# Archaeobotanical Evidence for Indigenous Burning Practices and Foodways at CA-SMA-113

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***Abstract*** On the central California coast, the low incidence of lightning fires, coupled with a relatively predictable regional vegetation succession pattern, leads to the expectation that in the absence of regular anthropogenic burning, the landscape would have been dominated by dense woody shrubland and forest cover with few plant food resources. Assessment of historical vegetation change in the Quiroste Valley research area supports this hypothesis. Archaeobotanical research at site CA-SMA-113 indicates that during the late Holocene (ca. cal AD 1000–1300), site inhabitants relied heavily on grassland seed foods, producing archaeobotanical assemblages much like those in contemporaneous interior central California sites. The CA-SMA-113 assemblage also contains several culturally or ecologically fire-associated plants in proportions higher than would be expected in the absence of anthropogenic burning. The CA-SMA-113 wood charcoal assemblage is composed mostly of taxa that are compatible with low intensity fire, in sharp contrast to the fire-susceptible trees and shrubs that dominate the landscape today. A synthetic interpretation of the CA-SMA-113 botanical data supports the hypothesis of frequent anthropogenic landscape burning around Quiroste Valley during the late Holocene.

***Resumen*** En la costa central de California, la baja incidencia de los incendios causados por rayos junto con un patrón de sucesión regional de vegetación relativamente predecible crean la expectativa de que, en ausencia de la quema antropogénica regular, el paisaje hubiera estado dominada por densos matorrales leñosos y la cubierta forestal con pocos recursos de plantas alimenticias. La evaluación del cambio de la vegetación histórica en el área de investigación en el valle Quiroste apoya esta hipótesis. La investigación arqueobotánica en el sitio CA-SMA-113 indica que durante el Holoceno Tardío (ca. 1000–1300), los habitantes del sitio dependían en gran medida de las semillas de pastizales como alimentos, dejando conjuntos arqueobotánicos similares a los sitios contemporáneos en el Interior de California central.

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El conjunto CA-SMA-113 también contiene varias plantas culturalmente o ecológicamente asociadas con incendios en mayor propoción de lo que cabría esperar en la ausencia de la quema antropogénica. El conjunto de carbón de leña del sitio CA-SMA-113 está compuesto principalmente de taxones que son compatibles con incendios de baja intensidad, en contraste con los árboles y arbustos que que son susceptibles a los incendios que dominan el paisaje hoy día. Una interpretación sintética de los datos botánicos de CA-SMA-113 apoya la hipótesis de quemas antropogénicas frecuentes del paisaje alrededor del valle Quiroste durante el Holoceno Tardío.

**Our research team's approach** to traditional resource and environmental management (TREM) research takes the position that synthesis of multiple lines of evidence from independent ecological, archaeological, and historical data sets can be used to assess anthropogenic burning practices through time (Lightfoot and Lopez, this issue). When considered in a historical ecological framework that examines the interplay of fire ecology and cultural plant uses, archaeobotanical data can be applied to research questions about indigenous landscape burning. In taking this approach at Quiroste Valley Cultural Preserve, this study contributes to an emerging body of research in California emphasizing ecological context in archaeobotanical studies of TREM practices and foodways (e.g., Anderson and Wohlgemuth 2012; Hammett 1991; Wohlgemuth 2010). This article employs ecological data, including published descriptions of regional vegetation dynamics and data on historical vegetation succession in the recent past, together with macrobotanical and anthracological data from site CA-SMA-113 (portions dating ca. cal AD 1000–1300) to explore whether these lines of evidence indicate landscape conditions consistent with a lightning fire regime or with anthropogenic burning during the late Holocene.

## Fire Ecology and Vegetation Dynamics in the Quiroste Valley Research Area

Lightning strike density is low in the coastal regions of central and northern California, with ca. 2 to 3 strikes/100 $km^2$/year. In contrast, the Cascade Range, the Sierra Nevada, the Northeast Plateau, and southern desert regions all have >20 strikes/100 $km^2$/year (Cuthrell et al. 2012:161–163; van Wagtendonk and Cayan 2008). Lightning ignition rates in the San Francisco Bay Area compiled by Keeley (2005) ranged from 1.8 to 5.3 ignitions/100 $km^2$/century (ca. 1.2 percent of strikes), and 86 years of lightning ignition data from Santa

Cruz County produced a similar rate of 3.4 ignitions/100 $km^2$/century (calculated from data in Greenlee and Langenheim 1990).

Based on these ignitions rates, lightning fires would need to average ca. 1,900–5,500 ha to sustain a 100–year fire return interval (FRI). A fire spread model by Greenlee and Langenheim (1990:243) used 50 years of historically recorded lightning fire ignitions in Santa Cruz County to predict fire spread and FRI under a lightning fire regime. In this model, the 28 lightning fires averaged ca. 800 ha in size (calculations based on Greenlee and Langenheim 1990: Figure 2), indicating a >200-year FRI for Santa Cruz County. Only one historical lightning-ignited fire was within 5 km of the coastline, and the area within 5 km of the coast predicted to burn was negligible over the simulated 50-year period. Greenlee and Langenheim (1990) also estimated an FRI of 135 years for upland redwood forests under a lightning fire regime.[1]

Researchers have predicted long FRIs in the central California Coast Ranges under lightning fire regimes, with several decades to over a century between successive fires in a given location (Davis and Borchert 2006; Greenlee and Langenheim 1990; Keeley 2002, 2005). On the central coast terraces, regular fogs maintain mesic conditions during the summer drought, and cool coastal summer weather prevents lightning storm formation (Keeley 2002). In coastal areas, lightning ignition rates may be much lower than regional averages, and FRIs consequently longer, perhaps 50 to 100 years or more.

In the central coast region, vegetation type conversion from grasslands to shrublands, woodlands, and forests in the absence of disturbance factors such as fire and grazing has been predicted and observed by many researchers (e.g., Ford 1991; Ford and Hayes 2007; Keeley 2002; McBride 1974; Williams et al. 1987). Under a lightning fire regime with FRIs of 50 to 100 or more years, most coastal terraces and foothills in the area around Quiroste Valley would probably be dominated by woody vegetation types, particularly northern coastal scrub and Douglas fir forests.

This prediction was tested by quantifying changes in the distribution of broad vegetation types over 30 years using historical aerial photographs and ground reconnaissance. Figure 1 compares landscape vegetation in 1982 to vegetation in 2012 in a ca. 50-ha area around CA-SMA-113. The extent of grasslands in the earlier map is the result of regular disturbance from agricultural and ranching activities since at least the late 1800s (Mowry 2004). After the California Department of Parks and Recreation acquired the land in the early 1980s, disturbance factors were removed. From 1982 to 2012, grassland cover decreased from 38.4 to 12.8 percent (Table 1). At the same time, Douglas fir cover increased from 10.1 to 35.5 percent, while woody shrubland

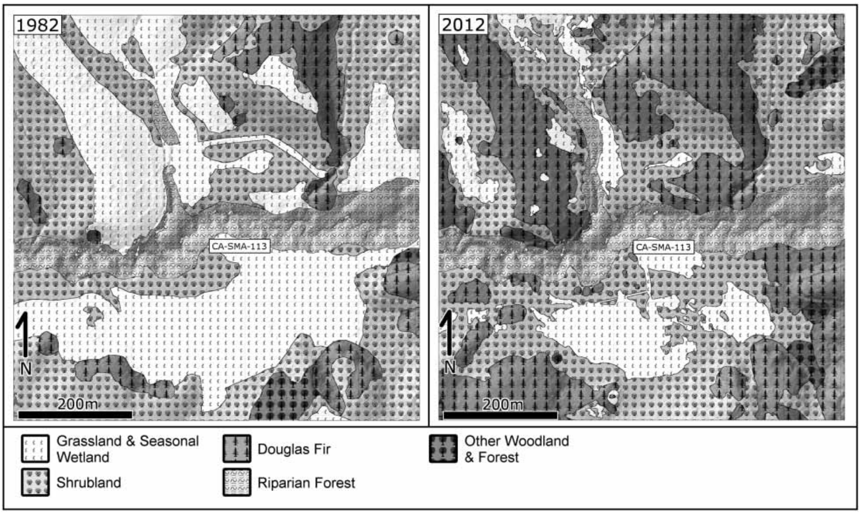


**Figure 1.** Map of general vegetation types in a 51.5-ha area in and around Quiroste Valley in 1982 (left) and 2012 (right). Assignment of vegetation type was based on aerial photographs and ground reconnaissance.

cover remained about the same. Although the proportion of shrubland cover did not change, this was not because shrublands failed to expand into grasslands. Figure 1 shows that while shrublands colonized grassland areas, some shrubland areas were converted to Douglas fir.

In the absence of fire, expansion of shrublands and Douglas fir into grasslands not only limits the amount of grassland resources available, but also

**Table 1.** Changes in Cover of Broad Vegetation Types in Quiroste Valley, CA-SMA-113 Vicinity, Between 1982 and 2012.

| | 1982 Area (ha) | 2012 Area (ha) | Difference (ha) | 1982 Cover (%) | 2012 Cover (%) | Difference (%) |
|---|---|---|---|---|---|---|
| Grassland/ Seasonal Wetland | 19.8 | 6.6 | –13.2 | 38.4 | 12.8 | –25.6 |
| Shrubland | 19.8 | 19.5 | –0.3 | 38.4 | 37.9 | –0.6 |
| Douglas Fir | 5.2 | 18.3 | +13.1 | 10.1 | 35.5 | +25.4 |
| Riparian | 5.8 | 6.3 | +0.5 | 11.3 | 12.2 | +1.0 |
| Other Woodland | 0.9 | 0.9 | 0.0 | 1.7 | 1.7 | 0.0 |

Note: Data from same area as depicted in Figure 1.

access to them. As the landscape becomes dominated by woody vegetation cover, mobility, visibility, and food resource productivity are all reduced. In the long-term absence of fire, coastal landscapes in much of central and southern California would have been relatively depauperate in terrestrial plant food resources (Keeley 2002; Wohlgemuth 2010). Grasslands would have been limited in extent except in the first ca. 15 to 25 years after stand-replacing fires (see Ford and Hayes 2007:204), decreasing the availability of highly reliable herbaceous plant seeds and geophytes. People living in these closed landscapes would have had to rely more on nuts, wetland geophytes, and fruit foods.

Records of the earliest Spanish explorers indicate that landscape burning along coastlines did not produce the type of expansive oak woodlands that were described in inland areas, such as from the western shores of San Francisco Bay to the Santa Clara Valley (Mayfield 1978). Oak woodlands are rare in the vicinity of Point Año Nuevo today, and a historical vegetation type map of the area indicates that this was also the case in 1935 (Wilson and Hanks 1935). Although tanoak (*Notholithocarpus densiflorus*) is common in redwood forest understories, it has not been observed growing in open areas, suggesting its range may be restricted to redwood forests. Although acorns would have provided a more efficient source of calories than grassland seed foods (Wohlgemuth 2010), the potential for expanding oak populations in this area was limited. In contrast, the potential for expanding grassland resources through anthropogenic burning was high.

The vegetation in and around Quiroste Valley today contrasts strongly with the open landscape of grass-covered hills described by the first Spanish explorers (Hylkema and Cuthrell, this issue; Mayfield 1978). To maintain a grassland-dominated landscape, I expect anthropogenic fire regimes to have been characterized by frequent FRIs, with annual to sub-decadal burning (i.e., generally 1 to 5 years but up to 10-year intervals) in many areas. These expectations are consistent with ethnographic accounts of landscape burning used to enhance grassland resources and maintain open woodlands elsewhere in California (Anderson 2005). With these expectations in mind, this article explores the potential of using archaeobotanical data from CA-SMA-113 to make interpretations about anthropogenic landscape burning.

## Macrobotanical Analysis Methods

Archaeological sampling at CA-SMA-113 included a robust flotation sampling strategy for recovery of botanical remains, small artifacts, and ecofacts (Cuthrell et al., this issue). From every excavated context, a 5- to 10-liter soil sample was collected for flotation. These systematic samples were termed "standard" flotation samples. Samples were also collected from discrete deposits such as ash lenses or fire-affected rock accumulations. These bulk samples were termed "intensive" samples, and varied in size from <1 to 10 liters. When possible, discrete deposits were collected in toto for flotation processing.

During excavations, 158 standard flotation samples, 35 intensive samples, and eight samples from a column were collected, for a total of 201 samples. Samples were processed either in the field or in the UC Berkeley archaeology laboratories using flotation systems constructed by the author. Light fraction materials were collected in a ca. 200–250 μm aperture mesh. Heavy fraction mesh sizes were 1.6 mm in 2007 and ≤1.0 mm afterward. Macrobotanical analysis was performed by the author at the McCown Archaeobotany Laboratory, UC Berkeley.

The light fractions of flotation samples were sieved into the following fraction sizes: <0.3, 0.3–0.5, 0.5–1.0, 1–2, and >2 mm. Archaeobotanical specimens recovered from light fractions were identified using reference collections in the McCown Archaeobotany Laboratory and online seed image databases. Portions of light fractions >2 mm in size were comprehensively sorted, separating all classes of archaeobotanical and other remains (i.e., "residue"). Macrobotanical remains >2 mm were sorted as seeds, wood, parenchyma, clinker, nutshell, and other unidentified materials. Weights were recorded for wood, parenchyma, clinker, and nutshell. In the 1–2 mm size fraction, wood and residue were not separated. In size fractions <1 mm, only seeds and seed fragments were pulled, and were sorted as identified taxa, potentially identifiable seeds, unidentified seeds (i.e., distorted, fragmentary), and other vegetative material. All size fractions greater than 0.5 mm were sorted in full, while size fractions between 0.3–0.5 mm were sub-sampled at 12.5–100 percent using a riffle splitter. Light fraction contents less than 0.3 mm in size were not analyzed.

After excavations at CA-SMA-113 were completed, recovered materials were assigned to interpretive contextual units termed "loci" (see Supplementary Table 1). To focus on the samples that best represent CA-SMA-113 site occupation, this study considers data from 75 samples collected from mixed midden deposits (hereafter termed "non-discrete deposits;" Loci 101–104; 44 samples) and features (hereafter termed "discrete deposits;" Loci 401, 402, 403, 404, 405, 406 and 409; 31 samples) collected from the central portion of the site. These two broad contextual categories include all analyzed "standard" and "intensive" flotation samples collected from each of the loci listed.

## Anthracological Analysis Methods

Anthracology refers to the study of ancient wood charcoal, either from archaeological sites (more specifically referred to as "archaeo-anthracology") or from natural environmental contexts. This field of study, which coalesced in Europe during the early 1990s, emphasizes an interdisciplinary approach employing ecological and archaeological perspectives (Vernet 2002). In California, archaeo-anthracology is still in an emergent stage, and there have been no publications systematically reporting diagnostic criteria for identifying small charcoal specimens. Sources reporting diagnostic criteria for California woody taxa or extra-local congeners (Esteban et al. 2004; Hoadley 1990; InsideWood 2013; Wheeler 2011) and physical reference materials were used to construct a genus-level identification key for 46 local wood taxa. Microanatomical characteristics were identified based on IAWA Committee (1989, 2004) descriptions. Time and resource constraints have not yet allowed for verification of diagnostic criteria of most genera using local reference materials.

Specimens were selected from the >2 mm size fraction of samples, beginning with the largest charcoal specimens and working towards smaller specimens in each sample. This was done to maximize the potential for identification, since smaller specimens tend to lack diagnostic features and are much more difficult to successfully prepare for analysis. Specimens were fractured or cut to produce transverse, radial, and sometimes tangential sections and viewed under reflected light at 50–500× magnification using an Olympus BX-51 microscope. Descriptions of micro-anatomical features and a qualitative measure of identification confidence were recorded for each specimen (Supplementary Table 2).

## Macrobotanical Remains from CA-SMA-113

### *Overview of the Macrobotanical Assemblage*

The 75 samples considered here produced 41,143 macrobotanical remains that have been identified to at least family level. Discrete deposits were more than twice as dense in identified remains (144.2 specimens/liter) as non-discrete deposits (59.4 specimens/liter). Over 90 percent of the assemblage can be grouped into ten taxonomic categories, which are used here to simplify the analysis. In decreasing order of assemblage proportion, these are grasses (Poaceae), panicled bulrush (*Scirpus microcarpus*), coast tarweed (*Madia* sp.), clovers (*Trifolium* spp.), composites (Asteraceae), bedstraws (*Galium* spp.), hazel (*Corylus cornuta* ssp. *californica*), phacelias (*Phacelia* spp.), tanoak (*Notholithocarpus densiflorus*), and wild cucumber (*Marah* sp.). All other identified

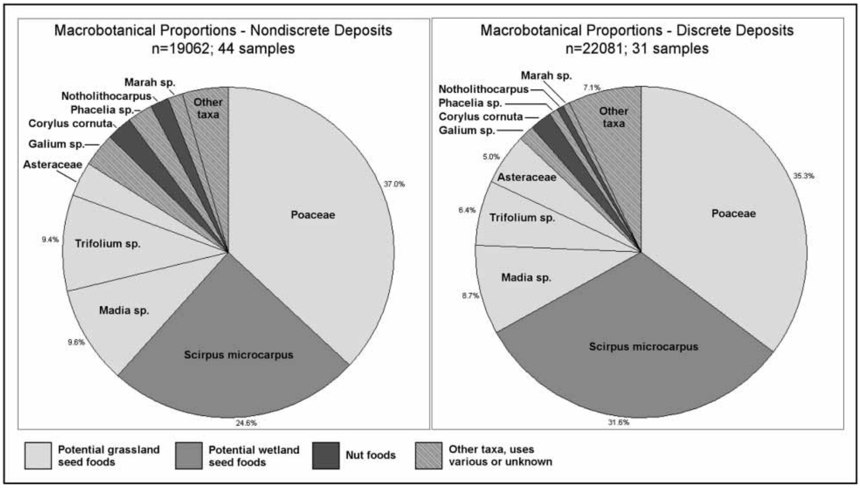


**Figure 2.** Proportions of macrobotanical taxa (10 taxon categories plus "other taxa") recovered from CA-SMA-113 non-discrete deposits (left) and discrete deposits (right). Taxon categories are shaded according to plant food type.

specimens are categorized as "other taxa." This analysis includes only identified charred botanical remains from light fractions. Addition of heavy fraction data would increase the amount of hazel recovered substantially, often doubling the amount recovered from light fractions.[2] Macrobotanical density and percentage data by sample and taxon category are presented in Supplementary Table 3.

Figure 2 compares proportions of botanical taxa recovered from discrete and non-discrete deposits at CA-SMA-113. The overall assemblage composition between the two contextual categories is similar, suggesting that the majority of macrobotanical remains in non-discrete midden deposits constitute spatially diffuse representations of the same types of activities (primarily food preparation) that generated the assemblages of discrete deposits. Due to the large sample size in each context category, any differences in taxon proportions greater than 0.8 percent between the two context categories are statistically significant to at least the 95 percent confidence level (van der Veen and Fieller 1982).[3] Discrete deposits have a significantly higher proportion of panicled bulrush and significantly lower proportions of bedstraws and phacelias (both plants whose seeds were probably not consumed) than non-discrete deposits. This could reflect slightly higher incidence of burning that was not related to food preparation in non-discrete midden deposits.

In the most comprehensive synthesis of macrobotanical data from California sites to date, Wohlgemuth (2004) quantified the density of grass and forb seeds (n/liter) and the ratio of acorn nutshell weights to seed counts (mg/n) to examine major shifts in plant food consumption through the Archaic, Emergent, and Protohistoric periods in central California.[4] In interior central California, there was a significant increase in the density of grass and forb seeds between the Upper Archaic Period (ca. 550 BC to AD 750) and the Lower Emergent Period (ca. AD 750–1450), reflecting their regular incorporation into foodways at this time, and seed densities continued to increase through time after the Archaic/Emergent transition.

Figure 3 compares density of grass and forb seeds in the CA-SMA-113 assemblage to values from Emergent Period interior central California sites. When considering only seeds greater than 0.5 mm in size,[5] seed density in CA-SMA-113 non-discrete deposits are similar to interior central California seed densities from the Lower Emergent Period, while seed densities in discrete deposits are higher, resembling seed density distributions in Upper Emergent Period (ca. AD 1450–1750) sites. These results suggest that for CA-SMA-113 inhabitants (ca. AD 1000–1300), grass and forb seed foods may have been of

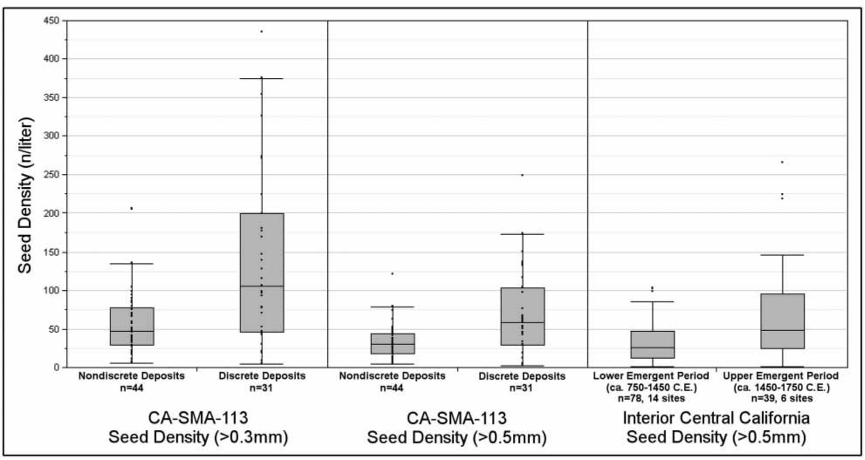


**Figure 3.** Box plots of seed density (seed count per liter of sediment volume) at CA-SMA-113 and at sites in Emergent Period interior central California reported by Wohlgemuth (2004:76; box plot data from Figure 4.2). Seeds included in density calculations at CA-SMA-113 include only the following taxon categories: Poaceae, *Scirpus microcarpus*, *Madia* sp., *Trifolium* sp., Asteraceae, *Galium* sp., and *Phacelia* sp. Including unidentified seeds in density calculations would substantially increase density values.

similar dietary importance as for people in contemporaneous interior central California sites.

In interior central California, as seed consumption increased from the Upper Archaic to the Lower Emergent periods, the ratio of acorn nutshell to grass and forb seeds decreased, but acorns remained well represented in Emergent Period through Protohistoric Period (post ca. AD 1750) macrobotanical samples, with ca. 1–4 mg of acorn nutshell for every seed recovered (Wohlgemuth 2004:76). Figure 4 compares acorn nutshell to seed ratios and total nutshell to seed ratios from CA-SMA-113 to the data from Emergent Period interior central California sites. Acorn nutshell to seed ratios from both discrete and non-discrete deposits are much lower at CA-SMA-113, with an overall median value of 0.055 mg/n, more than an order of magnitude less than contemporaneous median values from interior central California. The observed divergence is in part due to the dominance of hazelnuts rather than acorns in the CA-SMA-113 nutshell assemblage. Although hazelnut shells are much more robust than acorn shells (and thus inflate nutshell to seed ratios when included with acorn nutshell weights), the median ratio of all nutshell to seeds at

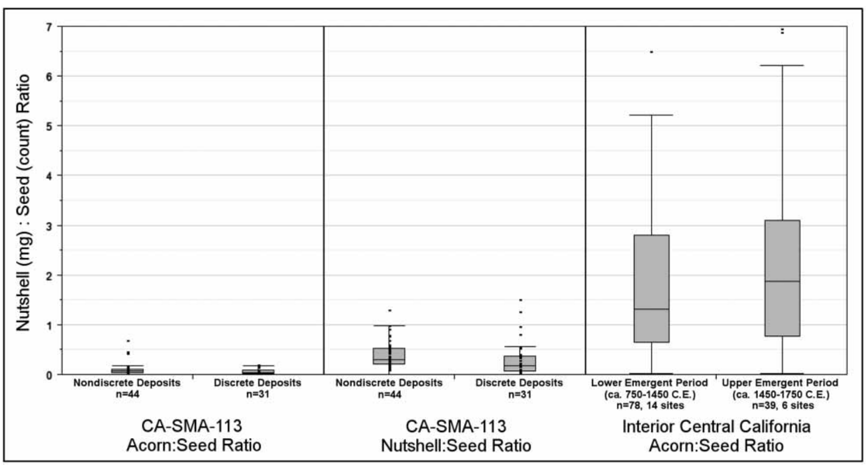


**Figure 4.** Box plots of nutshell (mg) to seed (count) ratios at CA-SMA-113 and at sites in Emergent Period interior central California reported by Wohlgemuth (2004:76; box plot data from Figure 4.2). Nutshell remains from CA-SMA-113 were quantified from size fractions >1 mm only. CA-SMA-113 acorn:seed ratio (left) includes nutshells of the genera *Notholithocarpus* and *Quercus* only; CA-SMA-113 nutshell:seed ratio (center) includes shells from hazel (*Corylus cornuta*) as well. Three outlier samples from Emergent Period interior central California with acorn:seed ratios greater than seven are not shown.

CA-SMA-113 (0.283 mg/n) is still about five times less than median acorn nutshell to seed ratios from Emergent Period interior central California.

The large difference in acorn nutshell representation between CA-SMA-113 and contemporaneous interior sites could indicate that nut foods were less prominent in the diets of CA-SMA-113 site inhabitants. Another possibility is that the paucity of nutshell reflects regional differences in the spatial sequence of acorn processing. If acorns were collected, stored, and shelled at sites closer to inland/upland oak stands, nutshell remains at CA-SMA-113 would consistently under-represent the contribution of acorns in the foodways of people at this site. Additional macrobotanical research at local sites in different topographical and micro-climatological zones is needed to clarify this topic.

Macrobotanical data indicates that the inhabitants of CA-SMA-113 regularly consumed a variety of grass and forb seeds collected from grassland, seasonal wetland, and/or wetland habitats. Considered together, grassland taxa potentially used as foods comprise the majority of the overall seed assemblage (57.5 percent; Figure 2), and a larger proportion (69.3 percent) of the seed assemblage >0.5 mm. Based on expectations for vegetation dynamics and grassland resource availability in the long-term absence of fire, the high degree of sustained grassland seed consumption at CA-SMA-113 is likely incompatible with lightning-ignited fire regimes alone. Several taxa in the CA-SMA-113 assemblage are notable for their unexpectedly high abundance in the assemblage (panicled bulrush) or for their potential associations with landscape burning practices (phacelias, tarweeds, hazel, and tobacco). Ecological information about these taxa and their implications for foodways and anthropogenic burning practices are discussed below.

### *Panicled Bulrush*

Seeds of the wetland perennial panicled bulrush are the second most abundant category of seeds at CA-SMA-113 after grasses, comprising 28.4 percent (n = 11,679) of identified macrobotanical remains (Figure 2). The very high proportion and ubiquity of panicled bulrush seeds in the assemblage was unexpected, since this taxon has not been reported as a common constituent of macrobotanical assemblages at other sites in central California. There are several possible explanations for why panicled bulrush has not been reported at other sites in central California: (a) the plant may have been used in a crafting or food practice that was local to Quiroste Valley, (b) the achenes may have been mistaken for stinging nettle (*Urtica dioica*) seeds, which they resemble when complete, (c) the seeds may not have been identified, since the overwhelming majority of panicled bulrush seeds in the CA-SMA-113 assemblage are lacking the achene shell, considerably altering morphology (Supplementary Figure 1), and/or (d) the seeds may not have been analyzed due to their small size.

Rumsen and Mutsun informants did not report consumption of sedge seeds, but sedge "roots" (possibly stem bases, roots, and/or rhizomes) were eaten, and "roots" (probably rhizomes) were used in basketry (Bocek 1984:255). Elsewhere in California, sedge seeds were eaten by native groups including Cahuilla, Klamath, and Northern Paiute peoples (Moerman 1998). Although panicled bulrush achenes are very small (ca. 0.5–1.0 mm in length), they are produced abundantly on highly visible inflorescences, and unlike most other sedges with larger fruits, the achene shells of this taxon are very thin, facilitating consumption. Because collection and consumption of stem bases, roots, or rhizomes for consumption or other purposes would not result in seed transport to residential sites, I interpret archaeobotanical panicled bulrush at CA-SMA-113 as a potential seed food gathered from seasonally wet meadows or wetlands in and around Quiroste Valley, possibly in association with collection of sedge materials for other uses.

### *Phacelias*

Although seeds of phacelias (*Phacelia* spp.) do not comprise a large proportion of the CA-SMA-113 assemblage, they are one of the ten most common taxa in the categorization scheme used here and they have a high ubiquity (92 percent) in the macrobotanical assemblage. This is in contrast to the rarity or absence of phacelias in modern Quiroste Valley. Many phacelias in southern California chaparral communities are fire-following annuals stimulated to germinate by chemical by-products of fire or charcoal (Keeley and Keeley 1987; Keeley et al. 1985). These taxa recruit more abundantly or exclusively within the first few years after a burn (Quinn and Keeley 2006). Of the four vouchered phacelia species within a ca. 15-km radius of Año Nuevo Point (Calflora 2013), one is reported as a fire-follower (*P. suaveolens*; Quinn and Keeley 2006) and three have not been studied for fire germination cues (*P. californica, P. malvifolia,* and *P. ramosissima*). Although more research is needed on fire responses of local phacelias, the consistent representation of phacelias in the CA-SMA-113 assemblage and their absence on the modern landscape could reflect the difference between frequent burning in Quiroste Valley during the late Holocene versus cessation of burning during the last century.

### *Tarweeds*

The seeds of tarweeds (*Madia* spp., *Centromadia* spp., and *Hemizonia* spp.) were eaten by native peoples throughout much of California, and ethnographic accounts from northern and central interior California report tarweed management through burning (Anderson 2005; Bocek 1984; Schenck and Gifford 1952; Timbrook et al. 1982). In northern California and Oregon, tarweed stands were burned after seed maturation but prior to seed dispersal (Schenck and Gifford 1952; Williams 2000). This roasted the seeds and probably facilitated seed collection by reducing viscidity of leaves and stems.

There has been little experimental research on fire ecology of tarweeds in the genus *Madia*. Two studies reported that exposure to the chemical by-products of fire did not affect germination in slender tarweed (*Madia gracilis*), but in one study common madia (*Madia elegans*) seed germination increased in response to chemical fire cues (Keeley and Keeley 1987; Maret and Wilson 2005). Tarweed in the CA-SMA-113 assemblage is morphologically consistent with coast tarweed (*Madia sativa*), the only tarweed species observed in modern Quiroste Valley. Even in the absence of disturbance, coast tarweed is common in open grasslands on the valley floor. Here, coast tarweed fruits from August to October, long after most other herbaceous grassland taxa have dispersed their seeds. Anthropogenic burning may have increased the extent of coast tarweed stands by reducing litter or by stimulating germination of tarweed seed banks, but more experimental research on coast tarweed is needed to explore fire effects.

### *California Hazel*

Unlike most archaeological sites in central California, at CA-SMA-113 California hazelnuts (*Corylus cornuta* var. *californica*.) rather than acorns were the most abundant nut food in the macrobotanical assemblage (Supplementary Figure 2), accounting for 85.5 percent of the edible nut assemblage by weight. Hazel is closely connected to fire management both in California and in the Pacific Northwest region, where native peoples burned hazel to produce straight sprouts suitable for crafting, to enhance nut production, and/or to facilitate nut collection (Anderson 2005:172–173; Boyd 1999; Turner 1999). There have been few experimental studies on the effects of fire on California hazel sprouting and nut production, and these are mostly from the Pacific Northwest region. Research on the closely related shrub beaked hazel (*Corylus cornuta*) indicates that it resprouts vigorously in the year after a fire, that fire can increase the total number of hazel sprouts in a stand, and that the underground portions of hazel can survive even high intensity and sustained burning (Gill and Healy 1974; Johnston and Woodward 1985).

In beaked hazel, nut production is closely connected to site conditions, with shaded plants producing nuts rarely or never (Gill and Healy 1974). Beaked hazel is also a masting species, producing an abundant nut crop only once every ca. five years, and year-to-year nut production can vary by more than two orders of magnitude. A study in Oregon suggested California hazel may be similarly variable in its fruiting behavior (Wender et al. 2004). In that study, only five hazelnuts were produced during four years of observations on 160 ha of experimental plots with different degrees of overstory thinning (Wender et al. 2004). If California hazel behaves similarly in the vicinity of Quiroste Valley, the abundance of hazel nutshell in the archaeological assemblage is difficult to reconcile with hazelnut production under natural conditions, suggesting some form of hazel management may have been used to increase nut production, produce basketry materials, or both (see also Fine et al., this issue).

### *Tobacco*

Although tobacco seeds comprise a small proportion of the CA-SMA-113 assemblage (0.52 percent of identified specimens), the site contains a higher ubiquity (57.3 percent) and absolute count (n = 216) of native tobacco (*Nicotiana* sp.) remains than any reported archaeological site in central California (Eric Wohlgemuth, personal communication 2013). The high ubiquity of tobacco in CA-SMA-113 samples could indicate that the site is distinct from most other habitation sites, with ceremonial associations dating to the late Holocene and evidenced in the eighteenth century by the presence of a large ceremonial structure in the valley. However, tobacco usually constitutes a small proportion of seeds in macrobotanical samples (<1 percent of seeds), and the difference between the CA-SMA-113 tobacco data and that of other sites might also be explained by differences in per-sample and total assemblage sample sizes.

Two native tobacco species grow near the central California coast north of Monterey, Indian tobacco (*N. quadrivalvis*) and coyote tobacco (*N. attenuata*). Coyote tobacco does not occur in coastal areas, and neither species is represented by a vouchered specimen recovered less than ca. 20 km inland from the shoreline along the central coast during the last hundred years (Baldwin et al. 2012; Calflora 2013). Charred seeds of these two species cannot currently be differentiated based on morphology, so it is not certain whether CA-SMA-113 inhabitants used either or both taxa. John P. Harrington recorded Indian tobacco (*N. quadrivalvis*) uses described by Rumsen and Mutsun informants

(Bocek 1984), but it is not clear whether informants were presented with both local species.

It is unclear whether tobacco was traded to CA-SMA-113 from inland locales or cultivated on the coast, outside of the plant's modern range. High ubiquities of archaeological tobacco seeds outside of the plant's natural range might be an indicator of cultivation. However, tobacco seeds might have entered the archaeological assemblage through trade. Indian tobacco is glandular and leaves are viscid. If entire plants or leaves were harvested around the time of seed dispersal, I expect that seeds would have adhered to traded leaves. Tobacco leaves offered to the fire, as well as the charred remnants of smoking material, would be expected to contain seeds, allowing their preservation in the archaeological record. If tobacco was cultivated on the coast, regular burning may have played a key role in sustaining it there. For native peoples in many parts of California, burning was used to enhance wild tobacco stands and to prepare plots prior to sowing tobacco seed (Anderson 2005; Hammett 2000). Seeds of coyote tobacco are sometimes strongly cued to germinate by fire (Baldwin et al. 1994), and in northern California dense stands of this plant are most commonly seen in recently burned areas (Todt 2007).

## Anthracological Remains from CA-SMA-113

Anthracological analysis was conducted on CA-SMA-113 material to explore whether the woody taxa used as fuel by site inhabitants are those that would be expected to dominate the landscape under lightning fire regimes, or those that would have been present under anthropogenic fire regimes. Considerations such as differences in charcoal fragmentation patterns between taxa, selection of particular taxa based on burning characteristics, differences in the ratio between vegetation cover and firewood production, and others, have the potential to complicate interpretations of anthracological data (Asouti and Austin 2005; Thery-Parisot et al. 2010). It is tempting to assume that native people would have acquired wood fuels according to a "principle of least effort" model, in which potential fuels (i.e., accessible materials of appropriate size and moisture content) would be collected based on proximity, and not due to cultural factors such as beliefs about the appropriateness of a fuel for a particular task (Shackleton and Prins 1992). In this model, charcoal remains recovered from an archaeological site would represent a randomly selected sample of wood fuel near a site, and this data could be used to reconstruct paleovegetation.

However, results of ethnographic studies suggest that fuel collection is rarely this simple. Fuel collection practices vary in response to overall fuel availability, and they are embedded in social and economic systems that can produce incongruities between actual fuel use and expectations of least effort models (Gelabert et al. 2011; Shackleton and Prins 1992). More archaeological, ethnographic, and ethnohistoric research is needed to address how these issues may have affected fuel choices among indigenous peoples of California. Due to these factors and to the small sample size analyzed so far, the results reported here should be considered preliminary.

As described above, in the absence of anthropogenic burning, the coastal terraces and foothills around Quiroste Valley are expected to have been dominated by the same types of woody vegetation that cover the landscape today, particularly northern coastal scrub (containing coyote brush [*Baccharis pilularis* ssp. *consanguinea*], poison oak [*Toxicodendron diversilobum*], and California coffeeberry [*Frangula californica*]) and Douglas fir forests. Under an anthropogenic fire regime characterized by frequent, low-intensity burns, woody vegetation would have been dominated by taxa that are resilient to fire or protected from fire by their location on the landscape. Redwoods are well known to be resilient to low-intensity fires, with fire scars on redwood stumps commonly indicating FRIs of about 10 to 30 years in forests throughout California (Lorimer et al. 2009), as well as in the region under study (Stephens and Fry 2005). California lilacs or blueblossoms (*Ceanothus* spp.) are fire-adapted shrubs common in central and southern California chaparral. Many California lilac species produce seeds that are stimulated to germinate by fire, and most species growing in the local region today are able to resprout from root crowns after being top-killed (Davis et al. 1999). I predict alders (*Alnus* spp.) would have been protected from low-intensity landscape fires by their position along banks of perennially moist and deeply incised stream channels in the Whitehouse Creek watershed.

A total of 110 wood charcoal specimens from the light fractions of six flotation samples recovered from the central midden area of CA-SMA-113 were analyzed. Proportions of woody plant taxa identified in the CA-SMA-113 charcoal assemblage and their compatibility with frequent, low-intensity landscape fires are presented in Figure 5. The most abundant archaeological taxon is redwood, comprising one third (32.7 percent) to about half (49.2 percent, with "cf. Redwood" category)[6] of charcoal remains. Three other woody taxa are represented by more than two identified specimens in the assemblage: California lilac (17.3 percent), alder (8.2 percent), and Douglas fir (6.4 percent). The rest of the assemblage (20 percent) comprises taxa represented by two or fewer specimens and unidentified specimens.

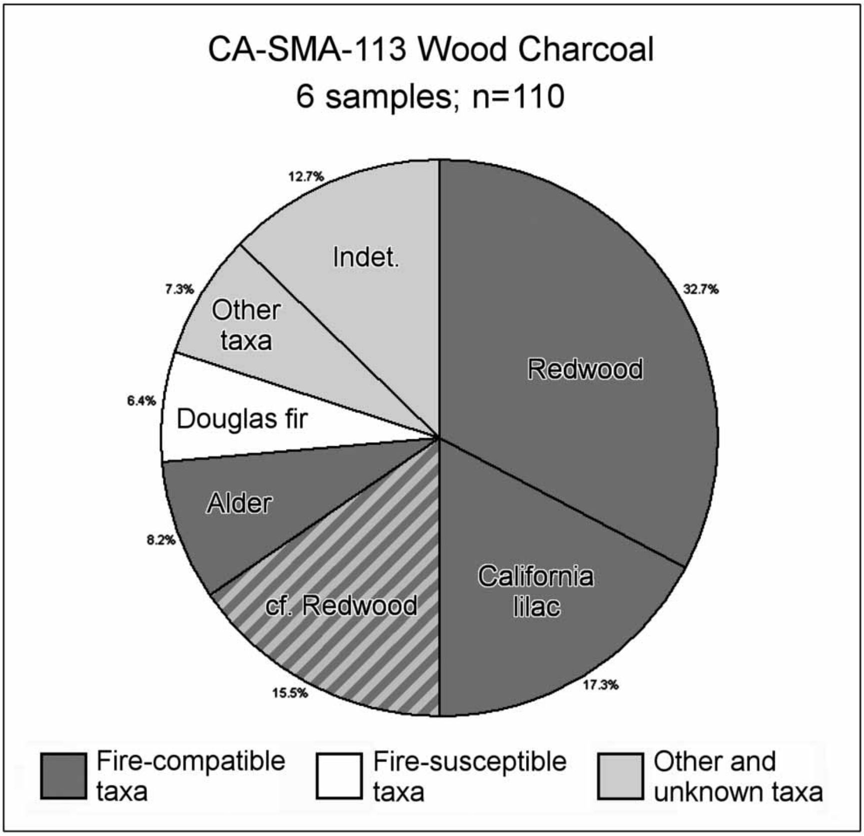


**Figure 5.** Proportions of major woody taxa in the CA-SMA-113 charcoal assemblage. Taxon categories are shaded based on compatibility with frequent landscape fires.

The only taxon in the archaeological charcoal assemblage that is both incompatible with landscape fire and represented by more than two specimens is Douglas fir (*Pseudotsuga menziesii*). Older Douglas fir trees are protected from low-intensity fires by thick bark and high crowns (Ryan et al. 1988). However, Engber and Varner (2012) reported a controlled burn of Douglas fir saplings in Redwood National Park that resulted in 94 percent tree mortality in 20 months. Under sub-decadal FRIs, I predict few Douglas fir seedlings would have survived to maturity.

Comparing the abundance of modern trees and shrubs in Quiroste Valley to woody taxa from CA-SMA-113 charcoal (see Supplementary Table 4, Figure 1, and Figure 5) shows marked contrasts in assemblage compositions. Today, major portions of the landscape are covered by Douglas fir, comprising 35.5 percent of overall vegetation cover (Table 1) and 71.8 percent of tree cover, yet this taxon is only 6.4 percent of charcoal specimens at CA-SMA-113. This pattern is reversed in redwood, which comprises up to half of the anthracological assemblage, but which is present today in just a few isolated riparian stands in the lower Whitehouse Creek watershed.[7] These observations, though based on a limited data set, suggest that Douglas fir cover may have been much lower in the past, making fire-resistant redwood the primary fuel source available in the vicinity of CA-SMA-113.

All of the dominant shrubs in the valley's modern coyote brush scrub vegetation type, which comprises 37.9 percent of modern vegetation cover (Table 1), are absent in the CA-SMA-113 charcoal assemblage. The most common type of shrub wood at the site is from the fire-adapted California lilac, whose seeds are stimulated to germinate by the heat of fires (Keeley 1991). This plant is uncommon in the watershed today, but blueblossom (*Ceanothus thyrsiflorus*) was recorded as a common understory shrub in some redwood forests north of Whitehouse Creek in 1935 (Wilson and Hanks 1935; Cowart and Byrne, this issue). This is also the only *Ceanothus* species that has been observed in the watershed today. Before twentieth-century fire suppression, fires in redwood understories at ca. 10 to 20 year intervals (see Stephens and Fry 2005) might have increased *Ceanothus thyrsiflorus* populations in redwood forests. Forrestel et al. (2011) documented explosive post-fire expansion of *Ceanothus thyrsiflorus* at Point Reyes National Seashore, with cover of this taxon increasing from 18 to 862 ha (ca. 4,600 percent) between 1994 and 2004 in areas burned by the 1995 Vision Fire. Although *Ceanothus thyrsiflorus* is of subgenus *Ceanothus*, which contains plants that resprout when top-killed (Davis et al. 1999), the local effects of sub-decadal FRIs on this taxon are unknown.

Although coyote brush (the dominant contemporary shrub) is able to resprout when top-killed, our observations following vegetation removal in Quiroste Valley indicate that repeated top-killing effectively suppresses its cover. After two successive years of top-killing (2008–2009), coyote brush near site CA-SMA-113 remains less than ca. 1 m in height three years later. Top-killed plants changed their growth form from having a few woody stems to having many small and more persistently suffrutescent stems (basal sprouts), which would have provided a poor source of fuel. These observations are consistent with results of coyote brush top-killing experiments at Jasper Ridge Biological Preserve (Hobbs and Mooney 1985). In a frequently burned landscape, I predict that repeated top-killing of coyote brush would (a) increase mortality of plants, particularly seedlings; (b) maintain older plants in a many-stemmed, suffrutescent state; and (c) reduce recruitment by destroying seeds in soil banks and by decreasing overall seed production.

Although the archaeological data set is small, and several factors may complicate interpretation, I think that the composition and distribution of taxa in the anthracological assemblage is so strikingly different from that of woody vegetation on the landscape today that a real distinction between modern and ancient woody plant cover is indicated. However, much additional analysis and theoretical development will be required to determine whether this preliminary result will hold under scrutiny. For now, the observed difference between anthracological data and contemporary woody vegetation cover can be most parsimoniously interpreted as an outcome of anthropogenic burning during the late Holocene and of disturbance factor removal from the study area during the past 30 years.

## Conclusion

The low incidence of lightning fires and relatively predictable pattern of plant succession on the central California coast makes this region a promising place to conduct research on the long-term history of indigenous burning practices. Based on historical and contemporary ecological research, I propose that under a lightning fire regime, coastal terraces around Quiroste Valley would have been dominated by woody vegetation types, and that grasslands would have been a more ephemeral post-fire community. However, two factors that may modify these expectations will require additional research. The first concerns the effects of changing climate on vegetation composition and succession in the research area. As discussed in detail by Lightfoot et al. (this issue), if the Medieval Climatic Anomaly created warmer and drier conditions on the central coast, lightning fires may have been more frequent during the early occupation of CA-SMA-113 (ca. AD 1000–1300), changing expectations for FRIs in a lightning fire regime. Additionally, climatic changes could have caused shifts in vegetation composition to types whose succession characteristics differed from those of contemporary plant communities. The second factor is the invasion of California grasslands by exotic taxa after Spanish colonization, producing contemporary coastal grasslands that are typically dominated by invasive exotics (Ford and Hayes 2007). Native coastal prairies comprising perennial bunchgrasses and native forbs may have had different post-fire succession characteristics than modern exotic annual grasslands.

Because the effects of disturbance factors on native and exotic grass taxa are variable, and disturbance factors interact with many other edaphic and biological factors to modify vegetation community composition, it is not possible to make simple predictions about the effects of fire on native or exotic grass abundance (Bartolome et al. 2004). As a consequence, it is difficult to predict how native grassland fire succession characteristics might have differed from those of contemporary grasslands. A long-term and well-controlled set of studies is needed to explore this issue.

Archaeobotanical data from site CA-SMA-113 are consistent with other lines of evidence presented in this issue that indicate the presence of extensive grasslands maintained by frequent anthropogenic burning in the Quiroste Valley research area during the late Holocene (summarized in Lightfoot et al., this issue). At late Holocene site CA-SMA-113 (ca. AD 1000–1300), the effects of frequent landscape burning on vegetation community dynamics were articulated through cultural plant use practices and are demonstrated in the archaeobotanical assemblage through: (a) high proportions and densities of grassland seed food taxa, (b) evidence for the presence of fire-following or fire-enhanced plants that are uncommon in the absence of fire, and (c) a low proportion or absence of charcoal from the fire-susceptible trees and shrubs that dominate the landscape in the long-term absence of fire. Additional research on the fire ecology of particular plant taxa, along with methodological improvements in archaeobotany allowing identification of macrobotanical remains to the species level, may greatly improve the interpretive potential of macrobotanical data sets with respect to research questions about anthropogenic burning.

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## Notes

1. Greenlee and Langenheim (1990) predicted 30- to 135-year lightning FRIs for conifer forests, but 1 to 15-year FRIs for prairies and coastal sage scrub communities, based in part on the expectation that "sleeper fires" would burn vast areas of these vegetation types frequently. Davis and Borchert (2006) suggested these FRI estimates were too short. I agree, and suggest that regional FRIs under a lightning fire regime in these vegetation types would be similar to those in forests (from many decades to over a century), and possibly even longer in coastal areas.
2. Exclusion of heavy fraction data from this macrobotanical analysis should not affect comparability of the CA-SMA-113 assemblage with data on interior central California reported by Wohlgemuth, since the overwhelming majority of that data is also from the light fraction only (Wohlgemuth 2004:57).
3. Statistical significance calculations were made using van der Veen and Fieller (1982) equation 1a, with maximum population proportion for any taxon set to 35 percent ($P = 0.35$). The number of specimens required to determine the percentage of a taxon with a 0.4 percent error range at a 95 percent level of confidence ($P = 0.05$) is 13,656. In the current study, when comparing discrete and non-discrete assemblages, any taxa with non-overlapping error ranges (difference in percentage >0.8 percent) are statistically significantly different at a greater than 95 percent level of confidence, and significance level increases for taxa that comprise smaller proportions of the population.
4. Wohlgemuth (2004) also used two other measures to explore plant food consumption, the density of acorn nutshell (mg/liter) and the proportion of acorn nutshell (mg acorn nutshell/mg total nutshell) in macrobotanical samples. Due to the dominance of hazelnuts rather than acorns in the CA-SMA-113 nutshell assemblage, these measures were not replicated in this study.
5. Quantitative data from only the >0.5 mm fraction of CA-SMA-113 light fractions is presented here to make data more comparable with results in interior central California reported by Wohlgemuth (2004), in which light fractions were sorted down to 0.5 mm or 0.7 mm size fractions.
6. The category "cf. Redwood" (Figure 5) represents specimens most consistent in morphology with redwood, but which due to irregularities in wood micromorphology and/or poor preservation cannot be identified as redwood with a high degree of certainty. Specimens in this category always had the following characteristics: (a) a lack of large resin canals, dentate ray tracheids, and pinoid cross-field pits (indicators of local pine species), and (b) a lack of small resin canals, spiral thickenings, and fusiform rays (indicators of Douglas fir). Often, they also displayed the following features, which prevented more certain identification as "Redwood": spiral checking (a sign of compression wood), low axial tracheid radial diameters (i.e., fine-grained wood), and extensive fissuring from charring.

7. Redwood forest is the dominant vegetation type in much of the upper portion of the Whitehouse Creek watershed, beginning ca. 500 m east of CA-SMA-113. It is not clear whether the higher abundance of archaeological redwood charcoal indicates that redwoods were more common in the lower portion of the watershed during the time of CA-SMA-113 occupation, or that people regularly collected redwood fuel from the nearby upper portion of the watershed.

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