Holocene Changes in the Distribution and Abundance of Oaks in California[1]

Roger Byrne Eric Edlund Scott Mensing[2]

Abstract: Our knowledge of the long-term history of oaks is primarily based on biogeographical analysis of anomalous distribution patterns and paleobotanical macrofossil evidence. Neither of these provide a continuous record of change. In this paper, we present fossil pollen evidence which records significant changes in oak abundance over the last 10,000 years. Between 10,000-5,000 years ago, oaks in the Sierra Nevada increased at the upper altitudinal limit of their range. Since the mid-19th century, oaks at low elevations in the Coast Ranges have increased. We believe that the early increase represents an upward migration of oaks in response to climatic warming and changes in the fire regime, while the recent change reflects an increase in woodland density following a cessation of burning by Indians, a change in grazing pressure, or both

Prior to the publication of Adam's first paper on the Clear Lake pollen record (Adam and others 1981), our knowledge of the long-term history of oaks in California was based almost entirely on biogeographical and paleobotanical evidence. The former involved the analysis of anomalous distribution patterns, such as disjunctions and zones of hybridization where both parent species no longer coexist (Axelrod 1981, Griffin and Critchfield 1976); the latter was heavily concerned with macrofossils, especially fossil leaves and acorns (Axelrod 1983, Wolfe 1979). Both of these lines of evidence have provided useful information, but it is information that is inherently discontinuous, both in space and time. In contrast, as Adam convincingly demonstrated at Clear Lake, fossil pollen can provide a continuous record of change, a record which in this case reflects changes in oak abundance on a regional scale.

Pollen analysis is an important paleoecologic tool and has been used to reconstruct vegetation history associated with climatic change and human induced environmental change (see Birks and West 1973, and Huntley and Webb 1988 for comprehensive reviews). Analyses of the contemporary pollen rain have shown that modern pollen distribution generally corresponds with the distribution of wind pollinated taxa (Anderson and Davis 1988, Bradshaw and Webb 1985, Heusser 1983, Wright 1967). Not all species produce sufficient quantities of pollen to leave a reliable record. However, oak is a prolific producer. Although taxonomic resolution for pollen is not as good as macrofossil evidence, pollen provides a continuous record of vegetation change over time. This record can be interpreted to identify causal factors associated with changes in species composition useful in predicting what impact management decisions or future climatic change may have on oak woodland distribution and composition.

This paper reports how pollen evidence from the Sierra Nevada and the Coast Ranges can be used to reconstruct changes in the distribution and abundance of oaks during the past 15,000 years. The Sierran record covers the whole of this time period and shows significant increases in oak abundance during the early and mid Holocene 10,000 to 5,000 years ago. The Coastal record provides high temporal resolution of the last 500 years. It shows a significant increase in oaks during the period of European settlement.

PREVIOUS CALIFORNIA POLLEN STUDIES

Pollen studies in California have primarily been applied to paleoclimatic reconstruction based on shifts in distributions of indicator taxa (Adam 1985). Of all paleoecological sites in California, the record from Clear Lake (fig. 1) presents the best evidence of long-term changes in the distribution of oak woodlands (Adam 1988). This record shows that the modern distribution of oak woodlands is a recent development in evolutionary time. The full glacial record indicates the virtual absence of oaks from the drainage basin. Under these colder conditions, pines were dominant, with sagebrush and Cupressaceae (incense cedar, cypress, juniper, etc.) more abundant than at present. With postglacial warming, oak reestablishment commenced ca. 13,000 years ago. Pollen percentages suggest that oaks were more abundant than at present during the early and middle Holocene (approximately 10,000-6,000 years ago).

Other records since the last glacial maximum are scarce in California, particularly within the present and/or past range of oak species. In the North Coast Ranges and the Sierra Nevada, work by Byrne (1988), Davis and Moratto (1988), Mackey and Sullivan (1986), Reed (1984), and West (1985) indicates that some lower elevation taxa increased in importance at higher elevations in the early and middle Holocene (approximately 10,000-5,000 years ago). These records show similar but not identical shifts in oak.

At Tule Lake and Lily Pond in the Mendocino National

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[2] Associate Professor and graduate students respectively, Department of Geography, University of California, Berkeley

Forest, oak began to increase in importance approximately 7,000 years ago, reaching maximum percentages around 5,000 years ago, and declining slightly to the present (West 1985). A similar pattern was revealed at Dogwood Pond (Reed 1984), where oak was uncommon before 7,000 years ago, but then increased to high levels in the middle Holocene. Most of the oak pollen at this site was identified as Canyon live oak (*Q. chrysolepis*).

At Gabbott Meadow in the central Sierra Nevada, oak pollen present at higher-than-modern values from approximately 9,000-5,000 years ago led Mackey and Sullivan (1986) to infer a warmer and/or drier climatic interval at this time. This interpretation was supported by other sites in the Stanislaus drainage analyzed by Byrne (1988); Swamp Lake and Lake Moran both show elevated levels of oak during the early and middle Holocene. Farther south, paleoecological work on Exchequer Meadow (Davis and Moratto 1988) also suggests an increase (less pronounced than at the Stanislaus sites) in oak at elevations above its modern range, reaching a maximum approximately 9,000-7,000 years ago.

Several pollen analyses of short cores have examined changes within the last few hundred years. Analysis of two midden sites in Tuolumne County near New Melones Dam found evidence that suggests oak woodland was more open in the late 18th and early 19th centuries, but that oak and pine expanded into formerly open areas in the late 19th and 20th centuries (Byrne and others, in press). Expansion is attributed to less frequent fires in the post-Indian period. West and Mossberg (1978) analyzed a short core from a sag pond near Tejon Pass. They found fluctuations in oak pollen, but were unable to interpret the significance without data on sedimentation rates. A sedimentation and pollen study of Zaca Lake in Santa Barbara County indicated a general increase in oak over the last two centuries (Peterson 1980). However inquiry into this vegetation change was not the focus of the analysis.

THE PRESENT STUDY

In this study, we have selected sites potentially sensitive to changes in oak abundance and distribution during the Holocene. Our study has two temporal foci: the early- and middle Holocene (10,000-5,000 years ago), a period of climatic warming; and the last 500 years, a period of major vegetation change associated with changes brought by European settlement. Examples include the introduction of livestock and alien plant species, and the decimation of the native Indian population. The long term record focuses on sites at the current upper elevational limit of black oak (*Q. kelloggii* Newb.) in the Sierra Nevada. In this paleoecologically sensitive zone we have identified evidence of altitudinal shifts in oak distribution associated with climatic warming. Sites in the northern and southern Sierra are being examined to identify possible regional trends (fig. 1).

Evidence for the more recent, pre-European period is from the Central Coast Ranges. These sites are located within the sphere of influence of Spanish missions and early settlement in areas affected by grazing and agriculture. The actual distribution of sites is constrained by the paucity of naturally occurring permanent lakes.

Lake sediments are extracted with a Livingstone piston corer, hand operated by two or three people from a small floating platform centered over the deepest section in a lake. Sediments are recovered in 1-meter sections with stratigraphy intact. Sediment analysis is done at the University of California Berkeley Palynology Laboratory. The sediment cores are sampled at intervals (typically 10 centimeters), and samples are chemically processed to concentrate the pollen and remove other organic and inorganic material (Faegri and Iversen 1975). A spike of a known quantity of *Lycopodium* spores is introduced as a control to calculate absolute pollen concentration and influx. Glass slides are prepared and examined under a Leitz microscope at 400x magnification. Approximately 250-400 grains are identified and counted, using photographic keys and reference specimens compiled in the Pollen Lab. Chronologic control is obtained with carbon-14 dates, identification of ash layers (Sarna-Wojcicki and others, 1983) and with introduced European pollen types which act as stratigraphic markers in sediments deposited in the past 200 years (Mudie and Byrne 1980, West and Mossberg 1978). Pollen diagrams (fig. 2-3) are produced using the CalPalyn software package (Bauerand Orvis 1990).

DISCUSSION OF PRELIMINARY RESULTS

Previous paleoecological work in the Sierra Nevada has pointed to early Holocene climatic warming as an important factor in vegetation change. In particular, at several (but not all) sites oaks seem to have expanded upslope beginning about 10,000 years ago. To examine this phenomenon more closely, we are undertaking work at several sites positioned near the upper limit of California black oak, between 1,500-2,000 meters (see fig. 1).

Lake Moran shows the strongest oak signal (Byrne 1988, Edlund and Byrne in press). Figure 2 shows that from about 10,000—5,000 years ago, oak pollen is present at above-modern levels, in association with increases in bracken (*Pteridium*), sagebrush (*Artemisia*) and dwarf mistletoe (*Arceuthobium*). Macrofossil and charcoal analysis of a second core from this site documents a shift from lodgepole—western white pine—sugar pine—mountain hemlock to a ponderosa pine dominated forest (Edlund and Byrne in press). The timing of the increase in ponderosa pine coincides with the increases in oak and dry understory species, and with an increase in charcoal influx to the lake sediments.

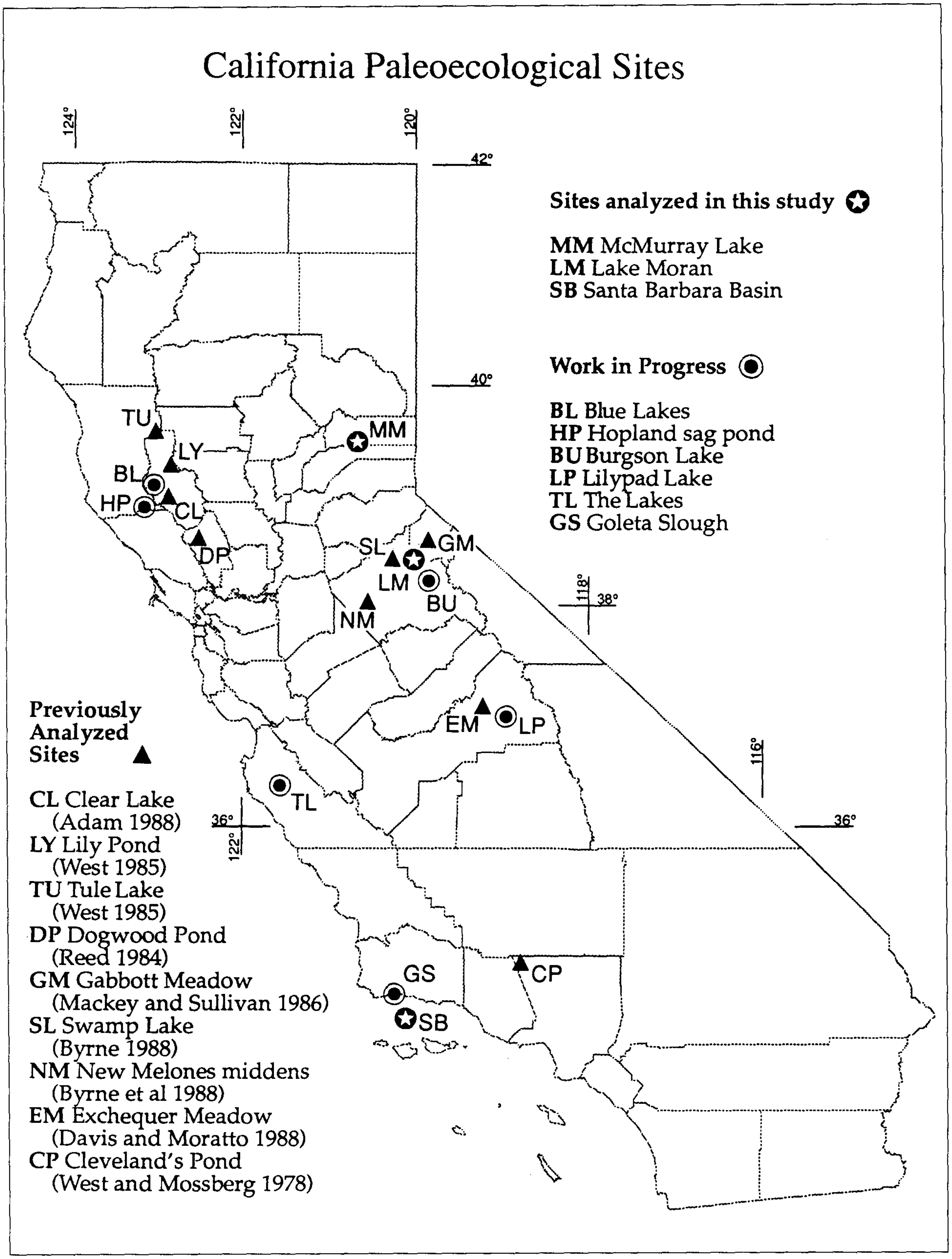

Figure 1—Site map of previously analyzed pollen sites, sites analyzed in this study, and work in progress.

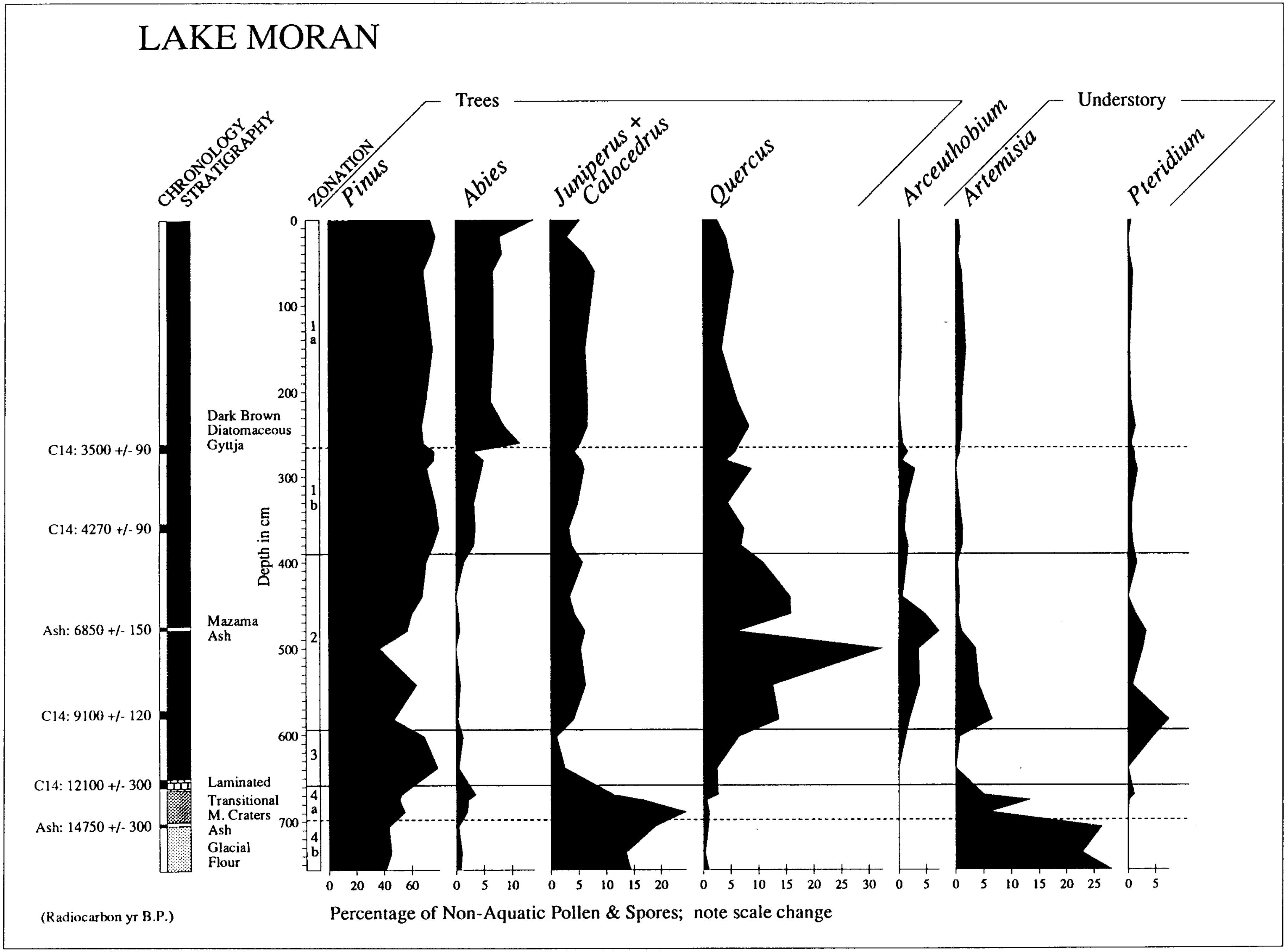

Figure 2—Pollen diagram for Lake Moran, Tuolumne County, California.

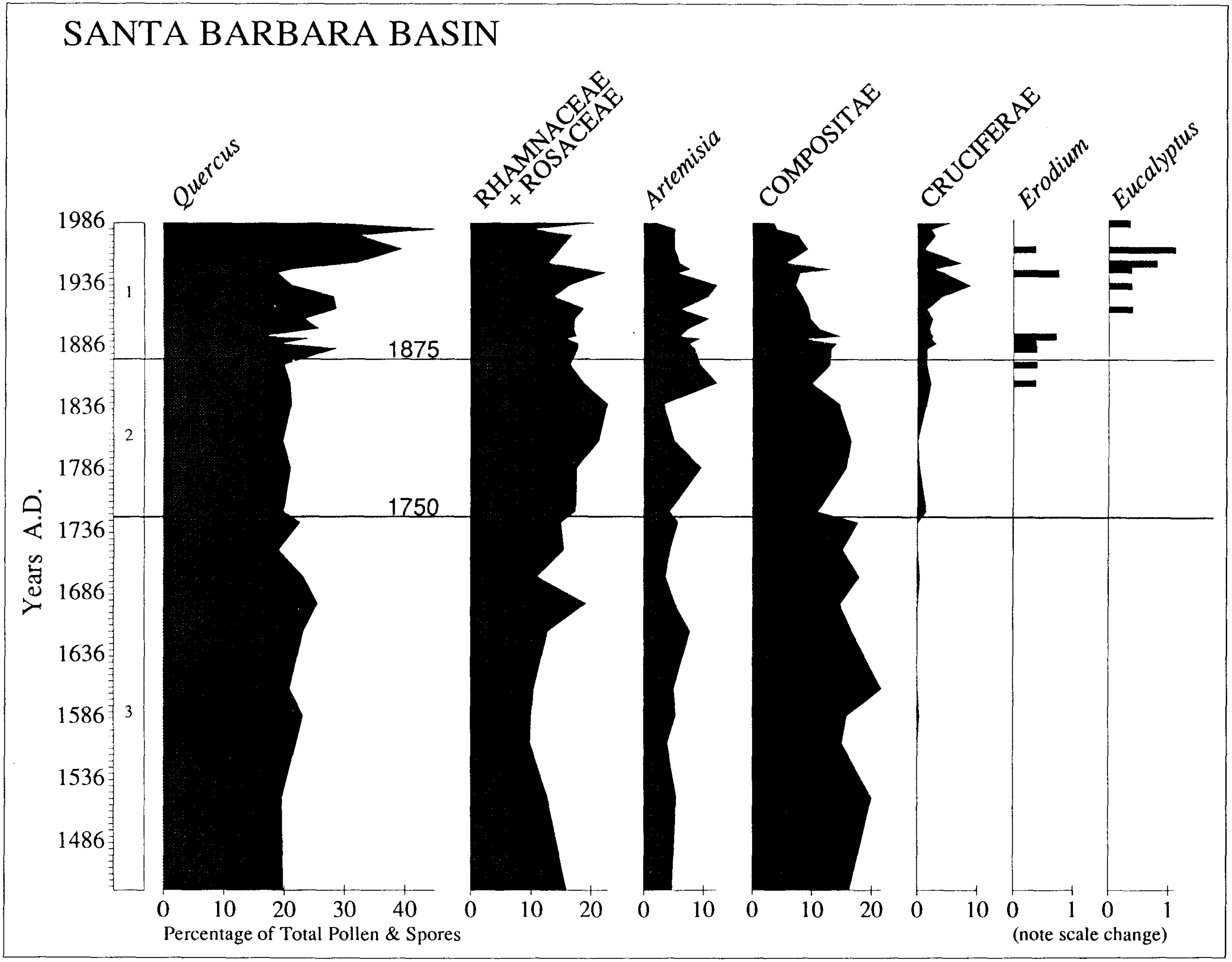

Figure 3—Pollen diagram for the Santa Barbara Basin, California.

Our interpretation of the Moran oak record is that dramatic changes commenced about 10,000 years ago. For at least a thousand years prior to this date, a dense, closed canopy forest included species whose distributions no longer overlap in the Sierra Nevada. Summers were sufficiently warm to support sugar pine (limited to <2100 meters elevation in the central Sierra today), while moisture was adequate for the survival of mountain hemlock, today restricted to high elevation sites (generally > 2500 meters) with abundant snowpack. Oaks were not important at this time.

We hypothesize that climatic warming at the close of the Pleistocene Epoch forced a change in the role of fire in the montane Sierra Nevada. The dense white pine/lodgepole pine canopy was consumed by fires, providing openings for bracken and sagebrush, and allowing ponderosa pine and black oak to out-compete the more poorly fire-adapted species which preceded them.

Work on changes in oak woodlands for the recent period has largely been confined to age structure analysis focusing on the last 200 years (Anderson and Pasquinelli 1984, McClaran 1986, Mensing 1988, Vankat and Major 1978, White 1966). Age structure analyses have identified potential changes in oak regeneration prior to European settlement (Mensing 1988) but are generally restricted to the historic period because of losses through cutting and natural mortality. Palynological work in the Coast Ranges has been frustrated by the difficulty in finding suitable sites with a sensitive pollen record. Recently, researchers at Scripps retrieved a core from the sediments of the Santa Barbara Basin which is continuously varved for the last 1,000 years (Schimmelmann and others 1990). The annual nature of the Santa Barbara varves has been confirmed by isotope dating (Bruland 1974, Koide and others 1972, Krishnawami and others 1973) and by sampling the near-surface sediments (Soutar and Crill 1977). Sediments consist of a dark, silt rich winter layer and a light diatomaceous spring layer. An unusually high sedimentation rate of 1.0 -2.0 millimeters per varve makes it possible to sample at yearly intervals, providing an accurate chronology spanning the period of European settlement. Sediment mineralogy has identified the Santa Clara and Santa Inez River drainages as the primary sources of material (Fleischer 1972). Vegetation in these drainages is a mosaic of oak woodland, chaparral, coastal sage scrub, grassland and conifer woodland. Previous pollen analysis from basin sediments found that the pollen record is primarily one of changes in the area adjacent to the channel, and not from long distance transport (Byrne and others 1977, Heusser 1978).

Approximately 500 years of the Santa Barbara core have been analyzed at intervals of 10-20 years. Core chronology has been worked out for the period 1760 to the present (Schimmelmann, unpublished data). For the period 1450-1760 a constant rate of sedimentation has been assumed, giving a figure of 1.2 years per varve. The results (fig. 3) indicate an increase in the importance of oak beginning about 1875. Prior to this period, oak averages 20 percent of the total pollen. It increases to an average of 27 percent in the late 1800s, and reaches as high as 45 percent in the late 1900s, more than twice the pre-European figure. This continued increase occurs at a time when oak distribution was probably decreasing due to clearing for agriculture and development.

Although further work is needed in analyzing this evidence, our tentative hypothesis is that oak woodland density has increased since the mid-19th century. We believe increased density may be the result of cessation of regular burning by Indians, or changes in grazing and woodcutting practices associated with population increases in the 1850s. If this hypothesis is correct, the present oak woodlands are more dense than the woodlands under Indian settlement. The increase in canopy and stem density may contribute to the present lack of regeneration in some areas.

We are testing the validity of these results through further analysis of the Santa Barbara Basin core, as well as analysis of a core we plan to retrieve from Goleta Slough. To test our hypothesis on a regional scale, we are analyzing core material from The Lakes in Monterey County, and from a short core out of Headquarters Lake, a sag pond at Hopland Field Station in Mendocino County. We also plan to collect cores from Blue Lakes in Lake County and Cleveland's Pond in Los Angeles County.

CONCLUSION

Our preliminary results reveal changes in oaks during the Holocene. First, 10,000-5,000 years ago, oaks in the montane Sierra Nevada increased in importance at the upper altitudinal limit of their range. We believe this environmental change was a response to climatic warming and to changes in the fire regime. More recently, following Spanish settlement and the introduction of exotic plant species, oak again increases. We hypothesize that this rise may reflect increased oak woodland density following a cessation of burning by Indians, or changes in grazing and woodcutting practices associated with intensified land use during the mid-19th century. Further analysis of microscopic charcoal and records from additional sites are needed to test these hypotheses and further clarify regional trends.

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