$ apatite | 12 | -2.030 | **.042** | M>F | 22 | -2.176 | **.030** | M>F |
| | Coll-apatite spacing | 12 | -2.030 | **.042** | M>F | 22 | -.396 | .692 | |
| Late Period | $\delta^{13}C$ collagen | 18 | -.311 | .756 | | 11 | -2.245 | **.025** | M>F |
| | $\delta^{15}N$ collagen | 18 | -1.822 | .068 | | 11 | -2.449 | **.014** | M>F |
| | $\delta^{13}C$ apatite | 17 | -.144 | .885 | | 11 | -.204 | .838 | |
| | Coll-apatite spacing | 17 | .000 | 1.000 | | 11 | -2.449 | **.014** | F>M |

[1] Statistically significant results ($p<.05$) are indicated by bold-faced type in the table.

[2] Direction of trend indicates which skeletal sample has a higher $\delta^{13}C$ or $\delta^{15}N$ value, or larger collagen-apatite spacing.

Compared with the Sacramento Valley, isotopic signatures in San Francisco Bay are more distinct between the sexes. For all time periods, male skeletons have slightly higher $\delta^{13}$C and $\delta^{15}$N values than female skeletons. Although the sample size is notably small, Late period males have significantly higher $\delta^{13}$C and $\delta^{15}$N values than females ($\delta^{13}$C, z = -2.245, p = .025; $\delta^{15}$N, z = -2.449, p = .014), and are enriched by .7‰ for $\delta^{13}$C and by 2.4‰ for $\delta^{15}$N. The smaller collagen-apatite spacing values in Late period male skeletons indicates that male individuals consumed greater amounts of $^{13}$C-enriched marine foods than females in the sample (z = -2.449, p = .014). Although isotopic signatures are significantly different between the sexes in the Late period sample, this finding may be the result of small sample size and is treated conservatively.

### ***Summary***

The stable isotope results have a number of important implications for central California prehistory. Comparisons between the lower Sacramento Valley and San Francisco Bay indicate that food consumption patterns were distinct between the two regions, with no overlap in dietary signatures. Overall, the isotopic data reflect food resources available from local food webs. In the lower Sacramento Valley, carbon and nitrogen isotopic signatures from bone collagen indicate a mixed diet that consisted primarily of C3 terrestrial resources. When compared with dietary signatures of locally available food resources, these signatures fall within expected ranges of terrestrial game (e.g., herbivores, carnivores), C3 plants (acorns, seeds), and freshwater fish. This result is supported by the collagen-apatite spacing values, which indicate that the dietary protein was less enriched in $^{13}$C than the whole diet. The high spacing (~6.6‰) further indicates heavy consumption of C3 plant carbohydrates, which could include acorns, seeds, geophytes, and berries. It is noteworthy that isotopic values do not reflect heavy consumption of $^{13}$C-enriched aquatic resources, such as anadromous fish. There is no evidence for a change in protein or carbohydrate resources through time for any of the dietary signatures.

In the San Francisco Bay, isotopic signatures clearly reflect the consumption of $^{13}$C-enriched marine proteins. Early period Bay skeletons have carbon and nitrogen isotopic signatures from bone collagen that indicate heavy consumption of high-trophic level marine resources, such as marine and anadromous fish, and sea mammals. The small collagen-apatite spacing (3.3‰) indicates that dietary protein was more enriched in $^{13}$C than the whole diet. C3 terrestrial resources appear to have made a relatively small contribution to the diet compared with animal protein resources. A significant dietary shift occurred between the Early and Middle period, which is indicated in carbon and nitrogen isotope signatures from collagen and carbon isotopes from apatite. Carbon and nitrogen isotope values from collagen indicate that Middle period groups consumed relatively smaller amounts of marine protein than Early period groups. Dietary signatures are consistent with the greater consumption of low-trophic level marine foods, such as shellfish, and also greater consumption of terrestrial resources, such as land mammals and C3 plants. The collagen-apatite spacing of 4.4‰ indicates that the $\delta^{13}$C of the protein component of the diet and the whole diet are the same. Late period isotopic signatures are nearly identical to those of Middle period Bay skeletons, although the smaller collagen-apatite spacing value of 4.0‰ indicates a slightly greater contribution of marine resources. The high correlation between carbon and nitrogen isotope values from bone collagen indicates that groups consumed similar sources of dietary protein over time, but in relatively different amounts. The larger collagen-apatite spacing values in Middle and Late period skeletons further indicate that terrestrial C3 resources made a greater contribution to the diet than in the Early period. Overall, stable isotope signatures between San Francisco Bay and the Sacramento Valley became more similar over time.

Although sample sizes are greatly reduced when partitioned by sex, there is some evidence to suggest dietary differences between males and females. In the Sacramento Valley, Middle period male skeletons have slightly higher $\delta^{15}N$ and collagen-apatite spacing values than females, which could be due to greater consumption of freshwater fish and C3 plant carbohydrates in males, and greater consumption of terrestrial game in females. In San Francisco Bay, male skeletons have higher carbon and nitrogen collagen isotope signatures than female skeletons, suggesting greater consumption of dietary protein. The significantly smaller collagen-apatite spacing in the Late period samples further indicates that male diets were more enriched in $^{13}C$ than female diets during this period, due to greater consumption of marine proteins in males.

# CHAPTER VI

# DENTAL PATHOLOGY

Studies of oral health have a long a history in anthropology for investigating dietary differences among human populations that practice different subsistence strategies. Since teeth directly interact with food, they can provide useful information on the relationship between diet and dental health. Although this relationship is complex, dental disease studies have been successfully used to make inferences regarding the importance of different food resources to the diet. In this chapter, I use dental caries, antemortem tooth loss, and alveolar abscesses in the adult dentition to examine differences in oral health by time period, by region, and by sex in prehistoric central California. I expect these conditions to be more prevalent during the Middle and Late period, associated with the greater consumption of carbohydrate staples such as acorns, small seeds, and root foods. Further, I expect to find a higher prevalence of dental disease among groups from the lower Sacramento Valley that had less access to marine proteins than among groups from San Francisco Bay. Finally, I expect female skeletons to show a higher prevalence of dental disease than male skeletons, reflecting sex differences in the consumption of protein and carbohydrate resources.

## *Literature Review*

Dental disease is among the most common conditions observed on prehistoric human skeletons (Hillson 2000; Jurmain 1990a). Although dental disease encompasses a variety of different conditions, this study focuses on those most relevant to diet including dental caries, antemortem tooth loss, and alveolar abscesses. Dental caries form where plaque deposits of inorganic salts accumulate on the external surfaces of teeth. These deposits comprise colonies of microorganisms (e.g., *Streptococcus mutans, Lactobacillus acidophilus*) that mineralize to form dental calculus, which adheres to tooth surfaces (Hillson 2000:258). These oral bacteria secrete organic acids resulting in focal demineralization of enamel hydroxyapatite (Larsen 1997:65). Caries initiation sites are influenced by crown morphology; hence posterior teeth are more susceptible than anterior teeth due to their greater number of pits and fissures. Bacterial fermentation of carbohydrates, especially dietary sugars, plays a major role in the formation of dental caries (Hunter 1988; Moore and Corbett 1971; Newbrun 1982). Numerous studies on living populations have confirmed the relationship between the consumption of carbohydrates and the development of dental caries, especially for foods with high sugar content (Hillson 1996, 2000, 2001; Hunter 1988; Newbrun 1982; Walker et al. 1998). Carbohydrate-rich foods that are sticky in texture may also contribute to caries, since food particles can become easily lodged within interproximal spaces, pits, and fissures of teeth (Larsen 1997; Nelson et al. 1999). In severe dental caries, much of the tooth crown is destroyed, opening the pulp chamber to oral bacteria that may inflame the gingiva and gums (Hillson 1996, 2000, 2001). Severe inflammation may result in the formation of periapical granulomas and abscesses within the alveolus (Ortner 2003:590-592). Although dental caries are a major cause of antemortem tooth loss, severe dental attrition may also expose the pulp chamber and lead to the shedding of teeth.

In addition to the vast clinical literature on dental disorders among living human populations, numerous bioarchaeological studies have found significant differences in the prevalence of dental caries and antemortem tooth loss between prehistoric forager and agricultural societies (Cohen and Armelagos 1984; Larsen 1997). In many areas of the world where agriculture was adopted, the caries rate shows a significant increase compared with earlier non-agricultural groups from the same region. This pattern is thought to mark the transition from a varied diet of meat and plant foods to the intensified focus on more cariogenic plant staples (Hillson 2001; Larsen et al. 1991; Larsen 1997). For the New World in particular, the high prevalence of dental caries among prehistoric agriculturalists is attributed to the adoption of maize as a staple crop (Larsen 1980, 1984, 1995; Larsen et al. 1991; Powell 1985; Schollmeyer and Turner II 2004). When processed into a sticky gruel, carbohydrate-rich foods such as maize, may promote tooth decay. Researchers have also found temporal differences in caries prevalence in prehistoric non-agricultural societies. For example, Walker and Erlandson (1986) found a significant decline in dental caries in prehistoric groups from southern coastal California, which they interpret as a change from consumption of cariogenic plants, such as roots and tubers, to the intensified use of marine resources, such as fish and sea mammals. Societies that consume high amounts of protein-rich foods, including terrestrial animal meat and fish, typically have lower caries rates, since protein raises the pH of plaque in the oral cavity, thus protecting tooth enamel from developing caries (Littleton and Frolich 1993; Mundorff et al. 1990; Mundorff-Shrestha et al. 1994).

### *Methods and Materials*

Prehistoric societies in central California consumed a variety of carbohydrate and protein resources that would have influenced caries rates. In this study, I hypothesize that increased consumption of plant staples such as acorns, beginning with the Middle period, should result in a higher prevalence of dental caries, antemortem tooth loss (AMTL), and alveolar abscesses. Acorns are rich in carbohydrates but contain relatively small amounts of sugar. However, when processed into a sticky gruel, acorn mush may have had cariogenic properties that would have promoted dental decay. To test this hypothesis, I examined the prevalence of dental caries, antemortem tooth loss, and alveolar abscesses in the maxillary and mandibular dentition following a protocol modified from *Standards for Data Collection* (Buikstra and Ubelaker 1994). I inventoried each tooth position as follows:

1) present, unerupted
2) present, in occlusion (with enamel height > 2 mm from CEJ, surrounding at least 50 percent of the crown circumference)
3) absent, unknown when tooth was lost
4) absent, lost antemortem (AMTL)
5) absent, lost postmortem (PMTL)
6) congenitally absent
7) present, with less than 2 mm of enamel remaining due to attrition
8) present, but not observable due to presence of adhesive or soil
9) partial root present, but most of tooth lost antemortem

I scored a tooth as AMTL when the alveolar bone showed clear evidence of resorption for that tooth position. For ambiguous cases, I only scored tooth sockets with depths of ~2 mm or less as lost antemortem. The calculation of AMTL frequency did not include unerupted teeth, tooth positions associated with postmortem alveolar damage, congenitally absent teeth, or teeth that showed partial antemortem loss (e.g., tooth roots remaining). Since agenesis of the third molar is common in humans, I scored this tooth as congenitally absent only when the corresponding occluding tooth was present (but lacked occlusal wear facets) and the individual was older than 25 years of age. When the third molar was absent and the corresponding occluding tooth showed evidence of wear, I scored the tooth as AMTL. For all other ambiguous cases, I scored the absence of the third molar as unobservable. To qualify as "observable" for the presence of caries, a tooth had to be present and in the occlusal plane with at least 2 mm of vertical enamel (as measured by calipers from the CEJ) surrounding at least 50 percent of the crown circumference. I diagnosed each carious lesion with the aid of a stainless steel dental probe and 10x hand lens following protocols outlined in Hillson (1996, 2001). Although tooth discolorations can signify early stages of caries, I did not record these features. For each carious tooth, I recorded the tooth type affected, the number of carious lesions per tooth, and the location of the lesion on the crown. I scored caries as follows:

1) no caries
2) occlusal surface caries
3) cervical caries (affecting mesial or distal surfaces)
4) caries affecting the smooth surfaces of the buccal or lingual aspects of the tooth (excluding fissures)
5) cervical root caries
6) large caries with severe crown destruction
7) interproximal caries
8) pulp exposure due to attrition (non-carious)
9) not scorable

Although detailed study of different types of carious lesions could provide additional information with respect to diet (Hillson 2001; Ortner 2003:590), I consider all forms of carious lesions together for the purposes of this study. Severe enamel attrition, AMTL, and postmortem damage are common in the sample and resulted in the loss of numerous teeth that could be scored for caries. To facilitate statistical comparison, I pooled left and right teeth from the maxillary and mandibular dentition by tooth class (molars, premolars, canines, incisors) and also for the dentition as a whole (all tooth types). Although sample pooling may introduce potential sources of bias, this is routinely done for archaeological collections that suffer from high levels of attrition and tooth loss (Larsen et al. 1991; Walker and Erlandson 1986). Since carious lesions are extremely rare in the subadult age category, I focus on adult individuals for this study.

In addition to calculating caries rates by individual tooth type, I also applied Lukacs' (1995, 1996) "decayed-missing" correction to calculate the prevalence of carious teeth. The correction accounts for disproportionate AMTL due to caries versus AMTL due to attrition. For this correction, the number of teeth lost antemortem is multiplied by the number of teeth with exposed pulp cavities due to caries, to estimate the number of teeth lost antemortem to caries. This value is added to the total number of carious teeth and then divided by the total number of teeth observed for caries, plus the total number of teeth lost antemortem. Lukacs' (1995: 155) correction is calculated as follows:

1) Estimated number of teeth lost due to caries (number of teeth lost antemortem x proportion of teeth with pulp exposure due to caries).
2) Total estimated number of teeth with caries (estimated number of teeth lost due to caries + number of carious teeth observed).
3) Total number of original teeth (number of teeth observed + number of teeth lost antemortem).
4) Corrected caries rate (total estimated number of teeth with caries / total number of original teeth)

For each tooth position, I also scored the presence or absence of alveolar abscesses. Periapical inflammation of buccal or lingual tooth roots (e.g., periapical abscess) may result in abscesses and ultimately tooth loss. For the purposes of this study, I consider all abscess types together as a single group. I compare abscess prevalence by tooth position, pooling left and right sides from the maxillary and mandibular dentition. I scored abscesses that encompassed more than one tooth position as "present" for each tooth position affected.

Since dental attrition can affect caries prevalence, I recorded wear scores for each tooth type following the protocol in *Standards for Data Collection* (Ubelaker and Buikstra 1994). This uses the scoring system developed by Smith (1984:45-46) for incisors, canines, and premolars, and by Scott (1979:214) for molars. To evaluate differences in attrition rates between samples, I subtracted the difference in the mean score of adult first and second molars (M1-M2 = attrition rate) following Walker et al. (1998). Since first molars erupt around 6 years of age and second molars around 12 years of age, the difference in mean wear score can be used as a relative measure of attrition rate. For all comparisons, I used the chi-square and Fisher's Exact statistic (when cell counts were less than five) to test for significant associations by time period, by region, by sex, and by age category. To account for the higher probability of obtaining statistically significant results ($p < .05$) due to random chance with multiple comparisons, I set the alpha level for statistical significance at $p< .017$. However, I treat p-values between .018 and .05 as approaching statistical significance.

## ***Results***

### *Age Effects*

Dental caries often show an age dependent pattern in many skeletal studies, so results may be affected by differences in the age distribution of the samples (Hillson 2001; Larsen et al. 1991). Table 6.1 and Figure 6.1 summarize the distribution of caries by age category in prehistoric central California. For the Sacramento Valley sample, the proportion of carious teeth shows a strong association with increasing age-at-death (Kruskal-Wallis, $X^2 = 52.943$, df = 2, p = .001). However, this pattern is not significant for the San Francisco Bay samples (Kruskal-Wallis, $X^2 = 1.452$, df = 2, p = .484).

To test for age bias in the samples, I compared age distributions by time period, by region, and by sex. The proportion of individuals within each age category is not significantly different between time periods for either the Sacramento Valley (Kruskal-Wallis, $X^2 = 4.252$, df = 2, p = .119) or the San Francisco Bay samples (Kruskal-Wallis, $X^2 = 2.461$, df = 2, p = .292). When compared by region, the age distributions are similar between the Sacramento Valley and San Francisco Bay for the Early and Middle period samples (Early, $X^2 = .277$, p = .599; Middle, $X^2 = .033$, p = .855). However, differences in the age-at-death distributions of the Late period samples approaches statistical significance ($X^2 = 5.309$, p = .021) due to the higher proportion of older adults (40+ years) in the Sacramento Valley sample.

The age distribution by sex is significantly different in the Sacramento Valley sample for the Middle ($X^2 = 10.535$, p = .001) period samples and approaches a significant difference for the Early period sample ($X^2 = 5.45$, p = .02). The age distributions are not significantly different for the Late period samples ($X^2$ = 1.578, p = .209). Significant differences in the age distribution are also found in the San Francisco Bay sample for the Late period sample ($X^2$ = 10.332, p = .001) but not for the Early ($X^2$ = .047, p = .828) and Middle ($X^2$ = 2.057, p = .152) period samples.

Table 6.1. Distribution of Dental Caries in the Sample by Age Category.

| | | **Early Period** | | | | **Middle Period** | | | | **Late Period** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Dental** | **Male** | | **Female** | | **Male** | | **Female** | | **Male** | | **Female** | |
| **Age** | **Caries** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** |
| **Sacramento Valley** | | | | | | | | | | | | | |
| 18-29 years | Maxillary | 5/161 | 3.1 | 7/55 | 12.7 | 5/141 | 3.5 | 2/81 | 2.5 | 4/45 | 8.9 | 5/109 | 4.6 |
| | Mandibular | 0/151 | 0.0 | 1/55 | 1.8 | 4/149 | 2.7 | 1/62 | 1.6 | 0/34 | 0.0 | 0/108 | 0.0 |
| | Total | 5/312 | 1.6 | 8/110 | 7.3 | 9/290 | 3.1 | 3/143 | 2.1 | 4/79 | 5.1 | 5/217 | 2.3 |
| 30-39 years | Maxillary | 10/42 | 23.8 | 10/55 | 18.2 | 3/72 | 4.2 | 5/45 | 11.1 | 1/27 | 3.7 | 2/24 | 8.3 |
| | Mandibular | 0/49 | 0.0 | 3/41 | 7.3 | 8/100 | 8.0 | 2/49 | 4.1 | 2/26 | 7.7 | 4/44 | 9.1 |
| | Total | 10/91 | 11.0 | 13/96 | 13.5 | 11/172 | 6.4 | 7/94 | 7.4 | 3/53 | 5.7 | 6/68 | 8.8 |
| 40+ years | Maxillary | 6/75 | 8.0 | 13//65 | 20.0 | 4/9 | 44.4 | 7/37 | 18.9 | 2/18 | 11.1 | 13/44 | 29.5 |
| | Mandibular | 3/136 | 2.2 | 6/86 | 7.0 | 2/25 | 8.0 | 6/56 | 10.7 | 1/28 | 3.6 | 14/58 | 24.1 |
| | Total | 9/211 | 4.3 | 19/151 | 12.6 | 6/34 | 17.6 | 13/93 | 14.0 | 3/46 | 6.5 | 27/102 | 26.5 |
| | All Teeth | 24/614 | 3.9 | 40/357 | 11.2 | 26/496 | 5.2 | 23/330 | 7.0 | 10/178 | 5.6 | 38/387 | 9.8 |
| **San Francisco Bay** | | | | | | | | | | | | | |
| 18-29 years | Maxillary | 0/64 | 0.0 | 0/29 | 0.0 | 0/98 | 0.0 | 4/69 | 5.8 | 1/38 | 2.6 | 0/110 | 0.0 |
| | Mandibular | 0/57 | 0.0 | 1/26 | 3.8 | 1/109 | .9 | 3/89 | 3.4 | 0/49 | 0.0 | 4/112 | 3.6 |
| | Total | 0/121 | 0.0 | 1/55 | 1.8 | 1/207 | .5 | 7/158 | 4.4 | 1/87 | 1.1 | 4/222 | 1.8 |
| 30-39 years | Maxillary | 0/0 | 0.0 | 2/7 | 28.6 | 0/55 | 0.0 | 0/27 | 0.0 | 0/42 | 0.0 | 0/1 | 0.0 |
| | Mandibular | 0/11 | 0.0 | 0/22 | 0.0 | 1/47 | 2.1 | 1/12 | 8.3 | 0/33 | 0.0 | 0/3 | 0.0 |
| | Total | 0/11 | 0.0 | 2/29 | 6.9 | 1/102 | 1.0 | 1/39 | 2.6 | 0/75 | 0.0 | 0/4 | 0.0 |
| 40+ years | Maxillary | 0/21 | 0.0 | 0/38 | 0.0 | 0/33 | 0.0 | 8/56 | 14.3 | 1/39 | 2.6 | 1/20 | 5 |
| | Mandibular | 0/33 | 0.0 | 1/44 | 2.3 | 0/33 | 0.0 | 0/56 | 0.0 | 0/31 | 0.0 | 0/23 | 0.0 |
| | Total | 0/54 | 0.0 | 1/82 | 1.2 | 0/66 | 0.0 | 8/112 | 7.1 | 1/70 | 1.4 | 1/43 | 2.3 |
| | All Teeth | 0/186 | 0.0 | 4/166 | 2.4 | 2/375 | .5 | 16/309 | 5.2 | 2/232 | .9 | 5/269 | 1.9 |

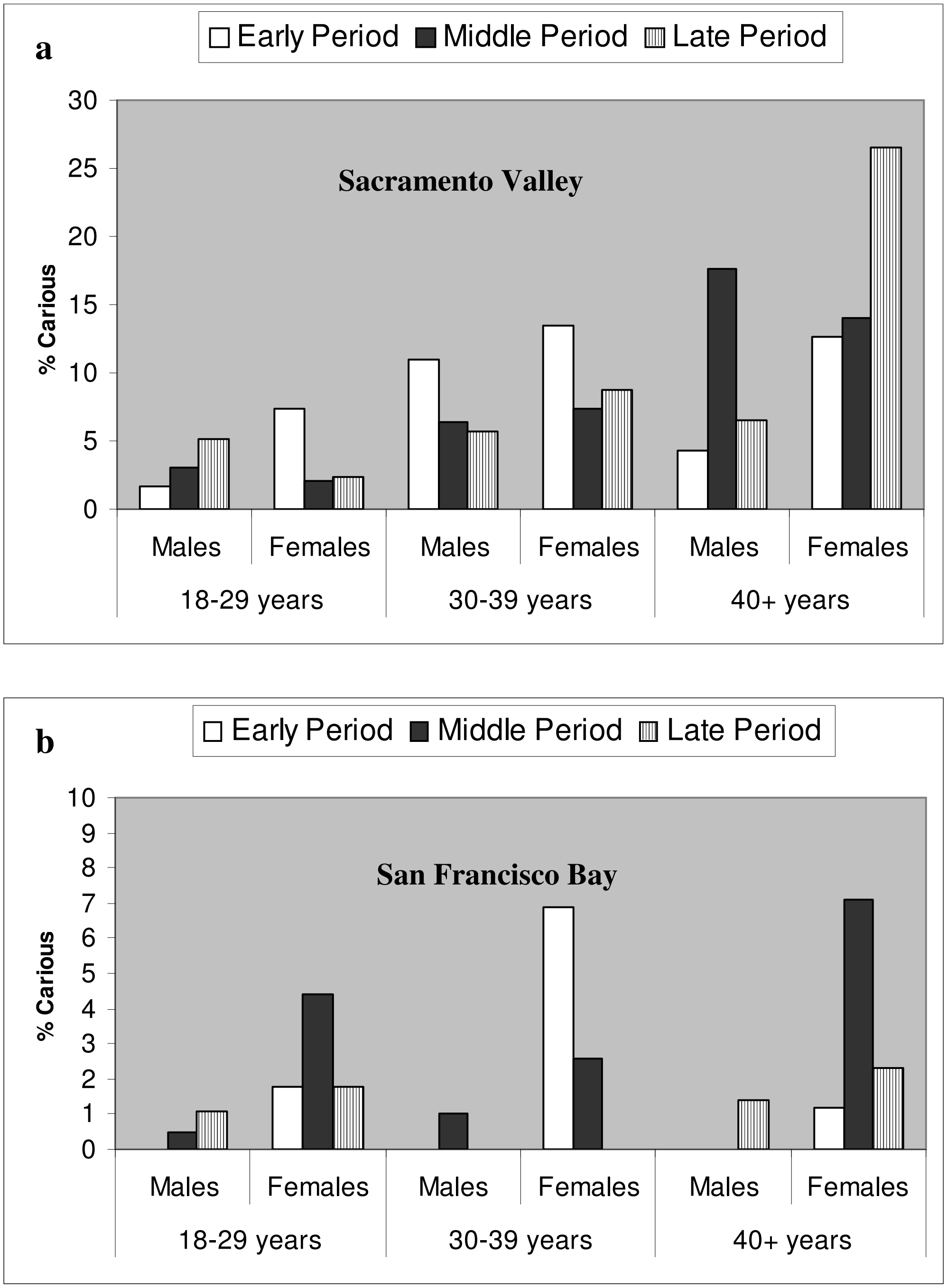

**Figure 6.1.** Caries prevalence by age category and by sex
(a = Sacramento Valley; b = San Francisco Bay).

### *Temporal Differences: Sacramento Valley*

Table 6.2 summarizes the distribution of dental caries in the Sacramento Valley sample by tooth type and by time period. In general, molars show the highest prevalence of caries and incisors the least. Table 6.3 shows that only differences in the canine caries rate for Middle and Late period females approaches statistical significance (Fisher's Exact, p = .028). Since the prevalence of carious lesions by individual tooth class was relatively small, I consider all tooth classes together as a group to examine overall caries prevalence. To adjust the total caries rate to account for AMTL due to caries, I applied the "correction factor" to the data (Lukacs 1995, 1996). Figure 6.2 presents the prevalence of caries-induced versus attrition-induced pulp exposure by time period and by region. The Sacramento Valley sample shows a greater proportion of caries-induced pulp exposure than the San Francisco Bay sample; however, attrition-induced pulp exposure appears to be the primary cause of antemortem tooth loss in both regions.

Table 6.4 and Figure 6.3 summarize the distribution of dental caries (uncorrected and corrected) by time period. Statistical results for the "corrected" caries prevalence are presented in Table 6.5. Overall, the total "uncorrected" prevalence of carious teeth is 4.9 percent for males and 9.5 percent for females. When the Lukacs' "correction" is applied to account for AMTL due to caries in the Sacramento Valley sample, the total caries rate increases to 6.8 percent for males and 18.5 percent for females. The "corrected" caries rate is 14.5 percent for the Early period, 9.5 percent for the Middle period, and 15.9 percent for the Late Period samples (sexes pooled). The proportion of carious teeth is significantly more common in the Early and Late period samples than in the Middle period sample (Early vs. Middle period, $X^2$ = 12.858, p = .001; Middle vs. Late periods, $X^2$ = 18.477, p = .001).

Table 6.2. Distribution of Dental Caries in Prehistoric Central California.

| | **Early Period** | | | | | | **Middle Period** | | | | | | **Late Period** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Male** | | **Female** | | **Indeterminate** | | **Male** | | **Female** | | **Indeterminate** | | **Male** | | **Female** | | **Indeterminate** | |
| **Tooth Type** | **n[1]** | **%** | **n[1]** | **%** | **n[1]** | **%** | **n[1]** | **%** | **n[1]** | **%** | **n** | **%** | **n[1]** | **%** | **n[1]** | **%** | **n[1]** | **%** |
| **Sacramento Valley** | | | | | | | | | | | | | | | | | | |
| Maxillary | | | | | | | | | | | | | | | | | | |
| Incisors | 0/52 | 0.0 | 2/30 | 6.7 | 0/3 | 0.0 | 1/36 | 2.8 | 0/25 | 0.0 | 0/1 | 0.0 | 0/15 | 0.0 | 3/38 | 7.9 | 0/0 | 0.0 |
| Canines | 4/41 | 9.8 | 3/26 | 11.5 | 0/4 | 0.0 | 3/35 | 8.6 | 0/19 | 0.0 | 0/0 | 0.0 | 0/13 | 0.0 | 4/27 | 14.8 | 0/0 | 0.0 |
| Premolars | 3/68 | 4.4 | 5/42 | 11.9 | 0/3 | 0.0 | 1/60 | 1.7 | 5/54 | 9.3 | 0/0 | 0.0 | 2/28 | 7.1 | 5/50 | 10.0 | 0/1 | 0.0 |
| Molars | 19/143 | 13.3 | 25/102 | 24.5 | 3/10 | 30.0 | 7/109 | 6.4 | 11/74 | 14.9 | 0/1 | 0.0 | 5/34 | 14.7 | 9/75 | 12.0 | 0/0 | 0.0 |
| Total Teeth | 26/304 | 8.5 | 35/200 | 17.5 | 3/20 | 15.0 | 12/240 | 5.0 | 16/172 | 9.3 | 0/2 | 0.0 | 7/90 | 7.8 | 21/190 | 11.1 | 0/1 | 0.0 |
| Mandibular | | | | | | | | | | | | | | | | | | |
| Incisors | 0/65 | 0.0 | 0/40 | 0.0 | 0/3 | 0.0 | 1/57 | 1.7 | 0/36 | 0.0 | 0/0 | 0.0 | 0/15 | 0.0 | 2/42 | 4.8 | 0/0 | 0.0 |
| Canines | 0/42 | 0.0 | 2/34 | 5.9 | 0/3 | 0.0 | 0/38 | 0.0 | 0/32 | 0.0 | 0/0 | 0.0 | 0/10 | 0.0 | 2/30 | 6.7 | 0/0 | 0.0 |
| Premolars | 0/92 | 0.0 | 2/52 | 3.8 | 0/0 | 0.0 | 2/83 | 2.4 | 1/46 | 2.2 | 0/3 | 0.0 | 0/21 | 0.0 | 5/60 | 8.3 | 0/1 | 0.0 |
| Molars | 4/154 | 2.6 | 6/83 | 7.2 | 1/6 | 16.7 | 12/116 | 10.3 | 9/69 | 13.0 | 3/5 | 60.0 | 3/42 | 7.1 | 10/89 | 11.2 | 0/0 | 0.0 |
| Total Teeth | 4/353 | 1.1 | 10/209 | 4.8 | 1/12 | 8.3 | 15/294 | 5.1 | 10/183 | 5.5 | 3/8 | 37.5 | 3/88 | 3.4 | 19/221 | 8.6 | 0/1 | 0.0 |
| **San Francisco Bay** | | | | | | | | | | | | | | | | | | |
| Maxillary | | | | | | | | | | | | | | | | | | |
| Incisors | 0/22 | 0.0 | 0/20 | 0.0 | 0/0 | 0.0 | 0/45 | 0.0 | 0/31 | 0.0 | 0/2 | 0.0 | 0/30 | 0.0 | 1/26 | 3.8 | 0/5 | 0.0 |
| Canines | 0/15 | 0.0 | 0/10 | 0.0 | 0/0 | 0.0 | 0/29 | 0.0 | 0/27 | 0.0 | 0/3 | 0.0 | 0/24 | 0.0 | 1/20 | 5.0 | 0/3 | 0.0 |
| Premolars | 0/25 | 0.0 | 0/20 | 0.0 | 0/0 | 0.0 | 0/56 | 0.0 | 2/51 | 3.9 | 0/6 | 0.0 | 0/37 | 0.0 | 0/44 | 0.0 | 0/2 | 0.0 |
| Molars | 0/39 | 0.0 | 2/34 | 5.9 | 0/0 | 0.0 | 0/81 | 0.0 | 11/80 | 13.7 | 0/10 | 0.0 | 2/63 | 3.2 | 1/66 | 1.5 | 0/4 | 0.0 |
| Total Teeth | 0/101 | 0.0 | 2/84 | 2.4 | 0/0 | 0.0 | 0/211 | 0.0 | 13/189 | 6.9 | 0/21 | 0.0 | 2/154 | 1.3 | 3/156 | 1.9 | 0/14 | 0.0 |
| Mandibular | | | | | | | | | | | | | | | | | | |
| Incisors | 0/16 | 0.0 | 0/17 | 0.0 | 0/0 | 0.0 | 0/40 | 0.0 | 0/38 | 0.0 | 0/4 | 0.0 | 0/26 | 0.0 | 0/22 | 0.0 | 0/3 | 0.0 |
| Canines | 0/15 | 0.0 | 0/9 | 0.0 | 0/0 | 0.0 | 0/27 | 0.0 | 0/26 | 0.0 | 0/7 | 0.0 | 0/15 | 0.0 | 0/21 | 0.0 | 0/3 | 0.0 |
| Premolars | 0/32 | 0.0 | 0/26 | 0.0 | 0/0 | 0.0 | 0/51 | 0.0 | 1/57 | 1.7 | 0/9 | 0.0 | 0/30 | 0.0 | 0/44 | 0.0 | 0/5 | 0.0 |
| Molars | 0/57 | 0.0 | 2/59 | 3.4 | 0/0 | 0.0 | 2/97 | 2.1 | 4/93 | 4.3 | 0/21 | 0.0 | 0/60 | 0.0 | 5/85 | 5.9 | 0/9 | 0.0 |
| Total Teeth | 0/120 | 0.0 | 2/111 | 1.8 | 0/0 | 0.0 | 2/190 | 1.1 | 5/214 | 2.3 | 0/41 | 0.0 | 0/131 | 0.0 | 5/172 | 2.9 | 0/20 | 0.0 |

[1] number affected/number scored.

Table 6.3. Chi-Square and Fisher's Exact Results for Temporal Comparisons of Caries by Individual Tooth Type.

| | | **Incisors** | | | **Canines** | | | **Premolars** | | | **Molars** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sex** | **Testing** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** |
| **Sacramento Valley** | | | | | | | | | | | | | |
| Males | EP vs. MP | F.E. | .195 | 0/117 vs. 2/93 | F.E. | 1.000 | 4/83 vs. 3/73 | F.E. | 1.000 | 3/160 vs. 3/143 | .085 | .771 | 23/297 vs. 19/225 |
| | EP vs. LP | F.E. | | 0/117 vs. 0/30 | F.E. | .575 | 4/83 vs. 0/23 | F.E. | .334 | 3/160 vs. 2/49 | .615 | .433 | 23/297 vs. 8/76 |
| | MP vs. LP | F.E. | 1.000 | 2/93 vs. 0/30 | F.E. | 1.000 | 3/73 vs. 0/23 | F.E. | .603 | 3/143 vs. 2/49 | .302 | .583 | 19/225 vs. 8/76 |
| Females | EP vs. MP | F.E. | .499 | 2/70 vs. 0/61 | F.E. | .061 | 5/60 vs. 0/51 | .162 | .687 | 7/94 vs. 6/100 | .472 | .492 | 31/185 vs. 20/143 |
| | EP vs. LP | F.E. | .449 | 2/70 vs. 5/80 | .165 | .685 | 5/60 vs. 6/57 | .179 | .672 | 7/94 vs. 10/110 | 1.894 | .169 | 31/185 vs. 19/164 |
| | MP vs. LP | F.E. | 1.000 | 0/61 vs. 5/80 | F.E. | .028 | 0/51 vs. 6/57 | .711 | .399 | 6/100 vs. 10/110 | .397 | .529 | 20/143 vs. 19/164 |
| **San Francisco Bay** | | | | | | | | | | | | | |
| Males | EP vs. MP | | | 0/38 vs. 0/85 | | | 0/30 vs. 0/56 | | | 0/57 vs. 0/107 | F.E. | .543 | 0/96 vs. 2/178 |
| | EP vs. LP | | | 0/38 vs. 0/56 | | | 0/30 vs. 0/39 | | | 0/57 vs. 0/67 | F.E. | .505 | 0/96 vs. 2/123 |
| | MP vs. LP | | | 0/85 vs. 0/56 | | | 0/56 vs. 0/39 | | | 0/107 vs. 0/67 | F.E. | 1.000 | 2/178 vs. 2/123 |
| Females | EP vs. MP | | | 0/37 vs. 0/69 | | | 0/19 vs. 0/53 | F.E. | .555 | 0/46 vs. 3/108 | 1.741 | .187 | 4/93 vs. 15/173 |
| | EP vs. LP | F.E. | 1.000 | 0/37 vs. 1/48 | F.E. | 1.000 | 0/19 vs. 1/41 | | | 0/46 vs. 0/88 | F.E. | 1.000 | 4/93 vs. 6/151 |
| | MP vs. LP | F.E. | .410 | 0/69 vs. 1/48 | F.E. | .436 | 0/53 vs. 1/41 | F.E. | .254 | 3/108 vs. 0/88 | 2.935 | .087 | 15/173 vs. 6/151 |

[1] Number of caries observed/number of teeth observed for caries.

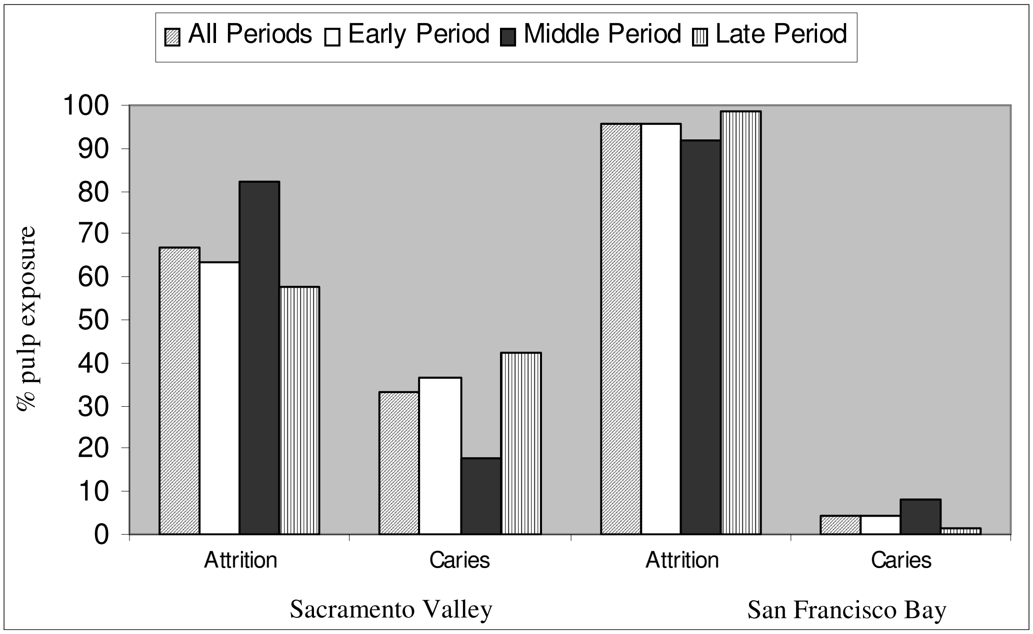

**Figure 6.2.** Relative proportion (%) of pulp-exposed teeth caused by caries versus attrition by region and time period.

In contrast, the proportion of carious teeth is similar between the Early and Late period samples ($X^2 = 1.404$, p = .238). When partitioned by sex, these patterns hold for both the male and female samples (Early vs. Middle period, males, $X^2 = 22.661$, p = .001; females, $X^2 = 21.142$, p = .001; Middle vs. Late periods, males, $X^2 = 9.65$, p = .001; females, $X^2 = 8.24$, p = .005).

Figure 6.4 summarizes the distribution of AMTL in the Sacramento Valley sample (also see Table 6.4). For males, the prevalence of AMTL is 7.6, 6.7, and 6.8 percent for the Early, Middle, and Late periods, respectively; these values are not significantly different. The prevalence of AMTL in females is 18.2, 25.5, and 16.8 percent for the Early, Middle, and Late periods, respectively. AMTL is significantly more common in the Middle period female sample than in the Early and Late period female samples (Early vs. Middle, $X^2$ = 15.88, p = .001; Middle vs. Late periods, $X^2$ = 18.691, p = .001; Table 6.5).

Table 6.6 summarizes the distribution of alveolar abscesses in the Sacramento Valley sample by individual tooth position and Table 6.7 presents statistical results for comparisons by time period. Abscesses affected 3.3 percent of males and 5.2 percent of females. For males, the total abscess prevalence (all tooth positions combined) is 3.3, 6.8, and 3.4 percent for the Early, Middle, and Late periods, respectively. Abscesses are significantly more common among Late period males than Middle period males for the molar tooth position (Middle vs. Late period, $X^2$ = 5.666, p = .017). For the incisor and premolar tooth positions, abscesses are significantly more common in Middle period males than in Early period males (Early vs. Middle period, incisors, $X^2$ = 18.547, p = .001; premolar, $X^2$ =9.677, p = .002). For females, the total prevalence of alveolar abscess (all tooth positions combined) is 5.2, 7.1, and 7.1 percent for the Early, Middle, and Late periods, respectively. Abscesses are significantly more common among Middle period females than among Early period females for the incisor tooth position ($X^2$ = 8.877, p = .003).

Table 6.4. Total Prevalence of Carious Teeth (Corrected and Uncorrected) and AMTL in Prehistoric Central California.

| | | | **Male** | | **Female** | |
|---|---|---|---|---|---|---|
| **Region** | **Period** | **Observation Type** | **n[1]** | **%** | **n[1]** | **%** |
| Sacramento Valley | Early Period | Observed caries | 30/657 | 4.6 | 45/409 | 11.0 |
| | | Corrected caries | 57/755 | 7.6 | 141/606 | 23.3 |
| | | AMTL | 98/1298 | 7.6 | 197/1083 | 18.2 |
| | Middle Period | Observed caries | 27/534 | 5.1 | 26/355 | 7.3 |
| | | Corrected caries | 35/589 | 5.9 | 78/598 | 13.0 |
| | | AMTL | 55/827 | 6.7 | 243/954 | 25.5 |
| | Late Period | Observed caries | 10/178 | 5.6 | 40/411 | 9.7 |
| | | Corrected caries | 13/198 | 6.6 | 104/539 | 19.3 |
| | | AMTL | 20/293 | 6.8 | 128/761 | 16.8 |
| | Periods Pooled | Observed caries | 67/1369 | 4.9 | 111/1175 | 9.5 |
| | | Corrected caries | 105/1357 | 7.7 | 323/1743 | 18.5 |
| | | AMTL | 173/2418 | 7.2 | 618/2798 | 22.1 |
| San Francisco Bay | Early Period | Observed caries | 0/221 | 0.0 | 4/195 | 2.1 |
| | | Corrected caries | 0/236 | 0.0 | 7/236 | 3.0 |
| | | AMTL | 15/334 | 4.5 | 41/433 | 9.5 |
| | Middle Period | Observed caries | 2/426 | .5 | 18/403 | 4.5 |
| | | Corrected caries | 2/440 | .5 | 26/468 | 5.6 |
| | | AMTL | 14/574 | 2.4 | 65/803 | 8.1 |
| | Late Period | Observed caries | 2/285 | .7 | 8/328 | 2.4 |
| | | Corrected caries | 2/376 | .5 | 8/357 | 2.2 |
| | | AMTL | 91/573 | 15.9 | 29/597 | 4.9 |
| | Periods Pooled | Observed caries | 4/932 | .4 | 30/9326 | 3.2 |
| | | Corrected caries | 4/1052 | .4 | 41/1061 | 3.9 |
| | | AMTL | 120/1481 | 8.1 | 135/1833 | 7.4 |

[1] number affected/number scored.

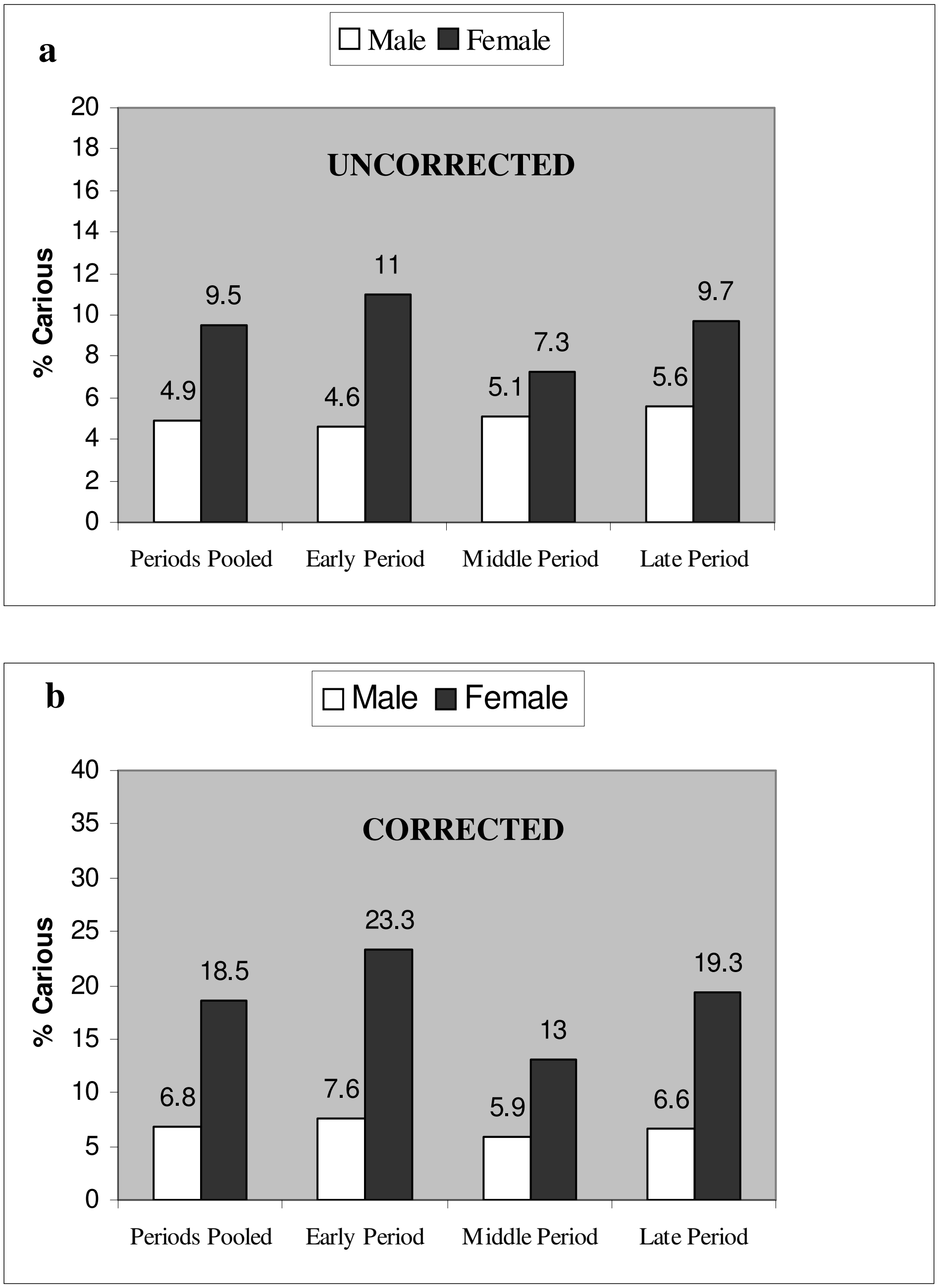

**Figure 6.3.** Caries prevalence in the Sacramento Valley sample by sex and time period (a = uncorrected; b = corrected).

Table 6.5. Chi-Square and Fisher's Exact Results for Temporal Comparisons of Total "Corrected" Caries Prevalence.

| Region | Sex | Comparison | $X^2$, F.E. | p value[1] | n[2] | Trend |
|---|---|---|---|---|---|---|
| Sacramento Valley | **Caries** | | | | | |
| | Males | EP vs. MP | 22.661 | **.001** | 57/755 vs. 35/589 | EP>MP |
| | | EP vs. LP | .223 | .637 | 57/755 vs. 13/198 | |
| | | MP vs. LP | 9.650 | **.001** | 35/589 vs. 13/198 | MP<LP |
| | Females | EP vs. MP | 21.142 | **.001** | 141/606 vs. 78/589 | EP>MP |
| | | EP vs. LP | 2.676 | .112 | 141/606 vs. 104/539 | |
| | | MP vs. LP | 8.240 | **.005** | 78/589 vs. 104/539 | MP<LP |
| | Sexes Pooled | EP vs. MP | 12.858 | **.001** | 198/1361 vs. 113/1187 | EP>MP |
| | | EP vs. LP | 1.404 | .238 | 198/1361 vs. 117/737 | |
| | | MP vs. LP | 18.477 | **.001** | 113/1187 vs. 117/737 | MP<LP |
| | **AMTL** | | | | | |
| | Males | EP vs. MP | .612 | .434 | 98/1298 vs. 55/827 | |
| | | EP vs. LP | .183 | .669 | 98/1298 vs. 20/293 | |
| | | MP vs. LP | .011 | .918 | 55/827 vs. 20/293 | |
| | Females | EP vs. MP | 15.880 | **.001** | 197/1083 vs. 243/954 | EP<MP |
| | | EP vs. LP | .578 | .447 | 197/1083 vs. 128/761 | |
| | | MP vs. LP | 18.691 | **.001** | 243/954 vs. 128/761 | MP>LP |
| San Francisco Bay | **Caries** | | | | | |
| | Males | EP vs. MP | F.E. | .545 | 0/236 vs. 2/440 | |
| | | EP vs. LP | F.E. | .525 | 0/236 vs. 2/376 | |
| | | MP vs. LP | F.E. | 1.000 | 2/440 vs. 2/376 | |
| | Females | EP vs. MP | 2.355 | .135 | 7/236 vs. 26/468 | |
| | | EP vs. LP | .303 | .602 | 7/236 vs. 8/357 | |
| | | MP vs. LP | 5.631 | **.018** | 26/468 vs. 8/357 | MP>LP |
| | Sexes Pooled | EP vs. MP | 3.476 | .088 | 7/472 vs. 28/908 | |
| | | EP vs. LP | .111 | .808 | 7/472 vs. 10/733 | |
| | | MP vs. LP | 3.403 | .068 | 28/908 vs. 10/733 | |
| | **AMTL** | | | | | |
| | Males | EP vs. MP | 2.875 | .090 | 15/334 vs. 14/574 | |
| | | EP vs. LP | 26.524 | **.001** | 15/334 vs. 91/573 | EP<LP |
| | | MP vs. LP | 62.305 | **.001** | 14/574 vs. 91/573 | MP<LP |
| | Females | EP vs. MP | .678 | .410 | 41/433 vs. 65/803 | |
| | | EP vs. LP | 8.425 | **.004** | 41/433 vs. 29/597 | EP>LP |
| | | MP vs. LP | 5.728 | **.017** | 65/803 vs. 29/597 | MP>LP |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number of caries observed/number of teeth observed for caries.

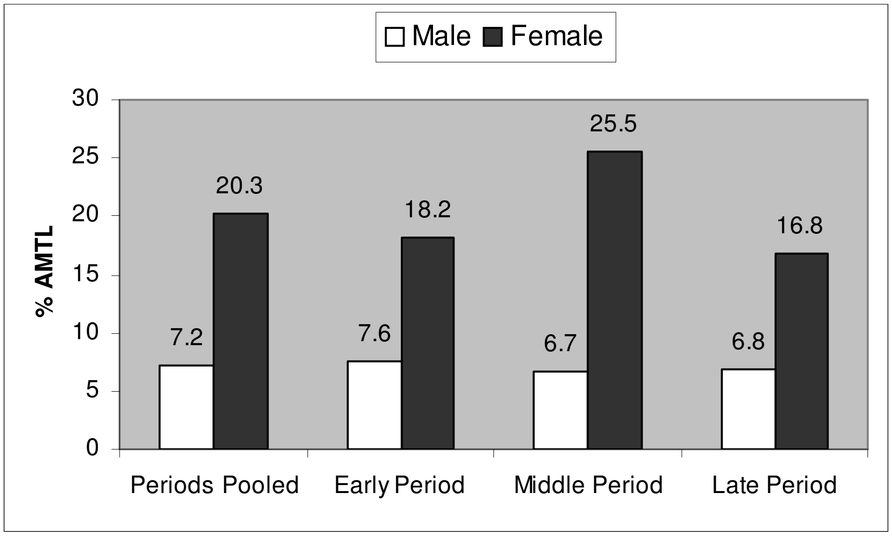

**Figure 6.4.** Prevalence of AMTL in the Sacramento Valley sample.

Evaluated alongside the caries data, female AMTL was highest during the Middle period, when the caries prevalence was the lowest (Table 6.4). Caries-induced pulp exposure was also the lowest during this period, which suggests that severe attrition may account for the higher prevalence of AMTL in these samples (Figure 6.2). Taken together, these results suggest that Early and Late Period diets were significantly *more* cariogenic than were diets during the Middle period, particularly for females.

Table 6.6. Distribution of Alveolar Abscesses in Prehistoric Central California by Time Period.

| | | **Early Period** | | | | | | **Middle Period** | | | | | | **Late Period** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Male** | | **Female** | | **Indeterminate** | | **Male** | | **Female** | | **Indeterminate** | | **Male** | | **Female** | | **Indeterminate** | |
| **Region** | **Tooth Type** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** | **n** | **%** |
| Sacramento Valley | Maxillary | | | | | | | | | | | | | | | | | | |
| | Incisors | 3/163 | 1.8 | 5/126 | 4.0 | 0/20 | 0.0 | 7/97 | 7.2 | 21/135 | 15.6 | 0/12 | 0.0 | 1/35 | 2.9 | 7/100 | 7.0 | 0/4 | 0.0 |
| | Canines | 4/85 | 4.7 | 4/67 | 6.0 | 1/10 | 10.0 | 3/53 | 5.7 | 10/70 | 14.3 | 0/6 | 0.0 | 0/18 | 0.0 | 7/51 | 13.7 | 0/2 | 0.0 |
| | Premolars | 3/172 | 1.7 | 14/139 | 10.1 | 2/20 | 10.0 | 14/109 | 12.8 | 16/139 | 11.5 | 0/12 | 0.0 | 4/40 | 10.0 | 11/106 | 10.4 | 0/4 | 0.0 |
| | Molars | 23/249 | 9.2 | 23/204 | 11.3 | 4/27 | 14.8 | 27/160 | 16.9 | 10/182 | 5.5 | 7/17 | 41.2 | 4/58 | 6.9 | 10/133 | 7.5 | 0/2 | 0.0 |
| | Total | 33/669 | 4.9 | 46/536 | 8.6 | 7/77 | 9.1 | 51/419 | 12.2 | 57/526 | 10.8 | 7/47 | 14.9 | 9/151 | 6.0 | 35/290 | 12.1 | 0/12 | 0.0 |
| | Mandibular | | | | | | | | | | | | | | | | | | |
| | Incisors | 0/157 | 0.0 | 3/132 | 2.3 | 0/15 | 0.0 | 2/101 | 2.0 | 2/106 | 1.9 | 0/4 | 0.0 | 0/37 | 0.0 | 4/97 | 4.1 | 0/0 | 0.0 |
| | Canines | 0/80 | 0.0 | 1/74 | 1.4 | 0/9 | 0.0 | 0/51 | 0.0 | 0/56 | 0.0 | 0/2 | 0.0 | 0/21 | 0.0 | 1/48 | 2.1 | 0/1 | 0.0 |
| | Premolars | 2/164 | 1.2 | 2/149 | 1.3 | 0/19 | 0.0 | 3/105 | 2.9 | 4/114 | 3.5 | 0/8 | 0.0 | 1/37 | 2.7 | 3/96 | 3.1 | 0/4 | 0.0 |
| | Molars | 8/233 | 3.4 | 5/202 | 2.5 | 0/28 | 0.0 | 1/157 | .6 | 5/154 | 3.2 | 1/10 | 10.0 | 0/49 | 0.0 | 4/133 | 3.0 | 0/6 | 0.0 |
| | Total | 10/634 | 1.6 | 11/557 | 2.0 | 0/71 | 0.0 | 6/414 | 1.4 | 11/430 | 2.6 | 1/24 | 4.2 | 1/144 | .7 | 12/374 | 3.2 | 0/11 | 0.0 |
| | All Teeth | 43/1303 | 3.3 | 57/1093 | 5.2 | 7/148 | 4.7 | 57/833 | 6.8 | 68/956 | 7.1 | 8/71 | 11.3 | 10/295 | 3.4 | 47/664 | 7.1 | 0/23 | 0.0 |
| San Francisco Bay | Maxillary | | | | | | | | | | | | | | | | | | |
| | Incisors | 2/39 | 5.1 | 0/48 | 0.0 | 0/0 | 0.0 | 0/72 | 0.0 | 0/96 | 0.0 | 0/6 | 0.0 | 10/77 | 13.0 | 0/85 | 0.0 | 0/8 | 0.0 |
| | Canines | 1/21 | 4.8 | 0/28 | 0.0 | 0/0 | 0.0 | 0/38 | 0.0 | 2/49 | 4.1 | 0/4 | 0.0 | 1/39 | 2.6 | 0/43 | 0.0 | 0/4 | 0.0 |
| | Premolars | 1/38 | 2.6 | 2/57 | 3.5 | 0/0 | 0.0 | 2/73 | 2.7 | 4/103 | 3.9 | 0/10 | 0.0 | 12/81 | 14.8 | 3/87 | 3.4 | 1/8 | 12.5 |
| | Molars | 4/54 | 7.4 | 5/74 | 6.8 | 0/0 | 0.0 | 13/106 | 12.3 | 23/147 | 15.6 | 4/19 | 21.1 | 25/120 | 20.8 | 20/124 | 16.1 | 2/10 | 20.0 |
| | Total | 8/152 | 5.3 | 7/207 | 3.4 | 0/0 | 0.0 | 15/289 | 5.2 | 29/395 | 7.3 | 4/39 | 10.3 | 48/317 | 15.1 | 23/339 | 6.8 | 3/30 | 10.0 |
| | Mandibular | | | | | | | | | | | | | | | | | | |
| | Incisors | 0/41 | 0.0 | 4/41 | 9.8 | 0/0 | 0.0 | 0/70 | 0.0 | 4/101 | 4.0 | 0/10 | 0.0 | 6/61 | 9.8 | 0/57 | 0.0 | 0/8 | 0.0 |
| | Canines | 1/23 | 4.3 | 2/28 | 7.1 | 0/0 | 0.0 | 1/34 | 2.9 | 1/53 | 1.9 | 0/7 | 0.0 | 3/33 | 9.1 | 0/32 | 0.0 | 0/4 | 0.0 |
| | Premolars | 0/49 | 0.0 | 2/63 | 3.2 | 0/0 | 0.0 | 0/70 | 0.0 | 2/110 | 1.8 | 0/14 | 0.0 | 2/68 | 2.9 | 0/68 | 0.0 | 0/8 | 0.0 |
| | Molars | 1/74 | 1.4 | 3/95 | 3.2 | 0/0 | 0.0 | 0/114 | 0.0 | 6/154 | 3.9 | 0/23 | 0.0 | 11/91 | 12.1 | 0/107 | 0.0 | 0/11 | 0.0 |
| | Total | 2/187 | 1.1 | 11/227 | 4.8 | 0/0 | 0.0 | 1/288 | .3 | 13/418 | 3.1 | 0/54 | 0.0 | 22/253 | 8.7 | 0/264 | 0.0 | 0/31 | 0.0 |
| | All Teeth | 10/339 | 2.9 | 18/434 | 4.1 | 0/0 | 0.0 | 16/577 | 2.8 | 42/813 | 5.2 | 4/93 | 4.3 | 70/570 | 12.3 | 23/603 | 3.8 | 3/61 | 4.9 |

Table 6.7. Chi-Square and Fisher's Exact Results for Temporal Comparisons of Alveolar Abscess Prevalence.

| | | | **Sacramento Valley** | | | | **San Francisco Bay** | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Tooth Type** | **Sex** | **Comparison** | **$X^2$, F.E.** | **p value[1]** | **n[2]** | **Trend** | **$X^2$, F.E.** | **p value[1]** | **n[2]** | **Trend** |
| Incisors | Males | EP vs. MP | 18.547 | **.001** | 3/320 vs. 9/198 | EP<MP | F.E. | .084 | 2/80 vs. 0/142 | |
| | | EP vs. LP | 5.054 | .025 | 3/320 vs. 1/72 | | .821 | .365 | 2/80 vs. 16/138 | |
| | | MP vs. LP | 2.090 | .148 | 9/198 vs. 1/72 | | 9.923 | **.002** | 0/142 vs. 16/138 | MP<LP |
| | Females | EP vs. MP | 8.877 | **.003** | 8/258 vs. 23/241 | EP<MP | F.E. | .261 | 4/89 vs. 4/197 | |
| | | EP vs. LP | 1.721 | .190 | 8/258 vs. 11/197 | | F.E. | .021 | 4/89 vs. 0/142 | |
| | | MP vs. LP | 2.374 | .123 | 23/241 vs. 11/197 | | F.E. | .143 | 4/197 vs. 0/142 | |
| Canines | Males | EP vs. MP | 1.995 | .158 | 4/165 vs. 3/104 | | F.E. | .457 | 2/44 vs. 1/72 | |
| | | EP vs. LP | 1.786 | .181 | 4/165 vs. 0/39 | | F.E. | .715 | 2/44 vs. 4/72 | |
| | | MP vs. LP | .008 | .931 | 3/104 vs. 0/39 | | F.E. | 1.000 | 1/72 vs. 4/72 | |
| | Females | EP vs. MP | 2.419 | .120 | 5/141 vs. 10/126 | | F.E. | 1.000 | 2/56 vs. 3/102 | |
| | | EP vs. LP | 2.335 | .127 | 5/141 vs. 8/99 | | F.E. | .181 | 2/56 vs. 0/75 | |
| | | MP vs. LP | .002 | .968 | 10/126 vs. 8/9 | | F.E. | .263 | 3/102 vs. 0/75 | |
| Premolars | Males | EP vs. MP | 9.677 | **.002** | 5/336 vs. 17/214 | EP<MP | F.E. | .777 | 1/87 vs. 2/143 | |
| | | EP vs. LP | 4.707 | .030 | 5/336 vs. 5/77 | | 3.102 | .078 | 1/87 vs. 14/149 | |
| | | MP vs. LP | .257 | .612 | 17/214 vs. 5/77 | | 6.018 | **.014** | 2/143 vs. 14/149 | MP<LP |
| | Females | EP vs. MP | 1.197 | .274 | 16/288 vs. 20/253 | | F.E. | .751 | 4/120 vs. 6/213 | |
| | | EP vs. LP | .391 | .532 | 16/288 vs. 14/202 | | F.E. | .703 | 4/120 vs. 3/155 | |
| | | MP vs. LP | .154 | .695 | 20/253 vs. 14/202 | | F.E. | .739 | 6/213 vs. 3/155 | |
| Molars | Males | EP vs. MP | 2.263 | .132 | 31/482 vs. 28/317 | | 4.379 | .036 | 5/128 vs. 13/220 | |
| | | EP vs. LP | 1.808 | .179 | 3/482 vs. 4/107 | | 14.190 | **.001** | 5/128 vs. 36/211 | EP<LP |
| | | MP vs. LP | 5.666 | **.017** | 28/317 vs. 4/107 | MP<LP | 5.294 | .021 | 13/220 vs. 36/211 | |
| | Females | EP vs. MP | .001 | .978 | 28/406 vs. 15/336 | | 3.584 | .058 | 8/169 vs. 29/301 | |
| | | EP vs. LP | .732 | .392 | 28/406 vs. 14/266 | | 2.309 | .129 | 8/169 vs. 20/231 | |
| | | MP vs. LP | .644 | .422 | 15/336 vs. 14/266 | | .149 | .699 | 29/301 vs. 20/231 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.
[2] Number of abscesses observed/number of tooth positions observed for abscesses.

Table 6.8 presents attrition rates calculated from the mean difference in wear score between M1 and M2. The higher attrition rate observed in the Middle period sample may have, in effect, resulted in the lower caries rate during this period, since rapid tooth wear could have outpaced enamel destruction due to caries. The higher prevalence of alveolar abscesses during this period may again be due to higher attrition rates that caused more frequent exposure of the pulp chamber (Table 6.6). If so, this may have caused increased levels of periodontal disease, which would have led to periapical inflammation and antemortem tooth loss.

Table 6.8. Mean Wear Scores and M1-M2 Differences.

| | | **M1-M2 Differences** | |
|---|---|---|---|
| **Region** | **Period** | **Male** | **Female** |
| Sacramento Valley | Early Period | 5.4 | 4.5 |
| | Middle Period | 5.9 | 4.9 |
| | Late Period | 4.8 | 3.0 |
| San Francisco Bay | Early Period | 4.0 | 3.0 |
| | Middle Period | 4.3 | 4.0 |
| | Late Period | .9 | 4.0 |

*Temporal Differences: San Francisco Bay*

Table 6.2 summarizes the distribution of dental caries in the San Francisco Bay sample by tooth type and by time period. Carious lesions are found only in molars for males and premolars and molars for females. The proportion of carious teeth is not significantly different between time periods for either male or female sample comparisons (Table 6.3).

Figure 6.5 shows that when all tooth classes are considered together as group, the “uncorrected” caries frequency is .4 percent for males and 3.0 percent for females (also see Table 6.4). When the Lukacs' correction is applied, the prevalence of carious teeth increases slightly to 3.9 percent for females but remains the same for males. Sex-pooled comparisons of the "corrected" frequencies are not significantly different between periods. However, the difference in caries rate between Middle and Late period females approaches statistical significance (Middle period = 5.6 percent; Late period = 2.2 percent; $X^2 = 5.631$, $p = .018$).

Figure 6.6 presents the distribution of AMTL in the San Francisco Bay sample (also see Table 6.4). The prevalence of AMTL is 8.1 percent for males and 7.4 percent for females. For males, the prevalence of AMTL is 4.5, 2.4, and 15.9 percent for the Early, Middle, and Late periods, respectively. AMTL is significantly more common in the Late period male sample than in the Early and Middle period male samples (Early vs. Late period, $X^2 = 26.524$, $p = .001$; Middle vs. Late periods, $X^2 = 62.305$, $p = .001$).

For females, the prevalence of AMTL is 9.5, 8.1, and 4.9 percent for the Early, Middle, and Late periods, respectively. AMTL is significantly more common in the Early and Middle period samples than in the Late period sample (Early vs. Late period, $X^2 = 8.425$, $p = .004$; Middle vs. Late period, $X^2 = 5.728$, $p = .017$). Figure 6.6 shows that the proportion of teeth lost antemortem declines through time in females, but shows a sharp increase in males between the Middle and Late periods. Although severe attrition probably accounts for the vast majority of cases of AMTL in the San Francisco Bay sample (Figure 6.2), the divergent patterns of AMTL between the sexes cannot be directly attributed to differences in attrition rates (see Table 6.8). For example, Late

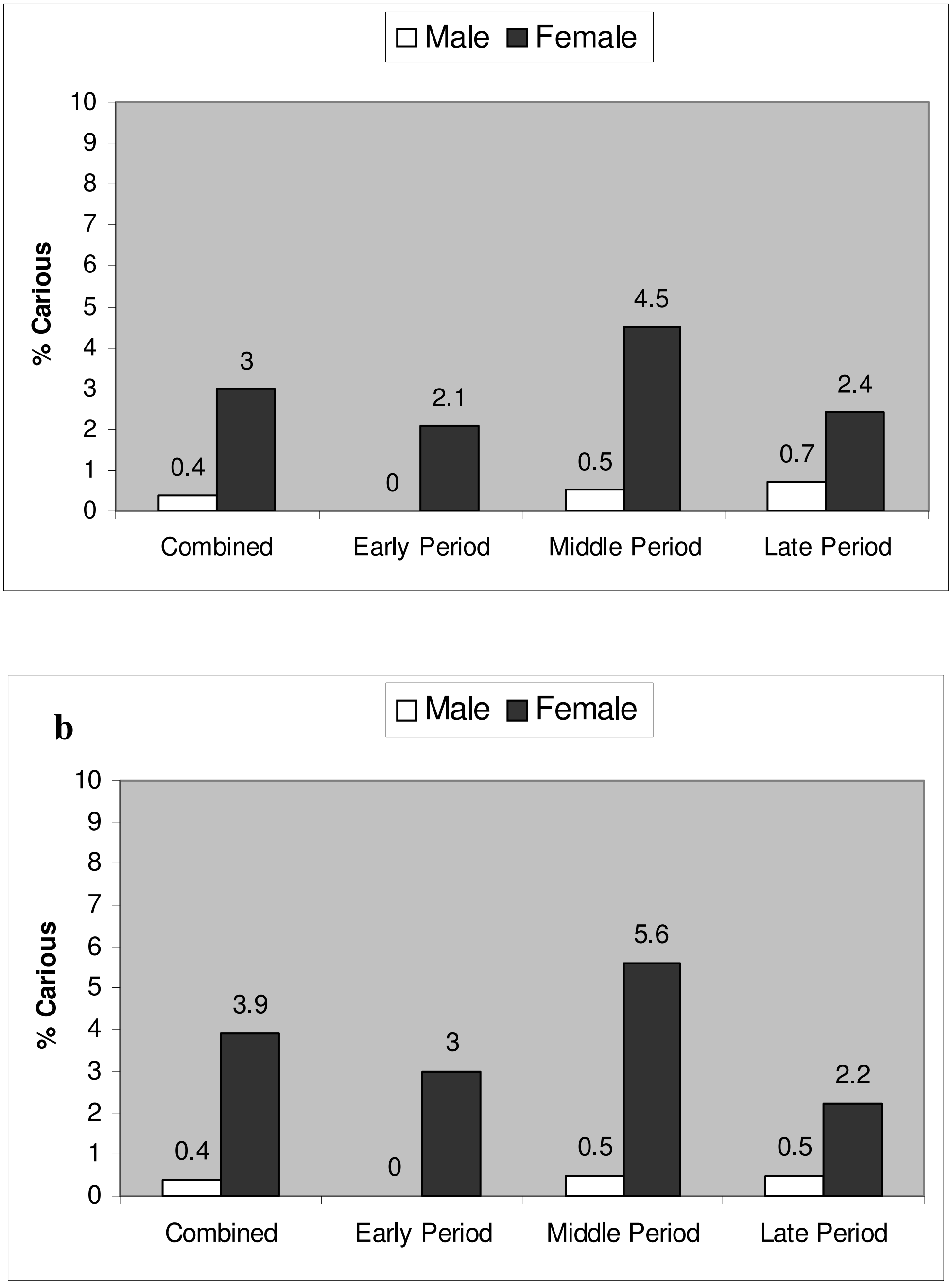

**Figure 6.5.** Caries prevalence in the San Francisco Bay sample by sex and time period (a = uncorrected; b = corrected).

period males have the lowest attrition rates but also the highest prevalence of AMTL for the whole sample.

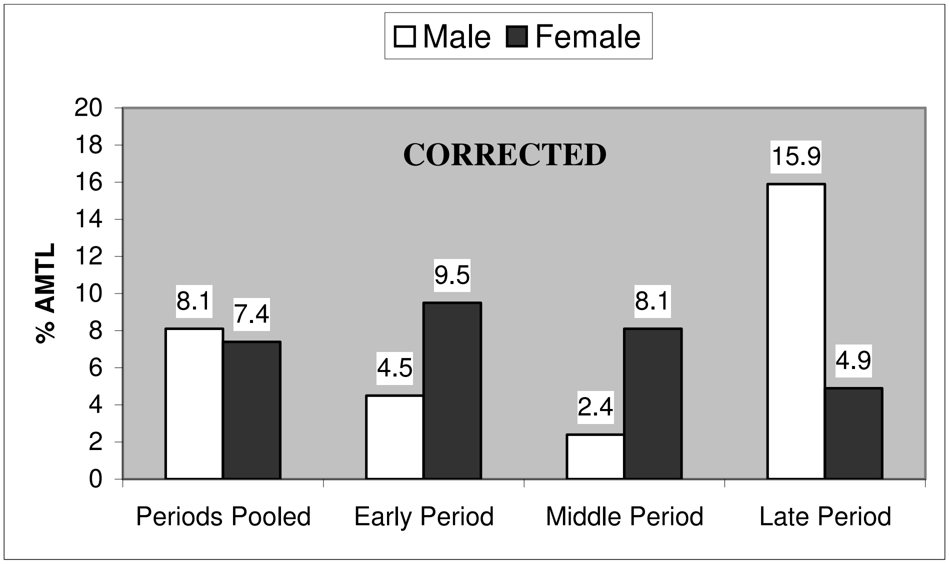

**Figure 6.6.** Prevalence of AMTL in the San Francisco Bay sample.

Alveolar abscesses are also relatively common in the San Francisco Bay sample and affected 6.0 percent of male dentitions and 4.4 percent of female dentitions (Table 6.6). For males, the total abscess prevalence (all tooth positions combined) is 2.9, 2.8, and 12.3 percent for the Early, Middle, and Late periods, respectively. Abscesses are significantly more common among Late period males than among Early period males for molars (Early vs. Late, $X^2 = 14.19$, p = .001). Alveolar abscesses are also significantly more prevalent in Late period male samples than in Middle period male samples for the premolar ($X^2 = 6.018$, p = .014) and incisor ($X^2 = 9.923$, df = 1, p = .002) tooth positions. For females, the total abscess prevalence (all tooth positions combined) is 4.1, 5.2, and

3.8 percent for the Early, Middle, and Late periods, respectively (Table 6.6). However, the prevalence of alveolar abscessing is not significantly different between time periods. The unusually high prevalence of alveolar abscesses in the Late period male sample is consistent with the high levels of AMTL for this period, although it is also associated with the lowest caries prevalence and attrition rates for the entire sample. For females, there is little similarity between the temporal trends for carious lesions, AMTL, and alveolar abscesses.

### *Regional Comparisons*

Table 6.4 presents the distribution of dental caries for the Sacramento Valley and San Francisco Bay samples (also see Figure 6.3 and 6.5). Table 6.9 presents the statistical results for inter-regional comparisons of dental caries and AMTL. Overall, carious lesions are twelve times more common in males and three times more common in females from the Sacramento Valley than in their male and female counterparts from San Francisco Bay ("uncorrected" caries, periods pooled, Table 6.4). When all periods are considered together as group, the prevalence of caries is 4.9 and 9.5 percent for Sacramento Valley males and females, respectively, and .4 and 3.2 percent for San Francisco Bay males and females, respectively. These differences are even more dramatic when the caries "correction" is applied (Sacramento Valley, males = 7.7 percent; females = 18.5 percent; San Francisco Bay, males = .4 percent = males; females = 3.9 percent). Carious teeth are significantly more prevalent in the Sacramento Valley sample than in the San Francisco Bay sample for male, female, and "pooled sex comparisons" for all time periods ($p<.001$, "corrected" caries).

AMTL is also significantly more common in the Sacramento Valley samples (p<.017) for male, female, and “sex-pooled” comparisons for all time periods, with one exception: the proportion of teeth lost antemortem is significantly higher for San Francisco Bay males than Sacramento Valley males in the Late period sample ($X^2$ = 7.497, p = .001; see Table 6.9).

Table 6.9. Chi-Square and Fisher’s Exact Results for Regional Comparisons of Caries and AMTL.

| **Observed** | **Sex** | **Period** | **$X^2$, F.E.** | **p value**[1] | **n**[2] | **Trend** |
|---|---|---|---|---|---|---|
| Caries | Males | Early Period | 18.905 | **.001** | 57/755 vs. 0/236 | SV>SFB |
| | | Middle Period | 67.533 | **.001** | 35/589 vs. 2/440 | SV>SFB |
| | | Late Period | 18.554 | **.001** | 13/198 vs. 2/376 | SV>SFB |
| | Females | Early Period | 48.319 | **.001** | 141/606 vs. 7/236 | SV>SFB |
| | | Middle Period | 16.719 | **.001** | 78/598 vs. 26/468 | SV>SFB |
| | | Late Period | 57.107 | **.001** | 104/539 vs. 8/357 | SV>SFB |
| | Sexes Pooled | Early Period | 56.172 | **.001** | 198/1361 vs. 7/472 | SV>SFB |
| | | Middle Period | 32.072 | **.001** | 113/1187 vs. 28/908 | SV>SFB |
| | | Late Period | 90.883 | **.001** | 117/737 vs. 10/733 | SV>SFB |
| AMTL | Males | Early Period | 3.857 | .050 | 98/1298 vs. 15/334 | SV>SFB |
| | | Middle Period | 12.835 | **.001** | 55/827 vs. 14/574 | SV>SFB |
| | | Late Period | 14.226 | **.001** | 20/293 vs. 91/573 | SFB>SV |
| | Females | Early Period | 17.778 | **.001** | 197/1083 vs. 41/433 | SV>SFB |
| | | Middle Period | 91.069 | **.001** | 243/954 vs. 65/803 | SV>SFB |
| | | Late Period | 46.822 | **.001** | 128/761 vs. 29/597 | SV>SFB |
| | Sexes Pooled | Early Period | 15.163 | **.001** | 295/2381 vs. 56/767 | SV>SFB |
| | | Middle Period | 89.302 | **.001** | 298/1781 vs. 79/1377 | SV>SFB |
| | | Late Period | 7.497 | **.006** | 148/1054 vs. 120/1170 | SV>SFB |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number of caries or AMTL observed/number of teeth observed in Sacramento Valley sample vs. number of caries or AMTL observed/number of teeth observed in San Francisco Bay sample.

Alveolar abscesses also show a similar pattern as dental caries and AMTL (see Table 6.10). Abscesses are significantly more common in the Sacramento Valley sample than in the San Francisco Bay sample for “sex-pooled” comparisons of the incisor and premolar tooth positions (incisors, 17.211, $p = .001$; premolars, $X^2 = 13.944$, $p = .001$); however, abscesses of the molar position are significantly more common in San Francisco Bay dentitions ($X^2 = 17.752$, $p = .001$). For comparisons of the Middle period samples, alveolar abscesses are significantly more common in Sacramento Valley dentitions than in San Francisco Bay dentitions for both incisors (males, Fisher's Exact, $p = .012$; females, $X^2 = 10.554$, $p = .001$) and premolars (males, $X^2 = 7.268$, $p = .007$; females, $X^2 = 5.671$, $p = .017$). However, the pattern for the Late period samples is more variable. San Francisco Bay males have a higher prevalence of abscesses of the molar tooth position ($X^2 = 11.425$, $p = .001$), while females are significantly more affected for the incisor ($X^2 = 8.171$, $p = .004$) and canine ($X^2 = 6.316$, $p = .012$) tooth positions.

A few exceptions aside, the higher prevalence of dental caries, AMTL, and alveolar abscessing in the Sacramento Valley samples suggests that these diets were significantly more cariogenic than were diets of the San Francisco Bay area; further, the extremely low caries rate among San Francisco Bay skeletons is consistent with data from other prehistoric groups that consumed high amounts of marine proteins, such as fish, which appear to inhibit caries formation (e.g., Littleton and Frohlich 1993; Walker and Erlandson 1986).

Table 6.10. Chi-Square and Fisher's Exact Results for Regional Comparisons of Alveolar Abscesses by Tooth Position.

| **Tooth Position** | **Sex** | **Period** | **$X^2$, F.E.** | **p value[1]** | **n[2]** | **Trend** |
|---|---|---|---|---|---|---|
| Incisors | Males | Early Period | 1.263 | .261 | 3/320 vs. 2/80 | |
| | | Middle Period | F.E. | **.012** | 9/198 vs. 0/142 | SV>SFB |
| | | Late Period | 6.592 | **.010** | 1/72 vs. 16/138 | SFB>SV |
| | Females | Early Period | .384 | .536 | 8/258 vs. 4/89 | |
| | | Middle Period | 10.554 | **.001** | 23/241 vs. 4/197 | SV>SFB |
| | | Late Period | 8.171 | **.004** | 11/197 vs. 0/142 | SFB>SV |
| Canines | Males | Early Period | .558 | .455 | 4/165 vs. 2/44 | |
| | | Middle Period | .426 | .514 | 3/104 vs. 1/72 | |
| | | Late Period | 2.227 | .136 | 0/39 vs. 4/72 | |
| | Females | Early Period | .000 | .993 | 5/141 vs. 2/56 | |
| | | Middle Period | 2.605 | .107 | 10/126 vs. 3/102 | |
| | | Late Period | 6.316 | **.012** | 8/9 vs. 0/75 | SFB>SV |
| Premolars | Males | Early Period | .057 | .812 | 5/336 vs. 1/87 | |
| | | Middle Period | 7.268 | **.007** | 17/214 vs. 2/143 | SV>SFB |
| | | Late Period | .553 | .457 | 5/77 vs. 14/149 | |
| | Females | Early Period | .895 | .344 | 16/288 vs. 4/120 | |
| | | Middle Period | 5.671 | **.017** | 20/253 vs. 6/213 | SV>SFB |
| | | Late Period | 4.812 | .028 | 14/202 vs. 3/155 | |
| Molars | Males | Early Period | 1.160 | .282 | 31/482 vs. 5/128 | |
| | | Middle Period | 1.571 | .210 | 28/317 vs. 13/220 | |
| | | Late Period | 11.425 | **.001** | 4/107 vs. 36/211 | SFB>SV |
| | Females | Early Period | .949 | .330 | 28/406 vs. 8/169 | |
| | | Middle Period | 1.645 | .200 | 15/336 vs. 29/301 | |
| | | Late Period | 2.231 | .135 | 14/266 vs. 20/231 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.
[2] Number of abscesses observed/number of tooth positions observed for abscesses in Sacramento Valley sample vs. San Francisco Bay sample.

*Sex Comparisons: Sacramento Valley*

Comparisons between the total numbers of carious teeth were performed to evaluate sex differences within each time period for the Sacramento Valley sample. Statistical results for sex comparisons of dental pathology are provided in Table 6.11.

For each tooth type, female dentitions show a higher prevalence of carious teeth than male dentitions (see Table 6.2).

When all tooth classes are considered together as a group, the prevalence of carious teeth is 4.9 percent for males and 9.5 percent for females ("uncorrected", Figure 6.3). When the "caries correction" is applied, sex differences are even more marked (males = 6.8 percent, females = 18.5 percent). Overall, carious teeth are significantly more common in female skeletons than in male skeletons ($X^2$ =130.736, p <.001). Sex differences are greatest for the Early period sample (15.7 percent), followed by Late period (12.7 percent) and Middle period (7.1 percent) samples. Carious teeth are significantly more common in female skeletons than in male skeletons for the Early ($X^2$ = 66.805, p = .001) and Late period ($X^2$ = 17.569, p = .001) samples. The prevalence of carious is not significantly different for comparisons of Middle period samples.

Although the Middle period sample is significantly biased toward older adult females, the proportion of carious teeth is similar between the sexes. However, significant sex differences in the Early period sample may be due to a greater proportion of older females. To evaluate whether an age-sex bias influenced the results, I removed individuals from the late adult category (40+ years). When only young and middle-aged individuals are included in the analysis, caries are significantly more common in female skeletons than in male skeletons for the Early period sample ($X^2$ = 8.716, p = .003). This suggests that sex differences during this period are not solely due to the biased age distribution.

In addition to sex differences in caries prevalence, Sacramento Valley female dentitions show a significantly higher proportion of AMTL than do male dentitions (females, 20.3 percent; males, 7.2 percent; $X^2$ = 183.902, p = .001; Figure 6.4). When examined separately by time period, AMTL is significantly more common in female skeletons than in male skeletons for all three periods (Early period, $X^2$ = 61.577, p = .001; Middle period, $X^2$ = 112.63, p = .001; Late period, $X^2$ = 17.506, p = .001). These differences are greatest for the Middle period (18.8 percent) sample, followed by the Early (10.6 percent) and Late (10.0 percent) period samples.

Table 6.11. Chi-Square and Fisher's Exact Results for Sex Comparisons of Caries and AMTL.

| **Observed** | **Region** | **Period** | **$X^2$, F.E.** | **p value[1]** | **n[2]** | **Trend** |
|---|---|---|---|---|---|---|
| Caries | Sacramento Valley | Early Period | 66.805 | **.001** | 57/755 vs. 141/606 | F>M |
| | | Middle Period | .930 | .351 | 35/589 vs. 78/598 | F>M |
| | | Late Period | 17.569 | **.001** | 13/198 vs. 104/539 | F>M |
| | | Periods Pooled | 130.736 | **.001** | 105/1357 vs. 323/1743 | F>M |
| | San Francisco Bay | Early Period | F.E. | **.015** | 0/236 vs. 7/236 | F>M |
| | | Middle Period | 19.745 | **.001** | 2/440 vs. 26/468 | F>M |
| | | Late Period | F.E. | .058 | 2/376 vs. 8/357 | |
| | | Periods Pooled | 24.441 | **.001** | 4/1052 vs. 41/1061 | F>M |
| AMTL | Sacramento Valley | Early Period | 61.557 | **.001** | 98/1298 vs. 197/1083 | F>M |
| | | Middle Period | 112.63 | **.001** | 55/827 vs. 243/954 | F>M |
| | | Late Period | 17.506 | **.001** | 20/293 vs. 128/761 | F>M |
| | | Periods Pooled | 183.902 | **.001** | 173/2418 vs. 618/2798 | F>M |
| | San Francisco Bay | Early Period | 6.903 | **.009** | 15/334 vs. 41/433 | F>M |
| | | Middle Period | 19.798 | **.001** | 14/574 vs. 65/803 | F>M |
| | | Late Period | 38.601 | **.001** | 91/573 vs. 29/597 | M>F |
| | | Periods Pooled | .628 | .428 | 120/1481 vs. 135/1833 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number of caries or AMTL observed/number of teeth observed in male sample vs. number of caries or AMTL observed/number of teeth observed in female sample.

Since the caries prevalence is lowest for female skeletons in the Middle period sample (Figure 6.3), the greater proportion of tooth loss during this period may be due to higher attrition rates (see Table 6.8).

Alveolar abscesses are also more prevalent in female skeletons than in male skeletons from the Sacramento Valley (Table 6.6). Overall, abscesses are significantly more common in females for the incisor and canine tooth positions, and approach a significant difference for the premolar tooth position (incisors, $X^2 = 11.448$, $p = .001$; canines, $X^2 = 6.328$, $p = .012$; premolars, $X^2 = 3.764$, $p = .052$). When the samples are examined separately by time period, alveolar abscesses are more common in female dentitions than in male dentitions for comparisons of the Early (premolars, $X^2 = 7.889$, $p = .005$) period samples.

### *Sex Comparisons: San Francisco Bay*

Similar to the pattern found in the Sacramento Valley, the prevalence of dental caries in San Francisco Bay is greater in female skeletons than in male skeletons for all tooth types (see Table 6.2). When all tooth classes are considered together as a group, the prevalence of carious teeth is .4 percent for males and 3.0 percent for females. Since caries-induced pulp exposure is rare in the samples, the “corrected” caries prevalence is similar to uncorrected values (.4 percent for males, 3.9 percent for females). Overall, the prevalence of carious teeth is significantly greater in female dentitions than in male dentitions ($X^2 =24.441$, $p = .001$).

Sex differences are greatest for the Middle period sample (5.1 percent), followed by the Early (3.0 percent) and Late (1.7 percent) period samples. Carious teeth are significantly more common in female skeletons than in male skeletons for comparisons of the Early and Middle period samples (Early period, Fisher's Exact, p = .015; Middle period, $X^2$ = 19.745, p = .001). Males and females show a similar caries prevalence for the Late period sample. Since the San Francisco Bay sample does not show an age-dependent pattern, the sex differences do not appear to be due to differences in the age composition of the samples.

In addition to the significant sex differences in caries, San Francisco Bay females also show a significantly higher prevalence of AMTL for the Early (females = 9.5 percent, males = 4.5 percent; $X^2$ = 6.903, p .009) and Middle period samples (females = 8.1 percent, males = 2.4 percent; $X^2$ = 19.798, p = .001). In contrast, Late period males show a significantly higher proportion of AMTL than females (males = 15.9 percent, females = 4.9 percent; $X^2$ = 138.601, p = .001). Although female skeletons generally show a higher prevalence of alveolar abscesses than male skeletons, these differences are not statistically significant (Table 6.6, Table 6.12). However, Late period male dentitions show a significantly greater proportion of alveolar abscesses than female dentitions for the incisor ($X^2$ = 17.462, p = .001), premolar ($X^2$ = 8.009, p = .005), and molar ($X^2$ = 7.038, p = .008) tooth positions.

Table 6.12. Chi-Square and Fisher's Exact Results for Sex Comparisons of Alveolar Abscesses by Tooth Position.

| Region | Tooth Types | Period | $X^2$, F.E. | p value[1] | n[2] | Trend |
|---|---|---|---|---|---|---|
| Sacramento Valley | Incisors | Early Period | F.E. | .070 | 3/320 vs. 8/258 | |
| | | Middle Period | 4.018 | .045 | 9/198 vs. 23/241 | |
| | | Late Period | F.E. | .191 | 1/72 vs. 11/197 | |
| | | Periods Pooled | 11.448 | **.001** | 13/590 vs. 42/696 | F>M |
| | Canines | Early Period | F.E. | .737 | 4/165 vs. 5/141 | |
| | | Middle Period | 2.727 | .099 | 3/104 vs. 10/126 | |
| | | Late Period | F.E. | .105 | 0/39 vs. 8/99 | |
| | | Periods Pooled | 6.328 | **.012** | 7/308 vs. 23/366 | F>M |
| | Premolars | Early Period | 7.889 | **.005** | 5/339 vs. 16/288 | F>M |
| | | Middle Period | .001 | .988 | 17/214 vs. 20/253 | |
| | | Late Period | .017 | .897 | 5/77 vs. 14/202 | |
| | | Periods Pooled | 3.764 | .052 | 27/627 vs. 50/743 | |
| | Molars | Early Period | .077 | .782 | 31/482 vs. 28/406 | |
| | | Middle Period | .895 | .344 | 28/317 vs. 15/336 | |
| | | Late Period | .386 | .534 | 4/107 vs. 14/266 | |
| | | Periods Pooled | .195 | .659 | 63/906 vs. 57/1008 | |
| San Francisco Bay | Incisors | Early Period | F.E. | .685 | 2/80 vs. 4/89 | |
| | | Middle Period | F.E. | .143 | 0/142 vs. 4/197 | |
| | | Late Period | 17.462 | **.001** | 16/138 vs. 0/142 | M>F |
| | | Periods Pooled | 6.252 | **.012** | 18/360 vs. 8/428 | M>F |
| | Canines | Early Period | F.E. | 1.000 | 2/44 vs. 2/56 | |
| | | Middle Period | F.E. | .643 | 1/172 vs. 3/102 | |
| | | Late Period | F.E. | .055 | 4/72 vs. 0/75 | |
| | | Periods Pooled | .995 | .319 | 7/188 vs. 5/233 | |
| | Premolars | Early Period | F.E. | .401 | 1/87 vs. 4/120 | |
| | | Middle Period | F.E. | .483 | 2/143 vs. 6/213 | |
| | | Late Period | 8.009 | **.005** | 14/149 vs. 3/155 | M>F |
| | | Periods Pooled | 1.738 | .187 | 17/379 vs. 13/488 | |
| | Molars | Early Period | .119 | .730 | 5/128 vs. 8/169 | |
| | | Middle Period | 2.38 | .123 | 13/220 vs. 29/301 | |
| | | Late Period | 7.038 | **.008** | 36/211 vs. 20/231 | M>F |
| | | Periods Pooled | 1.044 | .307 | 54/559 vs. 57/701 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number of abscesses observed/number of teeth observed for abscess in male sample vs. female sample.

### *Summary*

Comparisons between the total number of carious teeth, the number of teeth lost antemortem, and the total number of alveolar abscesses show a number of statistically significant associations that provide insight into dietary differences between time periods, regions, and the sexes. Temporal comparisons indicate that both Sacramento Valley male and female skeletal samples show a higher prevalence of carious teeth during the Early and Late periods than in the Middle period. These patterns are more variable for AMTL and alveolar abscesses. Males show no significant differences in AMTL through time, while females show a significantly higher proportion of AMTL in the Middle period than in the Early and Late period. Alveolar abscesses are also significantly more common for some tooth positions in the Middle period sample than in the Early and Late period samples.

Temporal comparisons of the San Francisco Bay skeletal samples indicate that the caries rate for Middle period females is significantly higher than that of Late period females. The prevalence of AMTL significantly increased in the Late period for males, but significantly decreased for females. Alveolar abscessing is also significantly more common for some tooth positions in Middle and Late period male samples, while the female samples showed a significant reduction in the prevalence of alveolar abscesses over time for the incisor tooth position.

Inter-regional comparisons suggest that the prevalence of carious teeth, AMTL, alveolar abscessing, and rate of enamel attrition was greater in skeletal samples from the Sacramento Valley than in skeletal samples from San Francisco Bay. The dramatic regional differences in caries prevalence in both sexes do not appear to reflect differences in attrition rates or differences in the age composition of the samples. This suggests that Sacramento Valley diets were significantly more cariogenic than those from the San Francisco Bay area. Although the prevalence of AMTL and alveolar abscesses is greater in Early and Middle period samples from the Sacramento Valley, the Late period male sample from the San Francisco Bay shows a significantly higher prevalence of these conditions.

For the Sacramento Valley, female skeletons show a significantly higher prevalence of carious teeth than do male skeletons for the Early and Late period samples. These differences appear to reflect true dietary differences, between the sexes in general, and do not appear to reflect sex differences in attrition rates or the age composition of the samples. Female dentitions also show a significantly higher prevalence of AMTL and alveolar abscesses than do male dentitions. Collectively, these significant sex differences in dental disease suggest that females consumed greater amounts of cariogenic plant foods than males, especially during the Early and Late periods in the Sacramento Valley.

For the San Francisco Bay sample, females also show a higher proportion of carious teeth than males, and these differences are significant for comparisons of the Early and Late period samples. AMTL was also significantly greater among females than males in the Early and Middle period samples, although males show a significantly higher prevalence of AMTL and alveolar abscesses in the Late period sample. Although sex differences are less marked in the San Francisco Bay samples than in the Sacramento

Valley samples, these results suggest that in general, female diets were much more cariogenic than male diets in prehistoric central California.

# CHAPTER VII

# PERIOSTEAL REACTIONS

Over the past few decades, the emphasis of paleopathological research has shifted away from the description and diagnosis of specific disease processes on individual skeletons to the study of multiple disease and stress indicators in large skeletal samples. This population-oriented approach has provided greater insight into the health status of prehistoric societies, and has oriented bioarchaeological studies within the greater context of anthropological archaeology (Buikstra 1991). The study of non-specific infection has been of major area of interest in osteological research, as it may provide insight regarding the prevalence of infectious pathogens in the past. In this chapter, I examine non-specific lesions of the tibia as a general measure of community health in prehistoric central California.

## *Literature Review*

Non-specific infections on bone have been commonly used in the reconstruction of health status among prehistoric human societies (Larsen 1995, 1997). Evidence of multiple periostoses on the La Ferrassie 1 Neandertal skeleton, excavated from the Dordogne region of France, indicates that such afflictions also affected earlier humans (Fennell and Trinkaus 1997). Although it is often assumed that lesions affecting the external cortex of the bone are caused by inflammation of the overlying periosteum (i.e., the vascular tissue that encases bones) due to infection, similar lesions may also result from direct trauma to the skeleton (Larsen 1997; Mensforth et al. 1978; Ortner 2003;

Roberts et al. 1998). Because bone tissue can only respond in a limited number of ways (i.e., bone growth or removal), the diagnosis of specific diseases in dry bone specimens continues to pose major challenges in paleopathological research.

There are a number of diseases that may cause inflammation of bone and adjacent tissues, including osteomyelitis, treponematosis, tuberculosis, leprosy, pulmonary osteoarthopathy, tumors, traumatic injury, and scurvy (Gladykowska-Rzeczycka 1998; Ortner 2003; Powell and Cook 2005a, 2005b; Schultz 2001). In the case of infection, skeletal involvement may occur through direct association with affected tissues, open wounds, or may be transmitted through the bloodstream (hematogenously) from another area of the body (Ortner 2003:181).

Non-specific lesions can be classified through examination of lesion characteristics, assessment of the pattern of involvement, and whether the lesion affects the inner or outer cortex of the bone. Periosteal reactions, alternately referred to as periostitis or periostoses, are among the most common lesions identified in prehistoric skeletons (Ortner 2003). Active lesions are characterized by subperiosteal deposition of porous, woven bone that forms superficial to the bone cortex (Ortner 2003:210). This may take on an “onion-skin” appearance and manifest as small patches of proliferative bone growth or may involve large portions of the bone diaphysis (Ragsdale et al. 1981). In the healed state, the reaction may encompass the circumference of the bone and appear as layers of thick, striated bone that are contiguous with the unaffected areas of the cortex. In many cases, it is not possible to identify the origin of the reaction.

Periosteal reactions (periostoses) may occur on their own, or in conjunction with other inflammatory conditions, such as osteomyelitis. Osteomyelitis is a pyogenic (pus forming) infectious condition that originates within the medullary cavity, mainly affecting the endosteal surfaces (Eyre-Brook 1983; Ortner 2003:181-184). In cases where the blood supply to the periosteum is disrupted, a sequestrum of necrotic bone may form, which aids in maintaining the infection. As the disease progresses, new periosteal bone deposition produces a shell of reactive bone called the involucrum. Cloacae openings develop in the involucrum to allow pus and necrotic bone to escape through the surface of the skin (Ortner 2003).

Although periostosis and osteomyelitis can involve diseases processes of their own, skeletal manifestations may also occur secondary to trauma, skin ulcers, and treponemal disease (Ortner 2003:206-208). Chronic ulcers of the skin and direct trauma to the skeleton may promote a proliferative response of the periosteum and adjacent tissues, and open wounds associated with these conditions provide the mechanism though which bacteria can readily enter the bloodstream. Researchers have noted that periosteal reactions show a predilection for the tibia, which is the most commonly affected element in archaeological skeletons (Larsen 1997:85; Ortner 2003:209). The reason for this is not well understood. However, since the anterior surface of the tibia is not well insulated by muscle, it is an area that is susceptible to both trauma and infection (Ortner 2003). The tibia is also commonly affected in treponemal disease, which might suggest that bacteria prefer the cooler, less insulated areas of the body.

Although nonspecific periosteal reactions can be caused by a variety of conditions, paleopathologists continue to use these lesions as a general measure of infectious disease in studies of prehistoric societies (e.g., Bright and Loveland 1999; Goodman et al. 1984; Lambert 1993; Larsen 1995, 1997; Larsen and Hutchinson 1999; Nelson 1999; Walker and Lambert 1991). In conjunction with other skeletal indictors, the prevalence of periostoses can be used to make general inferences regarding health status through periods of subsistence change, such as the transition to agriculture (Larsen 1997:84). Many studies of sedentary agricultural and nonagricultural (e.g., southern California) societies report significant increases in the prevalence of periosteal lesions through time, compared with earlier foragers from the same region (e.g., Cohen and Armelagos 1984, ed.; Lambert 1993; Walker and Lambert 1991; Inhorn and Brown 1990; Larsen 1995, 1997). For example, in twelve of eighteen case studies reported in *Paleopathology at the Origins of Agriculture*, the authors found an increase in the prevalence of periosteal reactions with the transition from foraging to farming (Cohen and Armelagos 1984). Increases in population density and sedentism during the Holocene are thought to have promoted conditions more conducive to the long-term survival of infectious pathogens, a hypothesis supported by research on modern human societies (Cohen 1977, 1989, 1997; Inhorn and Brown 1990; Larsen 1995, 1997). Among densely settled communities, opportunity to spread infection is increased through a greater degree of person-to-person contact in daily activities (Inhorn and Brown 1990). The accumulation of waste also promotes unsanitary conditions that are conducive to the spread of infection, which may result in the contamination of drinking water.

In addition to the study of nonspecific bone lesions, considerable interest has been directed at identifying treponemal diseases in prehistoric skeletons (Baker and Armelagos 1988; Cook and Powell 2005a; Merbs 1992; Powell 1991; Powell and Cook 2005). North American researchers have identified skeletal lesions consistent with yaws and syphilis (endemic and venereal), although paleopathological diagnosis of specific treponemal diseases continues to be debated (Baker and Armelagos 1988; Powell and Cook 2005a, 2005b). Treponematosis is caused by the bacterial spirochete, *Treponema spp.,* and includes four closely related diseases—yaws, pinta, endemic syphilis (bejel, treponarid), and venereal syphilis (Hacket 1976; Ortner 2003:274). Transmission of yaws, pinta, and endemic syphilis occurs through direct contact with the skin or mucous membranes, while venereal syphilis occurs through sexual contact, but may also be passed congenitally from mother to fetus across the placenta (Roberts and Manchester 1995:155). Yaws and endemic syphilis are usually acquired during childhood, while pinta predominately affects adults during the third decade of life (Roberts and Manchester 1995:152). Although yaws and syphilis (endemic and venereal) often affect the long bones, pinta does not affect the skeleton. Ortner et al. (1992:343) report that only ten to twenty percent of individuals with the treponemal diseases that affect bone will show evidence of skeletal involvement.

The identification of treponematosis in dry bone specimens is problematic, since periosteal reactions and osteomyelitis often occur as part of the disease process (Ortner

2003). The overlapping pattern of involvement of syphilis and yaws are also similar, so it may not be possible to distinguish between them on the skeleton (Ortner 2003:274; Schultz 2001). For endemic and venereal syphilis, gummatous lesions (i.e., caries sicca) may develop on the cranial vault, and infection may involve the nasal cavity and the long bones. Tibial lesions may be pronounced in both yaws and syphilis (endemic and venereal), producing a "saber shin" appearance caused by appositional bone growth along the anterior diaphysis; sclerotic trabecular bone may also envelope the medullary cavities (endostosis) of long bones (Ortner 2003:286). Recent studies in ancient DNA and bone histology have successfully identified specific treponemal diseases in skeletal remains (Centurion-Lara et al. 1998; Fraser et al. 1998; Kolman et al. 1999; Schultz 2001; Walker et al. 2005).

### *Methods*

Since the tibia is more predisposed to record periostoses than any other skeletal element, I focus on this bone as a general health indicator for the present study. For each tibia, I examined the external surface for signs of periosteal bone deposition and recorded the location of the lesion on the bone following *Standards for Data Collection* (Buikstra and Ubelaker 1994). For the 0-5 year-old category, I took a conservative approach to avoid confusing periosteal reactions with normal periosteal bone deposition. Although I examined all complete and fragmentary tibiae, I only include elements that were at least 60 percent complete in the analysis. I described the macroscopic characteristics (e.g., plaque-like deposit, striated compact bone) of each lesion, and determined whether it was active, healed, or actively healing (mixed). In my examination of cranial vault bones for porotic hyperostosis, I observed no instances of healed or active stellate scars (i.e., caries sicca) in any of the samples; however, I observed skeletal manifestations of "saber-shin" lesions in a few cases. I only noted a single case of nasopalatal resorption, but did not systematically score this feature. Since I did not examine all long bones for periostosis, I provide only summary data for cases in which more than one element was affected. This precluded the calculation of prevalence rates for any bones other than the tibia. I use the chi-square and Fisher's Exact statistic to test for significant associations between the proportion of individuals with tibial periostoses and age, sex, time period, and region. To account for the increased probability of obtaining statistically significant results ($p < .05$) due to random chance with multiple comparisons, I set the alpha level for statistical significance at $p< .017$. However, I treat p-values between .018 and .05 as approaching statistical significance.

### *Results*

Large periosteal reactions that affected more than one-third of the diaphyseal surface are the most common lesion type in the sample (Sacramento Valley = 38.7 percent; San Francisco Bay = 45.9 percent). I observed saber-shin deformity – a common characteristic of treponemal disease – in 3.2 percent of tibiae from the Sacramento Valley and 13.5 percent of tibiae from the San Francisco Bay. I observed osteomyelitis of the tibia in three cases, all of which came from the San Francisco Bay sample.

Table 7.1 presents the distribution of unilateral and bilateral lesions in the sample. For individuals that had both tibiae present for observation, bilateral involvement was more common than unilateral involvement (66.7 versus 33.3 percent, respectively) in the Sacramento Valley sample, but was nearly equal (52.4 versus 47.6 percent, respectively) in the San Francisco Bay sample. The high degree of bilateral involvement in conjunction with lesions on other long bones suggests that many of the periostoses are part of a systemic disease, most likely of infectious origin. Although I did not score other bones systematically, I noted at least eight cases (Sacramento Valley, n = 4; San Francisco Bay, n = 4) of tibial periostoses that were associated with other affected elements, especially femora, fibulae, radii, and ulnae.

Table 7.1. Distribution of Unilateral and Bilateral Tibial Periosteal Reactions.

| **Lesion Type** | **Region** | ***n*** | **% affected** |
|---|---|---|---|
| Unilateral Lesions | Sacramento Valley | 6/18 | 33.3 |
| | San Francisco Bay | 10/21 | 47.6 |
| Bilateral Lesions | Sacramento Valley | 12/18 | 66.7 |
| | San Francisco Bay | 11/21 | 52.4 |

Table 7.2 presents the distribution of lesions by state of healing. For both the Sacramento Valley and San Francisco Bay samples, healed lesions comprise roughly one-half of the tibiae affected by periostosis. The Sacramento Valley sample shows a higher prevalence of active lesions than the San Francisco Bay sample. In both regions, male skeletons show a higher prevalence of active tibial lesions at the time of their deaths than female skeletons. These results indicate that the vast majority of periostoses were either healed or in the process of healing at the time of death.

Table 7.2. Distribution of Healed and Unhealed Tibial Periosteal Reactions in Central California Samples by Region.

| | | **n** | | | | **% affected** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Region** | **Lesion State** | **Male** | **Female** | **Subadult** | **Total** | **Male** | **Female** | **Subadult** | **Total** |
| Sacramento Valley | Active Lesion | 4/29 | 0/29 | 5/29 | 9/31 | 13.8 | 0.0 | 17.2 | 29.0 |
| | Healed Lesion | 4/29 | 5/29 | 3/29 | 14/31 | 13.8 | 17.2 | 10.3 | 45.2 |
| | Mixed Reaction | 4/29 | 2/29 | 2/29 | 8/31 | 13.8 | 6.9 | 6.9 | 25.8 |
| San Francisco Bay | Active Lesion | 1/32 | 0/32 | 0/32 | 2/37 | 3.1 | 0.0 | 0.0 | 5.4 |
| | Healed Lesion | 5/32 | 13/32 | 0/32 | 21/37 | 15.6 | 40.6 | 0.0 | 56.8 |
| | Mixed Reaction | 6/32 | 5/32 | 2/32 | 14/37 | 18.8 | 15.6 | 6.3 | 37.8 |

I examined the relationship between age and the distribution of tibial periosteal lesions to assess whether certain age classes were more susceptible to involvement. Figure 7.1 presents the distribution of tibial periostoses by age class. Periosteal reactions are absent in the 0 to 5 year-old age class, and are rare in young children overall (< than 10 years of age). In contrast, the 11 to 16 year-old age class shows the highest prevalence of tibial lesions (13 percent). For late adolescents (17-19 years) and adults (20+ years), the percentage of affected tibiae is between eight and ten percent. The proportion of individuals with tibial lesions is not significantly different between age classes ($X^2$ = .904, df = 3; p = .825).

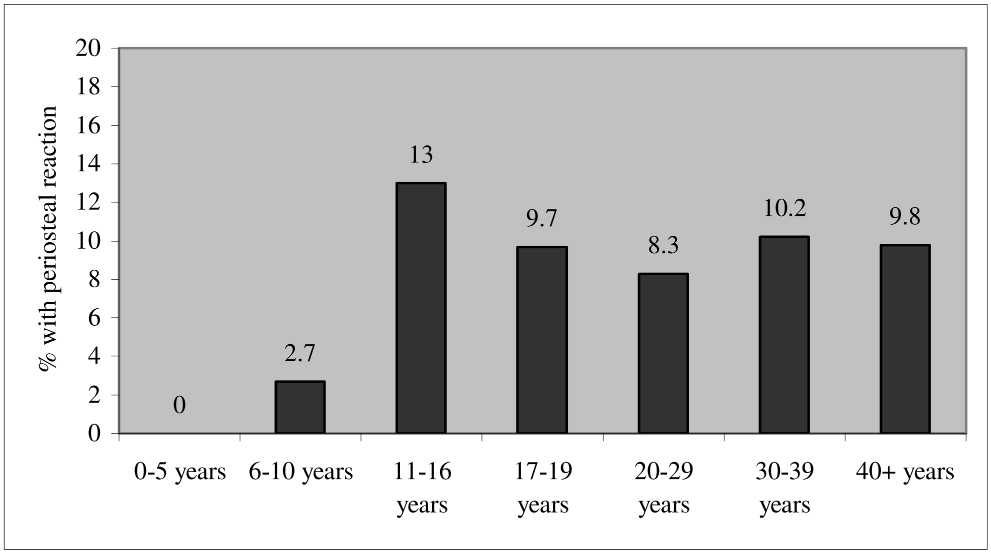

**Figure 7.1.** Prevalence of tibial periosteal reactions by age class.

### *Temporal Comparisons*

Table 7.3 summarizes the distribution of tibial periosteal reactions in the Sacramento Valley sample by region and time period. Figure 7.2 presents the prevalence of periostoses for the right tibia to illustrate general trends in the samples. Statistical results for chi-square and Fisher's Exact test are provided in Table 7.4.

Table 7.3. Distribution of Tibial Periosteal Reactions in Central California by Geographic Region, Time Period, and Sex.

| | | | Male | | Female | | Indeterminate | | Subadult | |
|---|---|---|---|---|---|---|---|---|---|---|
| Region | Time Period | Prevalence | Left | Right | Left | Right | Left | Right | Left | Right |
| Sacramento Valley | Early Period | n | 0/39 | 0/40 | 0/30 | 0/29 | 1/4 | 1/4 | 0/16 | 0/15 |
| | | % affected | 0.0 | 0.0 | 0.0 | 0.0 | 25.0 | 25.0 | 0.0 | 0.0 |
| | Middle Period | n | 3/25 | 4/25 | 2/33 | 1/32 | 0/0 | 0/0 | 4/11 | 2/10 |
| | | % affected | 12.0 | 16.0 | 6.1 | 3.1 | 0.0 | 0.0 | 36.4 | 20.0 |
| | Late Period | n | 3/14 | 2/14 | 2/27 | 2/28 | 0/0 | 0/0 | 2/7 | 2/7 |
| | | % affected | 21.4 | 14.3 | 7.4 | 7.1 | 0.0 | 0.0 | 28.6 | 28.6 |
| San Francisco Bay | Early Period | n | 2/13 | 1/11 | 6/18 | 4/21 | 0/0 | 0/0 | 0/7 | 0/8 |
| | | % affected | 15.4 | 9.1 | 33.3 | 19.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Middle Period | n | 3/25 | 2/26 | 4/35 | 2/34 | 1/2 | 1/4 | 1/6 | 1/6 |
| | | % affected | 12.0 | 7.7 | 11.4 | 5.9 | 50.0 | 25.0 | 16.7 | 16.7 |
| | Late Period | n | 1/11 | 3/10 | 1/5 | 1/9 | 2/2 | 0/0 | 0/2 | 0/2 |
| | | % affected | 9.1 | 30.0 | 20.0 | 11.1 | 100 | 0.0 | 0.0 | 0.0 |

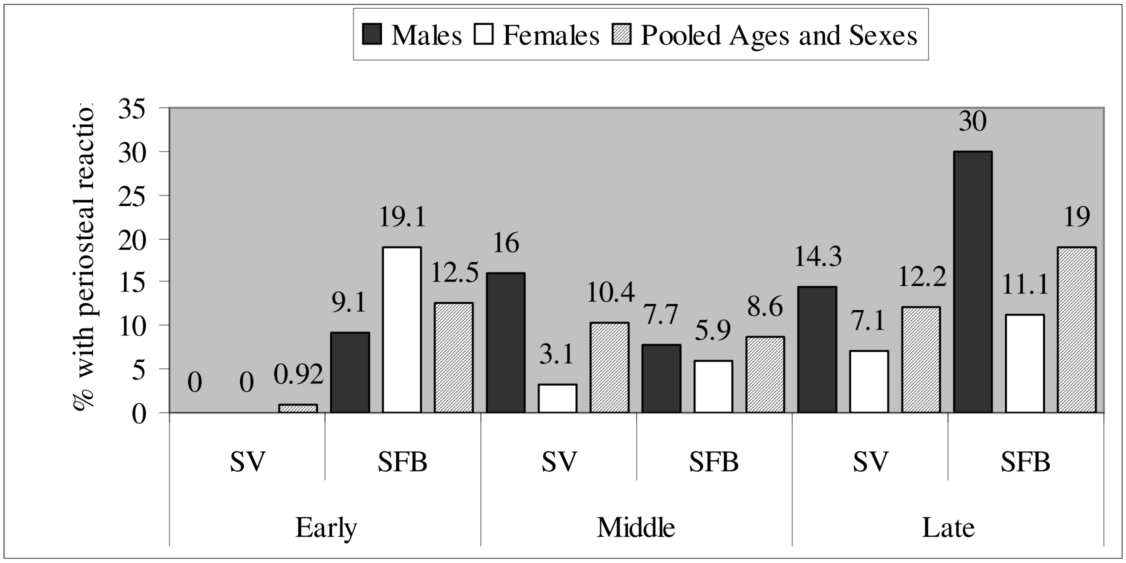

**Figure 7.2.** Prevalence of tibial periosteal reactions by region and time period for right tibiae (pooled sample includes subadults and individuals of indeterminate sex).

The prevalence of tibial periostoses increased through time for the Sacramento Valley sample. For the sample as a whole (pooled ages and sexes), the lesion prevalence is 1.1, 11.6, and 13.4 percent for the Early, Middle, and Late period, respectively. Tibial lesions are significantly more common in the Middle and Late period samples than in the Early period sample (Early vs. Middle period, Fisher's Exact, p = .003, left tibia; Early vs. Late period, Fisher's Exact, p = .008, left tibia; Fisher's Exact, p = .009, right tibia). However, the prevalence for right tibiae approaches significance only for comparisons between the Early and Middle period samples (Fisher's Exact, p = .021). For the male sample, the proportion of left tibiae with periostoses also increases between the Early and Late period (Fisher's Exact, p = .016). The difference between the Early and Middle period approaches significance in males for right tibiae only (Fisher's Exact, p = .019, right tibia). However, no temporal pattern is observed in the female sample. In the subadult category, the proportion of affected left tibiae approaches statistical significance for comparisons between the Early and Middle period sample only (Fisher's Exact, p = .019, left tibia).

Table 7.3 summarizes the distribution of tibial periosteal reactions by region and time period for the San Francisco Bay sample. For the sample as a whole (pooled ages and sexes), the lesion prevalence is 16.7, 10.9, and 19.5 percent for the Early, Middle, and Late period, respectively. However, the proportion of individuals with tibial periostoses is not significantly different between time periods (Table 7.4). This pattern also holds for temporal comparisons of the adult and subadult categories.

Table 7.4. Chi-Square and Fisher's Exact Test Results for Tibial Periostoses by Time Period.

| **Sex/Ages** | | **Left** | **P value[1]** | **n[2]** | **Trend** | **Right** | **p value[1]** | **n[2]** | **Trend** |
|---|---|---|---|---|---|---|---|---|---|
| **Sacramento Valley** | | | | | | | | | |
| Males | EP vs. MP | F.E. | .055 | 0/39 vs. 3/25 | | F.E. | .019 | 0/40 vs. 4/25 | EP<MP |
| | EP vs. LP | F.E. | **.016** | 0/39 vs. 3/14 | EP<LP | F.E. | .064 | 0/40 vs. 2/14 | |
| | MP vs. LP | F.E. | .647 | 3/25 vs. 3/14 | | F.E. | 1.000 | 3/25 vs. 3/14 | |
| Females | EP vs. MP | F.E. | .493 | 0/30 vs. 2/33 | | F.E. | 1.000 | 0/29 vs. 1/32 | |
| | EP vs. LP | F.E. | .474 | 0/30 vs. 2/27 | | F.E. | .491 | 0/29 vs. 2/28 | |
| | MP vs. LP | F.E. | 1.000 | 2/33 vs. 2/27 | | F.E. | 1.000 | 1/32 vs. 2/28 | |
| Subadults | EP vs. MP | F.E. | .019 | 0/16 vs. 4/11 | EP<MP | F.E. | .150 | 0/15 vs. 2/10 | |
| | EP vs. LP | F.E. | .083 | 0/16 vs. 2/7 | | F.E. | .091 | 0/15 vs. 2/7 | |
| | MP vs. LP | F.E. | 1.000 | 4/11 vs. 2/7 | | F.E. | 1.000 | 2/10 vs. 2/7 | |
| Ages & Sexes Pooled | EP vs. MP | F.E. | **.003** | 1/89 vs. 9/69 | EP<MP | F.E. | .021 | 1/88 vs. 7/67 | EP<MP |
| | EP vs. LP | F.E. | **.008** | 1/89 vs. 7/48 | EP<LP | F.E. | **.009** | 1/88 vs. 6/49 | EP<LP |
| | MP vs. LP | $X$ =.057 | .812 | 9/69 vs. 7/48 | | $X^2$ = .092 | .762 | 7/67 vs. 6/49 | |
| **San Francisco Bay** | | | | | | | | | |
| Males | EP vs. MP | F.E. | 1.000 | 2/13 vs. 3/25 | | F.E. | 1.000 | 1/11 vs. 2/26 | |
| | EP vs. LP | F.E. | 1.000 | 2/13 vs. 1/11 | | F.E. | .311 | 1/11 vs. 3/10 | |
| | MP vs. LP | F.E. | 1.000 | 3/25 vs. 1/11 | | F.E. | .119 | 2/26 vs. 3/10 | |
| Females | EP vs. MP | F.E. | .071 | 6/18 vs. 4/35 | | F.E. | .188 | 4/21 vs. 2/34 | |
| | EP vs. LP | F.E. | 1.000 | 6/18 vs. 1/5 | | F.E. | 1.000 | 4/21 vs. 1/9 | |
| | MP vs. LP | F.E. | .507 | 4/35 vs. 1/5 | | F.E. | .515 | 2/34 vs. 1/9 | |
| Subadults | EP vs. MP | F.E. | .462 | 0/7 vs. 1/6 | | F.E. | .429 | 0/8 vs. 1/6 | |
| | EP vs. LP | F.E. | | 0/7 vs. 0/2 | | F.E. | | 0/8 vs. 0/2 | |
| | MP vs. LP | F.E. | 1.000 | 1/6 vs. 0/2 | | F.E. | 1.000 | 1/6 vs. 0/2 | |
| Ages & Sexes Pooled | EP vs. MP | $X^2$ = 1.106 | .293 | 8/38 vs. 9/68 | | F.E. | .524 | 5/40 vs. 6/70 | |
| | EP vs. LP | F.E. | 1.000 | 8/38 vs. 4/20 | | F.E. | .706 | 5/40 vs. 4/21 | |
| | MP vs. LP | F.E. | .481 | 3/25 vs. 1/11 | | F.E. | .231 | 6/70 vs. 4/21 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number affected/number examined.

### *Regional Comparisons*

Table 7.3 summarizes the distribution of tibial periostoses by region. Statistical results for inter-regional comparisons are presented in Table 7.5. Overall, the prevalence of tibial periostoses is greater in the San Francisco Bay sample than in the Sacramento Valley sample (Figure 7.2). When all periods are considered together as a group, 7.8 (16/206) percent of left and 6.4 percent (13/204) of right tibiae have lesions in the Sacramento Valley sample, whereas 17.3 percent (22/127) of left and 11.5 percent of right (15/131) tibiae have lesions in the San Francisco Bay sample. Statistically significant differences are found for left tibia ($X^2 = 7.097$, p = .008), but not the right tibia ($X^2 = 2.685$, p = .101). When partitioned by time period, significant differences are found only for the Early period samples (Fisher's Exact, p = .001, left tibia; p = .011, right tibia). Table 7.3 shows that this result is largely due to inter-regional differences between Early period females (Sacramento Valley, left: 0/30 = 0 percent, right: 0/29 = 0 percent; San Francisco Bay, left: 6/18 = 33.3, right: 4/21 = 19.1 percent). Tibial lesions are significantly more common among female skeletons from San Francisco Bay than among females from the lower Sacramento Valley (Fisher's Exact, p = .002, left tibia; p = .026, right tibia). However, there are no significant differences in the proportion of tibiae with periostoses for either the male or subadult sample.

Table 7.5. Chi-Square and Fisher's Exact Test Results for Regional Differences in Tibial Periosteal Reactions in the Sacramento Valley and San Francisco Bay Samples.

| Period | SV vs. SFB Males |  |  | SV vs. SFB Females |  |  |  | SV vs. SFB Subadults |  |  | SV vs. SFB Ages and Sexes Pooled |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | $X^2$, F.E. | P value[1] | n[2] | $X^2$, F.E. | p value[1] | n[2] | Trend | $X^2$, F.E. | p value[1] | n[2] | $X^2$, F.E. | p value[1] | n[2] | Trend |
| **Left Side** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Early Period | F.E. | .059 | 0/39 vs. 2/13 | F.E. | **.002** | 0/30 vs. 6/18 | SFB> SV | F.E. | - | 0/16 vs. 0/7 | F.E. | **.001** | 1/89 vs. 8/38 | SFB>SV |
| Middle Period | F.E. | 1.000 | 3/25 vs. 3/25 | F.E. | .674 | 2/33 vs. 4/35 |  | F.E. | .600 | 4/11 vs. 1/6 | .001 | .973 | 9/69 vs. 9/68 |  |
| Late Period | F.E. | .604 | 3/14 vs. 1/11 | F.E. | .292 | 2/27 vs. 1/5 |  | F.E. | 1.000 | 2/7 vs. 0/2 | F.E. | .465 | 7/48 vs. 4/20 |  |
| **Right** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Early Period | F.E. | .216 | 0/40 vs. 1/11 | F.E. | .026 | 0/29 vs. 4/21 | SFB> SV | F.E. | - | 0/15 vs. 0/8 | F.E. | **.011** | 1/88 vs. 5/40 | SFB>SV |
| Middle Period | F.E. | .419 | 4/25 vs. 2/26 | F.E. | 1.000 | 1/32 vs. 2/34 |  | F.E. | 1.000 | 2/10 vs. 1/6 | .140 | .708 | 7/67 vs. 6/70 |  |
| Late Period | F.E. | .615 | 2/14 vs. 3/10 | F.E. | .432 | 2/28 vs. 1/9 |  | F.E. | 1.000 | 2/7 vs. 0/2 | F.E. | .437 | 6/49 vs. 4/21 |  |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number of affected/total examined in SV sample vs. number of affected/total examined in SFB sample.

### *Sex Comparisons*

The distribution of tibial periosteal lesions by sex is summarized in Table 7.3, and statistical results are provided in Table 7.6. In general, periosteal lesions are more common among males than among females in the Sacramento Valley sample. When all periods are considered together as a single group, the prevalence of periostoses for males is 7.7 percent (6/78) for the left, and 7.6 percent (6/79) for the right tibia. For females, 3.3 percent (3/90) of left and 2.2 percent (2/89) of right tibiae are affected. However, the proportion of affected tibia is not significantly different between males and females for any of the comparisons (Table 7.6). For the San Francisco Bay sample, periostoses affected 12.2 percent (6/49) of left and 12.8 percent (6/47) of right tibiae for males, and 19 percent (11/58) of left and 10.9 percent (7/64) of right tibiae for females. However, the prevalence of tibial lesions is also not significantly different by sex for any of the comparisons.

Table 7.6. Chi-Square and Fisher's Exact Test Results for Sex Differences in Tibial Periosteal Reactions by Region.

| | **Sacramento Valley** | | | **San Francisco Bay** | | |
|---|---|---|---|---|---|---|
| **Period** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** |
| **Left tibia** | | | | | | |
| Early Period | F.E. | - | 0/39 vs. 0/30 | F.E. | .412 | 2/13 vs. 6/18 |
| Middle Period | F.E. | .643 | 3/25 vs. 2/33 | F.E. | 1.000 | 3/25 vs. 4/35 |
| Late Period | F.E. | .107 | 3/14 vs. 2/27 | F.E. | 1.000 | 1/11 vs. 1/5 |
| Periods Combined | F.E. | .306 | 6/78 vs. 4/90 | .898 | .343 | 6/49 vs. 11/58 |
| **Right tibia** | | | | | | |
| Early Period | F.E. | - | 0/40 vs. 0/29 | F.E. | .637 | 1/11 vs. 4/21 |
| Middle Period | F.E. | .157 | 4/25 vs. 1/32 | F.E. | 1.000 | 2/26 vs. 2/34 |
| Late Period | F.E. | .254 | 2/14 vs. 2/28 | F.E. | .582 | 3/10 vs. 1/9 |
| Periods Combined | F.E. | .150 | 6/79 vs. 3/89 | .088 | .767 | 6/47 vs. 7/64 |

[1] Number affected/number examined of males vs. females.

### ***Summary***

The abundance of large periosteal reactions, the high degree of bilateral involvement, and the polyostotic pattern in several individuals suggests that many of these lesions are the result of infection rather than trauma. The distribution of tibial periosteal reactions in the samples provides some support for resource intensification models in prehistoric central California. The prevalence of tibial lesions significantly increased through time in males and for the sample as a whole in the Sacramento Valley, which is expected with higher levels of infection associated with greater population and sedentism. In contrast, the San Francisco Bay sample shows no significant trends through time with respect to the prevalence of tibial lesions. Inter-regional comparisons, however, indicate that a greater proportion of individuals in the San Francisco Bay sample have tibial periostoses compared with those in the Sacramento Valley skeletal series, especially during the Early period. Both sexes had a similar prevalence of tibial periostoses, which suggests that males and females had similar levels of exposure to infection and/or trauma.

# CHAPTER VIII

# STATURE

The association between adult stature and other indicators of health status has been documented in numerous studies of living human populations (Bogin and Rios 2003; Bogin et al. 2002; Leonard et al. 2000; Martorell 1989; Martorell and Habicht 1986; Saunders and Hoppa 1993; Stinson 1985, 2002). Because short stature is often linked with malnutrition, undernutrition, and the prevalence of infectious disease in modern human populations, it is often used as a comparative measure of health status. In this chapter, I use mean femoral length as a proxy measure of stature differences in prehistoric central California. I examine differences in femoral length by time period, between regions, and between the sexes.

## ***Literature Review***

Disease and nutritional stress are recognized as important factors that control the rate and velocity of long bone growth (Cameron and Demerath 2002; King and Ulijaszek 1999). Although there has been considerable debate, human biologists recognize that poor nutrition and disease during critical periods of growth and development (e.g., birth to age three) are associated with elevated risk of morbidity and mortality throughout the lifespan. In sum, individuals (modern and prehistoric) who experience significant growth disruption due to nutritional stress or disease have a tendency to die at younger ages than individuals who experienced childhoods without major episodes of health stress (Cameron and Demerath 2002; Kemkes-Grottenthaler 2005; Martorell and Habict 1986; Martorell 1989; Saunders and Hoppa 1993; Stinson 2002).

Although genetic factors and adequate vitamin D synthesis influence growth rates, nutrition and disease are recognized as the most important factors that regulate long bone growth in modern human populations (Bogin et al. 2002; Martorell 1989; Steckel 1995; Stinson 2002). For example, Bogin et al. (2002) compared growth rates in adult Maya and their children from Guatemala with growth rates of recent Maya American immigrants to the United States. They found that American-born Maya average 11.54 cm taller than their Guatemalan counterparts, which the authors attribute to improvements in childhood nutrition and access to health care in the U.S. (Bogin et al. 2002:753). In a retrospective study of Dutch male stature from AD 50 to 1997, Maat (2005) found fluctuations in height that corresponded to changing health conditions in the past. During the Roman Period, the movement toward urbanization was associated with a negative secular trend in stature, a decline in dietary quality, and poorer sanitary conditions (Maat 2005:283-287). Improvements in nutrition and health from the middle of the nineteenth century to 1997 were associated with a positive secular trend in stature, which accounts for the high mean stature among modern Dutch males. These studies support the notion that nutrition and disease play an important role in the attainment of maximum stature.

During early growth and development, the young are highly susceptible to perturbations caused by nutritional deficiencies, such as protein and/or calorie malnutrition, and infection (Cameron and Demerath 2002; Stinson 2002). Poor maternal health and/or malnutrition may account for initial growth stunting in infants and young children, and later to diminished adult stature (Saunders and Hoppa 1993:132). Low birth-weight infants are also more susceptible to growth retardation and poorly developed immune systems than are healthy infants, and consequently show higher rates of morbidity and mortality. Poor maternal health, inadequate infant nutrition, and high pathogen load – in conjunction with immuno-compromised health status – account for the high rates of infant mortality and morbidity in many developing nations, and presumably for archaeological populations as well (Saunders and Hoppa 1993). For those individuals who experienced childhood growth arrest but survived to adulthood, stunting (i.e., short adult stature) can be used as a measure of stressful childhood conditions (Cameron and Demerath 2002; Kemkes-Grottenthaler 2005; Martorell and Habict 1986; Martorell 1989; Saunders and Hoppa 1993; Stinson 2002).

### *Methods*

Although there are a number of formulae for estimating stature from long bone length, none are appropriate for central California populations. Some researchers (e.g., Sciulli and Giesen 1993; Sciulli et al. 1990) have used Fully's anatomical method to generate stature regression formulae for archaeological samples. These formulae are then applied to other archaeological samples to estimate stature from long bones lengths. This method has had some success in comparing stature trends within a specific archaeological region, but cannot be extrapolated to prehistoric samples from other regions. Lambert (1993, 1994) simply used mean femoral length to compare the relative stature of populations from different regions and time periods in the Channel Islands area of southern California. This method has several advantages. First, it avoids having to estimate stature using regression formulae that are only appropriate to the reference samples from which they are derived. Second, since femoral length shows a high correlation with living height and accounts for approximately 27 percent of total adult stature, measurements are directly comparable between skeletal samples (Lambert 1993). As with any comparison of stature, this assumes a degree of genetic homogeneity within and between time periods for a given archaeological region.

For the sake of comparison with data from prehistoric southern California (Lambert 1993, 1994) and the other reasons mentioned above, I use mean femoral length as a proxy measure of adult stature. I measured the maximum length of adult right femora, substituting the left side in cases when the right side was damaged or missing. I measured reconstructed femora only in instances where joins were complete and properly aligned, avoiding femora with damage to the superior aspect of the femoral head or the distal articular surface of the femoral condyles. I collected all measurements using a standard osteometric board and recorded maximum bone length to the nearest millimeter. I examined normality in the sample distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests before comparing stature data. I used the one-way ANOVA and Student's T-test to examine differences in mean femoral length by time period, by region, and by sex.

### ***Results***

Statistical comparisons of ratio level data can be influenced by departure from normality and by differences in the sample variances. The hypothesis that a sample comes from a normal distribution can be examined using tests of normality, such as Kolmogorov-Smirnov and Shapiro-Wilk tests. Since sex-pooled comparisons tend to show a bimodal distribution of femoral length due to sexual dimorphism, I examined sample distributions for males and females separately. Based on examination of box-and-whisker plots, I eliminated three outliers from the analysis (one male, two females). I then examined the normality distribution in each sample using the Kolmogorov-Smirnov and Shapiro-Wilk tests and through visual examination of Q-Q plots. Statistically significant values ($p<.05$) indicate that a sample is not normally distributed, while non-significant values suggest that a sample is within the range of the normal distribution. Although no significant differences are found in any of the Sacramento Valley samples, femoral lengths in Early period males and females and Middle period females in the San Francisco Bay sample show significant departures from normality. Based on these results, I limit most statistical comparisons to the Sacramento Valley samples.

Mean femoral lengths and standard deviations are presented by site in Table 8.1. For the Sacramento Valley sample as a whole (periods combined), mean femoral length was 449.5 mm for males and 420.7 mm for females. The longest femora for males are from SJO-142, and the shortest are from SAC-60. For females, in contrast, the longest femora are found in the SAC-06 sample and the shortest are found in the SAC-43 sample. For the San Francisco Bay sample as a whole (periods combined), mean femoral length was 450.2 mm for males and 409.5 for females. For the male sample, the longest femora are from ALA-309, while the shortest femora are from ALA-329. For females, in contrast, the longest femora are found in the ALA-307 sample, and the shortest are found in the ALA-328 sample.

Table 8.1. Mean Femoral Lengths (in mm) in Prehistoric Central California by Site.

| | | **Males** | | | **Females** | |
|---|---|---|---|---|---|---|
| **Site** | **Mean** | **S.D.** | **n** | **Mean** | **S.D.** | **n** |
| **Sacramento Valley** | | | | | | |
| SJO-68 | 450.90 | 20.51 | 30 | 428.82 | 12.92 | 17 |
| SJO-142 | 457.88 | 14.95 | 16 | 428.71 | 12.23 | 7 |
| SJO-154 | 440.50 | 13.89 | 4 | 411.17 | 12.19 | 6 |
| SAC-43 | 450.06 | 16.07 | 17 | 409.72 | 12.97 | 18 |
| SAC-60 | 437.20 | 19.64 | 10 | 417.45 | 17.45 | 11 |
| SAC-06 | 444.83 | 15.77 | 6 | 433.00 | 14.79 | 8 |
| Total | 449.48 | 18.52 | 83 | 420.73 | 16.22 | 67 |
| **San Francisco Bay** | | | | | | |
| Ala-307 | 449.33 | 2.31 | 3 | 421.86 | 17.53 | 7 |
| Ala-309 | 459.75 | 9.38 | 8 | 406.14 | 16.04 | 7 |
| Ala-328 | 449.78 | 16.94 | 9 | 403.42 | 13.12 | 12 |
| Ala-329 | 443.30 | 22.46 | 10 | 410.33 | 10.15 | 12 |
| Total | 450.23 | 17.29 | 30 | 409.50 | 14.72 | 38 |

### *Temporal Comparisons*

The distribution of mean femoral lengths in the Sacramento Valley sample is presented by time period in Figure 8.1 and Table 8.2. ANOVA results are presented in Table 8.3. Femur length for females shows a significant decline between the Early and Middle period (p = .001, Bonferroni Test; difference of 1.75 cm), and then a significant increase between the Middle and Late periods (p = .008, Bonferroni Test; difference of 1.42 cm). Since femoral length accounts for approximately 27 percent of total adult stature (Lambert 1993), these differences account for a reduction in female stature of approximately 6.5 cm (1.75/.27 = 6.48 cm) between the Early and Middle period, followed by an increase of roughly 5.3 cm (1.42/.27 = 5.26) between the Middle and Late period. Temporal change in femur length only approaches statistical significance for males between the Early and Middle period (p = .107, Bonferroni Test).

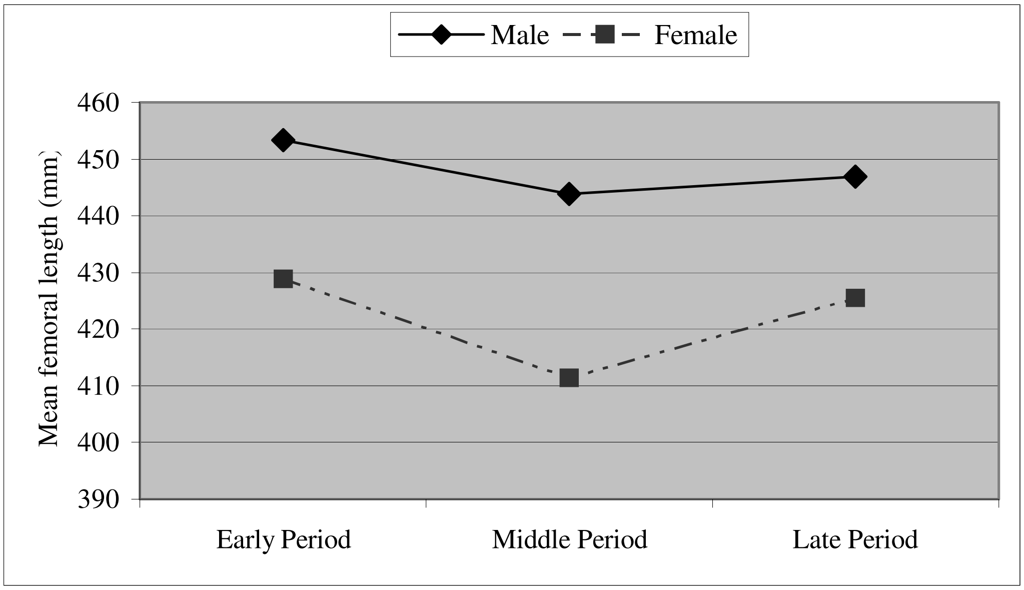

**Figure 8.1.** Comparison of male and female femoral length through time in the Sacramento Valley.

Table 8.2. Distribution of Mean Femoral Length by Sex and Time Period in Prehistoric Central California.

| | **Males** | | | **Females** | | |
|---|---|---|---|---|---|---|
| **Period** | **Mean** | **S.D.** | **n** | **Mean** | **S.D.** | **n** |
| **Sacramento Valley** | | | | | | |
| Early Period | 453.33 | 18.89 | 46 | 428.79 | 12.46 | 24 |
| Middle Period | 443.89 | 17.54 | 27 | 411.29 | 13.51 | 28 |
| Late Period | 446.90 | 18.52 | 10 | 425.47 | 17.86 | 15 |
| **San Francisco Bay** | | | | | | |
| Early Period | 454.20 | 12.33 | 5 | 418.44 | 16.64 | 9 |
| Middle Period | 449.56 | 17.20 | 16 | 407.48 | 13.03 | 21 |
| Late Period | 449.22 | 21.00 | 9 | 404.75 | 14.23 | 8 |

Table 8.2 and Figure 8.2 present the distribution of mean femoral lengths in the San Francisco Bay sample by sex and time period. Although statistical comparisons could not be computed due to small sample size, mean femoral length is shorter in the Middle and Late period samples than in the Early period sample. A larger sample size is needed to test whether temporal differences between other periods are statistically significant.

Table 8.3. ANOVA Results for Temporal
Femoral Length Comparisons in Prehistoric Central California.

| **Males** | | | | | | **Females** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **F-statistic** | **Df** | **p value**$^1$ | **Bonferroni**$^2$ | **Trend** | **Mean Difference (cm)** | **F-statistic** | **df** | **p value**$^1$ | **Bonferroni**$^2$ | **Trend** | **Mean Difference (cm)** |
| **Sacramento Valley** | | | | | | | | | | | |
| 2.398 | 80 | .097 | .107 | EP>MP | .94 | 10.844 | 64 | **.001** | **.001** | EP>MP | 1.75 |
| | | | .945 | EP>LP | .64 | | | | 1.000 | EP>LP | .33 |
| | | | 1.000 | MP<LP | .30 | | | | **.008** | MP<LP | 1.42 |
| **San Francisco Bay** | | | | | | | | | | | |
| | | | | EP>MP | .46 | | | | | EP>MP | 1.10 |
| | | | | EP>LP | .50 | | | | | EP>LP | 1.40 |
| | | | | MP>LP | .03 | | | | | MP>LP | .56 |

1 Statistically significant results are indicated by bold-faced type in the table.
2 Bonferroni test indicates which ANOVA comparisons are statistically significant within a three-way comparison.

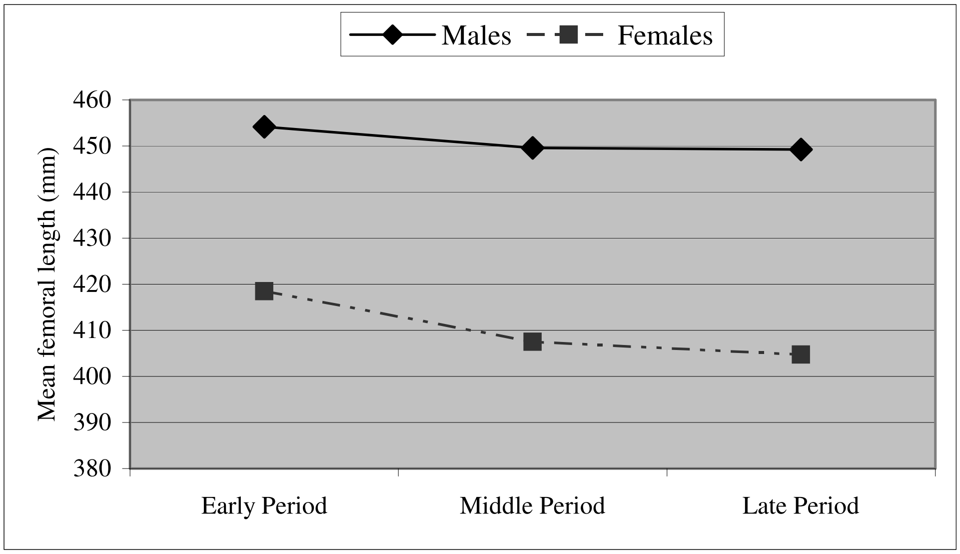

**Figure 8.2.** Comparison of male and female femoral length through time in San Francisco Bay.

*Regional Comparisons*

I controlled sex to compare stature differences between the Sacramento Valley and San Francisco Bay samples (Table 8.2). Figures 8.3 and 8.4 illustrate regional differences in mean femoral length for males and females, respectively. The results of Student's t-tests are provided in Table 8.4. For the statistical comparisons that could be computed, femora are significantly longer in the Sacramento Valley female sample than in the San Francisco Bay female sample (t = 2.829, df = 21, p = .01). Although differences are not significant (or could not be computed) for most comparisons, San Francisco Bay males are, on average, slightly taller than their Sacramento Valley counterparts, while the opposite is true for females (and significantly so for the Late period sample). Although these patterns are interesting, no substantive conclusions can be drawn, except that Late period females in the Sacramento Valley sample were significantly taller (~7.7 cm) than females in the San Francisco Bay sample.

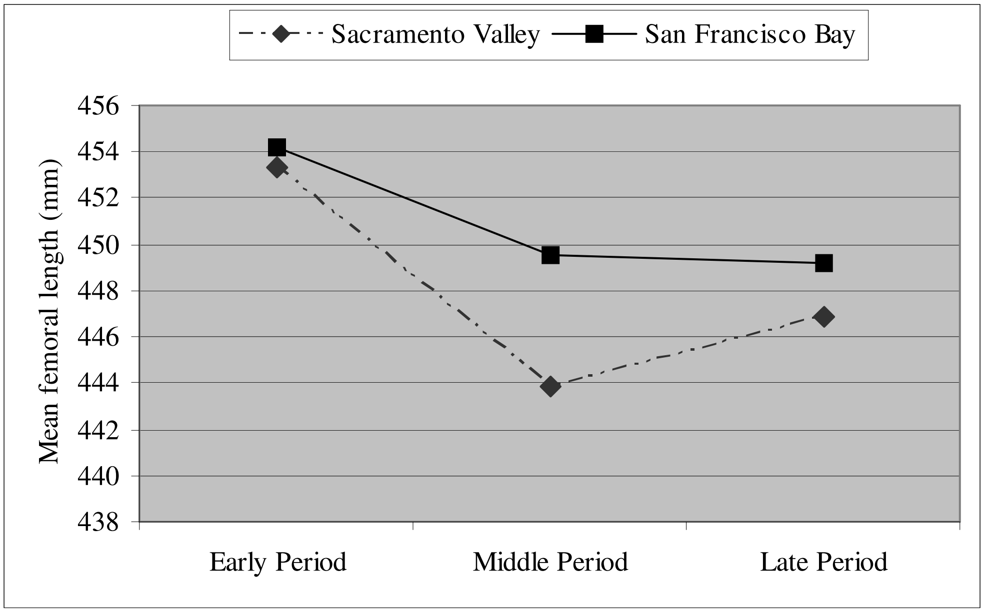

**Figure 8.3.** Regional comparison of femoral length in Sacramento Valley and San Francisco Bay males.

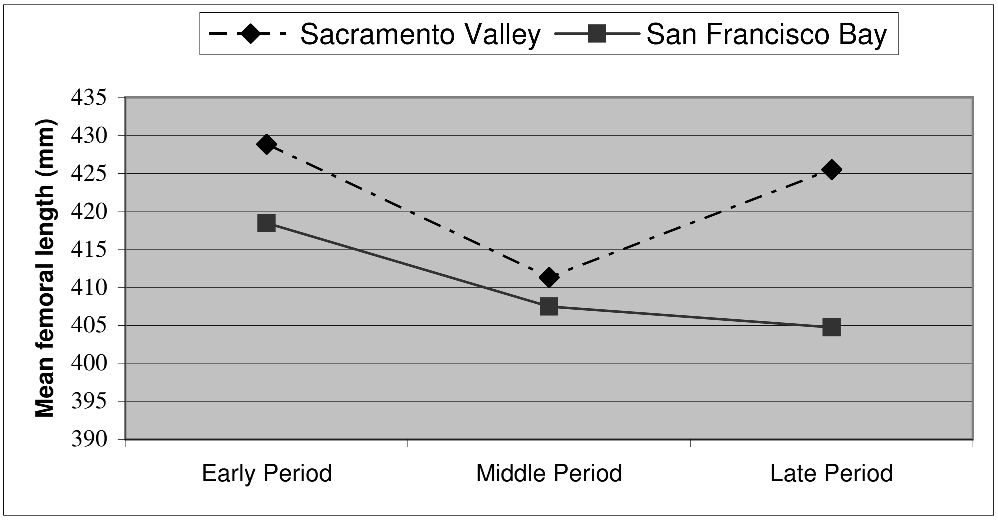

**Figure 8.4.** Regional comparison of femoral length in Sacramento Valley and San Francisco Bay females.

Table 8.4. T-test Results for Regional Differences in Mean Femoral Length.

| Period | t-statistic | df | p-value[1] | Trend | Difference (cm) |
|---|---|---|---|---|---|
| **Males** | | | | | |
| Early Period | | | | SFB>SV | .09 |
| Middle Period | -1.032 | 41 | .308 | SFB>SV | .57 |
| Late Period | -.269 | 17 | .791 | SFB>SV | .23 |
| **Females** | | | | | |
| Early Period | | | | SV>SFB | 1.03 |
| Middle Period | | | | SV>SFB | .38 |
| Late Period | 2.828 | 21 | **.010** | SV>SFB | 2.07 |

[1] Statistically significant results (p<.05) are indicated by bold-faced type in the table.

### *Sex Comparisons*

Sex differences in mean femoral length are presented in Table 8.2 and Figure 8.1 for the Sacramento Valley sample. The results of Student's t-tests are provided in Table 8.5. Due to the degree of sexual dimorphism expressed in many Amerindian populations, significant sex differences are expected in studies of prehistoric skeletal samples (Larsen 1997). However, relative differences in stature between the sexes can provide insight into biologically and/or culturally mediated factors that had differential effects on health during the period of growth and development (Ortner 1998, 2003). For the Sacramento Valley sample, mean femoral length is greater in males than females, and these differences are statistically significant for all three periods (Early period, t = 6.505, df = 64.122, p = .001; Middle period, t = 7.738, df = 53, p = .001; Late period, t = 3.021, df = 23, p = .006). The mean difference is 2.45 cm for the Early period, 3.26 cm for the Middle period, and 2.14 cm for the Late period, which corresponds to approximate total stature differences of 9.1, 12.1, and 7.9 cm, respectively.

Table 8.5. T-test Results for Mean Femoral Length Differences Between Males and Females in Central California.

| **Period** | **t-statistic** | **df** | **p-value**[1] | **trend** | **Difference (cm)** |
|---|---|---|---|---|---|
| **Sacramento Valley** | | | | | |
| Early Period | 6.505 | 64.122 | **.001** | M>F | 2.45 |
| Middle Period | 7.738 | 53 | **.001** | M>F | 3.26 |
| Late Period | 3.021 | 23 | **.006** | M>F | 2.14 |
| **San Francisco Bay** | | | | | |
| Early Period | | | | M>F | 3.58 |
| Middle Period | | | | M>F | 4.21 |
| Late Period | 5.040 | 15 | **.001** | M>F | 4.45 |

[1] Statistically significant results are indicated by bold-faced type in the table.

Sex differences in mean femoral length are presented in Table 8.2 and Figure 8.2 for the San Francisco Bay sample. Although a non-normal distribution prevented statistical comparisons for the Early and Middle period samples, differences in mean femoral length between the sexes follow a similar pattern to that identified for the Sacramento Valley sample. The mean difference is 3.58 cm for the Early period, 4.21 cm for the Middle period, and 4.45 cm for the Late period. In the Late period, significant sex differences are found between males and females (t = 5.04, df = 15, p = .001). The difference in mean femoral length is 4.45 cm, which corresponds to an approximate stature difference of approximately 16.5 cm.

### ***Summary***

In the Sacramento Valley sample, mean femoral length significantly declined between the Early and Middle period in females, although this trend was reversed in the Late period. Although small sample size prevented most comparisons in the San Francisco Bay sample, mean femoral length was higher for Early period males and females than in their Middle and Late period counterparts. Late period Sacramento Valley females were also significantly taller than their San Francisco Bay counterparts. Sexual dimorphism in mean femoral length peaked during the Middle period in both the Sacramento Valley and San Francisco Bay samples. In the Late period, sex differences in mean femoral length in the San Francisco Bay exceeded that found in the Sacramento Valley sample, which may suggest a greater level of sexual inequality in overall health and/or nutritional status during this time period in San Francisco Bay.

# CHAPTER IX

# POROTIC HYPEROSTOSIS

“Porotic hyperostosis” refers to porotic or sieve-like lesions that are commonly observed on prehistoric crania. Most researchers interpret these lesions as osseous responses to acquired childhood anemia caused by iron-deficient diets, parasitism, and infection, or by a combination of these factors (Blom et al. 2005; El-Najjar et al. 1976; Facchini et al. 2004; Glen-Haduch et al. 1997; Grauer 1993; Kent 1986; Mensforth et al. 1978; Salvadei et al. 2001; Stuart-Macadam 1985, 1987a, 1987b, 1992; Sullivan 2005; Walker 1985, 1996; Wright and Chew 1999). In this chapter, I examine differences in the prevalence of porotic hyperostosis in prehistoric crania from central California by time period, by region, and by sex as a measure of childhood health status.

## *Literature Review*

Recent bioarchaeological studies emphasize the multi-factorial nature of acquired anemia, and recognize that both nutritional status and pathogen load may work synergistically in the development of cranial lesions. Although the genetic anemias (e.g., sickle-cell anemia and thalassemia) show a similar pattern of skeletal involvement as the acquired anemias, these conditions were not present in the Americas during the pre-Columbian period (Angel 1966; Hershkovitz et al. 1997; Ortner 2003:370). Porotic hyperostosis is a common condition found in archaeological skeletons, especially among prehistoric agricultural societies (Cohen and Armelagos 1984; El-Najjar et al. 1976; Holland and O’Brien 1997; Larsen 1995, 1997; Walker 1985). Early studies of porotic hyperostosis took a strictly nutritional interpretation, since heavy consumption of iron-deficient plant staples is linked with childhood anemia in many living societies (El-Najjer 1976; El-Najjar et al. 1976; Lallo et al. 1977). For instance, El-Najjar et al. (1976) interpreted porotic lesions in prehistoric crania from the southwestern United States as evidence of iron-deficiency anemia, resulting from the heavy consumption of iron-poor maize.

Anemia is a condition in which the number of red blood cells or the amount of hemoglobin within them is below normal levels. Hemoglobin, the main protein of red blood cells, is responsible for oxygen transport from the lungs to other bodily tissues via the bloodstream. Adequate iron intake is critical for cellular growth, oxygen transport to bodily tissues, and oxidative metabolism, and can only be met through sufficient iron in the diet (Ryan 1997:25). Hence, iron-deficiency anemia occurs when the amount of dietary iron that is absorbed by the digestive system is insufficient to meet nutritional requirements and adequate production of red blood cells (erythropoiesis). Although infants accumulate iron in utero, these stores are depleted between the first four to six months of life, after which the diet becomes the primary source of iron (El-Najjar et al. 1976; Wright and Chew 1999). The human digestive system can readily access heme and ferrous iron from meats and fish, although bioavailability in many plant foods is significantly lower (Roberts and Manchester 1995; Ryan 1997). Some plant staples, such as maize, are deficient in iron and contain phytic acids that may further inhibit iron absorption by the digestive system. Deficiencies in other dietary nutrients, such as ascorbic acid, proteins, and amino acids also contribute to the depletion of bioavailable iron (Ryan 1997). Present in many plant foods including acorns, tannins also inhibit iron and vitamin B-12 intake by the digestive system. In contrast, foods that are high in Vitamin C may aid in the absorption of bioavailable iron (Roberts and Manchester 1995).

Although inadequate dietary iron is one cause of acquired anemia, weanling diarrheal disease due to parasitic infestation (helminthiasis) or bacterial infection may also result in secondary loss of blood and iron (Goodman 1994; Holland and O'Brien 1997; Kent 1986, 1992; Larsen 1995, 1997; Mensforth et al. 1978; Rothschild 2002; Ryan 1997; Stuart-Macadam 1992a, 1992b; Walker 1986; Wright and Chew 1999). The fact that some non-agricultural societies have high levels of porotic hyperostosis suggests that non-dietary factors also play a role. For example, coastal populations that consumed iron-rich marine foods from southern California and British Columbia show frequencies of porotic hyperostosis that are as high as that reported for many agricultural groups (Bathurst 2004; Cybulski 1977, 1992; Lambert 1994; Lambert and Walker 1991; Walker 1986).

Helminthiasis can be acquired through contaminated water supply, consumption of fish and sea mammals that carry parasites, or direct contact with skin, and may cause anemia through chronic abdominal bleeding and diarrhea (Bathurst 2004; Blom et al. 2005; Merid et al. 2001; Rothschild 2002; Walker 1986). Helminth infestation is a common problem in modern developing nations and is often associated with unsanitary living conditions and high population density (Aufderheide and Rodríguez-Martín 1998:223; Crompton 1999; Goncalves et al. 2003).

Recent archaeoparasitological research has identified eggs of fish tapeworm (*Diphyllobothrium spp.*) and human roundworm (*Ascaris lumbricoides*) in prehistoric shell mound sites from the Pacific Coast of Canada (Bathurst 2004). *Diphyllobothrium spp.* use freshwater and anadromous fish as an intermediary to human hosts and has been linked to pernicious anemia in humans (vitamin B12 deficiency). Salmon are common carriers of tapeworm in the Pacific region and larvae may survive in raw, dried, or even cold-smoked fish (Bathurst 2004:5). *Ascaris lumbricoides* is specific to humans and is acquired through consumption of food or water that is contaminated by fertilized eggs (Goncalves et al. 2003). Porotic hyperostosis identified in crania from the Pacific Coast of Canada provides support for the role of parasites in the development of acquired anemia in some maritime settings (Cybulski 1977, 1992).

Some researchers have interpreted anemia as an adaptive response to heavy or chronic pathogen load rather than iron deficient diets, a hypothesis referred to as the "anemia of chronic disease" or the "anemia of infection" (Kent 1986, 1992; Stuart-Macadam 1992a, 1992b). For example, researchers have found that the digestive system is capable of adjusting its capacity to absorb dietary iron, based not only on daily need but also in response to microbial invasion. This argument states that the withholding of iron (hypoferremia) is part of body's natural defense mechanism from invading microorganisms, such as bacteria and parasites (Stuart-Macadam 1987b, 1992a, 1992b, Weinberg 1992). Mild anemia may then lower the absorption of dietary iron and decrease serum iron levels, thus protecting against microbial infection. Stuart-Macadam (1987b, 1992a, 1992b) has argued that the association between high levels of porotic hyperostosis and agricultural subsistence is coincidental, since agricultural populations are sedentary and present conditions that are conducive to bacterial infection. Since individuals who are even mildly anemic have reduced work capacity, diminished motor function, and higher rates of mortality, many researchers have rejected the premise that iron-deficiency can be viewed as adaptive (Goodman 1994; Holland and O'Brien 1997).

Angel (1966) coined the term "porotic hyperostosis" (alternately, spongy hyperostosis, symmetrical osteoporosis, or cribra cranii externa) to describe porotic lesions located on crania from prehistoric Greece. "Cribra orbitalia" is used to refer specifically to lesions that affect the orbital plate of the frontal bone, whereas cranial porotic hyperostosis is often used to describe the lesions of the cranial vault (Ortner 2003). The high degree of association between orbital and vault lesions suggests a link between the two features (Roberts and Manchester 1995:167; Stuart-Macadam 1987a, 1989). Porotic hyperostosis and cribra orbitalia are characterized by pitting of the external lamina of the cranial vault and the superior border of the eye orbit, respectively (Schultz 2001; Stuart-Macadam 1985). Approximately 90 percent of lesions show bilateral involvement (Aufderheide and Rodríguez-Martín 1998:349; Stuart-Macadam 1989).

Anemia-related porotic hyperostosis is defined by enlarged marrow spaces (i.e., marrow hyperplasia) within the diploë of the orbital roof and cranial vault. Increased pressure from hematopoietic tissue within the vault produces thinning of the external lamina, which becomes porous, thus permitting the exposure of underlying cancellous bone (diploë). Orbital and vault lesions occur between infancy and early childhood when cranial bones are thin and pliable (Stuart-Macadam 1985, 1987a). In adulthood, fatty yellow marrow replaces much of the hematopoietic tissue in the diploë space, preventing the formation of new lesions. Hence, porotic hyperostosis observed in adult crania represents a childhood condition (Stuart-Macadam 1985). Cribra orbitalia often manifests during infancy and is believed to precede vault lesions (Stuart-Macadam 1989). This suggests that orbital lesions provide a better record of acquired anemia during infancy, while vault lesions provide a better record of early childhood anemia. In its active stage, porotic hyperostosis may show significant vault thickening and may produce the classic "hair-on-end" appearance observed on radiographs (Stuart-Macadam 1987a). Active lesions are most common in juvenile crania between the ages of six months and five years of age (Stuart-Macadam 1989). In the healed state, lesions show sclerotic margins with smooth edges and range from small pits (< 1 mm) on the external table to large fenestrae that perforate into the diploë (Stuart-Macadam 1989).

### *Methods*

A limiting factor in paleopathological research is that differential skeletal preservation, excavation methods, and cultural burials practices all reduce the number and representation of skeletal elements available for observation (Walker et al. 1988). To address this problem, I scored the degree of completeness of left and right eye orbits and cranial vault bones as follows:

1) 76 to 100 percent complete
2) 51 to 75 percent complete
3) 26 to 50 percent complete
4) 0 to 25 percent complete.

For each adult and subadult cranium, I scored the presence or absence of cribra orbitalia of the orbital roof and porotic hyperostosis of the cranial vault. In this analysis, I include crania that had least one orbital roof that was > 50 percent complete. Since I scored both sides, I used the side with the most severe expression to represent the condition. When one side was incomplete or absent, I used the side that was present to represent the condition. In scoring vault porosity, I include observations for crania that are reasonably intact. To be included in the analysis, a cranium had to have at least one complete parietal bone, and also at least one frontal and occipital bone that were >50 percent complete.

I scored the severity of expression of cribra orbitalia and porotic hyperostosis using the following system, which is adapted from *Standards for Data Collection* (Buikstra and Ubelaker 1994). I scored lesion severity as follows:

1) Porosity absent
2) External table porosity only, no evidence of cranial vault thickening
3) External table porosity, with coalescence of foraminae, no evidence of cranial vault thickening
4) External table porosity, with coalescence of foraminae with coral-like hyperostosis, evidence of cranial vault thickening
5) Slight porosity, pinpoint size (indeterminate porosity, limited to external table)

Evidence of pinprick porosity (score = 4) may represent mild cases of porotic hyperostosis but was not considered in this analysis. The small pore size of this condition may be due to scalp infection, osteoporosis, or the result of taphonomic erosion. Since mild lesions (score = 1) may also be ambiguous in this regard, I compared the presence and absence of cribra orbitalia and porotic hyperostosis both with and without these lesions included. I also combined the frequency of moderate and severe lesions into a moderate/severe category. I scored lesions based on whether they appeared to be active, healed, or showed signs of both processes. Since aboriginal Californians did not practice cranial deformation, this did not warrant consideration in lesion assessments. I use the chi-square and Fisher's Exact statistic to test for significant associations between the proportion of individuals with cranial and orbital lesions and age, sex, time period, and region. To account for the increased probability of obtaining statistically significant results ($p < .05$) due to random chance with multiple comparisons, I set the alpha level for statistical significance at $p< .017$. However, I treat p-values between .018 and .05 as approaching statistical significance.

### ***Results***

In this section, I first describe the distribution of lesions that were active, healed, or in the process of healing at the time of death. I use the term "cribra orbitalia" to refer to lesions of the orbital roof and "porotic hyperostosis" to refer specifically to the porous lesions on the cranial vault. Table 9.1 summarizes the distribution of cribra orbitalia and porotic hyperostosis by state of healing for each geographic region. The vast majority of the lesions are fully healed, ranging from 85.3 to 96.3 percent healed in adults and from 60 to 100 percent healed in subadults. In general, subadults show the highest prevalence of active and mixed reaction lesions, which is consistent with the hypothesis that lesions develop in childhood and represent healed scars in adults. Although I classified lesions as "active" in three adults for cribra orbitalia and two adults for porotic hyperostosis, this may be due to observer error in the classification of healing stages. There are no consistent patterns between the sexes or between the regions with respect to healing state for either orbital roof or cranial vault lesions.

Table 9.1. Distribution of Healed and Non-Healed Orbital and Vault in Prehistoric Central California.

| | | | Cribra orbitalia | | | Porotic hyperostosis | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Sex/Age** | **Affected** | **Active** | **Healed** | **Mixed** | **Active** | **Healed** | **Mixed** |
| Sacramento Valley | Males | N | 1/21 | 20/21 | 0/21 | 0/45 | 42/45 | 3/45 |
| | | % affected | 4.8 | 95.2 | 0.0 | 0.0 | 93.3 | 6.7 |
| | Females | N | 1/34 | 29/34 | 4/34 | 1/44 | 40/44 | 3/44 |
| | | % affected | 2.9 | 85.3 | 11.8 | 2.3 | 90.9 | 6.8 |
| | Subadults | n | 0/17 | 12/17 | 5/17 | 2/13 | 9/13 | 2/13 |
| | | % affected | 0.0 | 70.6 | 29.4 | 15.4 | 69.2 | 15.4 |
| San Francisco Bay | Males | n | 0/27 | 26/27 | 1/27 | 1/56 | 50/56 | 5/56 |
| | | % affected | 0.0 | 96.3 | 3.7 | 1.8 | 89.3 | 8.9 |
| | Females | n | 0/28 | 26/28 | 2/28 | 1/48 | 46/48 | 1/48 |
| | | % affected | 0.0 | 92.9 | 7.1 | 2.1 | 95.8 | 2.1 |
| | Subadults | n | 0/6 | 6/6 | 0/6 | 0/5 | 3/5 | 2/5 |
| | | % affected | 0.0 | 100 | 0.0 | 0.0 | 60.0 | 40.0 |

### *Temporal Comparisons*

Table 9.2 and Figure 9.1 summarize the distribution of cribra orbitalia in the Sacramento Valley sample. Statistical results for temporal comparisons are presented in Table 9.3. The “total” column in Table 9.2 includes all adult and subadult crania. The prevalence of cribra orbitalia in the total sample (pooled periods) is 34.1 percent. When partitioned by severity, moderate to severe lesions account for 11.0 percent of the total lesions. When adults and subadults are considered as a group, the prevalence of cribra orbitalia is 30.7, 28.8, and 51.2 percent for the Early, Middle, and Late periods, respectively (Table 9.2). Orbital lesions are significantly more common in the Late period sample than in the Middle period sample (Middle vs. and Late period, $X^2$= 5.818, p = .016). The difference in the proportion of affected crania approaches significance for comparisons between the Early and Late period samples ($X^2$ = 5.433, p = .02).

When the data are partitioned by sex, cribra orbitalia is present in 26.3, 35.7, and 12.5 percent of male crania and 31.4, 25.0, and 51.9 percent of female crania for the Early, Middle, and Late period sample, respectively. The prevalence of orbital lesions approaches a significant difference only for comparisons of Middle and Late period females ($X^2$ = 4.799, p = .028). For subadults, the prevalence of orbital lesions is 36.4, 33.3, and 87.5 percent for the Early, Middle, and Late period samples, respectively. Differences in the proportion of affected crania approach statistical significance for comparisons between the Early and late period samples (Fisher's Exact, p = .035). When only moderate to severe lesions are considered, similar trends and statistical patterns hold as found by the previous comparisons (Table 9.3).

The distribution of porotic hyperostosis in the Sacramento Valley sample is presented in Table 9.2 and Figure 9.2. Porotic hyperostosis affected nearly one-half of all crania (47.7 percent) in the "pooled periods" sample, and moderate to severe lesions account for 18.4 percent of the total lesions. When adults and subadults are considered as a group, the prevalence of porotic hyperostosis is 42.9, 48.0, and 61.9 percent for the Early, Middle, and Late period samples, respectively. Vault lesions are more common in the Late period sample than in the Early period sample, but this difference only approaches statistical significance ($X^2$ = 4.359, p = .037; Table 9.3). When the data are partitioned by sex, the prevalence of vault lesions is 60.0, 65.5, and 28.6 percent for

Table 9.2. Distribution of Cribra Orbitalia and Porotic Hyperostosis in Prehistoric Central California.

| **Period** | | **Cribra Orbitalia (All Levels)** | | | | **Cribra Orbitalia (Moderate/Severe)** | | | | **Porotic Hyperostosis (All Levels)** | | | | **Porotic Hyperostosis (Moderate/ Severe)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Affected** | **Male** | **Female** | **Subadult** | **Total**[1] | **Male** | **Female** | **Subadult** | **Total**[1] | **Male** | **Female** | **Subadult** | **Total**[1] | **Male** | **Female** | **Subadult** | **Total**[1] |
| **Sacramento Valley** | | | | | | | | | | | | | | | | | |
| Early Period | N | 10/38 | 11/35 | 8/22 | 31/101 | 2/39 | 3/35 | 2/22 | 7/102 | 24/40 | 13/37 | 5/22 | 45/105 | 10/40 | 4/37 | 2/22 | 16/105 |
| | % affected | 26.3 | 31.4 | 36.4 | 30.7 | 5.1 | 8.6 | 9.1 | 6.9 | 60.0 | 35.1 | 22.7 | 42.9 | 25.0 | 10.8 | 9.1 | 15.2 |
| Middle Period | N | 10/28 | 9/36 | 2/6 | 21/73 | 4/28 | 1/36 | 1/6 | 6/73 | 19/29 | 13/35 | 2/8 | 35/75 | 10/29 | 5/35 | 1/8 | 16/75 |
| | % affected | 35.7 | 25.0 | 33.3 | 28.8 | 14.3 | 2.8 | 16.7 | 8.2 | 65.5 | 37.1 | 25.0 | 48.0 | 34.5 | 14.3 | 12.5 | 21.3 |
| Late Period | N | 1/8 | 14/27 | 7/8 | 22/43 | 1/8 | 6/27 | 4/8 | 11/43 | 2/7 | 18/27 | 6/8 | 26/42 | 2/7 | 4/28 | 3/8 | 9/43 |
| | % affected | 12.5 | 51.9 | 87.5 | 51.2 | 12.5 | 22.2 | 50.0 | 25.6 | 28.6 | 66.7 | 75.0 | 61.9 | 28.6 | 14.3 | 37.5 | 20.9 |
| Pooled Periods | N | 21/74 | 34/98 | 17/36 | 74/217 | 7/75 | 10/98 | 7/36 | 4/218 | 45/76 | 44/99 | 13/38 | 106/222 | 22/76 | 13/100 | 6/38 | 41/223 |
| | % affected | 28.4 | 34.7 | 47.2 | 34.1 | 9.3 | 10.2 | 19.4 | 11.0 | 59.2 | 44.4 | 34.2 | 47.7 | 28.9 | 13.0 | 15.8 | 18.4 |
| **San Francisco Bay** | | | | | | | | | | | | | | | | | |
| Early Period | N | 4/8 | 6/15 | 3/6 | 13/29 | 2/8 | 3/15 | 0/6 | 5/29 | 13/15 | 16/22 | 3/9 | 32/46 | 9/15 | 6/22 | 3/9 | 18/46 |
| | % affected | 50.0 | 40.0 | 50.0 | 44.8 | 25.0 | 20.0 | 0.0 | 17.2 | 86.7 | 72.7 | 33.3 | 69.6 | 60.0 | 27.3 | 33.3 | 39.1 |
| Middle Period | N | 14/24 | 14/30 | 0/4 | 32/65 | 8/24 | 7/31 | 0/3 | 18/65 | 23/26 | 19/32 | 1/4 | 51/70 | 20/26 | 10/32 | ¼ | 36/70 |
| | % affected | 58.3 | 46.7 | 0.0 | 49.2 | 33.3 | 22.6 | 0.0 | 27.7 | 88.5 | 59.4 | 25.0 | 72.9 | 76.9 | 31.3 | 25.0 | 51.4 |
| Late Period | N | 9/23 | 8/22 | 3/5 | 22/53 | 7/23 | 5/22 | 2/5 | 15/53 | 20/24 | 13/22 | 1/5 | 36/53 | 14/24 | 11/22 | 0/5 | 26/53 |
| | % affected | 39.1 | 36.4 | 60.0 | 41.5 | 30.4 | 22.7 | 40.0 | 28.3 | 83.3 | 59.1 | 20.0 | 67.9 | 58.3 | 50.0 | 0.0 | 49.1 |
| Pooled Periods | N | 27/55 | 28/67 | 6/15 | 67/147 | 17/55 | 15/68 | 2/14 | 38/147 | 56/65 | 48/65 | 5/18 | 119/169 | 43/65 | 27/76 | 4/18 | 80/169 |
| | % affected | 49.1 | 41.8 | 40.0 | 45.6 | 30.9 | 22.1 | 14.3 | 25.9 | 86.0 | 73.8 | 27.8 | 70.4 | 66.2 | 35.5 | 22.2 | 47.3 |

[1] Totals include individuals of indeterminate sex.

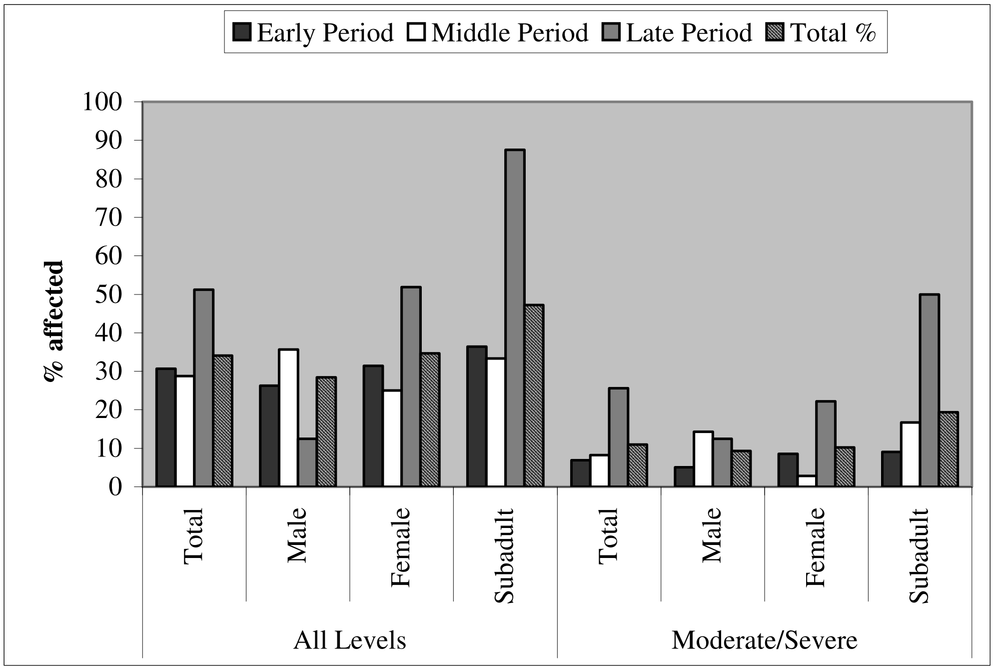

**Figure 9.1.** Distribution of cribra orbitalia in the Sacramento Valley sample.

Table 9.3. Chi-Square and Fisher's Exact Test Results for Temporal Differences in Prevalence of Cribra Orbitalia and Porotic Hyperostosis in Prehistoric Central California.

| | | | Cribra Orbitalia (All Levels) | | | | Cribra Orbitalia (Moderate/Severe) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Region** | **Sex** | **Testing** | **$X^2$, F.E..** | **p value$^1$** | **n$^3$** | **Trend** | **$X^2$, F.E.** | **p value$^1$** | **n$^3$** | **Trend** |
| Sacramento Valley | Males | EP vs. MP | .674 | .412 | 10/38 vs. 10/28 | | F.E. | .227 | 2/39 vs. 4/28 | |
| | | EP vs. LP | F.E. | .658 | 10/38 vs. 1/8 | | F.E. | .436 | 2/39 vs. 1/8 | |
| | | MP vs. LP | F.E. | .388 | 10/28 vs. 1/8 | | F.E. | 1.000 | 4/28 vs. 1/8 | |
| | Females | EP vs. MP | .362 | .547 | 11/35 vs. 9/36 | | F.E. | .357 | 3/35 vs. 1/36 | |
| | | EP vs. LP | 2.642 | .104 | 11/35 vs. 14/27 | | F.E. | .160 | 3/35 vs. 6/27 | |
| | | MP vs. LP | 4.799 | .028 | 9/36 vs. 14/27 | MP<LP | F.E. | .036 | 1/36 vs. 6/27 | MP<LP |
| | Subadults | EP vs. MP | F.E. | 1.000 | 8/22 vs. 2/6 | | F.E. | .530 | 2/22 vs. 1/6 | |
| | | EP vs. LP | F.E. | .035 | 8/22 vs. 7/8 | EP<LP | F.E. | .029 | 2/22 vs. 4/8 | EP<LP |
| | | MP vs. LP | F.E. | .091 | 2/6 vs. 7/8 | | F.E. | .301 | 1/6 vs. 4/8 | |
| | Total$^2$ | EP vs. MP | .075 | .784 | 31/101 vs. 21/73 | | .114 | .736 | 7/102 vs. 6/73 | |
| | | EP vs. LP | 5.433 | .020 | 31/101 vs. 22/43 | EP<LP | 9.748 | **.002** | 7/102 vs. 11/43 | EP<LP |
| | | MP vs. LP | 5.818 | **.016** | 21/73 vs. 22/43 | MP<LP | 6.522 | **.011** | 6/73 vs. 11/43 | MP<LP |
| San Francisco Bay | Males | EP vs. MP | F.E. | .703 | 4/8 vs. 14/24 | | F.E. | 1.000 | 2/8 vs. 8/24 | |
| | | EP vs. LP | F.E. | .689 | 4/8 vs. 9/23 | | F.E. | 1.000 | 2/8 vs. 7/23 | |
| | | MP vs. LP | 1.733 | .188 | 14/24 vs. 9/23 | | .045 | .831 | 8/24 vs. 7/23 | |
| | Females | EP vs. MP | .180 | .671 | 6/15 vs. 14/30 | | F.E. | 1.000 | 3/15 vs. 7/31 | |
| | | EP vs. LP | .050 | .823 | 6/15 vs. 8/22 | | F.E. | 1.000 | 3/15 vs. 5/22 | |
| | | MP vs. LP | .552 | .458 | 14/30 vs. 8/22 | | F.E. | 1.000 | 7/31 vs. 5/22 | |
| | Subadults | EP vs. MP | F.E. | .200 | 3/6 vs. 0/4 | | F.E. | 1.000 | 0/6 vs. 0/3 | |
| | | EP vs. LP | F.E. | 1.000 | 3/6 vs. 3/5 | | F.E. | .182 | 0/6 vs. 2/5 | |
| | | MP vs. LP | F.E. | .167 | 0/4 vs. 3/5 | | F.E. | .464 | 0/3 vs. 2/5 | |
| | Total$^2$ | EP vs. MP | .156 | .693 | 13/29 vs. 32/65 | | 1.185 | .276 | 5/29 vs. 18/65 | |
| | | EP vs. LP | .084 | .771 | 13/29 vs. 22/53 | | 1.243 | .265 | 5/29 vs. 15/53 | |
| | | MP vs. LP | .701 | .402 | 32/65 vs. 22/53 | | .005 | .942 | 18/65 vs. 15/53 | |

Table 9.3 Continued.

| | | | Porotic Hyperostosis (All Levels) | | | | Porotic Hyperostosis (Moderate/Severe) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Region** | **Sex** | **Testing** | **$X^2$, F.E..** | **p value[1]** | **n[3]** | **Trend** | **$X^2$, F.E.** | **p value[1]** | **n[3]** | **Trend** |
| Sacramento Valley | Males | EP vs. MP | .218 | .641 | 24/40 vs. 19/29 | | .734 | .391 | 10/40 vs. 10/29 | |
| | | EP vs. LP | F.E. | .217 | 24/40 vs. 2/7 | | F.E. | 1.000 | 10/40 vs. 2/7 | |
| | | MP vs. LP | F.E. | .103 | 19/29 vs. 2/7 | | F.E. | 1.000 | 10/29 vs. 2/7 | |
| | Females | EP vs. MP | .031 | .859 | 13/37 vs. 13/35 | | F.E. | .732 | 4/37 vs. 5/35 | |
| | | EP vs. LP | 6.214 | **.013** | 13/37 vs. 18/27 | EP<LP | F.E. | .717 | 4/37 vs. 4/28 | |
| | | MP vs. LP | 5.314 | .021 | 13/35 vs. 18/27 | MP<LP | F.E. | 1.000 | 5/35 vs. 4/28 | |
| | Subadults | EP vs. MP | F.E. | 1.000 | 5/22 vs. 2/8 | | F.E. | 1.000 | 2/22 vs. 1/8 | |
| | | EP vs. LP | F.E. | .028 | 5/22 vs. 6/8 | EP<LP | F.E. | .102 | 2/22 vs. 3/8 | |
| | | MP vs. LP | F.E. | .132 | 2/8 vs. 6/8 | | F.E. | .569 | 1/8 vs. 3/8 | |
| | Total[2] | EP vs. MP | .468 | .494 | 45/105 vs. 35/75 | | 1.112 | .292 | 16/105 vs. 16/75 | |
| | | EP vs. LP | 4.359 | .037 | 45/105 vs. 26/42 | EP<LP | .704 | .401 | 16/105 vs. 9/43 | |
| | | MP vs. LP | 2.090 | .148 | 35/75 vs. 26/42 | | .003 | .959 | 16/75 vs. 9/43 | |
| San Francisco Bay | Males | EP vs. MP | F.E. | 1.000 | 13/15 vs. 23/26 | | F.E. | .300 | 9/15 vs. 20/26 | |
| | | EP vs. LP | F.E. | 1.000 | 13/15 vs. 20/24 | | .011 | .918 | 9/15 vs. 14/24 | |
| | | MP vs. LP | F.E. | 1.000 | 23/26 vs. 20/24 | | 1.982 | .159 | 20/26 vs. 14/24 | |
| | Females | EP vs. MP | 1.019 | .313 | 16/22 vs. 19/32 | | .099 | .753 | 6/22 vs. 10/32 | |
| | | EP vs. LP | .910 | .340 | 16/22 vs. 13/22 | | 2.397 | .122 | 6/22 vs. 11/22 | |
| | | MP vs. LP | .001 | .983 | 19/32 vs. 13/22 | | 1.929 | .165 | 10/32 vs. 11/22 | |
| | Subadults | EP vs. MP | F.E. | 1.000 | 3/9 vs. 1/4 | | F.E. | 1.000 | 3/9 vs. 1/4 | |
| | | EP vs. LP | F.E. | 1.000 | 3/9 vs. 1/5 | | F.E. | .258 | 3/9 vs. 0/5 | |
| | | MP vs. LP | F.E. | 1.000 | 1/4 vs. 1/5 | | F.E. | .444 | 1/4 vs. 0/5 | |
| | Total[2] | EP vs. MP | .148 | .701 | 32/46 vs. 51/70 | | 1.687 | .194 | 18/46 vs. 36/70 | |
| | | EP vs. LP | .031 | .861 | 32/46 vs. 36/53 | | .983 | .322 | 18/46 vs. 26/53 | |
| | | MP vs. LP | .354 | .552 | 51/70 vs. 36/53 | | .068 | .794 | 36/70 vs. 26/53 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.
[2] Total includes individuals of indeterminate sex.
[3] Number affected/number examined.

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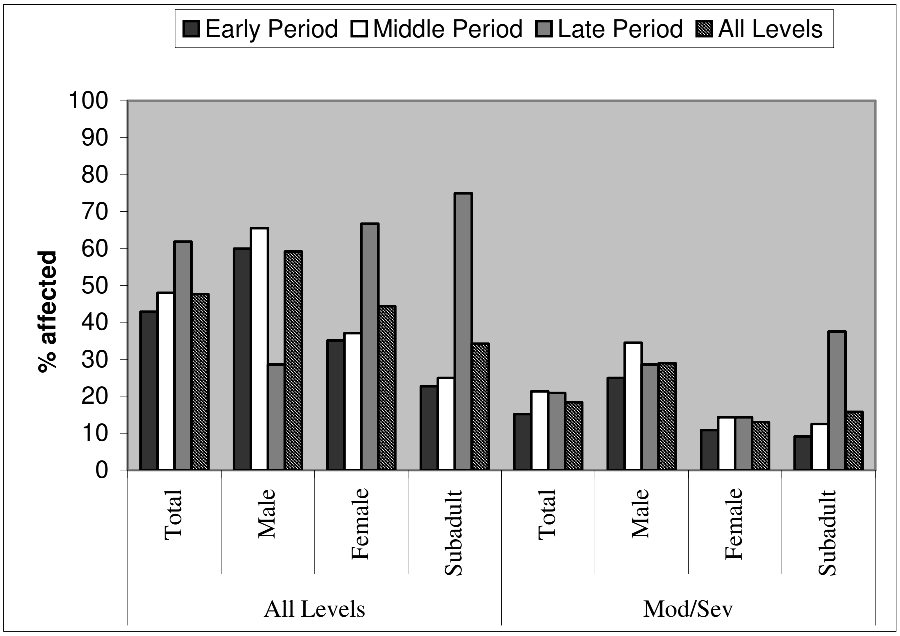

**Figure 9.2.** Distribution of porotic hyperostosis in the Sacramento Valley sample.

male crania, and 35.1, 37.1, and 66.7 percent for female crania for the Early, Middle, and Late period samples, respectively. Vault lesions are significantly more common in Late period females than in Early period females (Early vs. Late period, $X^2 = 6.214$, p = .013). However, the proportion of affected crania only approaches a significant difference for comparisons between the Middle and Late period female samples ($X^2 = 5.314$, p = .021). For subadults, the prevalence of vault lesions is 22.7, 25.0, and 75.0 percent for the Early, Middle, and Late period samples, respectively. Vault lesions are more common in the Late period sample than in the Early period sample for this group, although the difference only approaches statistical significance (Fisher's Exact, p = .028). When only moderate to severe lesions are considered, the proportion of individuals with porotic hyperostosis is not significantly different for all temporal comparisons of the adult and subadult samples.

The distribution of cribra orbitalia in the San Francisco Bay sample is summarized in Table 9.2 and Figure 9.3. The prevalence of cribra orbitalia in the total sample (pooled periods) is 45.6 percent. When partitioned by severity, moderate to severe lesions account for 25.9 percent of the total lesions. When adults and subadults are considered together as a group, the prevalence of cribra orbitalia is 44.8, 49.2, and 41.5 percent for the Early, Middle, and Late period samples, respectively; the prevalence of orbital lesions is not significantly different between time periods (Table 9.3).

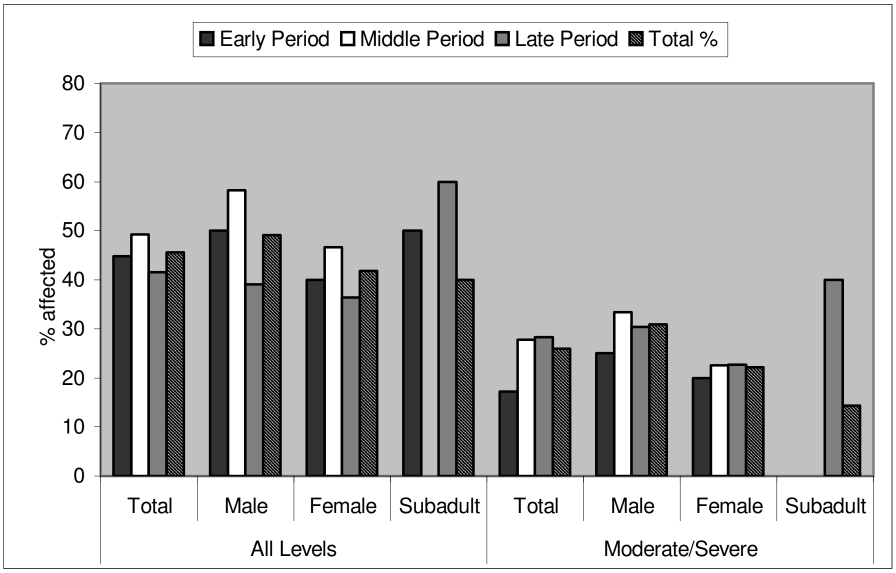

**Figure 9.3.** Distribution of cribra orbitalia in the San Francisco Bay sample.

When the data are partitioned by sex, cribra orbitalia is present in 50.0, 58.3, and 39.1 percent of male crania, and 40.0, 46.7, and 36.4 percent of female crania for the

Early, Middle, and Late period samples, respectively. The prevalence of orbital lesions is also not significantly different between time periods. Samples sizes for the subadult category are too small to be statistically meaningful.

The distribution of porotic hyperostosis in the San Francisco Bay sample is summarized in Table 9.2 and Figure 9.4. The prevalence of vault lesions in the total sample (pooled periods) is 70.4 percent. When partitioned by severity, moderate to severe lesions account for 47.3 percent of the total lesions. When adults and subadults are considered together as a group, vault lesions are present in 69.6, 72.9, and 67.9 percent of crania for the Early, Middle, and Late period samples, respectively. When the data are partitioned by sex, the prevalence of vault lesions is 86.7, 88.5, and 83.3 percent for male crania, and 72.7, 59.4, and 59.1 percent for female crania for the Early, Middle, and Late period samples, respectively. Similar to the trend observed for cribra orbitalia, the prevalence of vault lesions is not significantly different between time periods (Table 9.3). Samples sizes for the subadult category are again too small to be statistically meaningful.

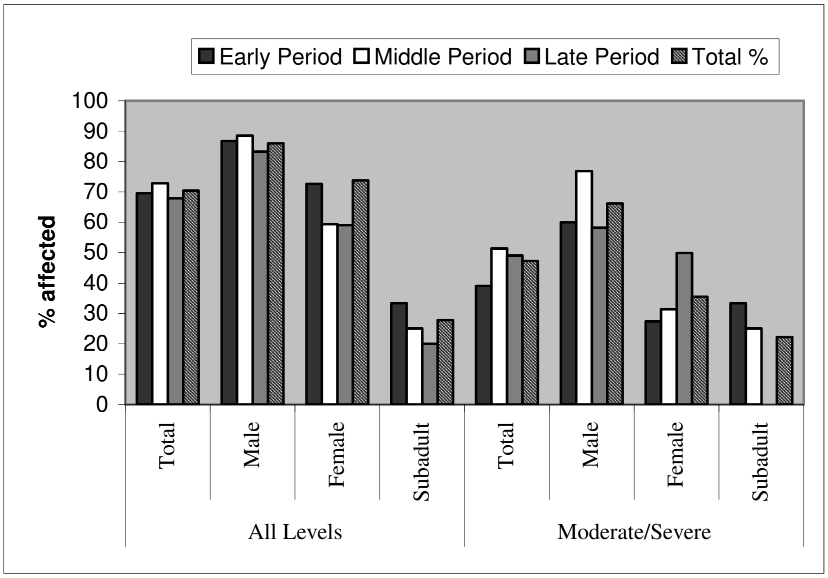

**Figure 9.4.** Distribution of porotic hyperostosis in the San Francisco Bay sample.

*Regional Comparisons*

Inter-regional comparisons of cribra orbitalia between the Sacramento Valley and San Francisco Bay samples are summarized in Table 9.2 and Figure 9.5. Statistical results for these comparisons are presented in Table 9.4. When adults and subadults are considered together as a group (pooled periods), the prevalence of orbital lesions is 45.6 percent for the San Francisco Bay sample and 34.1 percent for the Sacramento Valley sample, a difference that approaches statistical significance ($X^2$ = 4.864, p = .027). When only moderate to severe lesions are considered, 25.9 percent of crania in the San Francisco Bay sample are affected, whereas 11.0 percent of the Sacramento Valley sample are affected, a statistically significant difference ($X^2$ = 13.714, p = .001). When examined by time period, orbital lesions are also significantly more common in the Bay sample than in the Valley sample during the Middle period (all levels of severity, $X^2$ = 6.087, p = .014; moderate to severe lesions, $X^2$ = 9.076, p = .003).

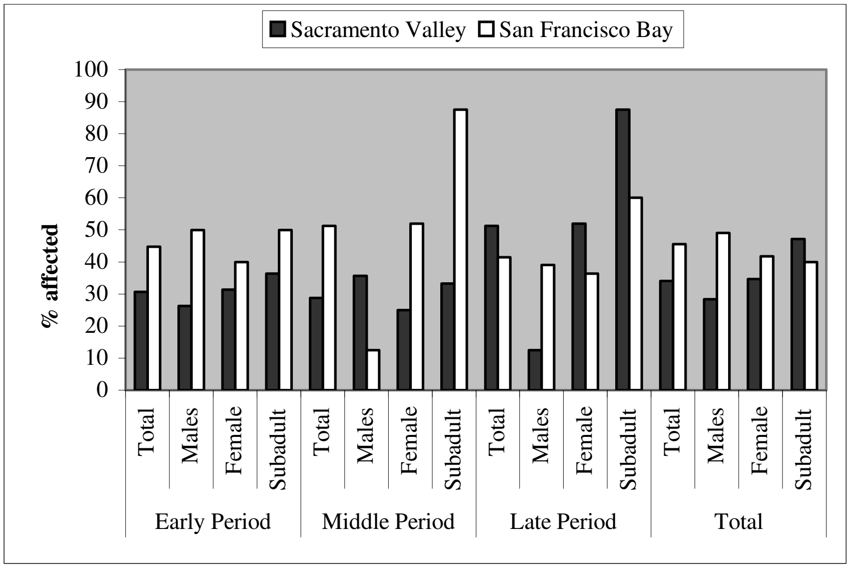

**Figure 9.5.** Distribution of cribra orbitalia (all levels of severity) in prehistoric central California by region.

Orbital lesions are significantly more common in male crania from San Francisco Bay than in male crania from the Sacramento Valley (all levels of severity: $X^2$ = 5.793, p = .016, moderate to severe lesions: $X^2$ = 9.813, p = .002). For female crania, the prevalence of moderate to severe lesions is higher in Bay samples than in Valley samples, although this difference only approaches statistical significance ($X^2$ = 4.41, p = .036). No significant differences are found between regions for the subadult samples.

Figure 9.6 summarizes the distribution of porotic hyperostosis by region (also see Table 9.2). Inter-regional comparisons of porotic hyperostosis mirror the patterns observed for cribra orbitalia. When adults and subadults are considered together as a

Table 9.4. Chi-Square and Fisher's Exact Test Results for Regional Comparisons of Cribra Orbitalia and Porotic Hyperostosis.

| | | **Cribra Orbitalia (All Levels)** | | | | **Cribra Orbitalia (Moderate/Severe)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sex/Age** | **Period** | **$X^2$, F.E.** | **p value[1]** | **n[3]** | **Trend** | **$X^2$, F.E.** | **p value[1]** | **n[3]** | **Trend** |
| Males | Early Period | F.E. | .222 | 10/38 vs. 4/8 | | F.E. | .129 | 2/39 vs. 2/8 | |
| | Middle Period | 2.660 | .103 | 10/28 vs. 14/24 | | F.E. | .186 | 4/28 vs. 8/24 | |
| | Late Period | F.E. | .222 | 1/8 vs. 9/23 | | F.E. | .642 | 1/8 vs. 7/23 | |
| | Periods Combined | 5.793 | **.016** | 21/74 vs. 27/55 | SFB>SV | 9.813 | **.002** | 7/75 vs. 17/55 | SFB>SV |
| Females | Early Period | .344 | .558 | 11/35 vs. 6/15 | | F.E. | .348 | 3/35 vs. 3/15 | |
| | Middle Period | 3.383 | .066 | 9/36 vs. 14/30 | | F.E. | .020 | 1/36 vs. 7/31 | SFB>SV |
| | Late Period | 1.175 | .278 | 14/27 vs. 8/22 | | F.E. | 1.000 | 6/27 vs. 5/22 | |
| | Periods Combined | .855 | .355 | 34/98 vs. 28/67 | | 4.41 | .036 | 10/98 vs. 15/68 | SFB>SV |
| Subadults | Early Period | F.E. | .657 | 8/22 vs. 3/6 | | F.E. | 1.000 | 2/22 vs. 0/6 | |
| | Middle Period | F.E. | .467 | 2/6 vs. 0/4 | | F.E. | 1.000 | 1/6 vs. 0/3 | |
| | Late Period | F.E. | .510 | 7/8 vs. 3/5 | | F.E. | 1.000 | 4/8 vs. 2/5 | |
| | Periods Combined | .223 | .637 | 17/36 vs. 6/15 | | F.E. | 1.000 | 7/36 vs. 2/14 | |
| Total[2] | Early Period | 2.010 | .156 | 31/101 vs. 13/29 | | 1.809 | .179 | 7/102 vs. 5/29 | |
| | Middle Period | 6.087 | **.014** | 27/73 vs. 32/65 | SFB>SV | 9.076 | **.003** | 6/73 vs. 18/65 | SFB>SV |
| | Late Period | .891 | .345 | 22/43 vs. 22/53 | | .089 | .765 | 11/43 vs. 15/53 | |
| | Periods Combined | 4.864 | .027 | 74/217 vs. 67/147 | SFB>SV | 13.714 | **.001** | 4/218 vs. 38/147 | SFB>SV |

Table 9.4 Continued.

| | | | | Porotic Hyperostosis (All Levels) | | | | Porotic Hyperostosis (Moderate/Severe) | |
|---|---|---|---|---|---|---|---|---|---|
| **Sex/Age** | **Period** | **$X^2$, F.E.** | **p value[1]** | **n[3]** | **Trend** | **$X^2$, F.E.** | **p value[1]** | **n[3]** | **Trend** |
| Males | Early Period | F.E. | .105 | 24/40 vs. 13/15 | | 5.91 | **.015** | 10/40 vs. 9/15 | SFB>SV |
| | Middle Period | 3.998 | .046 | 19/29 vs. 23/26 | SFB>SV | 9.959 | **.002** | 10/29 vs. 20/26 | SFB>SV |
| | Late Period | F.E. | **.012** | 2/7 vs. 20/24 | SFB>SV | F.E. | .220 | 2/7 vs. 14/24 | |
| | Periods Combined | 12.516 | **.001** | 45/76 vs. 56/65 | SFB>SV | 19.519 | **.001** | 22/76 vs. 43/65 | SFB>SV |
| Females | Early Period | 7.801 | **.005** | 13/37 vs. 16/22 | SFB>SV | F.E. | .152 | 4/37 vs. 6/22 | |
| | Middle Period | 3.312 | .069 | 13/35 vs. 19/32 | | 2.769 | .096 | 5/35 vs. 10/32 | |
| | Late Period | .299 | .584 | 18/27 vs. 13/22 | | 7.483 | **.006** | 4/28 vs. 11/22 | SFB>SV |
| | Periods Combined | 6.038 | **.014** | 44/99 vs. 48/65 | SFB>SV | 12.477 | **.001** | 13/100 vs. 27/76 | SFB>SV |
| Subadults | Early Period | F.E. | .660 | 5/22 vs. 3/9 | | F.E. | .131 | 2/22 vs. 3/9 | |
| | Middle Period | F.E. | 1.000 | 2/8 vs. 1/4 | | F.E. | 1.000 | 1/8 vs. 1/4 | |
| | Late Period | F.E. | .103 | 6/8 vs. 1/5 | | F.E. | .231 | 3/8 vs. 0/5 | |
| | Periods Combined | .232 | .630 | 13/38 vs. 5/18 | | F.E. | .711 | 6/38 vs. 4/18 | |
| Total[2] | Early Period | 9.13 | **.003** | 45/105 vs. 32/46 | SFB>SV | 10.466 | **.001** | 16/105 vs. 18/46 | SFB>SV |
| | Middle Period | 9.321 | **.002** | 35/75 vs. 51/70 | SFB>SV | 14.257 | **.001** | 16/75 vs. 36/70 | SFB>SV |
| | Late Period | .375 | .541 | 26/42 vs. 36/53 | | 8.107 | **.004** | 9/43 vs. 26/53 | SFB>SV |
| | Periods Combined | 19.416 | **.001** | 106/222 vs. 119/169 | SFB>SV | 37.763 | **.001** | 41/223 vs. 80/169 | SFB>SV |

[1] Statistically significant (p<.017) results are indicated by bold-faced type in the table.

[2] Total includes individuals of indeterminate sex.

[3] Number affected/number examined.

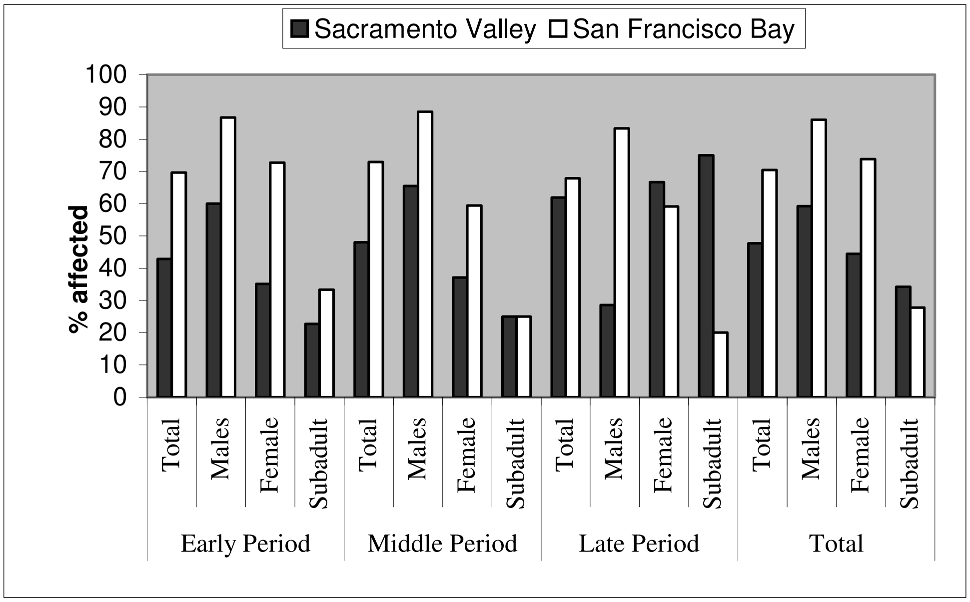

**Figure 9.6.** Distribution of porotic hyperostosis (all levels of severity) in prehistoric central California by region.

group (pooled periods), 70.4 percent of crania in the San Francisco Bay sample have vault lesions compared with 47.7 percent of crania in the Sacramento Valley sample, a statistically significant difference (all levels of severity, $X^2 = 19.416$, p = .001; moderate to severe lesions, $X^2 = 37.763$, p = .001).

When partitioned by time period, vault lesions are also significantly more common in the San Francisco Bay sample than in the Sacramento Valley sample, a pattern that also holds for all three periods (Early period, all levels of severity: $X^2 = 9.13$, p = .003, moderate to severe lesions: $X^2 = 10.466$, p = .001; Middle period, all levels of severity: $X^2 = 9.321$, p = .002, moderate to severe lesions: $X^2 = 14.257$, p = .001; Late period, moderate to severe lesions: $X^2 = 8.107$, p = .004). When the data are further partitioned by sex, porotic hyperostosis affected 86.0 percent of male crania from San

Francisco Bay and 59.2 percent of crania from the Sacramento Valley. For females, the prevalence of vault lesions is 73.8 and 44.4 percent for the San Francisco Bay and Sacramento Valley samples, respectively. Table 9.4 shows that San Francisco Bay males and females have a significantly higher prevalence of vault lesions than do their Sacramento Valley counterparts. When examined by time period, these patterns hold, with one exception: the prevalence of vault lesions is not significantly different between regions for Middle period females. These robust trends indicate that the overall prevalence of cribra orbitalia and porotic hyperostosis was significantly higher in crania from San Francisco Bay than in crania from the Sacramento Valley.

### *Sex Comparisons*

Table 9.2 summarizes the distribution of cribra orbitalia and porotic hyperostosis in the Sacramento Valley sample (also see Figures 9.1 and 9.2). For the sample as a whole, the prevalence of cribra orbitalia is similar between males and females (males = 28.4 percent; females = 34.7 percent). Statistical results presented in Table 9.5 indicate no significant association between sex and prevalence of orbital lesions for any time period. However, male crania show a higher prevalence of porotic hyperostosis than female crania for the Early and Middle period samples, although these differences only approach statistical significance (Early period: males = 60.0 percent; females = 35.1 percent, $X^2 = 4.761$, p = .029; Middle period, males = 65.5 percent; females = 37.1 percent; $X^2 = 5.107$, p = .024).

Table 9.2 summarizes the distribution of cribra orbitalia and porotic hyperostosis in the San Francisco Bay sample (also see Figures 9.3 and 9.4). The prevalence of cribra

Table 9.5. Chi-Square and Fisher's Exact Test Results of Sex Comparisons of Cribra Orbitalia and Porotic Hyperostosis.

| | | Sacramento Valley | | | | San Francisco Bay | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Lesion Type** | **Period** | **$X^2$, F.E.** | **p value[1]** | **n** | **Trend** | **$X^2$, F.E.** | **p value[1]** | **n** | **Trend** |
| Cribra Orbitalia (all levels of severity) | Early Period | .232 | .630 | 10/38 vs. 11/35 | | F.E. | .685 | 4/8 vs. 6/15 | |
| | Middle Period | .866 | .352 | 10/28 vs. 9/36 | | $X^2$ = .727 | .394 | 14/24 vs. 14/30 | |
| | Late Period | F.E. | .101 | 1/8 vs. 14/27 | | $X^2$ = .037 | .848 | 9/23 vs. 8/22 | |
| | Periods Combined | .773 | .379 | 21/74 vs. 34/98 | | $X^2$ = .650 | .420 | 27/55 vs. 28/67 | |
| Cribra Orbitalia (moderate/severe) | Early Period | F.E. | .662 | 2/39 vs. 3/35 | | F.E. | 1.000 | 2/8 vs. 3/15 | |
| | Middle Period | F.E. | .159 | 4/28 vs. 1/36 | | $X^2$ = .789 | .375 | 8/24 vs. 7/31 | |
| | Late Period | F.E. | 1.000 | 1/8 vs. 6/27 | | $X^2$ = .342 | .559 | 7/23 vs. 5/22 | |
| | Periods Combined | .804 | .849 | 7/75 vs. 10/98 | | $X^2$ = 1.237 | .266 | 17/55 vs. 15/68 | |
| Porotic Hyperostosis (all levels of severity) | Early Period | 4.761 | .029 | 24/40 vs. 13/37 | M>F | F.E. | .431 | 13/15 vs. 16/22 | |
| | Middle Period | 5.107 | .024 | 19/29 vs. 13/35 | M>F | $X^2$ = 6.075 | **.014** | 23/26 vs. 19/32 | M>F |
| | Late Period | F.E. | .097 | 2/7 vs. 18/27 | | $X^2$ = 3.327 | .068 | 20/24 vs. 13/22 | |
| | Periods Combined | 3.751 | .053 | 45/76 vs. 44/99 | | $X^2$ = 9.572 | **.002** | 56/65 vs. 48/65 | M>F |
| Porotic Hyperostosis (moderate/severe) | Early Period | 2.601 | .107 | 10/40 vs. 4/37 | | $X^2$ = 3.963 | .047 | 9/15 vs. 6/22 | M>F |
| | Middle Period | 3.605 | .058 | 10/29 vs. 5/35 | | $X^2$ = 11.984 | **.001** | 20/26 vs. 10/32 | M>F |
| | Late Period | F.E. | .576 | 2/7 vs. 4/28 | | $X^2$ = .321 | .571 | 14/24 vs. 11/22 | |
| | Periods Combined | 6.893 | **.009** | 22/76 vs. 13/100 | M>F | $X^2$ = 13.147 | **.001** | 43/65 vs. 27/76 | M>F |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

orbitalia is similar (and statistically insignificant) between males and females in the San Francisco Bay sample (males = 49.1 percent; females, = 41.8 percent; Table 9.5). In contrast, porotic hyperostosis is significantly more common in male crania than in female crania (males = 86 percent; females = 73.8 percent, all levels of severity: $X^2$ = 9.5732, p = .002; moderate to severe lesions: $X^2$ = 13.147, p = .001). When partitioned by period, males also show a higher prevalence of vault lesions in the Middle period sample (Middle period, all levels of severity: $X^2$ = 6.075, p = .014, moderate to severe lesions: $X^2$ = 11.984, p = .001).

### ***Summary***

The distribution of cribra orbitalia and porotic hyperostosis in the skeletal samples shows a number of interesting trends that have important implications for changes in health status during the late Holocene. Overall, the proportion of individuals with orbital and cranial vault lesions significantly increased over time in the Sacramento Valley. This pattern is consistent with the expectation that the acorn-dependent economies of the Middle and Late periods would contribute to higher levels of acquired anemia in children, since heavy consumption of acorns could result in iron-deficient diets; additionally, the greater level of sedentism and population aggregation associated with these time periods would have been more conducive to the spread of infection, which would have also lowered the bioavailability of dietary iron. In contrast, the proportion of individuals with orbital and vault lesions remained unchanged through time in San Francisco Bay, an unexpected result. However, a few exceptions aside, skeletal samples from San Francisco Bay had a significantly higher prevalence of both orbital and vault lesions, which suggests that acquired anemia was a more serious health consequence for infants and children from the San Francisco Bay area. Since marine resources that carry parasites (e.g., anadromous fish) were consumed in both regions, helminthiasis may have contributed to the anemic status of both groups.

Sex comparisons also shed light on health patterns between males and females. Although the prevalence of orbital lesions was similar in males and females, the prevalence of vault lesions was higher in male crania in both regions, particularly in the San Francisco Bay sample. This might suggest that female children were better buffered against nutritional stress and/or pathogen load than male children; this would be expected if male and female children were exposed to different levels of risk during early childhood. Since vault lesions are expected to have a later age of onset than orbital lesions, this could also suggest that sex differences in anemia were less pronounced in infancy, but disproportionately affected males in early childhood.

# CHAPTER X

# ENAMEL HYPOPLASIA

Dental enamel hypoplasias are deficiencies in enamel thickness caused by physiological disruption during tooth crown formation (Goodman and Rose 1990; Hillson 1996). Hypoplasias provide a sensitive record of early childhood stress events and do not remodel with age. Consequently, enamel defects can still be observed in the adult dentition. However, the lesions are nonspecific in nature and may result from nutritional stress (e.g., malnutrition, undernutrition), infection, trauma to the developing tooth germ, or other disease conditions that temporarily disrupt enamel formation (Goodman and Rose 1990). In this chapter, I examine the prevalence of enamel hypoplasia to explore differences in childhood stress through time, between regions, and between the sexes.

## *Literature Review*

During normal enamel formation, ameloblasts secrete layers of a proteinaceous matrix, beginning at the cusp and proceeding cervically. Calcification of the matrix begins as water and protein are removed during amelogenesis and results in enamel that is composed primarily of inorganic salts. The external surface of a tooth crown records the enamel formation process in small, horizontal linear bands called perikymata (Hillson and Bond 1997:91). Since amelogenesis of the permanent dentition lasts from birth to seven years of age (excluding third molars), perturbations that occur in teeth that develop at different ages can provide a record of stress events throughout different periods of childhood (Hillson 1996; Skinner and Goodman 1992; Wright 1997).

Enamel hypoplasia defects can be classified based on their size and appearance. The most common defect is a linear enamel hypoplasia (LEH), which appears as a horizontal layer of thin enamel that traverses the labial surface of the tooth crown (Hillson 1996; Hillson and Bond 1997). In general, these lesions manifest as furrow-form defects that can be observed with the naked eye, although smaller defects can be detected with the aid of a microscope. Less common hypoplasias include pit-form defects and a linear array of pits, which are more ambiguous to record than LEH defects (Hillson 1996; Hillson and Bond 1997; Buikstra and Ubelaker 1994). Opacities and hypocalcifications are caused by poorly mineralized zones of enamel and are often considered together with hypoplastic defects (Hillson 1996). However, in archaeological skeletons, enamel discolorations may be hard to distinguish from enamel staining from the burial environment.

Despite the nonspecific nature of enamel hypoplasias, the formation of these defects is well understood and has clinical significance (Hillson 1996). Malnourished and undernourished children in developing nations show a higher prevalence of hypoplasia than groups who received nutritional supplementation (Goodman et al. 1987; May et al. 1993). In many archaeological settings, agricultural societies have a higher proportion of individuals with hypoplastic defects compared with earlier forager societies from the same region (Cohen and Armelagos 1984; Goodman and Rose 1990; Larsen 1995, 1997).

The relative timing of hypoplastic events has been the subject of much research in both archaeological and clinical studies, and many authors have sought a link between "peak stress" ages and the infant weaning or "post-weaning" period (Blakey et al. 1994; Goodman and Rose 1990). However, estimation of the timing of defect formation is hindered by the use of different methods between researchers (Hillson 1996; Hillson and Bond 1997; Hodges and Wilkinson 1990). Recently, Hillson and Bond (1997) have demonstrated that differences in crown geometry and the differing growth velocities of different teeth also influence the relationship between the position of an enamel defect on the crown and the chronological age at which it developed. Hence, the position of a hypoplasia on the crown may not accurately reflect the timing of a stress event based on current dental development standards. Despite these limitations, the relative timing of defects can still be compared between subsets within a skeletal series to evaluate general differences in hypoplasia formation times (Lovell and Whyte 1999).

### *Methods*

For this study, I scored enamel hypoplasias in 313 adult dentitions from central California. Since the subadult sample was insufficient for statistical comparison, the main focus of this analysis is on adult individuals. The sample sizes for each tooth class are small due to tooth loss (antemortem and postmortem) and severe tooth attrition. I scored the presence and absence of enamel hypoplasia on teeth that had at least 2 mm of continuous enamel on the labial surface of the crown as measured from the cemento-enamel junction (CEJ) to the occlusal surface. This is a true measure of crown height for unworn teeth and can also be used to measure the average amount of enamel removed through attrition. I measured crown heights from the CEJ to the occlusal surface for incisors, canines, and premolars following *Standards for Data Collection* (Buikstra and Ubelaker 1994). Since the amount of enamel lost through attrition is age-dependent, tooth wear has the effect of mechanically removing hypoplastic defects that were acquired during childhood (Skinner and Goodman 1992). This biases the study samples toward younger individuals who have more scorable enamel present.

I scored enamel defects as linear enamel hypoplasia (LEH), major growth arrest, or linear horizontal array of pits (Buikstra and Ubelaker 1994). Since most the observed defects in the sample are LEH, I treat all hypoplasia types as a single category for the purposes of this study. I examined all teeth with the naked eye under strong oblique lighting and used a 10x hand lens to aid in the identification and classification of each hypoplastic defect. Since microscopy was not used in this study, I consider the reported hypoplasia prevalence a minimum estimate.

Mandibular canines and central maxillary incisors are the most sensitive teeth to record hypoplastic defects, although posterior teeth can provide evidence of more severe stress episodes (Goodman and Armelagos 1985; Goodman and Rose 1990). I considered three tooth classes (maxillary and mandibular) in this analysis: central incisors, canines, and third premolars (P3). Central incisor enamel formation spans the period from about three months to 4.5 years of age for the maxillary dentition and three months to four years of age for the mandibular dentition. Maxillary canines span the period from about four months to six years of age and maxillary and mandibular third premolars span from two to six years of age. Modern standards indicate that mandibular canines develop between four months and six years of age. However, I assume that amelogenesis of this tooth is complete by 4.5 years of age based on research on prehistoric Amerindian populations (Skinner and Goodman 1992; Wright 1997:238). Since all teeth were examined for hypoplasia, I used the side with the greatest expression for a given individual to represent the condition. For teeth that lacked hypoplastic defects, I used the side with the least attrition (as measured by labial crown height).

I measured the location of each hypoplastic defect (to the nearest .02 mm) from the buccal midpoint of the CEJ to the occlusal-most edge of the defect using Digimatic Mitutoyo calipers. Although this measure provides only an estimate of the age of defect formation, it is suitable for general comparisons between skeletal samples (Lovell and Whyte 1999). I calculated the approximate age of each hypoplastic defect using regression formulae published in Goodman and Song (1999), which are presented in Table 10.1 below. These formulae are based on the mean crown heights from Swärdstedt (1966) and the dental development timing from Massler et al. (1941) as presented in Goodman and Song (1999:224).

Table 10.1. Regression Formulae Used to Estimate Age of Hypoplasia Defect Formation, Corrected for Buried Cuspal Enamel (Goodman and Song 1999:224, Table 9.4).

| Tooth Type | Cuspal enamel time (in years) | Equation C[1] | Enamel represented (in mm)[3] | Developmental ages represented (in years)[4] |
|---|---|---|---|---|
| **Maxillary** | | | | |
| I1 | .8 | Age = (-.374 x Ht) + 4.5 | 5 mm | 3.0-4.5 years |
| C | 1.0 | Age = (-.521 x Ht)+ 6.0 | 4 mm | 3.9-6.0 years |
| P3 | 1.0 | Age = (-.395 x Ht) + 6.0 | 4 mm | 4.4-6.0 years |
| **Mandibular** | | | | |
| I1 | .6 | Age = (-.391 x Ht) + 4.0 | 4 mm | 2.4-4.0 years |
| C[2] | .8 | Age = (-.490 x Ht) + 4.5 | 4 mm | 2.5-4.5 years |
| P3 | 1.0 | Age = (-.538 x Ht) + 6.0 | 4 mm | 3.8-6.0 years |

[1] Age = age in years; Ht = distance of hypoplastic defect in mm from CEJ.
[2] Assuming amelogenesis of the mandibular canine is complete by 4.5 years.
[3] Minimum cut-off for inclusion in analysis (as measured from CEJ).
[4] Developmental ages (in years) represented by each segment of enamel for each tooth type.

Cuspal enamel that forms within the first year of life is buried under the surface of the crown and cannot be scored for hypoplastic defects without undertaking histological analysis. To account for buried cuspal enamel, some researchers have recommended the use of “corrected” regression formulae (Goodman and Song 1999; Skinner and Goodman 1992; Wright 1997). From the dental literature, Goodman and Song (1999) assume that the first .8 years of central maxillary incisor and premolar development and the first year of canine development are buried under cuspal enamel (Table 10.1). This correction provides an older estimate of defect formation near the cusp but has little effect on defects that are near the CEJ. I use these “corrected” equations for the present study (Goodman and Song 1999:225, Table 9.4).

The degree of dental attrition in the adult sample is severe and significantly biases the sample toward younger individuals. To address differential attrition in the samples, I only consider observations scored in the same section of enamel for each tooth included in the analysis (see Wright 1997). Hence, enamel defects located above the "cut-off" point (representing the earliest period of tooth development) are not included in the analysis. For the maxillary incisor, I include teeth that had a minimum of 5 mm of scorable enamel on the labial surface as measured from the CEJ at the midline (Table 10.1). For all other tooth types, I set the cut-off point at 4 mm from the CEJ. The sections of enamel considered by all tooth classes represent the dental development period between 2.4 and 6.0 years of age. Although this excludes early forming hypoplastic defects (e.g., .25 to 2.3 dental development years), it ensures direct comparability between the samples. I consider each tooth as an independent test of stress levels by time period, by region, and by sex. I examined differences for each tooth type using the chi-square test, and used Fisher's Exact test when cell counts were less than five. To account for the increased probability of obtaining statistically significant results ($p < .05$) due to random chance with multiple comparisons, I set the alpha level for statistical significance at $p< .017$. However, I treat p-values between .018 and .05 as approaching statistical significance. I also used one-way ANOVA (with Bonferroni post-hoc test) and independent sample t-tests to examine differences in the mean age of defect timing between samples. I consider these results to be statistically significant at $p<.05$.

## ***Results***

### *Temporal Comparisons*

Hypoplastic defects are relatively common in the Sacramento Valley sample and are most prevalent in mandibular canines. Table 10.2 presents the distribution of enamel hypoplasias by time period and tooth class. At least 45.6 percent of adult individuals had at least one hypoplastic stress event recorded in a mandibular canine. Maxillary canines are the second most affected tooth class (36.5 percent), followed by the maxillary central incisors (30.2 percent), mandibular central incisors (11.4 percent), and maxillary third premolars (5.2 percent). I did not observe any hypoplasias in mandibular third premolars; hence this tooth will not be discussed further.

The small number of observable defects in central incisors and premolars hinders statistical comparisons between periods. However, the prevalence of hypoplastic defects in maxillary canines increases from 14.3 to 42.4 percent between the Early and Middle period, and reaches 50 percent in the Late period. Statistical results presented in Table 10.3 indicate that the proportion of individuals with hypoplasia is significantly different between the Early and Late period ($X^2 = 6.034$, $p = .014$) samples, and approaches statistical significance for comparisons between the Early and Middle period samples ($X^2 = 4.711$, $p = .03$). No other significant differences are found for any of the other tooth types, although small sample size prevented statistical comparisons in some cases.

Table 10.2. Distribution of Enamel Hypoplasia
Defects in Prehistoric Central California.

| | Early Period | | Middle Period | | Late Period | | Pooled Periods | |
|---|---|---|---|---|---|---|---|---|
| **Tooth Type** | **Maxilla** | **Mandible** | **Maxilla** | **Mandible** | **Maxilla** | **Mandible** | **Maxilla** | **Mandible** |
| **Sacramento Valley** | | | | | | | | |
| Incisors (I1) | | | | | | | | |
| N | 4/17 | 1/13 | 4/15 | 1/18 | 5/11 | 3/13 | 13/43 | 5/44 |
| % affected | 23.5 | 7.7 | 26.7 | 5.6 | 45.5 | 23.1 | 30.2 | 11.4 |
| Canines | | | | | | | | |
| N | 3/21 | 11/26 | 14/33 | 14/31 | 10/20 | 11/22 | 27/74 | 36/79 |
| % affected | 14.3 | 42.3 | 42.4 | 45.2 | 50.0 | 50.0 | 36.5 | 45.6 |
| Premolars (P3) | | | | | | | | |
| N | 0/15 | 0/22 | 3/28 | 0/26 | 0/15 | 0/14 | 3/58 | 0/62 |
| % affected | 0.0 | 0.0 | 10.7 | 0.0 | 0.0 | 0.0 | 5.2 | 0.0 |
| **San Francisco Bay** | | | | | | | | |
| Incisors (I1) | | | | | | | | |
| N | 6/12 | 0/4 | 7/26 | 2/15 | 5/17 | 1/13 | 18/55 | 7/32 |
| % affected | 50.0 | 0.0 | 26.9 | 13.3 | 29.4 | 7.7 | 32.7 | 21.9 |
| Canines | | | | | | | | |
| N | 11/15 | 8/14 | 8/31 | 12/32 | 4/21 | 5/19 | 23/67 | 25/65 |
| % affected | 73.3 | 57.1 | 25.8 | 37.5 | 19.0 | 26.3 | 34.3 | 38.5 |
| Premolars (P3) | | | | | | | | |
| N | 1/12 | 0/12 | 0/26 | 4/25 | 0/16 | 0/19 | 1/54 | 4/56 |
| % affected | 8.3 | 0.0 | 0.0 | 13.8 | 0.0 | 0.0 | 1.9 | 7.1 |

Table 10.4 presents the mean developmental ages for hypoplastic defects in the Sacramento Valley sample and Table 10.5 presents the statistical results for temporal comparisons. Since the mean age of hypoplastic defects in adults and subadults was nearly identical, I included permanent teeth from subadults in the analysis to increase the sample sizes.

Table 10.3. Chi-Square and Fisher's Exact Results for Temporal Comparisons of Enamel Hypoplasias in Prehistoric Central California.

| | | **Incisors (I1)** | | | **Canines** | | | | **Premolars (P3)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tooth Type** | **Comparison** | **$X^2$, F.E.** | **p value[1]** | **n[2]** | **$X^2$, F.E.** | **p value[1]** | **n[2]** | **Trend** | **$X^2$, F.E.** | **p value[1]** | **n[2]** |
| **Sacramento Valley** | | | | | | | | | | | |
| Maxillary | EP vs. MP | F.E. | 1.000 | 4/17 vs. 4/15 | 4.711 | .030 | 3/21 vs. 14/33 | EP<MP | F.E. | .541 | 0/15 vs. 3/28 |
| | EP vs. LP | F.E. | .409 | 4/17 vs. 5/11 | 6.034 | **.014** | 3/21 vs. 10/20 | EP<LP | | - | 0/15 vs. 0/15 |
| | MP vs. LP | F.E. | .419 | 4/15 vs. 5/11 | .288 | .591 | 14/33 vs. 10/20 | | F.E. | .541 | 3/28 vs. 0/15 |
| Mandibular | EP vs. MP | F.E. | 1.000 | 1/13 vs. 1/18 | .047 | .829 | 11/26 vs. 14/31 | | | - | 0/22 vs. 0/26 |
| | EP vs. LP | F.E. | .593 | 1/13 vs. 3/13 | .284 | .594 | 11/26 vs. 11/22 | | F.E. | .429 | 0/22 vs. 0/14 |
| | MP vs. LP | F.E. | .284 | 1/18 vs. 3/13 | .121 | .728 | 14/31 vs. 11/22 | | | | 0/26 vs. 0/14 |
| **San Francisco Bay** | | | | | | | | | | | |
| Maxillary | EP vs. MP | F.E. | .270 | 6/12 vs. 7/26 | 9.418 | **.002** | 11/15 vs. 8/31 | EP>MP | F.E. | .316 | 1/12 vs. 0/26 |
| | EP vs. LP | F.E. | .438 | 6/12 vs. 5/17 | 10.609 | **.001** | 11/15 vs. 4/21 | EP>LP | | - | 1/12 vs. 0/16 |
| | MP vs. LP | F.E. | 1.000 | 7/26 vs. 5/17 | F.E. | .741 | 8/31 vs. 4/21 | | | - | 0/26 vs. 0/16 |
| Mandibular | EP vs. MP | F.E. | 1.000 | 0/4 vs. 2/15 | 1.529 | .216 | 8/14 vs. 12/32 | | F.E. | .302 | 0/12 vs. 4/25 |
| | EP vs. LP | F.E. | 1.000 | 0/4 vs. 1/13 | 3.208 | .073 | 8/14 vs. 5/19 | | | - | 0/12 vs. 0/19 |
| | MP vs. LP | F.E. | 1.000 | 2/15 vs. 1/13 | .671 | .413 | 12/32 vs. 5/19 | | F.E. | .142 | 4/25 vs. 0/19 |

[1] Statistically significant results ($p<.017$) are indicated by bold-faced type in the table.

[2] Number affected/number examined.

Table 10.4. Mean Age of Hypoplasia Formation in Prehistoric Central California.

| | **Incisor (I1)** | | | **Canine** | | | **Premolar (P3)** | | | **All tooth types** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **Mean[1]** | **SD** | **n** | **Mean[1]** | **SD** | **n** | **Mean[1]** | **SD** | **n** | **Mean[1]** | **SD** | **n** |
| **Sacramento Valley** | | | | | | | | | | | | |
| Early Period | 3.15 | .47 | 8 | 3.27 | .67 | 27 | 4.71 | .49 | 3 | 3.36 | .73 | 38 |
| Middle Period | 3.35 | .43 | 16 | 3.76 | .83 | 40 | 4.82 | .22 | 6 | 3.75 | .80 | 62 |
| Late Period | 3.28 | .41 | 13 | 3.63 | .83 | 26 | 4.97 | .57 | 3 | 3.61 | .81 | 42 |
| Periods Combined | 3.28 | .43 | 37 | 3.58 | .81 | 93 | 4.83 | .37 | 11 | 3.61 | .80 | 142 |
| **San Francisco Bay** | | | | | | | | | | | | |
| Early Period | 3.22 | .33 | 8 | 3.93 | .85 | 35 | 5.16 | .25 | 3 | 3.89 | .87 | 46 |
| Middle Period | 3.29 | .51 | 13 | 3.86 | .86 | 31 | 4.88 | .32 | 5 | 3.81 | .86 | 49 |
| Late Period | 3.20 | .34 | 9 | 3.78 | .87 | 16 | 5.02 | .69 | 2 | 3.68 | .85 | 27 |
| Periods Combined | 3.25 | .41 | 30 | 3.88 | .85 | 82 | 4.99 | .36 | 10 | 3.81 | .86 | 122 |

[1] Represents mean developmental age of hypoplastic defects in the scored section of enamel.

Table 10.5. ANOVA and Bonferroni Test Results for Temporal Comparisons of Mean Age of Hypoplasia Formation in Prehistoric Central California.

| | **Sacramento Valley** | | | | **San Francisco Bay** | | | |
|---|---|---|---|---|---|---|---|---|
| **Tooth Type** | **F-statistic** | **p value[1]** | **Trend** | **Bonferroni[2]** | **F-statistic** | **p value[1]** | **Trend** | **Bonferroni[2]** |
| Incisors | .578 | .567 | | | .129 | .880 | | |
| Canines | 3.151 | **.048** | EP<MP | **.045** | .182 | .834 | | |
| All teeth | 2.993 | .053 | EP<MP | **.047** | .503 | .606 | | |

[1] Statistically significant results (p<.05) are indicated by bold-faced type in the table.

[2] Bonferroni test indicates which ANOVA comparisons are statistically significant within a three-way comparison.

Mean developmental ages are skewed toward later forming enamel defects since variation in attrition restricted the amount of scorable sections of enamel included in the analysis (see Table 10.1). For all tooth classes, the mean age of hypoplastic defect increases through time. When all tooth classes are considered as a single group, there is a significant increase in the mean defect age from 3.36 to 3.75 years between the Early and Middle period (Bonferroni test, p = .047). For canines, the mean age also significantly increases from 3.27 to 3.76 years between the Early and Middle period

(Bonferroni test, p = .045). Although the range of scorable enamel for this tooth (3.9-6.0 developmental years) is restricted due to variation in attrition, this suggests that young children experienced a slighter later age of peak stress episode (approximately three months), or experienced stress episodes of longer duration, during the Middle period than in the Early period.

Hypoplastic defects are also relatively common in the San Francisco Bay sample, and again are most prevalent in mandibular canines. Table 10.2 presents the distribution of enamel hypoplasias by time period and tooth class. At least 38.5 percent of adult individuals had at least one hypoplastic stress event recorded in a mandibular canine. Maxillary canines are the second most affected tooth class (34.3 percent), followed by the maxillary central incisors (32.7 percent), mandibular central incisors (21.9 percent), mandibular third premolars (7.1 percent), and maxillary third premolars (1.9 percent).

The small number of observable defects in central incisors and premolars again hinders statistical comparisons between periods. However, the prevalence of hypoplastic defects in maxillary canines decreases from 73.3 to 25.8 percent between the Early and Middle period, with no change in the Late period (26.3 percent). Statistical results presented in Table 10.3 indicate that the proportion of individuals with hypoplastic defects is significantly different between the Early and Middle period ($X^2$ = 9.418, p = .002) and between the Early and Late period ($X^2$ = 10.609, p = .001) samples. No other significant differences are found for any of the other tooth types although small sample size prevented statistical comparisons in some cases. The decline in the prevalence of enamel hypoplasias contrasts with the trend for the Sacramento Valley sample, which shows a significant increase in the prevalence of hypoplastic defects through time.

Table 10.4 presents the mean developmental ages of hypoplasias in the San Francisco Bay sample. Since the mean defect age in adults and subadults was nearly identical, I again included permanent teeth from subadults in the analysis to increase sample size. The mean defect age is 3.89, 3.81, and 3.68 developmental years for the Early, Middle, and Late period samples, respectively. The mean age of hypoplasia formation is not significantly different between time periods (see Table 10.5).

### *Regional Comparisons*

The distribution of enamel defects in the Sacramento Valley and San Francisco Bay samples is presented in Figures 10.1 through 10.3 for the incisors, canines, and premolars, respectively (also see Table 10.2). Statistical results for these comparisons are presented in Table 10.6. Although the pattern is inconsistent across all tooth types, maxillary canine defects are significantly more common in the Early period Bay sample than in the Early period Valley sample (San Francisco Bay = 73.3 percent; Sacramento Valley = 14.3 percent; $X^2$ = 12.837, p = .001). However, for the Late period sample comparisons, the proportion of hypoplastic defects is higher in the Valley sample than in the Bay sample (San Francisco Bay = 50.0 percent; Sacramento Valley = 19.0 percent). This difference in LEH prevalence approaches statistical significance ($X^2$ = 4.364, p = .037).

Table 10.4 presents the mean age of defect formation for the Sacramento Valley and San Francisco Bay samples. Statistical results for comparisons of mean defect formation ages are presented in Table 10.7. Overall, mean ages are slightly older in the Sacramento Valley samples for central incisors but are older in canines and third premolars in the San Francisco Bay sample. Considering all time periods together, the mean age of hypoplasia formation for all teeth is older in the San Francisco Bay sample (3.88 years) than in the Sacramento Valley sample (3.58). These differences are statistically significant (t = -2.371, p = .019). The mean defect age is also significantly older for canines in the Early period Valley sample (Sacramento Valley = 3.27 years; San Francisco Bay = 3.93 years, t = -3.447, p = .001).

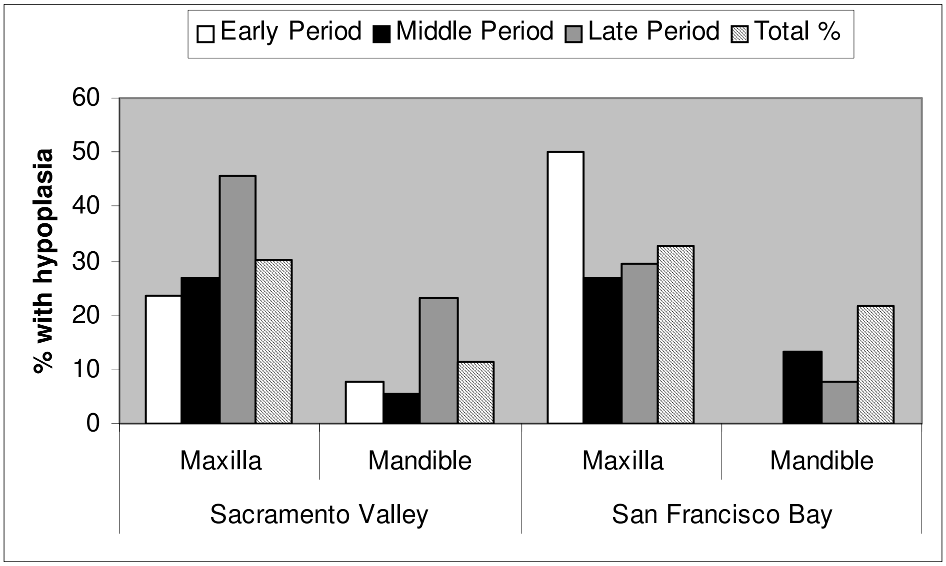

**Figure 10.1.** Comparison of the distribution of enamel hypoplasia of central incisors in prehistoric central California.

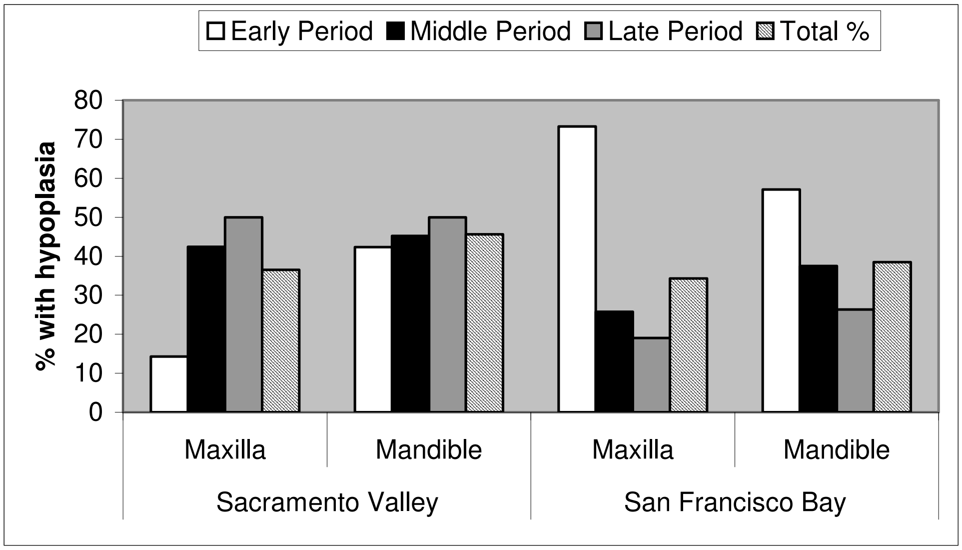

**Figure 10.2.** Comparison of the distribution of enamel hypoplasia of canines in prehistoric central California.

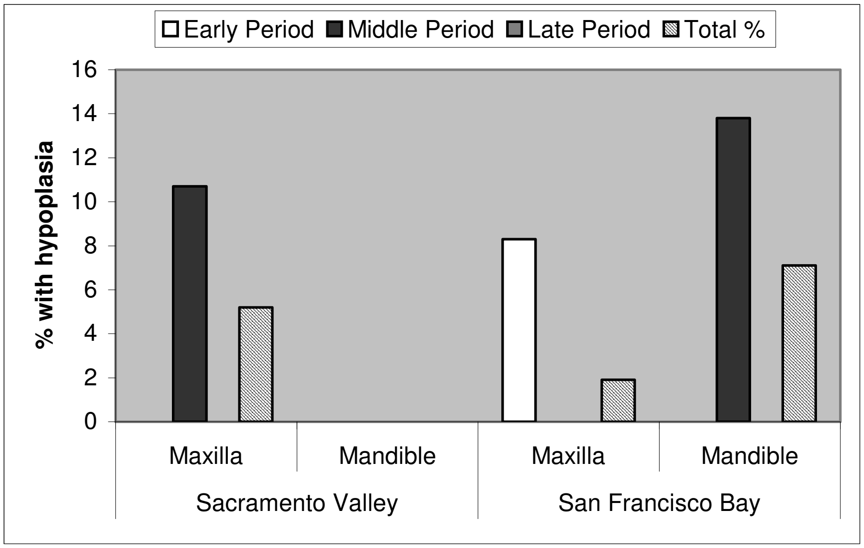

**Figure 10.3.** Comparison of the distribution of enamel hypoplasia of third premolars in prehistoric central California

The mean number of hypoplastic defects is presented by tooth type in Table 10.8. The P3 and mandibular canine samples are too small to be meaningful. However, the mean number of defects is greater overall in the San Francisco Bay sample than in the Sacramento Valley sample for the maxillary incisor and maxillary and mandibular canines. Together these results suggest that stress episodes during enamel formation were more common in the San Francisco Bay sample overall, and showed a significantly higher prevalence in maxillary canines during the Early period. However, the trend is reversed in the Late period, when hypoplastic defects of the maxillary canines are more prevalent in the Sacramento Valley sample.

### *Sex Comparisons*

Table 10.9 presents the distribution of hypoplasias by sex in prehistoric central California. Although hypoplasias are slightly more prevalent in females than males overall (combined periods), the results reported in Table 10.10 indicate that these differences are not statistically significant for either the Sacramento Valley or San Francisco Bay samples. However, the small sample sizes in these comparisons may be a contributing factor to the lack of statistical differences.

Table 10.6. Chi-Square and Fisher's Exact Results for
Regional Comparisons of Enamel Hypoplasias in Prehistoric Central California.

| Tooth Type | Period | $X^2$, F.E. | p value[1] | n[2] | Trend |
|---|---|---|---|---|---|
| **Maxillary** | | | | | |
| Incisors (I1) | Early Period | F.E. | .236 | 4/17 vs. 6/12 | |
| | Middle Period | F.E. | 1.000 | 4/15 vs. 7/26 | |
| | Late Period | F.E. | .444 | 5/11 vs. 5/17 | |
| | Periods Combined | .069 | .792 | 13/43 vs. 18/55 | |
| Canines | Early Period | 12.837 | **.001** | 3/21 vs. 11/15 | SFB>SV |
| | Middle Period | 1.957 | .162 | 14/33 vs. 8/31 | |
| | Late Period | 4.364 | .037 | 10/20 vs. 4/21 | SV>SFB |
| | Periods Combined | .022 | .882 | 27/74 vs. 23/67 | |
| Premolars (P3) | Early Period | F.E. | .444 | 0/15 vs. 1/12 | |
| | Middle Period | F.E. | .237 | 3/28 vs. 0/26 | |
| | Late Period | | | 0/15 vs. 0/16 | |
| | Periods Combined | F.E. | .619 | 3/58 vs. 1/54 | |
| **Mandibular** | | | | | |
| Incisors (I1) | Early Period | F.E. | 1.000 | 1/13 vs. 0/4 | |
| | Middle Period | F.E. | .579 | 1/18 vs. 2/15 | |
| | Late Period | F.E. | .593 | 3/13 vs. 1/13 | |
| | Periods Combined | F.E. | 1.000 | 5/44 vs. 7/32 | |
| Canines | Early Period | .803 | .370 | 11/26 vs. 8/14 | |
| | Middle Period | .381 | .537 | 14/31 vs. 12/32 | |
| | Late Period | 2.403 | .121 | 11/22 vs. 5/19 | |
| | Periods Combined | .0738 | .390 | 36/79 vs. 25/65 | |
| Premolars (P3) | Early Period | | | 0/22 vs. 0/12 | |
| | Middle Period | F.E. | .113 | 0/26 vs. 4/25 | |
| | Late Period | | | 0/14 vs. 0/19 | |
| | Periods Combined | F.E. | .056 | 0/62 vs. 4/56 | |

[1] Statistically significant results (p<.017) are indicated by bold-faced type in the table.

[2] Number of affected/total examined in SV sample vs. number of affected/total examined in SFB sample.

Table 10.7. T-Test Results for Regional Comparisons of Mean Age of Hypoplasia Formation Between Samples.

| Time Period | Tooth Type | T-statistic | p value[1] | Trend |
|---|---|---|---|---|
| Early Period | Incisors (I1) | -.356 | .727 | |
| | Canines | -3.447 | **.001** | SV<SFB |
| Middle Period | Incisors (I1) | .352 | .728 | |
| | Canines | -.496 | .622 | |
| Late Period | Incisors (I1) | .437 | .667 | |
| | Canines | -.582 | .564 | |
| Periods Combined | Incisors (11) | .344 | .732 | |
| | Canines | -2.371 | **.019** | SV<SFB |

[1] Statistically significant results (p<.05) are indicated bold-faced type in the table.

Table 10.8. Mean Number of Hypoplastic Defects by Tooth Class.

| | Incisor (I1) | | Canine | | Premolar (P3) | |
|---|---|---|---|---|---|---|
| Region | Maxillary | Mandibular | Maxillary | Mandibular | Maxillary | Mandibular |
| Sacramento Valley | 1.13 | 1.33 | 1.11 | 1.18 | 1.00 | 1.00 |
| San Francisco Bay | 1.26 | 1.00 | 1.36 | 1.32 | 2.00 | 1.00 |

Table 10.9. Sex Distribution of Enamel Defects in Prehistoric Central California.

| | | **Early Period** | | **Middle Period** | | **Late Period** | | **Combined Periods** | |
|---|---|---|---|---|---|---|---|---|---|
| **Tooth Type** | **Affected** | **Male** | **Female** | **Male** | **Female** | **Male** | **Female** | **Male** | **Female** |
| **Sacramento Valley** | | | | | | | | | |
| Maxillary | | | | | | | | | |
| Incisors (I1) | n | 4/12 | 0/5 | 1/10 | 3/5 | 1/3 | 4/8 | 6/25 | 7/18 |
| | % affected | 33.3 | 0.0 | 10.0 | 60.0 | 33.3 | 50.0 | 24.0 | 38.9 |
| Canines | n | 2/14 | 1/7 | 6/20 | 7/12 | 5/8 | 5/12 | 13/42 | 13/31 |
| | % affected | 14.3 | 14.3 | 30.0 | 58.3 | 62.5 | 41.7 | 31.0 | 41.9 |
| Premolars (P3) | n | 0/12 | 0/3 | 2/14 | 1/14 | 0/6 | 0/9 | 2/32 | 1/26 |
| | % affected | 0.0 | 0.0 | 14.3 | 7.1 | 0.0 | 0.0 | 6.3 | 3.8 |
| Mandibular | | | | | | | | | |
| Incisors (I1) | n | 1/8 | 0/5 | 1/13 | 0/5 | 1/3 | 2/10 | 3/24 | 2/20 |
| | % affected | 12.5 | 0.0 | 7.7 | 0.0 | 33.3 | 20.0 | 12.5 | 10 |
| Canines | n | 8/21 | 3/5 | 9/20 | 5/11 | 2/5 | 9/17 | 19/46 | 17/33 |
| | % affected | 38.1 | 60.0 | 45.0 | 45.5 | 40.0 | 52.9 | 41.3 | 51.5 |
| Premolars (P3) | n | 0/18 | 0/4 | 0/17 | 0/8 | 0/6 | 0/8 | 0/41 | 0/20 |
| | % affected | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **San Francisco Bay** | | | | | | | | | |
| Maxillary | | | | | | | | | |
| Incisors (I1) | n | 3/6 | 3/6 | 2/12 | 4/13 | 2/9 | 3/7 | 7/27 | 10/26 |
| | % affected | 50.0 | 50.0 | 16.7 | 30.8 | 22.2 | 42.9 | 25.9 | 38.5 |
| Canines | n | 7/8 | 4/7 | 6/16 | 2/13 | 2/9 | 2/10 | 15/33 | 9/31 |
| | % affected | 87.5 | 57.1 | 37.5 | 15.4 | 22.2 | 20.0 | 45.5 | 29.0 |
| Premolars (P3) | n | 1/6 | 0/6 | 0/13 | 0/12 | 0/7 | 0/9 | 1/26 | 0/28 |
| | % affected | 16.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 0.0 |
| Mandibular | | | | | | | | | |
| Incisors (I1) | n | 0/3 | 0/1 | 0/6 | 2/7 | 1/6 | 0/6 | 1/14 | 2/6 |
| | % affected | 0.0 | 0.0 | 0.0 | 22.2 | 16.7 | 0.0 | 6.7 | 12.5 |
| Canines | n | 5/8 | 3/6 | 4/15 | 7/13 | 3/7 | 2/10 | 12/30 | 12/29 |
| | % affected | 62.5 | 50.0 | 26.7 | 53.8 | 42.9 | 20.0 | 40.0 | 46.4 |
| Premolars (P3) | n | 0/7 | 0/5 | 0/12 | 4/11 | 0/9 | 0/9 | 0/28 | 4/29 |
| | % affected | 0.0 | 0.0 | 0.0 | 26.7 | 0.0 | 0.0 | 0.0 | 13.8 |

Table 10.10. Chi-Square and Fisher's Exact Results for Sex Comparisons in Prehistoric Central California.

| | Sacramento Valley | | | | | | San Francisco Bay | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maxillary | | | Mandibular | | | Maxillary | | | Mandibular | | |
| **Period** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** | **$X^2$, F.E.** | **p value** | **n[1]** |
| **Incisors (I1)** | | | | | | | | | | | | |
| Periods Combined | 1.100 | .294 | 6/25 vs. 7/18 | F.E. | 1.000 | 3/24 vs. 2/20 | .955 | .328 | 7/27 vs. 10/26 | F.E. | 1.000 | 1/14 vs. 2/6 |
| Early Period | F.E. | .261 | 4/12 vs. 0/5 | F.E. | 1.000 | 1/8 vs. 0/5 | F.E. | 1.000 | 3/6 vs. 3/6 | | - | 0/3 vs. 0/1 |
| Middle Period | F.E. | .077 | 1/10 vs. 3/5 | F.E. | 1.000 | 1/13 vs. 0/5 | F.E. | .645 | 2/12 vs. 4/13 | F.E. | .486 | 0/6 vs. 2/7 |
| Late Period | F.E. | 1.000 | 1/3 vs. 4/8 | F.E. | 1.000 | 1/3 vs. 2/10 | F.E. | .596 | 2/9 vs. 3/7 | F.E. | 1.000 | 1/6 vs. 0/6 |
| **Canines (C)** | | | | | | | | | | | | |
| Periods Combined | .938 | .333 | 13/42 vs. 13/31 | .808 | .369 | 19/46 vs. 17/33 | 1.839 | .175 | 15/33 vs. 9/31 | .012 | .914 | 12/30 vs. 12/29 |
| Early Period | F.E. | 1.000 | 2/14 vs. 1/7 | F.E. | .620 | 8/21 vs. 3/5 | F.E. | .282 | 7/8 vs. 4/7 | F.E. | 1.000 | 5/8 vs. 3/6 |
| Middle Period | F.E. | .150 | 6/20 vs. 7/12 | F.E. | 1.000 | 9/20 vs. 5/11 | F.E. | .238 | 6/16 vs. 2/13 | 2.157 | .142 | 4/15 vs. 7/13 |
| Late Period | F.E. | .700 | 5/8 vs. 5/12 | F.E. | 1.000 | 2/5 vs. 9/17 | F.E. | 1.000 | 2/9 vs. 2/10 | F.E. | .593 | 3/7 vs. 2/10 |
| **Premolars (P3)** | | | | | | | | | | | | |
| Periods Combined | F.E. | 1.000 | 2/32 vs. 1/26 | | - | 0/41 vs. 0/20 | F.E. | .481 | 1/26 vs. 0/28 | F.E. | .112 | 0/28 vs. 4/29 |
| Early Period | | - | 0/12 vs. 0/3 | | - | 0/18 vs. 0/4 | F.E. | 1.000 | 1/6 vs. 0/6 | | - | 0/7 vs. 0/5 |
| Middle Period | F.E. | 1.000 | 2/14 vs. 1/14 | | - | 0/17 vs. 0/8 | | - | 0/13 vs. 0/12 | F.E. | .106 | 0/12 vs. 4/11 |
| Late Period | | - | 0/6 vs. 0/9 | | - | 0/6 vs. 0/8 | | - | 0/7 vs. 0/9 | | - | 0/9 vs. 0/9 |

[1] Number of affected/total examined in male sample vs. number of affected/total examined in female sample.

### *Summary*

The analysis of enamel hypoplasia defects provides conflicting trends within the two regions. In the Sacramento Valley sample, the prevalence of hypoplastic defects in maxillary canines significantly increased through time, as predicted by resource intensification models. However, in the San Francisco Bay skeletal series, the prevalence of hypoplastic defects significantly decreased through time. The latter finding in Bay Area samples is more consistent with the seasonal-stress hypothesis originally postulated for the lower Sacramento Valley.

The prevalence and mean number of hypoplastic defects is also significantly higher in Early period San Francisco Bay skeletons than in Early period Sacramento Valley skeletons. However, this trend is reversed in the Late period, when a higher proportion of hypoplastic defects is observed in the Sacramento Valley samples. Although small sample size may be a factor, the prevalence of hypoplastic defects does not appear to be significantly different between the sexes for either region.

# CHAPTER XI

# SUMMARY AND DISCUSSION

In Chapter III, I presented a series of models derived from human behavioral ecology that might account for changes in subsistence patterns in prehistoric central California. These models established a set of predictions regarding late Holocene subsistence change, and provide the conceptual framework from which I examined diet and health trends in lower Sacramento Valley and San Francisco Bay. R*esource intensification models* predict that foraging efficiency decreased during the late Holocene as a result of overexploitation of high-ranked taxa, and by the increased use of more costly, lower-ranked resources (Broughton 1999). A key prediction of resource intensification is that reduced foraging efficiency should be associated with a decline in health, as observed in osteological indicators of nutritional stress and disease (Broughton and O'Connell 1999).

In this study, I evaluated whether expected changes in diet and health were evident in human skeletal remains dating to the mid-to-late Holocene in central California. Although many of the expectations of resource intensification were met, there is significant regional variation that suggests a more complex picture of health in the region. There is far less support for the *seasonal-stress hypothesis*, however, which argues that health status improved through time associated with intensified reliance on acorns and smaller fauna during the Middle and Late periods (see Dickel et al. 1984). In this chapter, I summarize the isotopic and osteological diet and health indicators, and then discuss the data with respect to resource intensification and seasonal-stress models.

I first discuss dietary patterns based on evidence from stable isotopes and dental pathology, and then summarize the paleopathological and growth stress indicator data. Finally, I address the limitations of the present study and some implications for future research.

## ***Dietary Trends***

### *Stable Isotopes: Temporal Differences*

Although stable isotope values often cannot identify specific foods that were consumed prehistorically, the data do provide a means for evaluating the importance of bulk dietary components derived from isotopically distinct food resources. These data can be compared with other sources of paleodietary information, such as that gleaned from archaeofaunal, archaeobotanical, and artifact use studies. Human behavioral ecology approaches, such as optimal foraging theory, predict that diet breadth expansion will ensue over time as high-ranked resources are depleted within a given resource patch; hence, the shift toward intensified use of more costly food resources can be examined only if food resources that differ in rank are also isotopically distinct. This would be realistic if, for instance, a population subsisted on two isotopically distinct food resources (e.g., marine mammals and small terrestrial mammals) that also had different return rates; however, prehistoric diets in central California included a variety of food resources, which prevents a robust test of the diet breadth model based on the isotopic evidence alone. Due to these limitations, the isotopic data can be used in more general ways to evaluate changes in diet breadth. For example, since high-ranked marine resources such as sea mammals, and also marine and anadromous fish, differ isotopically (due to their higher trophic level) from some low-ranked resources, such as shellfish, the dietary signatures may provide some insight on the relative importance of these resources to the diet. Additionally, an increase in collagen-apatite spacing values through time would indicate greater consumption of lower-ranked plant carbohydrate resources, as predicted by the diet breadth model.

In the lower Sacramento Valley, comparisons of stable isotope values indicate that the proportion of dietary proteins and carbohydrates, as well as the sources of these macronutrients (i.e., aquatic vs. terrestrial), did not significantly change over time. Mean values of collagen $\delta^{13}C$ and $\delta^{15}N$, apatite $\delta^{13}C$, and collagen-apatite spacing are nearly identical between the Early, Middle, and Late periods. Compared with dietary signatures of locally available food resources, these signatures fall within expected ranges of terrestrial game (e.g., herbivores, carnivores), C3 plants (e.g., acorns, geophytes, seeds), and freshwater fish in particular. This result is supported by the collagen-apatite spacing values, which indicate that the dietary protein was less enriched in $^{13}C$ than the whole diet. The high collagen-apatite spacing (~6.6‰) further indicates that heavy consumption of C3 plants and freshwater fish, which have low $\delta^{13}C$ values, probably contribute the most to the diet.

Broughton's (1994a) analysis of late Holocene Sacramento Valley archaeofaunal assemblages suggested a temporal decline in the abundance of medium and large-sized terrestrial mammals and anadromous fish, relative to smaller freshwater fishes. Although food resources should be depleted in order of their rank (i.e., return rate), it is possible that some high-ranked resources could have been exploited, yet have contributed little to average dietary signatures. For example, although the isotopic signatures from Sacramento Valley skeletons are consistent with a diet of freshwater fish, terrestrial game, and C3 plants, harvesting of anadromous fish over brief intervals (e.g., spring and fall spawning runs) may not be detectable in isotope signatures. Although freshwater fish and terrestrial mammals overlap somewhat in collagen $\delta^{13}C$ values, $\delta^{15}N$ values are higher than would be expected for a strictly herbivore protein diet. The mean $\delta^{15}N$ value of herbivore flesh is 5.0±.1.6‰, so protein derived solely from these mammals would produce $\delta^{15}N$ values of 8.0 to 9.0‰ in humans (accounting for the 3-4‰ trophic level effect between diet and bone collagen). The mean $\delta^{15}N$ value of ~11.0‰ in Sacramento Valley skeletons indicates a significant contribution from a higher trophic level food resource other than herbivore flesh. This could include terrestrial carnivores and omnivores (e.g., coyote, bear, raccoon), which have a mean $\delta^{15}N$ value of 8.8±.9‰, or more likely freshwater fish, which have $\delta^{15}N$ values that can range from 5.0 to 14‰. The only isotopic data available for freshwater fish from the Valley is from Sacramento sucker, which has $\delta^{15}N$ values around 9.5‰. If this value is representative of other freshwater fish species in the Sacramento Valley, then the $\delta^{15}N$ values in the human bone collagen most likely reflect heavy consumption of freshwater fish. For comparison, skeletons from the Santa Barbara Channel mainland of southern California (circa 5000 B.C. to A.D. 1150) have isotopic signatures that are similar to those of the Sacramento Valley (Walker and DeNiro 1986). Mean $\delta^{13}C$ values of -18.0‰ and $\delta^{15}N$ values of 9.8‰ in these groups are consistent with a diet composed primarily of terrestrial C3 protein and freshwater fish.

Given the importance of salmon in the Sacramento Valley documented in ethnohistoric accounts (see Yoshiyama 1999), it is somewhat surprising that bone isotope values do not reflect consumption of this food resource. Overall, collagen $\delta^{13}C$ and $\delta^{15}N$ values in Valley skeletons indicate that anadromous fish (which show both high $\delta^{13}C$ and $\delta^{15}N$ values similar to marine fish) did not contribute significant amounts of protein to the diet. In contrast, prehistoric skeletons from sites along major salmon rivers in British Columbia have significantly higher collagen $\delta^{13}C$ values that clearly indicate heavy consumption of salmon (Chisholm 1983; Lovell et al. 1986). Lovell et al. (1986:103) reported a mean $\delta^{13}C$ value of $-15.5 \pm .3$‰ (n=8) in prehistoric skeletons from inland British Columbia, which is consistent with heavy consumption of salmon (the only $^{13}C$-enriched resource available in the area). Similarly, in a site located downstream from Lovell's study, Chisholm (1987, cited in Schwarcz 1991:270) found a mean $\delta^{13}C$ value of $-15.8$‰ (n=13) in prehistoric bone collagen. These signatures are clearly distinct from Sacramento Valley skeletons, which have a mean $\delta^{13}C$ value of $-19.9$‰ (n=51). In addition, the average $\delta^{15}N$ value of ~11‰ in the Valley samples is substantially lower than would be expected if anadromous fish were stored and consumed in any great quantity throughout the year.

Schulz (1981:39) hypothesized that salmon were most likely taken with gills nets in the lower Sacramento Valley and Delta, since the volume and force of water would have been too great for the construction of weirs. He cites only four ethnographically documented weirs in the mid-Central Valley, all of which were constructed across smaller tributaries of the Sacramento and San Joaquin Rivers. The high labor costs of constructing gill nets (see Lindström 1996) may have also reduced the economic value of salmon in high flow areas of the lower Sacramento and San Joaquin Rivers. Gobalet et al. (2004) found that archaeological salmon (*Oncorhynchus spp*) and sturgeon (*Acipenser spp*) remains are poorly represented in many areas within the Sacramento River drainage, especially in comparison with freshwater fish remains. Although an ecological argument may explain the lack of intensified salmon exploitation in the lower Sacramento Valley, the hypothesis that salmonids may have been over-harvested during the prehistoric period should be examined using a more extensive isotopic dataset that includes the northern Valley sites (see arguments in Broughton 1994b; Butler 2000).

In contrast to the Valley, skeletons from San Francisco Bay show clear evidence of dietary change through time. Collagen $\delta^{13}C$ and $\delta^{15}N$ values are significantly higher in Early period skeletons than in Middle and Late period skeletons; these values reflect heavy consumption of high trophic level marine resources, such as marine and anadromous fish, piscivorous birds, and sea mammals. The mean collagen $\delta^{13}C$ value of –14.3‰ and $\delta^{15}N$ value of 16.0‰ is similar (within 1‰ difference) to dietary signatures from the British Columbia coast (Chisholm et al.1983:397), as well as Late period (A.D. 1150 to 1800) groups from the Santa Barbara Channel Islands and coast of southern California (Chisholm et al.1983; Goldberg 1993; Walker and DeNiro 1986). The high $\delta^{13}C$ and $\delta^{15}N$ values in these coastal groups can be best interpreted as evidence for the heavy consumption of marine fish and sea mammals, which are well represented in archaeofaunal assemblages from both regions (Goldberg 1993; Walker and DeNiro 1986). Farther south along the Baja California coast, high $\delta^{13}C$ and $\delta^{15}N$ values reflect even greater consumption of sea mammals, which are the top of the marine food chain (King 1997; Molto and Kennedy 1991).

The Early period Bay Area sample is from the West Berkeley Village site (ALA-307), located along the northeastern shore of San Francisco Bay. In the lower 3.7 m of the shell mound, grooved and notched stone “net sinkers” were recovered in abundance; however, these artifacts were almost non-existent in the upper 1.8 m of the mound that dates to the Middle period (Wallace and Lathrap 1975:21). Net sinkers demonstrate the use of gill nets or seines for fishing, and may have been used in conjunction with tule balsas, the watercraft of the Ohlone people during the ethnohistoric period (Follett 1975:79-84). Archaeofaunal studies of Bay Area sites also clearly indicate the importance of fish; particularly bat ray, sturgeon, salmon, herring, sardine, anchovy, and sharks (Broughton 1997; Gobalet et al. 2004). Although comparing isotopic signatures between the upper and lower portions of the mound would have been ideal, a suitable sample of adult skeletons from the upper 1.8 m of the mound was not available.

Mean collagen $\delta^{13}C$ and $\delta^{15}N$ values of Middle and Late period Bay skeletons are similar to each other, but are significantly lower than Early period Bay skeletons. Furthermore, their values suggest a shift toward greater consumption of terrestrial resources. Dietary signatures are consistent with the heavy consumption of terrestrial mammals, and also low trophic level marine foods such as shellfish, that have similar $\delta^{13}C$ and $\delta^{15}N$ values. Given their abundance in Middle and Late period faunal assemblages, marine and anadromous fish, marine mammals, and water birds continued to be exploited; however, isotopic signatures suggest that these food items contributed proportionately less to the diet than did terrestrial protein sources and shellfish. Broughton (1999) and Simons (1992) both identified significant changes in Bay Area faunal assemblages during the late Holocene, in particular, the increase in sea otters relative to large marine mammals and artiodactyls. This trend suggests that resource depression of large marine mammals and artiodactyls resulted in greater exploitation of otters, in addition to other lower-ranked prey. Between the Middle and Late periods, the small +.5 ‰ shift in $\delta^{13}C$ values and +.7‰ in $\delta^{15}N$ values could indicate slightly greater consumption of otters; however, this difference is small, and may be the result of sampling bias. The high linear correlation between collagen $\delta^{13}C$ and $\delta^{15}N$ values suggests that two isotopically distinct food resources were being consumed in the Bay Area: $^{13}C$-depleted terrestrial animal protein and shellfish, and $^{13}C$-enriched marine proteins. However, the degree of overlap of dietary signatures in both the Middle and Late period samples indicates that a high level of variation in food consumption patterns, with some individuals consuming greater amounts of marine animal proteins than others. A change toward more seasonal residence between the Bay and the interior or changes in post-marital residence patterns may account for this variation.

The collagen-apatite spacing provides a means from which to evaluate the importance of carbohydrates and fats to the diet. The small mean collagen-apatite spacing in Early period skeletons (3.3‰) indicates that dietary protein was more enriched in $^{13}C$ than the whole diet, consistent with the heavy consumption of high trophic level marine animal proteins. In contrast, the mean collagen-apatite spacing in Middle period skeletons is 4.4‰, indicating that the $\delta^{13}C$ of dietary protein and that of the whole diet are the same. This is consistent with a diet composed primarily of terrestrial resources, such as C3 plants, terrestrial mammals, and shellfish. In Late period skeletons, collagen-apatite spacing values decreased to 4.0‰, which suggests slightly greater consumption of marine proteins; this is further supported by the slightly higher $\delta^{13}C$ and $\delta^{15}N$ values in these samples. The larger collagen-apatite spacing in Middle and Late period skeletons is consistent with greater consumption of C3 plants (e.g., acorns, roots, and seeds) over time. This observation is in accordance with the abundance of mortars and pestles recovered from Middle and Late period Bay Area sites, which suggest a greater emphasis on plant staples (Basgall 1987). In sum, the isotopic evidence for dietary change in San Francisco Bay may be consistent with expectations of late Holocene resource intensification. However, evidence for dietary change in the lower Sacramento Valley is not evident in stable isotope ratios.

### *Stable Isotopes: Regional Differences*

As summarized in Chapter V, the most dramatic dietary differences are found between regions. Sacramento Valley collagen $\delta^{13}C$ and $\delta^{15}N$ values reflect heavy consumption of freshwater fish and/or terrestrial mammals, while San Francisco Bay isotope signatures reflect greater consumption of marine fauna. The difference in collagen-apatite spacing between the Valley and Bay are also illustrative of the importance of $^{13}C$-depleted resources, such as plant carbohydrates. Compared with the Bay, Valley skeletons show higher collagen-apatite spacing values, indicating that plant carbohydrates comprised a greater proportion of their diet. The non-overlapping signatures between regions indicate that individuals from the Bay and Valley were consuming food resources derived from isotopically distinct food webs. However, while dietary differences were maintained, isotopic signatures became more similar through time, as Bay Area diets became more terrestrially focused.

### *Stable Isotopes: Sex Differences*

Some of the variability in isotope signatures may be attributable to sex differences in diet. In the Sacramento Valley, male skeletons have slightly higher $\delta^{15}N$ and collagen-apatite spacing values than females for the Middle period sample, which may have resulted from greater consumption of freshwater fish by males. In San Francisco Bay, males have higher $\delta^{13}C$ and $\delta^{15}N$ values than females, suggesting that they consumed greater amounts of animal protein in their diets. The smaller collagen-apatite spacing values in Late period males also suggest that they consumed greater amounts of $^{13}C$-enriched marine protein than females during this period. Although isotope values may reflect true differences in food consumption patterns between the sexes, these results should be treated conservatively due to the small sample size.

## ***Dental Disease***

### *Temporal Differences*

In this study, I hypothesized that the increased consumption of plant staples, such as acorns, would result in increased caries prevalence through time. These predictions are not supported by the dental pathology results for either the lower Sacramento Valley or San Francisco Bay skeletal series. Contrary to expectations, caries prevalence in the Valley significantly *decreased* between the Early and Middle period, and then significantly *increased* between the Middle and the Late period. The Middle period sample has the lowest caries rate, but has greater AMTL, alveolar abscessing, and also higher attrition rates. However, greater rapidity of tooth wear may have contributed to the lower caries rate and higher prevalence of AMTL during this period, since heavily worn teeth with exposed pulp-chambers are susceptible to bacterial infection that causes alveolar abscessing and subsequent shedding of teeth. In the Bay Area skeletal series, the caries rate is higher in Middle period females than in Early and Late period females; however, the prevalence of AMTL and alveolar abscessing (incisor tooth position) decreased through time. In contrast, the caries rate in males did not change over time, although AMTL and alveolar abscessing significantly increased between the Middle and Late periods.

Previous research on dental disease in central California has provided mixed results. For example, Newman (1957) and Kennedy (1960) both reported an increase in the proportion of carious teeth over time in skeletal series from the lower Sacramento Valley. In contrast, Schulz (1981) found no change in caries prevalence over time in the region. These discrepancies most likely reflect differences in the representation and size of the samples, as well as the methods used to calculate caries rates. In this study, the prevalence of carious teeth in the Valley is highest during the Early and Late period, but is significantly lower during the Middle period. Although higher attrition rates in the Middle period may explain some of this trend, this may also reflect decreased consumption of cariogenic plant resources.

Although heavy acorn consumption during the Middle and Late period was expected to result in a higher caries rate, the cariogenic properties of acorns have not been critically evaluated. Many nut foods have cariostatic properties that neutralize bacterial acids in the oral cavity, and thus may actually protect tooth enamel from caries. For instance, dental health studies suggest that foods that are high tannin and fat but low in sugar content may help prevent caries (Bowen 1994; Kandra et al. 2004). Since acorns are rich in both tannins and fats and are especially low in sugar, greater consumption of acorns may also account for the lower caries rates observed during the Middle period. Other resources, such as root foods and berries, would be expected to have more cariogenic properties – due to their higher sugar content – and thus, may account for the higher prevalence of caries in the Early and Late period series.

### *Regional Differences*

Inter-regional comparisons suggest that the prevalence of carious teeth, AMTL, alveolar abscessing, and rate of enamel attrition was greater in the Sacramento Valley than in San Francisco Bay. One exception was found: AMTL and alveolar abscesses are significantly more common among Late period males from the Bay Area. The very low caries rate in Bay Area dentitions is consistent with heavy consumption of marine animal proteins, as demonstrated by the stable isotope data. Indeed, I expected the dental caries rate to be substantially lower in Bay Area skeletons than in those from the Sacramento Valley. Jurmain’s (1990a) dental pathology study of skeletons from the Ryan Mound site (ALA-329, using a different curated skeletal series from the present study) also reported a very low caries rate (.57 percent), which is consistent with the results of the present study. In southern California, Walker and Erlandson (1986) found a lower prevalence of caries among groups that subsisted on marine resources, such as fish and sea mammals, than among earlier groups from the same region that consumed terrestrial plant resources. The regional differences found in this study are in accordance with previous research that shows lower caries rates among groups that consumed marine resources than among those that consumed high amounts of terrestrial plants (Costa 1980; Littleton and Frolich 1993; Mundorff et al. 1990; Shrestha-Mundorff et al. 1994).

Comparisons of dental attrition rates between the Valley and the Bay also shed light on regional differences in diet. The higher attrition rate in Sacramento Valley dentitions is consistent with a greater focus on plant carbohydrates, which require intensive processing with grinding implements that introduce grit into the diet. In comparison, the lower attrition rates in San Francisco Bay samples implies that these groups consumed smaller amounts of plants that required grinding. In conjunction with the isotopic differences between the regions, the dental pathology data provide an additional line of evidence to suggest that prehistoric diets in the lower Sacramento Valley were more focused on plant staples compared with those of San Francisco Bay.

### *Sex Differences*

Sex comparisons of oral health provide additional information regarding male-female food consumption patterns. In the Sacramento Valley, the caries rate was higher in female dentitions for all time periods, with statistically significant differences found in the Early and Late period samples. The average percent difference in caries rate between males and females is 15.7, 7.1, and 12.7 percent for the Early, Middle, and Late periods, respectively (“corrected” caries rate; Luckas 1996). These differences appear to reflect true dietary differences between the sexes in general, and are not due to differences in attrition rates or the age structure of the samples. Females also show a significantly higher prevalence of AMTL and alveolar abscesses than do males. Together, these differences suggest that females consumed greater amounts of cariogenic plant foods than males, especially during the Early and Late periods. These findings are in accordance with Schulz’s (1981) study, which found that dental caries were significantly more common among females than males in the lower Sacramento Valley.

In San Francisco Bay, the caries rate was also higher in female dentitions, with statistically significant differences found in the Early and Late period samples. The average percent difference in caries rate between males and females is 3.0, 5.1, and 1.7 percent for the Early, Middle, and Late periods, respectively (“corrected” caries rate). Males are unaffected by caries in the Early period, and have only slight involvement in the Middle and Late period skeletal series. AMTL and alveolar abscessing are also significantly more common in female dentitions in the Early and Middle period samples; however, the prevalence of these conditions is greater for males in the Late period sample. Although sex differences in oral health are less marked in San Francisco Bay than in the lower Sacramento Valley, these results support the hypothesis that female diets were more cariogenic than male diets in the region.

That females are more often affected than males with respect to dental disease is commonly reported in other studies of agricultural and non-agricultural populations (Cucina and Tiesler 2003; Larsen et al. 1991; Lukacs 1996; Sutter 2001; Walker and

Erlandson 1986; Walker and Hewlett 1990). Marked sex differences in oral health may provide some insight regarding sexual division of labor. Ethnohistoric and ethnographic data sources indicate that females were largely responsible for the gathering, processing, and cooking of vegetal foods in California (Heizer and Elsasser 1980; E. Wallace 1978; Willoughby 1963). If this were the case during the prehistoric period, then females may have consumed greater amounts of cariogenic plant foods than males. In addition, if males were primarily responsible for hunting, as suggested by ethnographic evidence, they may have consumed greater amounts of animal protein that protects against caries. While sex differences in oral health may have been an unintended consequence of sexual division of labor, sexual inequality in access to protein may also have played a role. Because the stable isotope data indicate only slight sex differences in the consumption of protein and carbohydrate resources, it is likely that differences in oral health reflect greater consumption of cariogenic foods by females than by males, but not necessarily substantial differences in overall carbohydrate consumption.

Given the generally higher prevalence of caries, AMTL, and alveolar abscessing in female skeletons, it was unexpected to find that the highest attrition rates occur among males. If males consumed greater amounts of processed foods that contained grit, then this may have resulted in faster wear rates in their dentitions. Alternately, it is also possible that sex differences in wear patterns are unrelated to diet, but instead reflect the use of teeth in various task activities (see Eshed et al. 2006, in press; Schulz 1977). Schulz (1977) documented a unique pattern of dental wear “grooving” in a small skeletal series from the lower Sacramento Valley, which he attributed to the use of the teeth for stripping fibers and cordage for making basketry and fishing equipment, as documented in ethnohistoric accounts. In sum, while the isotopic and dental pathology findings suggest sex differences in food consumption patterns, there is little data to suggest that these differences became more demarcated over time, as predicted by resource intensification models.

## ***Health Trends***

### *Tibial Periosteal Reactions*

Bioarchaeologists often record periosteal reactions on prehistoric human skeletons because they believe that these lesions provide an indirect measure of exposure levels to infectious pathogens (Larsen 1997). In their article, "The Osteological Paradox", Wood et al. (1992) argue that individuals with periosteal reactions may actually be *healthier* than those without, since the presence of these lesions indicates that an individual *survived* long enough to record evidence of it on their skeleton. Because periosteal lesions are generally more common among prehistoric agriculturalists, Wood et al. (1992) suggest that these groups may have been healthier than earlier forager groups that would have succumbed to death from infection before skeletal lesions had time to manifest. However, research in modern non-industrialized nations indicates that pathogens pose the greatest health risks, particularly among densely settled communities with poor sanitary conditions (Inhorn and Brown 1990). Hence, the increased prevalence of infectious lesions in prehistoric skeletons should correlate with other archaeological measures of population density and health status (Cohen 1989a, 1989b; Larsen 1995).

Resource intensification models predict that osteological measures of poor health should increase concomitant with higher population density, poorer sanitation conditions, and reduced dietary quality (Lambert 1993, 1994; Lambert and Walker 1991; Larsen 1998, 2002; Walker et al. 2005). In the lower Sacramento Valley, the prevalence of tibial lesions significantly increased over time. The total lesion prevalence increased from 1.1 percent to 13.4 between the Early and Late periods. In contrast, the prevalence of tibial lesions in the San Francisco Bay samples showed no significant trend through time for any of the sample comparisons.

The increase in tibial lesion prevalence in Sacramento Valley skeletons may reflect greater susceptibility to either infection or trauma, perhaps related to elevated risks incurred during travel away from village sites (Larsen 1995, 1997). Overall, the majority of affected tibiae have periosteal reactions that are large and diffuse (i.e., affecting more than one-third of the diaphysis). Involvement of both tibiae, as well as other bones of the skeleton, is also common. These observations suggest that many of the lesions are the result of systemic infection rather than traumatic injury. The presence of sabre-shin deformity in some individuals, as well as the polyostotic distribution in many individuals, is also consistent with some forms of treponematosis, such as yaws or endemic syphilis (Ortner 2003; Walker et al. 2005). While the proportion of individuals with tibial lesions remained unchanged in San Francisco Bay, lesions are significantly more common in the Early period Bay samples than in the Early period Valley skeletal series. Also, the similar prevalence between the sexes in both regions suggests that males and females had similar levels of exposure to infection and/or trauma.

In the Santa Barbara Channel area, the prevalence of tibial periostoses significantly increased through time, with peak involvement during the late Middle period (circa A.D. 580-1380; Lambert 1993, 1994:183-184). When mainland and island groups are analyzed separately, however, these trends are only significant for the islander groups (Lambert 1993, 1994). In comparison with data from southern California, the prevalence of tibial lesions is substantially lower in central California. For example, 20 to 30 percent of skeletons examined from three sites from the mainland coast of southern California are affected (Walker et al. 2005:283, Table 11.2). On the other hand, five sites from the Northern Channel Islands are more similar to central California, and show a prevalence of tibial lesions that ranges from 0.0 to 12.7 percent (Walker et al. 2005:283, Table 11.2). Based on examination of lesion characteristics, the pattern of skeletal involvement, and the results of histological analyses, Walker et al. (2005) hypothesized that many of the periosteal lesions in the Santa Barbara Channel area are most likely the result of treponemal infection:

> Although osteoperiostitis can result from traumatic injury or nontreponemal infections, cancer, and other disorders, we believe that many if not most of the tibial lesions seen in Santa Barbara Channel area collections are responses to treponemal infection. This conclusion is based on four related observations: the polyostotic nature of the disease in many of the affected individuals (an indication of systemic infection); the tibial predilection of the lesions (a typical feature of treponematosis); the late age of osseous involvement; and histological evidence for the long-standing presence of a condition resembling endemic syphilis…[Walker et al. 2005:290 ]

Although some of the tibial lesions observed in this study may have resulted from treponemal disease, this hypothesis needs to be tested through more extensive study of the pattern of involvement in the skeletal samples. Overall, the significant increase in the prevalence of tibial periostoses in the lower Sacramento Valley is consistent with resource intensification models; however, this expectation was not met in the San Francisco Bay skeletal series, which shows no evidence of change in lesion prevalence through time.

### *Stature*

In this study, I hypothesized that femoral length would decline over time, concomitant with reduction in dietary quality and greater exposure to infectious pathogens during the late Holocene. The data provide some support for a reduction in stature through time. In the Sacramento Valley, femoral length in females significantly declined between the Early and Middle period, accounting for a stature reduction of approximately 6.5 cm. However, a rebound in femoral length was observed between the Middle and Late periods, accounting for an increase in female stature of approximately 5.3 cm. In the San Francisco Bay samples, femoral lengths are highest during the Early period, and are equally shorter during the Middle and Late period, although small sample size and deviations from normality prevented most statistical comparisons between groups.

Previous research suggests significant declines in stature during the late Holocene in California (Ivanhoe 1995; Ivanhoe and Chu 1996; Lambert 1993, 1994). Ivanhoe (1995) found a significant reduction in stature between the Early and Late period in prehistoric groups from the Central Valley, which he attributed to protein deficiency caused by high dependency on acorns. Ivanhoe's (1995) study sample is more representative of the Central Valley as a whole than the present study because it includes skeletal samples from multiple sub-regions within interior central California. Although the trend is less dramatic than that identified in the Central Valley, Ivanhoe and Chu (1996) also observed a significant reduction in stature in skeletal series from San Francisco Bay, with the greatest declines between the Early and Early-Middle period transition, and between phases 1 and 2 of the Late period. In the Santa Barbara Channel Island area of southern California, Lambert (1993, 1994) also observed a significant reduction in femoral length during the late Holocene; this trend was observed in both sexes, and is in agreement with other indicators of nutritional stress (Lambert and Walker 1991; Walker 1986, 1989).

Inter-regional sample comparisons indicate that femora are generally longer in Bay Area skeletons for males, while femora are longer in the Valley skeletons for females. Valley females have significantly longer femora than their Bay counterparts during the Late period; this trend reflects a rebound in femoral length between Middle and Late period in the Valley. Sexual dimorphism in femoral length may also have peaked during the Middle period, in both the Sacramento Valley and San Francisco Bay skeletal series. This implies that stature changes may have impacted growth patterns of females to a greater degree than males. The stature trends offer general support for late Holocene resource intensification, although sample size hinders interpretations of temporal trends in the San Francisco Bay area. The decline in stature between the Early and Middle period in the lower Sacramento Valley is consistent with greater nutritional or disease-related stress, as would be expected with reduced foraging efficiency.

### *Porotic Hyperostosis*

In the Sacramento Valley, the proportion of crania with cribra orbitalia and porotic hyperostosis significantly increased over time. This trend is consistent with the expectation that the acorn-dependent economies of the Middle and Late periods would have contributed to higher levels of acquired anemia in children, since heavy consumption of acorns could have resulted in iron-deficient diets. Additionally, increased sedentism and population aggregation within more circumscribed village communities would have resulted in poorer sanitation, and may have contributed to the anemic status of children by promoting conditions more conducive to the spread of pathogens and parasites (Cohen 1977;1989a; 1989b; Cohen and Armelagos 1984; Larsen 1995, 1997). In contrast to the Valley, the prevalence of orbital and vault lesions in San Francisco Bay remained similar through time.

A few exceptions aside, the prevalence of orbital and vault lesions was higher in the Bay Area skeletal series than in the Valley series, which suggests that acquired anemia was a more serious health consequence for infants and young children in the Bay Area. The stable isotope results from this study indicate that San Francisco Bay populations probably consumed adequate amounts of dietary protein, which suggests that the high prevalence of orbital and vault lesions is not the result of inadequate consumption of dietary iron. This pattern is consistent with other studies that have documented a high prevalence of porotic hyperostosis among prehistoric societies that consumed marine resources as a major part of the diet (Blom et al. 2005; Cybulski 1977, 1992; Walker 1986; Walker and Lambert 1991). Among costal groups, the high prevalence of orbital and vault lesions is attributed to non-dietary factors, such as weanling diarrheal disease, or chronic intestinal bleeding caused by parasites (helminthiasis) or bacterial infection, which results in secondary loss of blood and iron (Goodman 1994; Holland and O'Brien 1997; Kent 1986, 1992; Larsen 1995, 1997; Mensforth et al. 1978; Walker 1986; Wright and Chew 1999).

Helminthes are a likely source of acquired anemia in prehistoric California, since these parasites are often present in anadromous fish and marine mammals. Bathurst (2004:5) notes that salmon of the Pacific region are commonly infested with tapeworm, which may have been a significant cause of anemia in coastal regions. In addition, helminthiasis can be acquired through contaminated water supply or through direct contact with the skin (Bathurst 2004; Blom et al. 2005; Merid et al. 2001; Rothschild 2002; Walker 1986). Recent studies have identified eggs of fish tapeworm (*Diphyllobothrium spp.*) and human roundworm (*Ascaris lumbricoides*) in prehistoric shell mounds from the Pacific coast of Canada (Bathurst 2004). Prehistoric coastal populations in this region also show high levels of porotic hyperostosis, which suggests that parasites may have posed a major health risk (Cybulski 1977, 1992). Although the presence of these parasites has not been examined in archaeological sites from central California, it is likely that they contributed to the prevalence of acquired anemia in the area. Likewise, greater population aggregation and circumscription of territories during the late Holocene may have resulted in a greater prevalence of infectious diseases, which could also have contributed to anemia in infants and children.

Sex comparisons indicate that males and females had a similar prevalence of orbital lesions (cribra orbitalia) in the lower Sacramento Valley and San Francisco Bay. Since these lesions are mostly likely to occur during late infancy, this suggests a similar level of childhood health between the sexes. In contrast, the prevalence of cranial vault lesions (porotic hyperostosis) is more common in male crania in both the Sacramento Valley and San Francisco Bay samples. These differences suggest that female children may have been buffered to a greater degree against nutritional stress and/or pathogen load than male children, an observation supported by the epidemiological and paleopathological literature (Ortner 1998, 2003). Alternately, differential cultural treatment of male and female children may also play a role in susceptibility to parasitic infestation or bacterial infection. Since vault lesions generally show a later age of onset than orbital lesions, sex differences in anemia may have been less pronounced during infancy, but disproportionately affected males during early childhood.

### *Enamel Hypoplasia*

Calculation of the total prevalence of dental enamel defects was hindered in this study by extreme dental attrition, AMTL, and postmortem tooth loss. Despite these limitations, the prevalence of hypoplastic defects is significantly different between time periods and regions. Overall, 45.6 percent of adult dentitions from the Valley and 38.6 percent from the Bay have at least one hypoplasia recorded in a mandibular canine, the most commonly affected tooth type. In the Valley skeletal series, the prevalence of hypoplastic defects significantly increased between the Early and Late periods for the maxillary canine only. In contrast, the prevalence of hypoplasias of the maxillary canine significantly decreased through time in skeletons from the Bay Area. The prevalence and mean number of hypoplastic defects of the maxillary canine is higher in the Bay series than in Valley series during the Early period. However, this trend is reversed in the Late period, when a higher proportion of hypoplastic defects is observed in the Valley sample. Although small sample size may be a factor, the prevalence of hypoplastic defects appears to have been similar between the sexes in both regions.

The hypoplasia data provide mixed support for resource intensification models in prehistoric California. In the lower Sacramento Valley, the prevalence of enamel hypoplasias of the maxillary canine increased through time (14.3, 42.4, 50.0 percent, for the Early, Middle, and Late periods, respectively). Schulz's (1981) study of enamel defects in the Valley reported a prevalence of 14.0, 11.0, and 18.5 percent for the Early, Middle, and Late period, respectively. The divergent results between Schulz (1981) and this study are striking given that both studies used many of the same skeletal samples. Schulz's (1981) study used a larger sample that derived from a greater number of archaeological sites than the current study, although a smaller number of individuals were included from each site. In Schulz's (1981) study, dental attrition was not controlled for, which may have skewed the prevalence of enamel defects towards samples with less dental wear or a younger mean age-at-death. In fact, the faster attrition rates identified in the Middle period sample may have reduced the number of enamel defects identified by Schulz for this time period. In this study, observations of hypoplasias were made within the same scorable section of enamel for all individuals in the study, which avoided the influence of differing attrition rates among the samples.

The increase in hypoplastic defects in the lower Sacramento Valley provides some support for late Holocene resource intensification models in central California. In San Francisco Bay, the prevalence of hypoplastic defects in the maxillary canine significantly decreased between the Early and Middle period from 73.3 to 25.8 percent. In contrast to the Valley, this finding provides some support for the seasonal-stress model, in that it implies an improvement in childhood health status in the Bay Area.

### ***Summary***

In this dissertation, I examined changes in diet and health during the mid-to-late Holocene in central California. Using predictions derived from resource intensification models, I tested three main hypotheses regarding expected subsistence changes in the lower Sacramento Valley and San Francisco Bay area. Paleodietary evidence from stable isotopes and dental disease was used to explore changes in food consumption patterns through time. These results indicate distinct dietary patterns between the Valley and the Bay.

For the lower Sacramento Valley, the stable isotope data indicate that the amount and sources of dietary macronutrients did not significantly change through time, and instead suggest a degree of dietary homogeneity extending back more than 4,000 years. Although food exploitation patterns may have varied through time, changes in diet breadth did not entail the consumption of new food resources that differed in isotopic composition. The collagen-apatite spacing values indicate that C3 plant carbohydrates were of greater importance to diets from the Valley compared with the Bay, which is further supported by regional differences in dental disease.

In San Francisco Bay, some support is offered for resource intensification models based on the stable isotope data. In the Early period, groups consumed heavy amounts of high trophic level marine resources; however, in the Middle and Late period, diets had shifted to include greater amounts of terrestrial C3 resources and low trophic level marine fauna, such as shellfish. Higher collagen-apatite spacing values during these periods indicate increased consumption of C3 plant resources through time, as predicted by resource intensification models.

Intensification theory also predicts temporal declines in health status, caused by poorer quality diets and increased levels of infection associated with high population density and sedentism during the late Holocene. These predictions are supported by comparisons of disease and nutritional stress indicators in the lower Sacramento Valley. The temporal increase in tibial periostoses, cribra orbitalia, porotic hyperostosis, dental enamel defects, and a reduction in stature support the hypothesis of declining health status during the late Holocene. Overall, these trends are most marked between the Early and Middle period, concomitant with archaeological evidence of intensified acorn use and higher population density. In San Francisco Bay, most of the expectations with respect to declining foraging efficiency are not supported based on the data at hand. The prevalence of tibial periostoses, cribra orbitalia, and porotic hyperostosis did not significantly change through time. However, the prevalence of enamel hypoplasias declined through time in the Bay Area, which suggests that nutritional status during childhood may have actually improved. The results of this study do not support the seasonal-stress hypothesis posited for the lower Sacramento Valley (Dickel et al. 1984), but instead provide some support for improvement in childhood health status (based on the hypoplasia data alone) in the San Francisco Bay area. Although few temporal differences are found in childhood health indicators in the Bay Area, health status in general appears to have been worse in this region compared with the Valley, especially with respect to indicators of anemia and tibial infection.

Sex differences in diet and health were also evaluated to identify evidence of sexual division of labor, as well as differences in childhood health status. Overall, the prevalence of dental disease was significantly higher in females than in males, which suggests that female consumed greater amounts of cariogenic plant foods. Isotopic evidence provides some support for greater protein consumption in males, especially for the San Francisco Bay skeletal series. Sex differences in tibial periostoses and growth stress indicators are less marked. Although male stature exceeded that of females in both regions (for all three time periods), sex differences are greatest for the Middle period samples, which implies that growth stunting may have been more pronounced in females than in males during this period. On the other hand, the fact that males had a higher prevalence of porotic hyperostosis than females also implies that female "buffering" may also have played a role in protecting against anemia during early childhood.

### ***Limitations of the Present Study***

Although the bioarchaeological data from this study provide multiple lines of evidence for examining subsistence change in the archaeological record, there are a number of limitations inherent to most studies of prehistoric skeletons. First, skeletal samples are not necessarily representative of the populations from they came, and may reflect only certain segments of society that were interred in a given place. Skeletal elements are further impacted by damage induced from the burial environment and from the excavation itself. Indeed, many of the skeletal samples examined in the study were excavated at time when archaeological field methods were in their infancy. In addition to these confounding variables, small sample size was also a limitation in the present study. Because microenvironmental differences may have affected diet choice and health status, larger sample sizes from different sub-regions of central California would allow for a more fine-grained analysis of the bioarchaeological patterns. Finally, the dearth of radiocarbon dates and the degree of uncertainty introduced by relative dating measures (e.g., burial seriation) is also a limiting factor in this study.

### *Implication for Future Research*

This dissertation demonstrates that the use of stable isotope data in conjunction with paleopathological evidence provides a robust approach from which to examine subsistence change in the archaeological record. The stable isotope evidence demonstrated distinct dietary patterns between regions within central California. The evidence from growth stress indicators and disease also demonstrated that health patterns were not uniform across geographic space, but instead appear to have been influenced more by local conditions.

This research provides an initial “first step” for revitalizing bioarchaeological research in central California. The stable isotope findings indicate a number of interesting patterns that merit further exploration. For example, it would be informative to examine stable isotope values in human skeletons from the northern Sacramento Valley, particularly among groups that lived along the Sacramento River and its tributaries. If heavy salmon consumption occurred during the prehistoric period in the northern Valley, then it should be evident in the carbon and nitrogen human bone isotope signatures. In San Francisco Bay, it would be important to examine paleodietary change in different areas of the estuary to gain a clearer understanding of food consumption patterns in various habitats. This would be of particular interest for evaluating changes in diet breadth during the late Holocene in the region. Because the paleodiets of the lower Sacramento Valley and San Francisco Bay do not overlap, it would also be of interest to examine where dietary signatures converge between the two regions. The addition of stable isotope analysis to the toolkit of the archaeologist should continue to complement other lines of evidence from archaeofaunal and archaeobotanical assemblages.

This research has also shown that changes in health status did not occur uniformly across different regions of central California during the mid-to-late Holocene. The lack of health changes in San Francisco Bay is interesting in light of the decline in health status in the lower Sacramento Valley. Future bioarchaeological research should explore these trends in greater detail, which would shed considerable light on variability in diet and health patterns within different ecological niches in central California.

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# APPENDIX A

*Age & Sex Data Forms* Site: ___________ Catalogue Number: _____________

Date: __________ Burial Number: ________________

| *Sex:* **PELVIS** | **Left** | **Right** | *Sex:* **CRANIUM** | **Left** | **Right** |
|---|---|---|---|---|---|
| Ventral Arc | | | Nuchal Crest (1-5) | | |
| Subpubic Concavity (1-3) | | | Mastoid Process (1-5) | | |
| Ischiopubic Ramus Ridge (1-3) | | | Supraorbital Margin | | |
| Greater Sciatic Notch (1-5) | | | Glabella (1-5) | | |
| Preauricular Sulcus (0-4) | | | Mental Eminence (1-5) | | |

Pelvis: Estimated Sex (0-5) Cranium: Estimated Sex (0-5)
Best Sex Estimate: ____________

**Pubic Symphysis Age** (Suchey-Brooks)
Left Phase ________ Age Range: __________
Right Phase ________ Age Range: __________

**Suture Closure** (Meindle 1985) Blank=unobservable; 0=open; 1=minimal; 2=significant; 3=obliterated

| **External Cranial Vault** | **Left** | **Right** | **Palate** | **Left** |
|---|---|---|---|---|
| 1. Midlambdoid | | | 11. Incisive | |
| 2. Lambda | | | 12. Anterior Median Palatine | |
| 3. Obelion | | | 13. Posterior Median Palatine | |
| 4. Anterior Sagittal | | | 14. Transverse Palatine | |
| 5. Bregma | | | **Internal Cranial Vault** | |
| 6. Midcoronal | | | 15. Sagittal | |
| 7. Pterion | | | 16. Left Lambdoid | |
| 8. Sphenofrontal | | | 17. Left Coronal | |
| 9. Inferior Sphenotemporal | | | **Vault Total (1-7):** | |
| 10. Superior Sphenotemporal | | | **Lat-Ant Total (6-10)** | |

Estimated Age Range: ______________

Transition Analysis: (Boldsen et al. 2002)

| **ECTOCRANIAL SUTURES** | **Left** | **Right** | **AURICULAR SURFACE** | **Left** | **Right** |
|---|---|---|---|---|---|
| Coronal pterica | | | Superior demiface topography | | |
| Sagittal obelica | | | Inferior demiface topography | | |
| Lambdoidal asterica | | | Superior surface morphology | | |
| Zygomatico maxillary | | | Apex surface morphology | | |
| Interpalatine/median palatine | | | Inferior surface morphology | | |
| Interpalatine/posterior portion | | | Inferior surface texture | | |
| **PUBIC SYMPHYSIS** | | | Superior posterior iliac exostoses | | |
| Symphyseal relief | | | Inferior posterior iliac exostoses | | |
| Symphyseal texture | | | Posterior iliac exostoses | | |
| Superior apex | | | | | |
| Ventral symphyseal margin | | | | | |
| Dorsal symphyseal margin | | | | | |

**CRANIAL PATHOLOGY:**
**(Cribra orbitalia, porotic hyperostosis)**

**Catalog #:** _______________
**Burial #:** ________________
**Site:** _________________
**Date:** _________________

**Porosity:**
0 = Absent
1 = External table porosity only, no thickening of cranial vault
2 = Porosity, coalescence of foraminae, no thickening of cranial vault
3 = Porosity, coalescence of foraminae with coral like hyperostosis
4 = Slight porosity, pinpoint (indeterminate, limited to outer table)

**Activity:**
0 = Absent
1 = Active at time of death
2 = Healed at time of death
3 = Mixed reaction, some active lesions and signs of healing
4 = Eroded lesion margins, uncertain activity at time of death

**Periostitis:**
0 = Absent
1 = New bone superficial to original cortex, woven only
2 = New bone, mixed woven and sclerotic
3 = Sclerotic bone only

*Preservation Score:*
0= Absent
1= 100% complete
2= 75% complete
3= 50% complete
4= 25% complete

| **Bone** | Porosity? | Active? | Periostitis? | Preservation Score |
|---|---|---|---|---|
| Left Orbit | | | | |
| Right Orbit | | | | |
| Left Frontal | | | | |
| Right Frontal | | | | |
| Left Parietal | | | | |
| Right Parietal | | | | |
| Left Occipital | | | | |
| Right Occipital | | | | |
| Left Sphenoid | | | | |
| Right Sphenoid | | | | |
| Left Temporal | | | | |
| Right Temporal | | | | |
| Endocranial Surface | | | | |

## *Dental Data Collection Protocol*

### ***Dental Inventory***
1 = present, but not in occlusion (not-erupted)
2 = present, development complete, in occlusion (with wear facets) (>/=2mm root present)
3 = absent, without associated alveolar bone (unknown when it was lost)
4= absent, with the alveolus remodelled or remodelling, antemortem tooth loss
5 = absent, without alveolar remodelling, postmortem loss
6 = absent, congenital, alveolar bone indicates that tooth never formed
7 = present, damaged, little info recorded (or less than 2mm below crown)
8 = present, but not observable (e.g., tooth in crypt, or impacted)
9 = root is present, but fractured, crown is absent

### ***Supernumerary teeth***
1 = located in tooth row
2 = within palate or on lingual aspect of mandible
3 = mesiodens, within the palate but on midline
4 = external to tooth row

### ***Development: following Moorrees stages (see chart)***
0 = not observable
1 = initial formation of the cusp
2 = union of the cusps
3 = cusp form is complete
4 = crown 1/2 (half the crown is complete)
5 = crown 3/4 (three-fourths of crown is complete)
6 = crown complete
7 = initiation of the root
8 = beginning division of the roots (molars)
9 = root 1/4 of full length formed
10 = root 1/2
11 = root 3/4
12 = root length complete
13 = apex half closed
14 = apex closed
15 = crown complete, root fractured & not observable

### ***Root Form (for deciduous teeth only)***
0 = fractured, not observable
1 = complete, without resorption
2 = complete, with a little resorption
3 = complete, 1/2 resorbed
4 = almost the entire root has been resorbed

## *Dental Data Collection Protocol*

***Caries: score each carie independently***

0 = no caries
1 = occlusal surface, including the pits, fissures and exposed dentine
2 = cervical regions, mesial & distal (excluding interproximal points of contact)
3 = smooth surfaces of buccal & lingual aspects, excluding fissures
4 = cervical regions, buccal and lingual, excluding interproximal areas
5 = root caries, below the cervical area
6 = large caries, have destroyed so much of the crown that point of origin is unclear
7 = interproximal surfaces at the contact points between teeth
8 = caries of the protostylid pit or circular caries (of hypoplasia)
9 = pulp exposed by attrition, not really caries

> ***Note:*** *cervical caries that encircle the entire circumference of the root are scored as one carie #2 and one carie #4.*

***Abscesses:*** *indicate the location of the abscess*

0 = no abscess, alveolus is complete
1 = buccal or labial channel
2 = lingual perforation
3 = evident pocket that extends from the buccal periodontal margin
4 = evident pocket that extends from the lingual periodontal margin
5 = periapical abscess
9 = the alveolus is not observable

*PERMANENT TEETH: Maxillary*

Site: ____________
Date: ____________
Catalogue Number: ______________
Burial Number: ________________

| | ***Tooth*** | ***Inventory*** | ***Development*** | ***Attrition*** | | ***Caries*** | | | ***Abscess*** | ***Periodontitis*** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Smith | Scott | 1 | 2 | 3 | Type | Type | Periosteal Reaction? |
| ***Max Left (L)*** | M3 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | M2 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | M1 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | P4 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | P3 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | C | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | I2 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | I1 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| ***Max Right (R)*** | I1 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | I2 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | C | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | P3 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | P4 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | M1 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | M2 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | M3 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |

*Dental age estimate:*
By dental development (Ubelaker) ___________________________

By attrition/tooth loss ___________________________

**Notes & Comments:**

*PERMANENT TEETH: Mandibular*

Site: __________
Date: __________
Catalogue Number: _____________
Burial Number: ______________

| | ***Tooth*** | ***Inventory*** | ***Development*** | ***Attrition*** | | ***Caries*** | | | ***Abscess*** | ***Periodontitis*** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Smith | Scott | 1 | 2 | 3 | Type | Type | Periosteal Reaction? |
| ***Mand*** | M3 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| ***Left*** | M2 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| ***(L)*** | M1 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | P4 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | P3 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | C | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | I2 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | I1 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| ***Mand*** | I1 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| ***Right*** | I2 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| ***(R)*** | C | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | P3 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | P4 | ______ | _______ | _____ | | _____ | _____ | _____ | _____ | ____ | _________ |
| | M1 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | M2 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |
| | M3 | ______ | _______ | | _____ | _____ | _____ | _____ | _____ | ____ | _________ |

*Dental age estimate:*
By dental development (Ubelaker) _________________________

By attrition/tooth loss _________________________

**Notes & Comments:**

*Permanent Dentition: Linear enamel hypoplasias*

**Catalog #:** _______________ **Site:** ____________________

**Burial #:** ________________ **Date:** ___________________

**Defect:** 0 = absence; 1 = linear horizontal grooves; 2 = major growth arrest (MGA wide & deep groove = SOD #1); 3 = linear horizontal array of pits; 4 = nonlinear array of pits

Maxilla:

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tooth | L M3 | L M2 | L M1 | L P4 | L P3 | L C | L I2 | L I1 | R I1 | R I2 | R C | R P3 | R P4 | R M1 | R M2 | R M3 |
| Presence | | | | | | | | | | | | | | | | |
| Wear code | | | | | | | | | | | | | | | | |
| Crown height | | | | | | | | | | | | | | | | |
| Defect 1 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |
| Defect 2 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |
| Defect 3 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |
| Defect 4 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |

Mandible: *←Left Right→*

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tooth | L M3 | L M2 | L M1 | L P4 | L P3 | L C | L I2 | L I1 | R I1 | R I2 | R C | R P3 | R P4 | R M1 | R M2 | R M3 |
| Presence | | | | | | | | | | | | | | | | |
| Wear code | | | | | | | | | | | | | | | | |
| Crown height | | | | | | | | | | | | | | | | |
| Defect 1 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |
| Defect 2 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |
| Defect 3 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |
| Defect 4 | | | | | | | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | | | | | | | |

*Deciduous Dentition: Linear enamel hypoplasias*

**Catalog #: _______________**
**Burial #: ________________**
**Site: ____________________**
**Date: ___________________**

**Defect:** 0= absence; 1= linear horizontal grooves; 2= major growth arrest (MGA wide & deep groove = SOD #1); 3= linear horizontal array of pits; 4= nonlinear array of pits

**Maxilla**:

| Tooth | Lm2 | Lm1 | Lc | Li2 | Li1 | Ri1 | Ri2 | Rc | Rm1 | Rm2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Presence | | | | | | | | | | |
| Moorrees code | | | | | | | | | | |
| Wear Code | | | | | | | | | | |
| Crown height | | | | | | | | | | |
| Defect 1 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |
| Defect 2 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |
| Defect 3 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |
| Defect 4 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |

*Mandible*: **←Left Right→**

| Tooth | Lm2 | Lm1 | Lc | Li2 | Li1 | Ri1 | Ri2 | Rc | Rm1 | Rm2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Presence | | | | | | | | | | |
| Moorrees code | | | | | | | | | | |
| Wear Code | | | | | | | | | | |
| Crown height | | | | | | | | | | |
| Defect 1 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |
| Defect 2 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |
| Defect 3 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |
| Defect 4 | | | | | | | | | | |
| Dist. From CEJ | | | | | | | | | | |

# VITA

Eric John Bartelink was born in Fremont, California in 1974. He attended Lake Orion High School in Michigan and graduated in 1992. He attended Central Michigan University from the fall of 1992 through the fall of 1995, and received a Bachelor of Science degree in anthropology with a minor in history. While at CMU, Eric was actively involved in the Anthropology Society.

Eric entered graduate school in the fall of 1997 at California State University, Chico. While at CSU-C, he studied California bioarchaeology and also assisted with forensic casework for the Human Identification Laboratory. Eric was a laboratory instructor for “Survey of Physical Anthropology” and also taught a summer course at Butte Community College in California. In May of 2001, he received his Master of Arts in anthropology from CSU-C.

Eric entered the Ph.D. program in anthropology at Texas A&M University in the fall of 2001. He taught laboratory sections of “Introduction to Physical Anthropology” while at A&M and also a forensic archaeology course at the State University of New York, Canton. During the summer of 2002 and 2003, Eric assisted the Office of Chief Medical Examiner in Manhattan, NY, with the identification of human remains from the World Trade Center disaster.

Eric received his Ph.D. in May 2006, and is currently an Assistant Professor of Anthropology at California State University, Chico. His address is 400 West First Street, Department of Anthropology, CSU Chico, Chico, CA 95929-0450.