A Paleolimnological Record of Late Holocene Vegetation Change from the Central California Coast

Alicia Cowart
Department of Geography, University of California, Berkeley, CA 94720 (alicia@berkeley.edu)

Roger Byrne
Department of Geography, University of California, Berkeley, CA 94720 (arbyrne@berkeley.edu)

Abstract In this paper, we present results of the analysis of the pollen and microscopic charcoal content of a sediment core from Skylark Pond near Point Año Nuevo in Santa Cruz County, California. The core covers approximately the last 3,000 years and is of interest because Skylark Pond is located only 1.8 km from Quiroste Valley State Cultural Preserve, an important ceremonial and habitation location for the historic Quiroste tribe containing numerous late Holocene archaeological sites. The results show an increase in fire activity from the fifteenth century to the present. Peaks in charcoal at ca. AD 1425 along with subsequent high charcoal abundance indicate either small, frequent fires ignited by humans or large natural conflagrations. Significant changes after European colonization include increases in grass, oak, and bracken fern, all of which indicate the opening of the redwood forest by logging and ranching. Historic period charcoal peaks can be attributed to the burning of logging slash.

Resumen En este trabajo, presentamos los resultados del análisis del polen y del contenido microscópico de carbón vegetal en un testigo de sedimento en el Estanque Skylark, localizado cerca de Punta Año Nuevo en el condado de Santa Cruz, California. El testigo cubre aproximadamente los últimos 3000 años, y es interesante porque el Estaque Skylark se encuentra a sólo 1.8 km del Quiroste Valley State Cultural Preserve, importante lugar ceremonial y habitacional de la tribu histórica Quiroste, con numerosos sitios arqueológicos del Holoceno tardío. Los resultados muestran un aumento en los incendios desde el siglo XV hasta la actualidad. Las máximas de carbón en ca. 1425 d.C., junto con su subsiguiente alto frecuencia, indican o incendios pequeños y frecuentes, generados por personas, o grandes conflagraciones naturales. Los cambios significativos

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después de la colonización europea incluyen el aumento de la hierba, robles y helechos; todos aquellos indican la apertura del bosque de secuoyas por la tala y la ganadería. Los máximos de carbón en el periodo histórico se pueden atribuir a la quema de restos de la tala.

The use of fire by Native Americans as a tool for managing landscapes is well documented in historical and ethnographic accounts (Anderson 2005; Brown 2001; Lewis 1973; Stewart 2002). Less certain, however, is the spatial extent of indigenous fire use and variability in fire frequencies through time. One leading theory is that frequent low-severity fires set by humans fundamentally changed landscape patterns to promote a heterogeneous, diverse array of species (Anderson 2005; Blackburn and Anderson 1993; Lewis 1973; Lightfoot and Parrish 2009; Stewart 2002). For example, changes in oak density have been attributed to cessation of burning by Native Americans after the arrival of Europeans (Byrne et al. 1991). Keeley (2002) argued that prehistoric human alteration of natural fire regimes resulted in more grasslands and shrublands in central coastal California, as this distribution has no other climatic or edaphic explanation. The opposing position by Vale (2002) and others is that native people only burned small areas surrounding villages, and therefore did not change vegetation significantly. They pointed out that in many parts of California, such as in the Sierra Nevada Mountains, natural fires were so frequent that human fire use would not be necessary to explain pre-European vegetation composition.

Paleoecological study of indigenous burning practices and their effects on vegetation is only now beginning to take place. The most direct evidence for indigenous fire use in central coastal California comes from fire scars which show a more frequent fire regime (ca. 8–12 year mean fire return intervals) prior to suppression policies in the early twentieth century (Brown et al. 1999; Stephens and Fry 2005). Coastal California also has a low occurrence of lightning-ignited fire (Keeley 2002; van Wagtendonk and Cayan 2008), so most prehistoric fires in this region were likely due to human ignition. However, fire scar evidence is generally only available for the last few centuries, and this time period includes the relatively cool and moist "Little Ice Age." Untangling the various factors that could have affected fire regimes and brought about vegetation change requires a long-term perspective. For example, in other parts of California climate changes have been shown to have an effect on fire regimes, with more frequent fire occurring at the end of wet phases and beginning of dry periods (Edlund and Byrne 1991; Mensing et al. 1999).

Here we present pollen and charcoal evidence of prehistoric fire frequencies from Skylark Pond, which is located 1.8 km from site CA-SMA-113, the focus of our research team's archaeological research. Archaeologists believe CA-SMA-113 to be the probable location of "Casa Grande," a large native settlement that was described in journals from the Portolá expedition of 1769 (Cuthrell et al. 2012, this issue). The pollen and charcoal record from Skylark Pond indicates an increase in burning after ca. AD 1425 and again after American settlement in the mid-nineteenth century due to logging activity in the area and the unmonitored burning of logging slash. A parallel study from Laguna de las Trancas, a marsh located ca. 10 km south of Quiroste Valley, will produce a long-term record of vegetation and fire regime change that will cover much of the Holocene and late Pleistocene. Findings from Laguna de las Trancas will be reported elsewhere.

Study Area

Skylark Pond (37°10′26″N, 122°18′52″W; Figure 1) is a small 15 m diameter sag pond formed by a landslide. It is located at an elevation of 268 m.a.s.l. approximately 1.8 km northeast of CA-SMA-113 and 4.5 km from the Pacific coast. The pond was filled in with gravel as part of a reclamation project during the historic period. Modern climate in this region is governed by the seasonal migration of the North Pacific High and the mid-latitude storm track. Seasonal temperatures range from 10 to 14°C in winter and 13 to 20°C in summer (Thomas 1961). Average precipitation is approximately 76–89 cm per year (National Atlas of the United States 2003) with two-thirds falling from December through March. Fog is frequent in the late spring and summer. The pond is located within the San Gregorio fault zone, which comprises seven or eight faults along which movement has occurred within the last 105,000 years (Weber 1981). The historic distribution of vegetation in the region can be seen in Supplementary Figure 1.

Currently, the vegetation around the pond is redwood forest with redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), tanoak (*Notholithocarpus densiflorus*), canyon live oak (*Quercus chrysolepis*), and coast live oak (*Quercus agrifolia*). Aquatic plants, including tule (*Schoenoplectus acutus* var. *occidentalis*), grow in and around the pond. The immediate area surrounding the pond is open grassland dominated by non-native grasses and forbs. It is not known whether the forest would naturally grow to the edges of the pond, but historical aerial photographs show that the forest has encroached in the last ca. 60 years (Aero Service Corporation 1943). The forest understory is largely

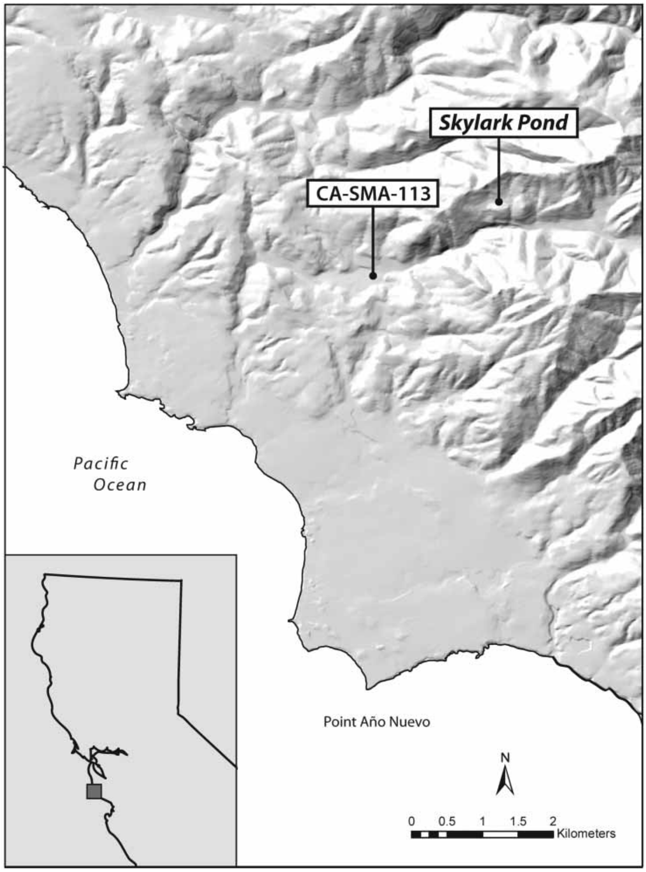

Figure 1. Area map showing location of Skylark Pond and CA-SMA-113.

composed of ferns, such as bracken fern (*Pteridium aquilinum*) and Western sword fern (*Polystichum munitum*), and herbaceous plants. On dry sites, species include knobcone pine (*Pinus attenuata*), chinquapin (*Chrysolepis chrysophylla*), coyote bush (*Baccharis pilularis*), blackberry (*Rubus ursinus*), madrone (*Arbutus menziesii*), manzanita (*Arctostaphylos* spp.), interior live oak (*Quercus wislizeni*), and toyon (*Heteromeles arbutifolia*).

Common species in the area around CA-SMA-113 on the floor of Quiroste Valley include coast tarweed (*Madia sativa*), poison oak (*Toxicodendron diversilobum*), California coffeeberry (*Frangula californica*), California lilac (*Ceanothus* spp.), toyon, blackberry, cow parsnip (*Heracleum maximum*), elderberry (*Sambucus* spp.), sedges (Cyperaceae), rushes (*Juncus* spp.), and many non-native grasses and forbs. In riparian areas near Whitehouse Creek, redwood and alder (*Alnus rhombifolia*) grow with understory vegetation including Western sword fern, bittercress (*Cardamine californica*), salmonberry (*Rubus spectabilis*), gambleweed (*Sanicula crassicaulis*), stinging nettle (*Urtica dioica*), and nightshades (*Solanum* spp.).

Vegetation on the near-coastal terraces west of Skylark Pond and CA-SMA-113 includes coyote bush, poison oak, coast buckwheat (*Eriogonum latifolium*), lupine (*Lupinus albifrons*), gumplant (*Grindelia* spp.), sage (*Artemisia californica*), Pacific wax myrtle (*Morella californica*), and willow (*Salix* spp.).

Methods

We extracted a 163 cm sediment core from Skylark Pond in 2009 using a modified Livingston coring system equipped with a 6 cm diameter polycarbonate tube that was driven into the sediments with a sledgehammer. The core was raised with the aid of a winch and pulley. The core was brought to UC Berkeley and stored in a 5°C cold room. The upper meter consisted of historic sand and gravel fill and was not analyzed. A 63 cm segment of the sediment core below the gravel fill was analyzed for pollen and microscopic charcoal.

Samples for pollen and microscopic charcoal analysis were taken at 1–2 cm intervals and pollen extracted using standard procedures (Faegri and Iversen 1989). Known quantities of *Lycopodium* spores were added to each sample prior to digestion to calculate pollen concentrations and accumulation rates. Sample residues were stored in silicone oil. Pollen was counted at 400× magnification using a Leitz Dialux microscope. A total of 36 samples was analyzed, with 33 samples counted to a minimum of 400 grains per sample. Pollen in the remaining three samples (126, 128, and 129 cm) was not counted due to very low concentrations. All 36 samples were analyzed for microscopic charcoal. Pollen and spores were identified using the University of California Museum of Paleontology pollen reference collection and published keys (Bassett 1978; Kapp 2000; McAndrews et al. 1973; Moore et al. 1991). Pollen and spore frequencies were plotted on diagrams as a percentage of total non-aquatic pollen for non-aquatics or a percentage of total pollen for aquatics.

We used the charcoal/pollen and spore ratio as a means of controlling for taphonomic effects. Since pollen, spores, and charcoal of the same approximate size are deposited by the same mechanisms (e.g. wind and water), comparing the concentration of microscopic charcoal to the concentration of pollen and spores allows us to determine when fires were occurring in the area. Microscopic charcoal concentrations were measured by digitally imaging slides at 4,000 dpi

(1 pixel = 6.35 micrometers) with a Nikon Coolscan V Ed scanner fitted with a Nikon FH-GI slide holder. Charcoal particles were identified in Adobe Photoshop and then counted and measured in ImageJ. Particles smaller than 20 μm^2 or those with large standard deviations of the grey scale value were not included in the count. The microscopic charcoal concentration was calculated by multiplying the total charcoal counts of each slide by the proportion of the slide used in calculating pollen and spore concentration. Microscopic charcoal was then calculated as a ratio of charcoal concentration to pollen and spore concentration by volume for each sample. Initial assessment of size-based analyses did not show significant variation between samples and is therefore not reported here.

Results

Chronology

Five AMS radiocarbon dates (Table 1; Figure 2) obtained for the lower section of the core show a very low sedimentation rate averaging only 0.5 mm per year. All dates are calendar dates and were calibrated using Calib 6.0 (Stuiver et al. 2010). The core has a basal date of ca. 3200 cal. B.P (ca. 1250 BC). Both the presence of *Rumex acetosella*, a non-native pollen type, and the two youngest radiocarbon dates indicate that the upper portion of this section of the core was deposited in the historic period.

The pollen and charcoal results are shown in Figures 3 and 4. For purposes of discussion, the diagrams are divided into three zones:

Table 1. AMS radiocarbon ages obtained from the Skylark Pond core. All radiocarbon ages were calibrated using Calib 6.0 (Stuiver et al. 2010).

Depth (cm)	Laboratory Sample #	Radiocarbon Age (yrs BP) and Error	Calibrated Age (yrs BP) 2 – σ	Calibrated Median Age (yrs BP)	Material	Sedimentation Rate (mm/yr)
115	USGS WW7667	170 ± 35	131–230	176	uncharred botanical	0.86
120	CAMS #155451	230 ± 70	123–232	234	charred botanical	0.86
130	CAMS #155452	495 ± 30	501–549	525	charred botanical	0.34
146	CAMS #155453	1,325 ± 45	1171–1318	1,255	charred botanical	0.22
163	USGS WW7666	2,995 ± 30	3077–3266	3,190	uncharred botanical	0.09

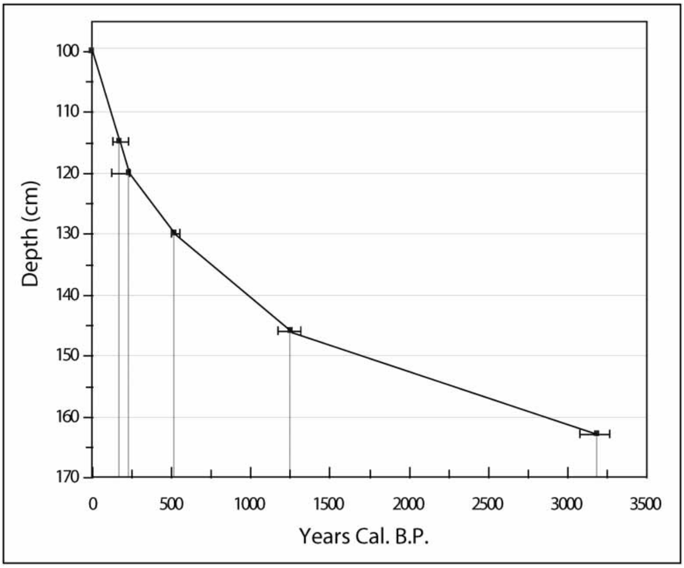

Figure 2. Age model. Solid line represents linear sedimentation rate between calibrated median probability ages listed in Table 1. Error bars indicate the 2-sigma range.

Zone 3 (163 cm—132 cm; 3190 cal. BP [1240 BC]—ca. 550 cal. BP [AD 1400]): Redwood pollen is the dominant pollen type in Zone 3, comprising 25–50 percent of total non-aquatic pollen. Aquatic pollen types, particularly the sedge type, are ca. 40 percent of total pollen at the bottom of the core. Bracken fern (1–15 percent) and Asteraceae (5–15 percent) fluctuate in this zone. Members of the three families Rhamnaceae, Rosaceae, and Anacardiaceae (RRA) total ca. 13 percent at the bottom of the core and decline through time. Brassicaceae pollen is present here at ca. 4–8 percent of the total. A peak in canyon live oak occurs at 142 cm depth. Organic content (LOI) is relatively low in this zone but increases gradually. Microscopic charcoal is present at low levels, with one peak at 154 cm depth.

Zone 2 (132 cm—116 cm; ca. 550 cal. BP [AD 1400]—ca. 200 cal. BP [AD 1750]): This zone includes a section of low organic content from 129–125 cm in which little pollen is preserved. Redwood is present at high levels from 40–55 percent, with a sharp decline near the top of the zone to ca. 20 percent. Asteraceae decreases to its lowest level at less than 3 percent, but then increases to greater than 10 percent. The RRA type increases substantially at the top of this zone to almost 20 percent. Microscopic charcoal increases in this zone

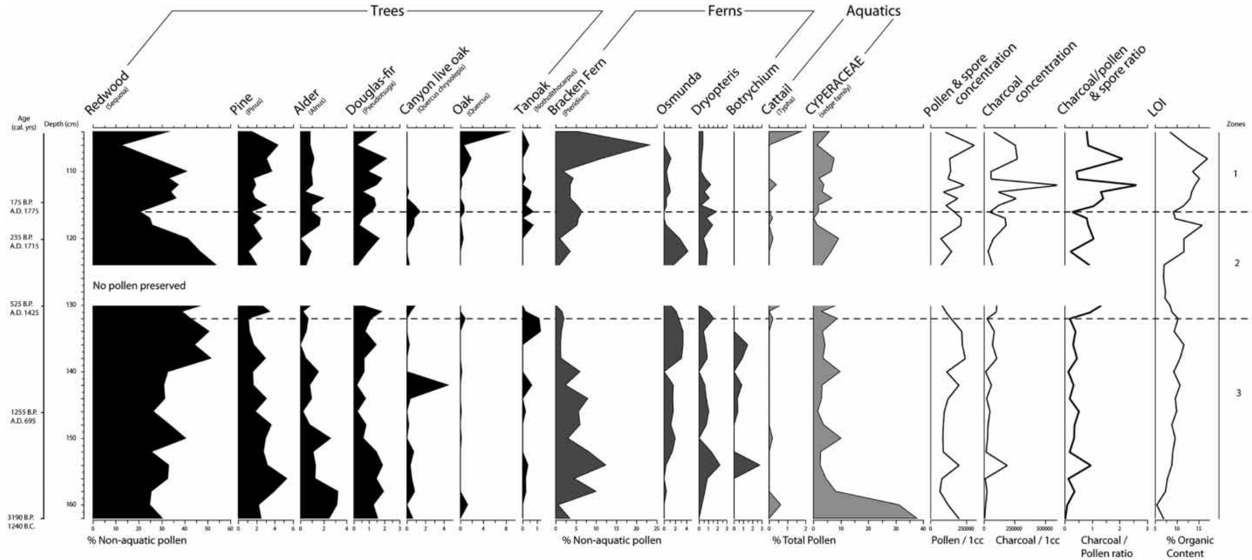

Figure 3. Percent pollen diagram of selected trees, ferns, and aquatics with charcoal concentration, pollen and spore concentration, charcoal/pollen and spore ratio, and loss-on-ignition (LOI). Note scale changes along x-axes.

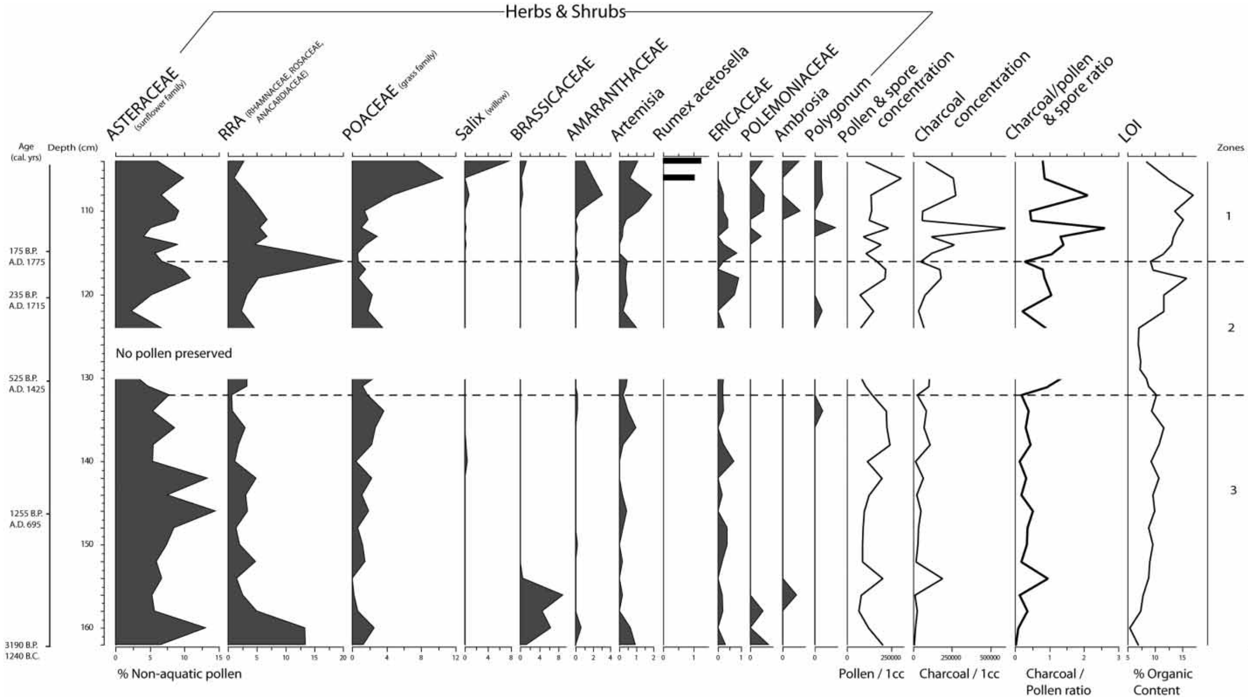

Figure 4. Percent pollen diagram of selected herbs and shrubs with charcoal concentration, pollen and spore concentration, charcoal/pollen and spore ratio, and loss-on-ignition (LOI). Note scale changes along x-axes.

with two peaks at 131 and 130 cm just before the section with little organic content. Other samples with higher than average charcoal include samples at 124, 120, 118, and 117 cm.

Zone 1 (116 cm—104 cm; ca. 200 cal. BP [AD 1750]—ca. 0 cal. BP [AD 1950]): Organic content increases in this zone. Redwood increases to 40 percent then drops to ca. 10 percent, but again increases near the top of the core. Pine increases slightly and oak and willow increase to 8 percent at the top. Bracken fern increases dramatically at the top of the core to ca. 23 percent. Members of the RRA families decrease to ca. 5 percent. Grasses increase at the top to greater than 10 percent. Sheep's sorrel (*Rumex acetosella*), a non-native species, is present at 106 and 104 cm. The highest peaks in charcoal occur in this zone at 112 and 108 cm. Both 115 and 114 cm samples also contain comparatively high levels of charcoal.

Discussion

Due to the low sedimentation rate, individual years or fire events were not distinguishable in the 1 cm^3 samples analyzed. However, the relative change in the abundance of microscopic charcoal enables us to assess when fires were more frequent. Due to the dominance of redwood in the core, we believe that most of the pollen and charcoal in the Skylark Pond sediments is of local origin. Redwood trees around the pond would have acted as a screen to filter out most extra-local pollen and charcoal (Tauber 1967). In this case, microscopic charcoal records counted on pollen slides can indicate low-intensity fires within a few kilometers (Pitkänen et al. 1999).

Zone 3 (163 cm—132 cm; 3190 cal. BP [1240 BC]—ca. 550 cal. BP [AD 1400]): The high redwood percentages indicate that Skylark Pond was surrounded by redwood forest throughout this time period. Low Douglas-fir percentages show that it was also locally present. High levels of sedge at the basal levels of the core indicate a marsh developed when the pond first established. Since a tectonically induced landslide created the pond, it is not surprising that plants characteristic of disturbed environments are present at moderate levels, such as members of the Rhamnaceae, Rosaceae, Anacardiaceae, Asteraceae, and Brassicaceae families. Species in these families that currently grow nearby include California coffeeberry (Rhamnaceae), California lilac (Rhamnaceae), blackberry (Rosaceae), toyon (Rosaceae), poison oak (Anacardiaceae), coyote bush (Asteraceae), and bittercress (Brassicaceae). With the exception of a single peak at 154 cm, low values of the charcoal to pollen and spore ratio indicate that fire was not important during this period.

Zone 2 (132 cm—116 cm; ca. 550 cal. BP [AD 1400]—ca. 200 cal. BP [AD 1750]): An increase in shrubby and herbaceous plants surrounding the pond is indicated by the increase in RRA and Asteraceae pollen at the top of this zone. Redwood is at its highest percentages at the bottom of this zone, but then appears to decline near the top. This decline may be due to the relative abundance of redwood pollen in a percentage diagram, rather than a decline in the actual number of redwoods in the area. Because microscopic charcoal increases in this zone, the increase in RRA and Asteraceae pollen could be a result of more frequent low-severity fires in the area. Species in these families that vigorously regenerate after fire include California coffeeberry, California lilac, toyon, chaparral cherry (*Prunus ilicifolia*), and poison oak. Another possible explanation is a large conflagration that could have reduced the area of redwoods surrounding the pond, allowing fire-adapted plants to colonize the newly opened environment.

An interesting aspect of this zone is the section with decreased organic content. Since two large charcoal peaks occur just before this section, it is probable that a fire reduced vegetative cover around the pond and allowed erosion to significantly increase. Since redwood pollen continues to be present at high levels just after this section, the fire event was likely low-severity. Alternatively, tectonic activity and subsequent landslides could be an explanation.

A radiocarbon date obtained from the 130 cm depth indicates that the first two major charcoal peaks date to the mid-fifteenth century (see Table 1). Subsequent levels with higher than average charcoal content may indicate regular burning in the area. The intact portion of the nearby archaeological site CA-SMA-113 was occupied ca. AD 1000–1300 and may have been occupied up to ca. AD 1770. Radiocarbon dates from other nearby archaeological sites in the Point Año Nuevo area indicate settlement at various times over the last two thousand years, with several dating to the thirteenth through sixteenth centuries (Hylkema and Cuthrell, this issue:Supplementary Table 1).

Although natural fire due to changes in climate cannot be ruled out as a reason for the increase in charcoal in this zone, we believe that this is unlikely for a number of reasons. The pollen frequencies show no evidence of drought, which would be expected to increase natural fire frequency. In fact, redwood pollen is at its highest levels in this zone. If a landslide were responsible for the erosive event rather than a fire, this could indicate a period of increased precipitation along with a tectonic event (Adam 1975). Few studies have addressed climatic changes along the central California coast during this time period, but studies from the San Francisco estuary report increased precipitation over central California from approximately AD 1200 to 1930 (Byrne et al. 2001) and a major flood deposit from ca. AD 1420 (Goman and Wells 2000). Finally, the upper portion of this zone is within the "Little Ice Age" (sixteenth through nineteenth centuries), which numerous studies have shown was a period of cooler and wetter climate in California (Malamud-Roam et al. 2006), yet microscopic charcoal is present at relatively high levels. Though natural fire return intervals of around 135 years would be expected for redwood forest in the Santa Cruz Mountains (Greenlee and Langenheim 1990), the low charcoal abundance prior to this period in Zone 3, with the exception of a single peak at 154 cm, indicates that natural fires occurred even less frequently. Therefore, the increase in charcoal in Zone 2 represents an important shift in fire regime for the local area.

Zone 1 (116 cm—104 cm; ca. 200 cal. BP [AD 1750]—ca. 0 cal. BP [AD 1950]): Zone 1 includes the historic period during which the most obvious changes in vegetation occur. The decrease in redwood near the top, along with the dramatic increases in grass and bracken fern and modest increases in oak, willow, Amaranthaceae, and *Artemisia* indicate significant changes in vegetation. The most probable explanation is the establishment of logging operations in the area after American settlement in the mid-nineteenth century. The first sawmill in the Santa Cruz Mountains was established in 1842 near the town of Felton (Thomas 1961). From 1867 to 1880, a large sawmill called Glen Mills was in operation less than a kilometer from Skylark Pond. A ranch was also established in the area around the same time. In 1892, Glen Mills shut down as all the large redwoods in the area had been cut, while farming and ranching continued (Mowry 2004). Large conflagrations often accompanied logging operations because of the burning of logging slash (Greenlee and Langenheim 1990). The highest charcoal peaks in the Skylark Pond core probably indicate large, uncontrolled fires in the late nineteenth century.

Conclusion

When members of the Portolá expedition left the "Casa Grande" village on October 24, 1769, Juan Crespí reported passing over hills that were "all burnt off, having very good soil, all of them bare of trees" (Brown 2001). Numerous reports from this expedition described burned vegetation in the area along the coast. The microscopic charcoal record from Skylark Pond provides evidence of regular fires from the fifteenth century to the present near Quiroste Valley, the probable location of "Casa Grande." We propose that at least some of these fires were ignited by humans because of the evidence of large settlements in the area. However, due to the limitations of low-resolution data and without fire scar evidence to calibrate the charcoal record, we cannot conclusively state whether the increase in charcoal from the fifteenth century to the present can be attributed to frequent low-severity fires ignited by humans or perhaps more frequent or more severe natural fires. The spatial scale of past fires is also difficult to determine without fire scar evidence or more paleoecological studies in the area. Ongoing fire scar research in Quiroste Valley, along with results from nearby Laguna de Las Trancas, will enable a more definitive conclusion. However, it is clear from the Skylark Pond record that the most dramatic changes in vegetation and fire regimes occurred after American settlement, when logging, farming, and ranching became widespread.

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