Late Holocene fire and vegetation reconstruction from the western Klamath Mountains, California, USA: A multi-disciplinary approach for examining potential human land-use impacts

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Abstract
The influence of Native American land-use practices on vegetation composition and structure has long been a subject of significant debate. This is particularly true in portions of the western United States where tribal hunter-gatherers did not use agriculture to meet subsistence and other cultural needs. Climate has been viewed as the dominant determinant of vegetation structure and composition change over time, but ethnographic and anthropological evidence suggests that Native American land-use practices (particularly through the use of fire) had significant landscape effects on vegetation. However, it is difficult to distinguish climatically driven vegetation change from human-caused vegetation change using traditional paleoecological methods. To address this problem, we use a multidisciplinary methodology that incorporates paleoecology with local ethnographic and archaeological information at two lake sites in northwestern California. We show that anthropogenic impacts can be distinguished at our Fish Lake site during the cool and wet 'Little Ice Age', when we have evidence for open-forest or shade-intolerant vegetation, fostered for subsistence and cultural purposes, rather than the closed-forest or shade-tolerant vegetation expected due to the climatic shift. We also see a strong anthropogenic influence on modern vegetation at both sites following European settlement, decline in tribal use, and subsequent fire exclusion. These results demonstrate that Native American influences on vegetation structure and composition can be distinguished using methods that take into account both physical and cultural aspects of the landscape. They also begin to determine the scale at which western forests were influenced by Native American land-use practices and how modern forests of northwestern California are not solely products of climate alone.

Introduction

The extent to which Native Americans in western North America influenced pre Euro-American landscape composition and structure has long been a subject of debate (Boyd, 1999; Denevan, 1992; Vale, 2002). Early researchers suggested that climate did not sufficiently explain the distribution of forests and grasslands throughout the western United States (Denevan, 1992; Sauer, 1947; Stewart, 2002). One argument has been that Native American land-use practices, particularly the use of fire, were sufficiently widespread to create the open-forest structure commonly found throughout the west at the time of European contact (Anderson, 2006; Boyd, 1999; Denevan, 1992; Lewis and Anderson, 2002). Another view is that human disturbance was most intense near permanent villages and camps and of little effect or absent on the majority of the landscape (Vale, 2002; Whitlock and Knox, 2002). Understanding the extent to which pre-European forest composition and structure were influenced by human activity or were the result of climate has important implications. If pre-European forest structure was created by a climatically controlled fire regime, then human influences do not need to be considered in interpreting late Holocene vegetation dynamics. However, if Native Americans played a larger than expected role in controlling forest composition and structure, then Holocene vegetation studies need to include a thorough understanding of human history in order to accurately interpret vegetation change through time. Distinguishing cultural impacts from natural variability can also help inform land management decisions aimed at sustaining ecosystem dynamics (Swetnam et al., 1999).

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Studies of Native American modification of vegetation through the use of fire or agriculture are relatively well documented in eastern North America where agriculture was widespread, although interpretations as to whether impacts are local or regional in scale differ (Abrams and Nowacki, 2008). Pollen assemblages and archaeological evidence in southern Ontario that include pollen from *Zea mays* (maize) and other disturbance indicators show local-scale human influences in areas of high settlement densities (Munoz and Gajewski, 2010). Other studies that review the anthropological and paleoecological literature regarding the impacts of Native Americans on forest change in the eastern United States argue for widespread forest impacts (Abrams and Nowacki, 2008; Stewart, 2002).

In most of western North America, agriculture cannot be used to identify Native American impacts because the presence of *Zea mays*, considered a signal of human habitation, is missing from most regions of western North America and absent from northern California prior to European arrival (Bean and Lawton, 1973). In northwestern California, Native Americans were primarily hunter-gatherers (Kroeber, 1925 [1975]), and efforts to identify human impacts on the landscape rely on our ability to distinguish changes in abundance of native plant taxa, reflective of tribal subsistence and cultural uses of the landscape that can be attributed to human activity.

Distinguishing human-caused vegetation change from climatically caused change in western paleoecological records is challenging, but there are ways to separate these factors (Whitlock et al., 2010). One approach, used in this paper, is to begin with sites selected using knowledge of local human history from ethnographic and archaeological studies to incorporate both paleoecological and anthropological evidence (Lewis and Anderson, 2002). The next step is to form a credible link between human land use and vegetation change through knowledge of Native American adaptations, technologies, population densities, and the characteristics of the environment in which they lived (Whitlock and Knox, 2002). Anthropogenic impacts would then be inferred by identification of anomalous fire regimes and vegetation dynamics that are not predicted by climate patterns but coincide with documented anthropogenic land-use practices (Abrams and Nowacki, 2008; Conedera et al., 2009; Munoz and Gajewski, 2010; Whitlock et al., 2010; Whitlock and Knox, 2002).

Native American tribes in California encouraged the growth of certain native species, such as oaks (*Quercus* spp.) and tanoak (*Notholithocarpus densiflorus*), in order to collect the acorns that formed a staple in many regional diets (Anderson, 2006). This was accomplished through frequent anthropogenic burning to reduce forest litter, kill pests and pathogens, and facilitate access for collection of acorns (Heffner, 1984; Schenck and Gifford, 1952). If Native Americans created a shorter fire return interval than would have occurred from climate alone, this could have potentially excluded late-successional species and created a more open-forest structure with a composition of shade-intolerant species adapted to frequent fires at a landscape scale. Anderson and Carpenter (1991) used charcoal and pollen to reconstruct vegetation and fire history in Yosemite Valley, California, over the past 1550 years. They identified a change in vegetation ~650 cal. yr BP from more shade-tolerant *Abies* spp. (firs) to more shade-intolerant *Quercus*. This change occurred following a sharp increase in charcoal production, indicative of a large fire event. The unusual aspect of this shift is that it persisted through a cooler period when forest closure would be expected, not the perpetuation of shade-intolerant vegetation such as *Quercus*. However, the authors noted that the archaeological record indicated a large change in Native American material culture at about the same time (650–750 cal. yr BP) and concluded that a new migrating tribal group arrived in the area and burned the forest more frequently, which maintained open-oak woodlands (an important source of subsistence and cultural

resources), even during a period of increasingly cool and wet climate that should have otherwise produced a closed-canopy coniferous forest. Similar to that study, we want to examine the potential impacts of humans on fire and vegetation dynamics in the western Klamath Mountains.

The objective of this study is to examine potential anthropogenic impacts on vegetation and fire dynamics in the paleoecological record using a methodology that incorporates elements of paleoecology, regional archaeology, and ethnographic accounts. To accomplish this, we examine the late Holocene paleoecological records of two sites in the Klamath Mountains of northwestern California. The Klamath Mountains offer a distinct set of physical proxy records and cultural traits that can be used to address possible linkages between human land-use practices and forest structure and composition. A number of studies from northwestern California and southwestern Oregon have used pollen and charcoal to reconstruct vegetation change and infer climatic change during the late Holocene in this region (Briles et al., 2008, 2011; Colombaroli and Gavin, 2010; Daniels et al., 2005; Mohr et al., 2000; Wanket, 2002). These studies have been at high-elevation sites, far removed from documented Native American settlements, and potentially used less by tribal groups (Lake, 2013), and their vegetation and fire dynamics have been interpreted as primarily climatically controlled. These climatically controlled sites form the baseline for identifying potentially anomalous vegetation change in our record. Any anomalous vegetation changes can then be compared to regional archaeological, ethnographic, and historical records of human occupation to identify potential human-caused change rather than climate-caused change, which the higher-elevation studies do not fully consider. We argue that in more human-influenced landscapes, vegetation change that is not consistent with climate change is most likely caused by human land-use practices, in particular, the use of fire to modify the vegetation for a range of subsistence and cultural reasons (Lake, 2013), such as clearing brush for travel, encouraging browse for game (Anderson, 2006), ensuring acorn production (Schenck and Gifford, 1952), and encouraging basketry and fishing gear materials (Anderson, 2006; Lake, 2007, 2013).

The results of this research are significant for three reasons. First, they can contribute to and inform the debate regarding the scale of anthropogenic impacts in California (Anderson, 2006; Lewis and Anderson, 2002). Second, they can push the disciplinary bounds of paleoecology by including both physical and cultural factors in our interpretations, an approach that is relatively uncommon in most paleoecological studies (Munoz and Gajewski, 2010; Whitlock et al., 2010). Finally, the detection of anthropogenic impacts in the late Holocene record will help clarify the range of factors that shaped modern forests and may lead to management techniques (Swetnam et al., 1999) that acknowledge anthropogenic burning practices as an element in reintroducing ecological resiliency and heterogeneity to the forests of California (Lake, 2007).

Regional background

Physical setting. The Klamath Mountains of northwestern California are known for their physical and biological diversity (DellaSala et al., 1999; Whittaker, 1960). The region's complex geologic history has created a highly dissected landscape of deep drainages and steep-sided mountains (Irwin, 1981). The climate is predominantly Mediterranean, typified by warm, dry, summers and cool, wet, winters. The majority of precipitation falls as rain from Pacific frontal storms between October and May with snowpack persisting on high elevation ridges into summer. Average annual precipitation ranges from 100.2 cm along the coast, in Eureka, to 125.7 cm at Happy Camp, along the mid-Klamath River, and decreases to 50.9 cm at Yreka, to the east (Figure 1). A
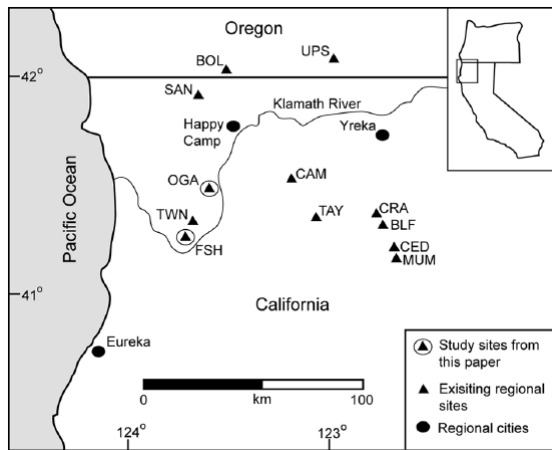
Figure 1. Location map of study sites in northwestern California Fish Lake (FSH) and Lake Ogaromtoc (OGA). Previous paleoecological studies are also displayed, including Twin Lakes (TWN; Wanket, 2002); Bluff (BLF) and Crater (CRA) Lakes (Mohr et al., 2000); Sanger (SAN) and Bolan (BOL) Lakes (Briles et al., 2008); Upper Squaw Lake (USL; Colombaroli and Gavin, 2010); Mumbo (MUM) Lake (Daniels et al., 2005); and Campbell (CAM), Taylor (TAY), and Cedar (CED) Lakes (Briles et al., 2011).

strong temperature gradient exists from the coastal to inland areas, with July temperatures averaging 16.7°C in Eureka along the coast and 35.0°C inland at Happy Camp (Western Regional Climate Center, n.d.).

Historically, prior to effective fire suppression starting in the early 1900s, the Klamath Mountain region has a mixed-severity fire regime characterized by small, low-intensity, frequent fires, punctuated by occasional larger, more intense burns. The variable topography and strong climatic gradients results in fire severity that varies drastically across fine scales (10s to 100s of meters), which has helped shape the forests of the Klamath Mountains into a complex mosaic of multi-aged stands (Halofsky et al., 2011). Summer and early fall lightning storms are common throughout the region with strike density increasing from the coast inland (Van Wagtendonk and Cayan, 2008). The western Klamath Mountains have lower strike density than areas further to the east (Rorig and Ferguson, 1999). Median fire return intervals vary based on forest type and elevation. Low-elevation forests have median fire return intervals from 6 to 22 years (Taylor and Skinner, 1998, 2003; Wills and Stuart, 1994), while higher-elevation forests have median fire return intervals from 25 to 74 years, largely due to cooler and wetter forest conditions (Agee, 1993; Skinner et al., 2006; Stuart and Salazar, 2000).

The Klamath Mountain region is at the confluence of Mediterranean, Pacific Northwest, and dry interior climatic zones, which causes high floristic diversity (Whittaker, 1960). Low-elevation forests (<600–800 m) are dominated by *Pseudotsuga menziesii* (Douglas-fir) and multiple *Pinus* (pine) species, with a broadleaf component of *Quercus kelloggii* (California black oak), *Notholithocarpus densiflorus* (tanoak), and *Arbutus menziesii* (Pacific madrone). Higher-elevation montane forests (up to ~1900 m) include *Abies concolor* (white fir) and *Abies magnifica* (red fir; Sawyer and Thornburg, 1988). Sub-alpine and alpine vegetation (>1900 m) zones are dominated by *Tsuga mertensiana* (mountain hemlock) and a zone of stunted *Pinus albicaulis* (white bark pine) along exposed ridge crests and peaks (Briles et al., 2011; Sawyer and Thornburg, 1988).

The structure and composition of forest ecosystems in the Klamath Mountains have undergone significant changes in the last century. This is particularly evident in the low-elevation oak

woodland zone, where altered fire regimes have allowed shade-tolerant, fire-sensitive taxa (such as *Pseudotsuga, Abies*, and *Notholithocarpus*) to encroach on stands of shade-intolerant, fire-adapted taxa (such as *Quercus*, Poaceae (grasses), and *Pteridium aquilinum* (bracken fern); Engber et al., 2011; Hunter and Barbour, 2001). As encroachment intensifies, understory shading increases and fine surface fuels (primarily grasses and forbs) that were available for frequent, low-intensity fire events have been largely removed from the system. This further promotes fire-sensitive species recruitment and stand conversion from an open-oak woodland to a closed-forest system (Engber et al., 2011).

Climate reconstructions indicate that the region was once cooler than at present, with this cooling trend beginning ~6000 cal. yr BP and becoming well established throughout northwestern California by ~4500 cal. yr BP. This cooling trend followed a mid-Holocene period when increased insolation led to warmer and drier regional conditions (Briles et al., 2008), and cooler conditions were indicated by regional increases in shade-tolerant taxa (such as *Abies, Pseudotsuga menziesii*, and *Tsuga mertensiana*) and decreases in shade-intolerant taxa (*Quercus* spp., *Calocedrus decurrens* (incense cedar), and Poaceae; Briles et al., 2005, 2011; Daniels et al., 2005; Mohr et al., 2000). Holocene-length records from the Klamath Mountain region suggest that the modern forest structure was well established by ~2000 cal. yr BP (Briles et al., 2008; Mohr et al., 2000).

Two climatic episodes mark the late Holocene climate record. The first episode is the Medieval Climate Anomaly (MCA), a warmer and drier period that occurred between ~1050 and 600 cal. yr BP (Cook et al., 2004; Stine, 1994). The second episode is the 'Little Ice Age' (LIA), a cooler, wetter period that occurred between ~600 and 100 cal. yr BP (Bradley and Jones, 1992; Graham et al., 2007). These climatic periods left evidence in the high-elevation paleoecological record of the Klamath region. Increases in shade-intolerant taxa and background charcoal accumulation are noted during the MCA (Briles et al., 2011; Colombaroli and Gavin, 2010; Daniels et al., 2005; Mohr et al., 2000), while increases in shade-tolerant taxa and a decrease in charcoal accompanied the LIA interval (Briles et al., 2011; Colombaroli and Gavin, 2010; Mohr et al., 2000).

Cultural setting. The region has a complex cultural history, potentially dating back more than 7000 years (Hildebrandt and Hayes, 1993). Archaeological records indicate regional shifts in material culture that suggest changes in tribal settlement patterns and subsistence strategies during the middle to late Holocene. Three archaeological patterns are widely recognized in northwestern California since the middle Holocene: the Borax Lake Pattern, the Mendocino Pattern, and the Gunther Pattern (Hildebrandt, 2007).

The Borax Lake Pattern was a terrestrially oriented subsistence strategy pervasive throughout northwestern California (Hildebrandt, 2007; Hildebrandt and Hayes, 1993), beginning at ~7950 cal. yr BP (Hildebrandt, 2007). The end of the Borax Lake Pattern is not distinct but is generally dated to 4500–5000 years ago (Hildebrandt, 2007). Warmer and drier mid-Holocene climatic conditions created an open-forest structure at higher elevations where more closed forests currently prevail (Briles et al., 2005, 2008; Daniels et al., 2005; Mohr et al., 2000). Non-sedentary, foraging, tribal hunter-gatherer populations lived in these higher elevations (Hildebrandt, 2007).

The second archaeological phase, the Mendocino Pattern, was evident by 4500 years ago and persisted until ~1500 years ago (Arnold and Walsh, 2010; Hildebrandt, 2007). The onset of the Mendocino Pattern is roughly coincident with widespread middle to late Holocene cooling in northwestern California (Briles et al., 2005; Daniels et al., 2005; Mohr et al., 2000; Wanket, 2002). This gradual cooling led to increasingly dense forests along previously

open ridges, which prompted populations to move into more open, lower elevation valleys (Hildebrandt and Hayes, 1993).

The final regional cultural phase, the Gunther Pattern, was established by ~1500 years ago and continued until European contact (Fredrickson, 1984; Hildebrandt, 2007). Archaeological assemblages from the Gunther Pattern represent a continued shift to a more sedentary, riverine or coastal subsistence strategy (Fredrickson, 1984). Demographic and technological changes are inferred during the Gunther Pattern as more resources were needed to support expanding populations (Arnold and Walsh, 2010). More intense land usage, potentially including an increase in tribal burning, and resource acquisition (particularly in the form of acorn gathering) occurred (Tushingham, 2009). The new technologies and larger populations were in large part due to multiple migrations from the Pacific Northwest to northwestern California (Golla, 2007).

Subsistence and cultural practices of northwestern California Native American groups emphasized the use of fire as an important tool to encourage open-structured forests, which supplied many of their terrestrial subsistence resources, including acorns and basketry materials, such as *Corylus cornuta* (California beaked hazel; Anderson, 2006; Lake, 2013). Fire was important to ensure adequate acorn production and collection in *Notholithocarpus densiflorus* and *Quercus kelloggii* stands (Heffner, 1984; Schenck and Gifford, 1952). Fire was also used to facilitate hunting and access to berry and geophyte-bulb resources in forest openings. Dense forests made hunting and gathering difficult, and areas were often burned to open the forest, encourage browse, concentrate game into predictable areas (Drucker, 1937), and promote growth of berries and bulbs (Anderson, 2006; Lake, 2007, 2013).

European settlement began in earnest with the discovery of gold at Sutter's Mill in the Sierra Nevada in AD 1848, followed by discoveries along the Klamath River at Orleans Bar (Busam, 2006). The introduction of large numbers of miners into the region led to significant conflicts between settlers and Native Americans, and many Indians along the Klamath River were killed or forcibly displaced (Bright, 1978). These often-violent struggles led to a significant disruption in Native American subsistence and cultural activities as river-side areas were seized for gold mining, and strict bans on burning were enacted (Agee, 2007). Modern forest management in northwestern California began with the establishment of the Trinity and Klamath Forest Reserves in AD 1905 (Busam, 2006), and a strict nationwide policy of fire suppression was instituted shortly thereafter (Pyne, 1982).

Study sites

Two research sites were selected in the Klamath Mountain region of northwestern California (Figure 1): Fish Lake (41°14′N, 123°42′W, elevation: 541 m) and Lake Ogaromtoc (41°32′N, 123°34′W, elevation: 596 m). Local geomorphology suggests that both lakes were formed by landslide activity, and each has minimal stream inputs. Both sites are in the oak woodland vegetation zone (Franklin and Dyrness, 1988). Fish Lake (FSH), located ~35 km east of the Pacific Ocean, is 13 m deep with a surface area of 9.8 ha. Overstory vegetation at the site consists mainly of *Pseudotsuga menziesii* and *Chamaecyparis lawsoniana* (Port Orford cedar), with lesser amounts of *Notholithocarpus densiflorus, Pinus lambertiana* (sugar pine), and *Pinus jeffreyi* (Jeffrey pine). *Salix* spp. (willow) and *Alnus* spp. (alder) are well represented in riparian areas. *Quercus* spp., Poaceae, and *Pteridium* are very rare around the basin but are present in isolated, open-canopied areas. The Fish Lake basin is ~3 km from the Klamath River. *Chamaecyparis lawsoniana* favors mesic sites with summer moisture, often in the form of fog (Zobel et al., 1985) and is indicative that frequent summer fog travels up the river valley from the Pacific Ocean.

Lake Ogaromtoc (OGA), located ~45 km east of the Pacific Ocean, is 6.3 m deep with a surface area of 1.5 ha. Vegetation at this site is similar to Fish Lake. The main exceptions are that *Calocedrus decurrens* replaces *Chamaecyparis lawsoniana* as an overstory constituent, and *Quercus* spp. (primarily *Q. kelloggii*) is more prevalent than at Fish Lake. As at other sites throughout the region, most of the larger, older *Q. kelloggii* have been overtopped by *Pseudotsuga menziesii* (Engber et al., 2011; Hunter and Barbour, 2001), and overall, *Quercus* regeneration appears poor. Understory constituents such as Poaceae and *Pteridium* are more prevalent around the basin in isolated canopy gaps or on soils developed from serpentine bedrock. The site is ~2 km from the Klamath River, and while coastal fog does influence the Lake Ogaromtoc basin, it is farther upstream than Fish Lake, which means it is slightly drier and subject to less frequent fog inundation, noted by the absence of *C. lawsoniana* (Zobel et al., 1985).

The study sites are in the ancestral territory of the Karuk Tribe, although Fish Lake is an area of joint use and of mutual interest located on the edge of ancestral Yurok Tribal lands along the Lower Klamath River (Kroeber, 1925 [1975]). The combined territories were extensive: Yurok and Karuk settlements ran from the mouth of the Klamath River upriver ~160 km to the modern town of Happy Camp (Kroeber, 1936). Other groups (Hupa, Wiyot, Tolowa, Chilula, Chimariko, and Shasta) have ancestral territories nearby (Kroeber, 1925 [1975]).

Materials and methods

Two overlapping cores were recovered from each site (OGA-09-1/OGA-09-2 and FSH-08-1/FSH-08-2) using a 5-cm-diameter modified Livingstone piston corer. Cores were extruded into plastic tubes in the field before transport. Surface cores of the sediment–water interface were recovered from each lake with a plastic tube core: 95 cm at Lake Ogaromtoc and 98 cm at Fish Lake. The unconsolidated sediments at the top of each core (~20 cm in both cases) were sub-sampled at 0.5-cm increments in the field to avoid sediment disturbance during transport. The top 450 cm of core OGA-09-1 (800 cm total length) was used for analysis at Lake Ogaromtoc and the top 450 cm of core FSH-08-1 (733 cm total length) was used at Fish Lake.

Cores were measured for magnetic susceptibility using a ring magnetometer, then split lengthwise, and changes in lithology were described and documented. Continuous 1-cm³ sediment samples were removed from the top 450 cm of each core and analyzed for total organic matter using the loss-on-ignition method at 550°C (Dean, 1974). Plant macrofossils were submitted for radiocarbon dating to the Center for Accelerator Mass Spectrometry (CAMS) and were cleaned using acid–base–acid treatment before graphitization and measurement by accelerator mass spectrometry (AMS) with standard methods. Surface bulk sediments from the top 25 cm at Lake Ogaromtoc and top 27 cm at Fish Lake were submitted to a commercial laboratory for ^{210}Pb dating. In each core, the top-most sediment was assumed to be deposited in the year the core was collected. We used the Bayesian-based Bacon software[1] (Blaauw and Christen, 2011) to develop age models from the ^{210}Pb and ^{14}C dates using the IntCal 13 (Reimer et al., 2013) and Northern Hemisphere Zone 1 (Hua et al., 2013) calibration curves. Use of Bayesian programs such as Bacon and OxCal (Bronk Ramsey, 2009) is highly desirable for radiocarbon-based age models because they use millions of Markov Chain Monte Carlo iterations to model the accumulation of sediment in a core and take into account the full probability density curve of each radiocarbon age. The iterations result in a probability envelope around the mean age model that allows for explicit estimation of the precision of the age model at any depth in the core (Figure 2A and B).
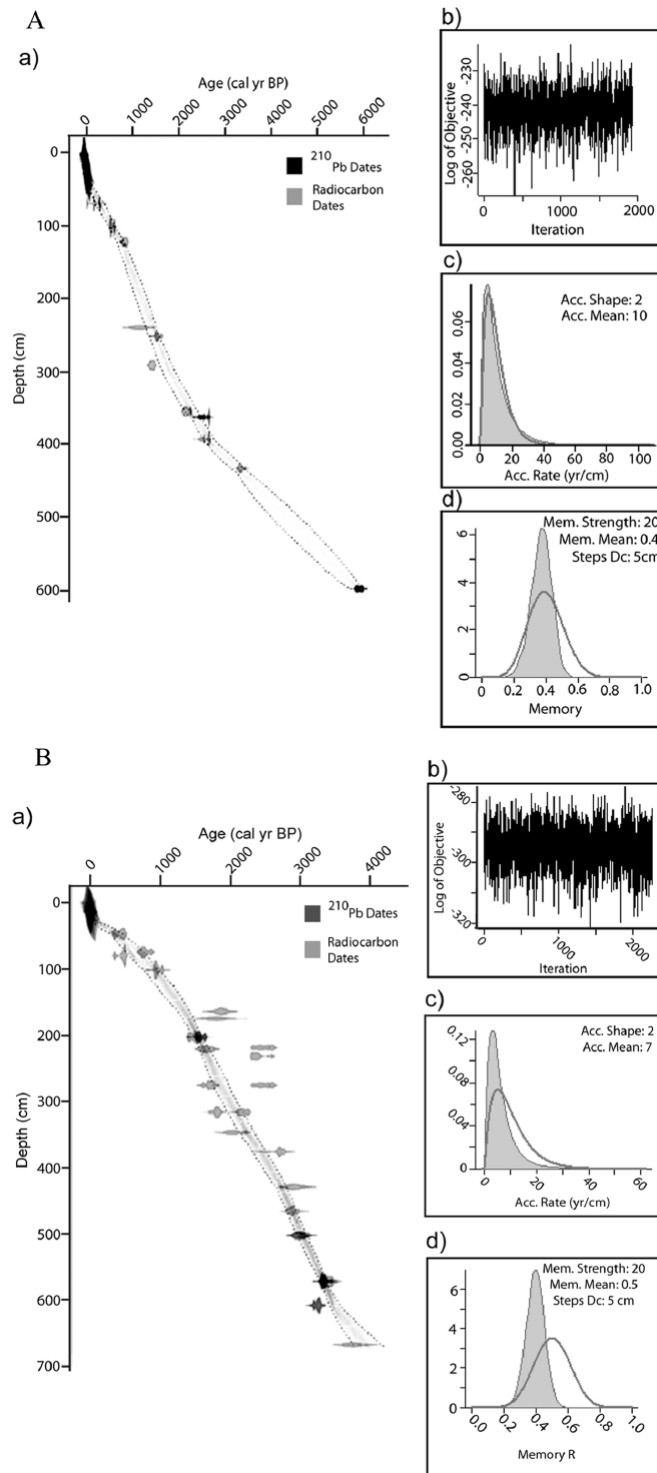
Figure 2. (A) Main panel shows (a) the Lake Ogaromtoc (OGA) age-to-depth results of Bacon modeling; the 2σ uncertainty band around the age model is enclosed by dotted lines, where the highest probability age is the darkest shading. Inset panels show (b) the distribution of the Markov Chain Monte Carlo (MCMC) iterations produced by Bacon, with a lack of structure indicating a stationary distribution; (c) the prior (solid gray line) and posterior (light gray histogram) distributions of the accumulation rates; and (d) prior and posterior distributions of the memory. Memory is a measure of the variability of the accumulation rate between neighboring depths in the cores and is relatively high for the homogeneous gyttja in this core. (B) Main panel shows (a) the Fish Lake (FSH) age-to-depth results of Bacon modeling; the 2σ uncertainty band around the age model is enclosed by dotted lines, where the highest probability age is the darkest shading. Inset panels show (b) the distribution of the Markov Chain Monte Carlo (MCMC) iterations produced by Bacon, with a lack of structure indicating a stationary distribution; (c) the prior (solid gray line) and posterior (light gray histogram) distributions of the accumulation rates; and (d) prior and posterior distributions of the memory. Memory is a measure of the variability of the accumulation rate between neighboring depths in the cores and is relatively high for the homogeneous gyttja in this core.

Pollen samples of 0.625 cm³ volume were prepared using standard methods (Faegri and Iversen, 1989). *Lycopodium* spore tracer tablets were added to each sample for calculating pollen concentration (Stockmarr, 1971). Samples were mounted and examined at 400× magnification. At least 400 terrestrial grains per level were counted and identified using reference guides (Kapp, 1969) and comparisons to University of Nevada Paleoecology Laboratory reference collections. The 15 major pollen types were analyzed using a single-link constrained cluster analysis (Birks and Gordon, 1985), and the resulting dendrogram was visually divided into pollen zones by placing boundaries between the clustered groups. Based on the vegetation life history traits (shade tolerance and fire sensitivity) of the vegetation present at out study sites, we used specific species and taxa to interpret what forest vegetation dynamics were doing over time. We primarily characterize the vegetation of interest as shade tolerant or fire sensitive (including *Pseudotsuga, Abies*, and *Notholithocarpus*) and shade intolerant or fire adapted (including *Quercus*, Poaceae, and *Pteridium*).

Macroscopic charcoal preparation (>125 μm) followed Long et al. (1998). Continuous 1-cm³ samples from the upper 450 cm of each core were disaggregated in sodium hexametaphosphate (5%) and sieved through 125- and 250-μm screens. Macroscopic charcoal fragments (>125 μm) have been demonstrated to represent charcoal deposition from local fire sources (Gardner and Whitlock, 2001; Whitlock et al., 2004). Sediments >125 μm were placed in a gridded Petri dish, and all charcoal fragments were counted at 35× magnification.

Charcoal counts were analyzed using CharAnalysis software (Higuera et al., 2009). This program compares long-term trends in background and short-term peaks in charcoal accumulation to determine charcoal peaks, interpreted to represent one or more fires occurring during a sample interval. Peak significance threshold was set at the 95th percentile, and the background smoothing window was set to 150 years.

Archaeological literature from northwestern California and southwestern Oregon was synthesized to identify changes in human land-use patterns and subsistence strategies. To accomplish this, we used published literature, unpublished reports from the archives of the Six Rivers National Forest, and special collections at Humboldt State University, in Arcata, California. Particular attention was paid to the cultural history of the lower and mid-Klamath River region, where our two study sites are located. Information on radiocarbon-dated materials, demographic changes, settlement patterns, and changes in material culture that may infer changes in subsistence strategies were collected.

Radiocarbon-dated materials from archaeological sites have been used to infer changes in prehistoric human populations from across the globe (Peros et al., 2010; Shennan and Edinborough, 2007). The relative abundance of radiocarbon-dated materials over time can be related to human population size since larger populations are likely to leave behind more materials (Peros et al., 2010). Potential bias within this method does exist although, as dateable materials will decay over time. This preservation bias renders it more likely that younger radiocarbon dates will be overrepresented in any record and lead to potential misinterpretations (Peros et al., 2010; Surrovell and Brantingham, 2007). Despite this potential bias, using temporal frequencies of radiocarbon dates from archaeological sites remains a common tool to examine prehistoric human demography (Louderback et al., 2010). Our methodology used the cultural synthesis described above to identify radiocarbon-dated sites, assign site usage to a specific cultural period, and infer general population dynamics during the late Holocene.

Results

Lithology

Both sediment cores are composed of unlaminated gyttja with occasional diatomaceous lenses (<1 cm thick). These lenses are uncommon during the period of analysis and do not appear to correlate with charcoal peaks or shifts in vegetation. Total organic matter (%TOM) at Fish Lake ranges from 10.3% to 47.6%, with higher values at Lake Ogaromtoc from 20.6% to 99.4%. The input of clastic sediments into lakes has often been associated with erosional events caused by fires (Gedye et al., 2000), but we saw no evidence of identifiable erosional events. Magnetic susceptibility (not shown) was consistently near zero at each site and showed minimal variation for the period of analysis.

Chronology

The chronology at Lake Ogaromtoc was established using the sediment–water interface (assumed to be the year of coring), 16 ²¹⁰Pb dates from the surface core, and 15 AMS radiocarbon dates from macrofossils found throughout the long core (Figure 2A and Table 1). Three ¹⁴C dates were extreme outliers and were not used for the Bacon age model. The surface core was taken ~1 m from the Livingston core and captured the sediment–water interface. According to field measurements, it overlapped the Livingston core by 28 cm. Because there were no stratigraphic markers within the upper sediments, we combined the two cores based on depth analyzing the upper 67 cm from the surface core and samples below that depth from the Livingstone core. The age model for the Lake Ogaromtoc core yielded an age of 6040 (±120) cal. yr BP at 600 cm. Sedimentation rates were rapid at this site ranging from 1 to 36 yr cm⁻¹ (10.0–0.28 mm yr⁻¹), with rates in the period of analysis ranging between 3 and 9 yr cm⁻¹.

The Fish Lake chronology uses the sediment–water interface, 13 ²¹⁰Pb dates from the surface core, and 19 AMS radiocarbon dates from macrofossils in the long core (Figure 2B and Table 2); we identified and excluded one outlier in the ¹⁴C dataset, and the Bacon model identified several others that were not temporally consistent with the overall age model. Cores were taken in a similar manner to Lake Ogaromtoc, and again there were no stratigraphic markers within the upper sediments; therefore, we combined the two cores based on depth, analyzing the upper 50 cm from the surface core and lower samples from the Livingstone core. The age model indicates that the Fish Lake core down to 675 cm covers the time interval since 4000 (+330/−100) cal. yr BP. Sedimentation rates were also rapid at Fish Lake, ranging between 1 and 25 yr cm⁻¹ (10.0–0.40 mm yr⁻¹). Most rates in the period of analysis were in the range of 3–5 yr cm⁻¹. The rapid sedimentation rates at both sites allow for good temporal constraint on vegetation change and fire events.

Pollen and charcoal

Selected pollen percentages and charcoal results for both sites are presented in Figure 3. Although most *Pinus* species are shade intolerant or fire adapted and indicative of more open-forest conditions, we do not rely heavily on them in our interpretation of site dynamics because *Pinus* throughout all vegetation zones is likely overrepresented due to its prolific pollen production and long-distance wind dispersal capability (Bradshaw and Webb, 1985). TC represents a combination of Taxodiaceae and Cupressaceae pollen due to the difficulty in differentiating these pollen types. Pollen accumulation rates (PARs) largely support the trends noted in the pollen percentage variations at each site. Selected PAR values for both sites are presented in Figure 4.

Lake Ogaromtoc pollen and charcoal summary. Relevant pollen and charcoal trends for Lake Ogaromtoc are summarized in Figure 3 and relevant PAR values in Figure 4. Unless otherwise specified, values represent average percent or charcoal accumulation values for the whole zone. PAR values are specified for a particular point in time. At Lake Ogaromtoc, high values for shade-intolerant *Quercus* (14.8%), low charcoal accumulations (0.19 particles

Table 1. Radiocarbon and ^{210}Pb dates used to create the Lake Ogaromtoc age model.

Sample	Depth (cm)	^{210}Pb age (yr BP)	Uncertainty (years)	Sample	Depth (cm)	^{210}Pb age yr BP	Uncertainty (years)
Surface	0	−59	10	210Pb_8	15.50	−34	2
210Pb_1	1.00	−58	2	210Pb_9	18.50	−27	2
210Pb_2	2.50	−56	2	210Pb_10	21.00	−23	2
210Pb_3	4.00	−55	2	210Pb_11	24.00	0	2
210Pb_4	5.50	−53	2	210Pb_12	26.00	6	2
210Pb_5	7.50	−50	2	210Pb_13	29.00	20	2
210Pb_6	9.50	−47	2	210Pb_14	33.00	36	2
210Pb_7	12.00	−42	2	210Pb_15	37.00	56	2

CAMS ID	Depth (cm)	Material	^{14}C age (yr BP)	Uncertainty (yr)	MAP^a (yr BP)	Minimum (yr BP)	Maximum (yr BP)	d13C (per mil)	Amount of C (mg)
144615	3	Fir needle	−46	2	−54	−54	−55.4	−25	0.42
144616	28	Fir needle	−7	2	9	14	10.1	−25	0.66
146904	28	Unknown seed	−7	2	9	14	10.1	−31.52	0.74
144617	69	Aquatic root	225	30	193	413	284.4	−25	0.65
144618	100	Aquatic root	545	30	509	644	529.2	−25	0.26
144619	121	Aquatic leaf	925	30	689	844	793.6	−25	0.30
146889	238	Bark	1250	120	1324	1589	1453	−32.14	0.03
144623	250	Twig	1670	35	1400	1635	1538	−25	0.96
144625	289	Twig	1565	30	1655	1925	1825.5	−25	0.99
144627	352	Fascicle	2235	30	2201	2461	2320	−25	0.98
146907	360	Unknown leaf	2590	35	2332	2552	2512.2	−25	0.21
146908	360	Charcoal	2495	40	2332	2552	2512.2	−25	0.27
144629	390	Unknown seed	2565	35	2617	2857	2728.2	−25	0.89
146909	430	Unknown seed	3215	45	3246	3536	3370.2	−25	0.13
144631	594	Large stick	5315	30	5917	6167	6028.3	−25	0.89
Rejected as outliers:									
146905	28	Sedge	695	30				−27.39	0.43
144620	155	Bark or twig	2540	40				−25	0.21
146906	50	Sedge	2635	30				−25	0.58

All ages calibrated with IntCal 13 (Reimer et al., 2013) and Northern Hemisphere Zone 1 (Hua et al., 2013) calibration curves.
^{a}Maximum a posteriori (MAP) is the maximum probability age.

cm^{-2} yr^{-1}), and low peak magnitudes are indicated in Zone 1 (3340–2240 cal. yr BP).

In Zone 2 (2240–1800 cal. yr BP), overall PAR values reach their highest levels on record (Figure 4). Overstory species, such as *Pseudotsuga* (14.1%) and *Pinus* (25.1%) remain stable throughout this zone, but shade-intolerant *Quercus* (8.3%) declines sharply while shade-tolerant *Abies* (1.1%) increases (Figure 3). Charcoal accumulations (0.43 particles cm^{-2} yr^{-1}) and peak magnitudes increase slightly in Zone 2.

Minimal changes begin to occur in Zone 3 (1800–1100 cal. yr BP). Overstory species average percentages do not change appreciably throughout this zone, but charcoal accumulation rates reach their highest levels (0.60 particles cm^{-2} yr^{-1}) in the Lake Ogaromtoc record. The largest charcoal peak recorded occurs at ~1400 cal. yr BP (Figure 3).

Shade-intolerant taxa, including *Pinus* (24.8%) and *Quercus* (8.0%) remain stable in Zone 4 (1100–590 cal. yr BP), but the shade-tolerant *Pseudotsuga* (15.4%) increases slightly from Zone 3. Charcoal accumulation rates (0.52 particles cm^{-2} yr^{-1}) and peak magnitudes decrease.

In Zone 5 (590–25 cal. yr BP), shade-tolerant *Pseudotsuga* (16.2%) increases and shade-intolerant *Quercus* (4.6%) declines. Decreased fire activity continues as charcoal accumulation (0.39 particles cm^{-2} yr^{-1}) and peak magnitudes continue to decline.

Modern forest dynamics in Zone 6 (25 to −59 cal. yr BP) indicate an increase in shade-tolerant species as *Pseudotsuga* pollen percentage (29.4%) and *Notholithocarpus* PAR (~8000 grains cm^{-2} yr^{-1}) reach their highest values since Zone 1. Conversely, *Quercus* PAR (~1200 grains cm^{-2} yr^{-1}) declines to its lowest

levels in the record as charcoal accumulations increase slightly (0.55 particles cm^{-2} yr^{-1}).

Fish Lake pollen and charcoal summary. Relevant percent pollen and charcoal trends for Fish Lake are summarized by zone in Figure 3 and selected PAR values in Figure 4. Unless otherwise specified, values represent average percent or charcoal accumulation values for the whole zone. PAR values are specified for a particular point in time.

Shade-intolerant, open-forest taxa including *Pinus* (19.2%), *Quercus* (3.6%), *Pteridium* (0.20%), and Poaceae (1.3%) are prevalent in Zone 1 (2850–2190 cal. yr BP). Overall charcoal accumulation rates at Fish Lake are much higher than at Lake Ogaromtoc, but in Zone 1, Fish Lake average charcoal accumulations are the lowest in the record (1.67 particles cm^{-2} yr^{-1}; Figure 3).

In Zone 2 (2190–1560 cal. yr BP), most pollen percentages remain stable, but charcoal accumulation rates (2.45 particles cm^{-2} yr^{-1}) and charcoal peak magnitudes increase. The largest charcoal peak in the Fish Lake record occurs at ~1580 cal. yr BP (Figure 4).

Shade-intolerant *Quercus* (4.1%) increases through Zone 3 (1560–1110 cal. yr BP), while shade-tolerant, closed-forest species, *Pseudotsuga* (10.3%) and *Abies* (0.50%), decrease slightly. These slight changes coincide with the highest average charcoal accumulation rate (3.36 particles cm^{-2} yr^{-1}) in the Fish Lake record (Figure 3).

Shade-intolerant species remain stable or increase through Zone 4 (1110–540 cal. yr BP) as *Quercus* (5.5%), Poaceae (0.87%), and *Pteridium* (0.50%) reach their highest average values in the

Table 2. Radiocarbon and ²¹⁰Pb dates used to create the Fish Lake age model.

Sample	Depth (cm)	²¹⁰Pb age (yr BP)	Uncertainty (years)	Sample	Depth (cm)	²¹⁰Pb age yr BP	Uncertainty (years)
Surface	0	−58	10	210Pb_7	14	−15	2
210Pb_1	2.75	−56	2	210Pb_8	14.75	−11	2
210Pb_2	6.25	−46	2	210Pb_9	16.25	−7	2
210Pb_3	8.75	−36	2	210Pb_10	19.25	6	2
210Pb_4	11	−28	2	210Pb_11	23.25	26	2
210Pb_5	12.5	−21	2	210Pb_12	27	48	2
210Pb_6	13.5	−17	2				

CAMS ID	Depth (cm)	Material	¹⁴C age (yr BP)	Uncertainty (yr)	MAPª (yr BP)	Minimum (yr BP)	Maximum (yr BP)	d13C (per mil)	Amount of C (mg)
153753	47	Charcoal	380	35	329	292	447	−25	0.13
153754	81	Charcoal	415	30	615	587	847	−25	0.17
152534	176	Charcoal	1900	110	1418	1348	1513	−25	0.04
148490	204	Bark	1680	30	1564	1534	1619	−25	1.09
148592	204	Bark	1695	35	1564	1534	1619	−25	1.00
148638	204	Wood	1615	30	1564	1534	1619	−25	0.94
152535	222	Charcoal	1775	50	1664	1599	1759	−25	0.11
148641	277	Bark	1805	35	1861	1798	2038	−25	0.23
148645	318	Wood	1905	35	2111	2016	2271	−25	0.25
153755	349	Charcoal	2110	80	2299	2206	2436	−25	0.05
153756	378	charcoal	2660	60	2475	2377	2592	−25	0.08
153757	431	Charcoal	2860	60	2775	2716	2886	−25	0.07
148650	468	Charcoal	2850	30	2940	2888	3028	−25	1.04
148658	505	Wood or leaf bits	2935	35	3049	3037	3177	−25	0.15
148590	505	Wood or leaf bits	2910	30	3049	3037	3177	−25	0.29
148660	575	Twig	3230	30	3431	3389	3469	−25	0.76
148491	575	Bark	3175	30	3431	3389	3469	−25	0.32
148582	611	Wood	3125	30	3567	3519	3689	−25	0.53
148585	671	Fine charcoal	3560	80	3990	3871	4286	−25	0.05
Rejected as outliers:									
143223	75	Aquatic roots	860	40				−25	0.14
148486	102	Aquatic roots	1050	30				−31	0.14
143225	165	Macros	1960	60				−25	0.07
143227	220	Macros	2460	35				−25	0.36
148639	233	Aquatic root	2405	30				−31	0.46
148580	277	Stem or root	2465	35				−25	0.08
148644	318	Stem or root	2220	40				−31	0.13
148492	575	Wood	3300	30				−25	0.81
146902	764	Twig	1570	25				−25.48	1.03

All ages calibrated with IntCal 13 (Reimer et al., 2013) and Northern Hemisphere Zone 1 (Hua et al., 2013) calibration curves.
ªMaximum a posteriori (MAP) is the maximum probability age.

record. Charcoal accumulation rates decrease from Zone 3 (3.07 particles cm⁻² yr⁻¹), but peak magnitudes remain high.

General increases in many taxa begin in Zone 5 (540–15 cal. yr BP). Shade-tolerant indicators *Pseudotsuga* (19.6%) and *Abies* (1.5%) increase, and shade-intolerant taxa such as *Pinus* (18.1%) remain stable. Peak *Quercus* PAR values are similar between Zone 4 (~5200 grains cm⁻² yr⁻¹) and Zone 5 (~6000 grains cm⁻² yr⁻¹; Figure 4), although Zone 5 *Quercus* percentage declines (3.5%). Charcoal accumulation decreases slightly in this zone (2.84 particles cm⁻² yr⁻¹).

As at Lake Ogaromtoc, Zone 6 (15 to −58 cal. yr BP) at Fish Lake shows shade-tolerant taxa *Pseudotsuga* (35.0%), *Abies* (1.6%), and *Notholithocarpus* (12.3%) all increasing. This occurs while shade-intolerant taxa *Quercus* (2.3%), Poaceae (0.48%), and *Pteridium* (not present in the pollen record in this zone) reach their lowest average values in the Fish Lake record. Charcoal accumulation (1.76 particles cm⁻² yr⁻¹) and peak magnitudes remain low, indicating decreasing fire activity in Zone 6.

Regional population and subsistence changes. The two most recent cultural patterns, the Mendocino and Gunther Patterns, indicate significant shifts in cultural subsistence patterns over the last ~4000 cal. yr BP, as terrestrial lifestyles gave way to mixed river-ine and upland foraging strategies. Our synthesis of radiocarbon-dated regional archaeological sites also infers that a relative population increase was occurring as cultural patterns changed over time. Many regional sites show evidence of initial habitation or intense usage in the last ~1500 cal. yr BP (Figure 5 and Table 3). This more intense usage is inferred from the greater number of sites (and related radiocarbon dates) in the Gunther Period.

Discussion

Regional climate patterns and anomalous vegetation change

If climate is the only control on forest composition and structure and fire dynamics, then we would expect our record of vegetation and fire to be consistent with existing reconstructed paleoclimato-logical records a greater distance and more remote from known tribal villages and camps (archaeological sites). Holocene vegetation records from the Klamath Mountain region suggest that modern forest structure was well-established by ~2000 cal. yr BP
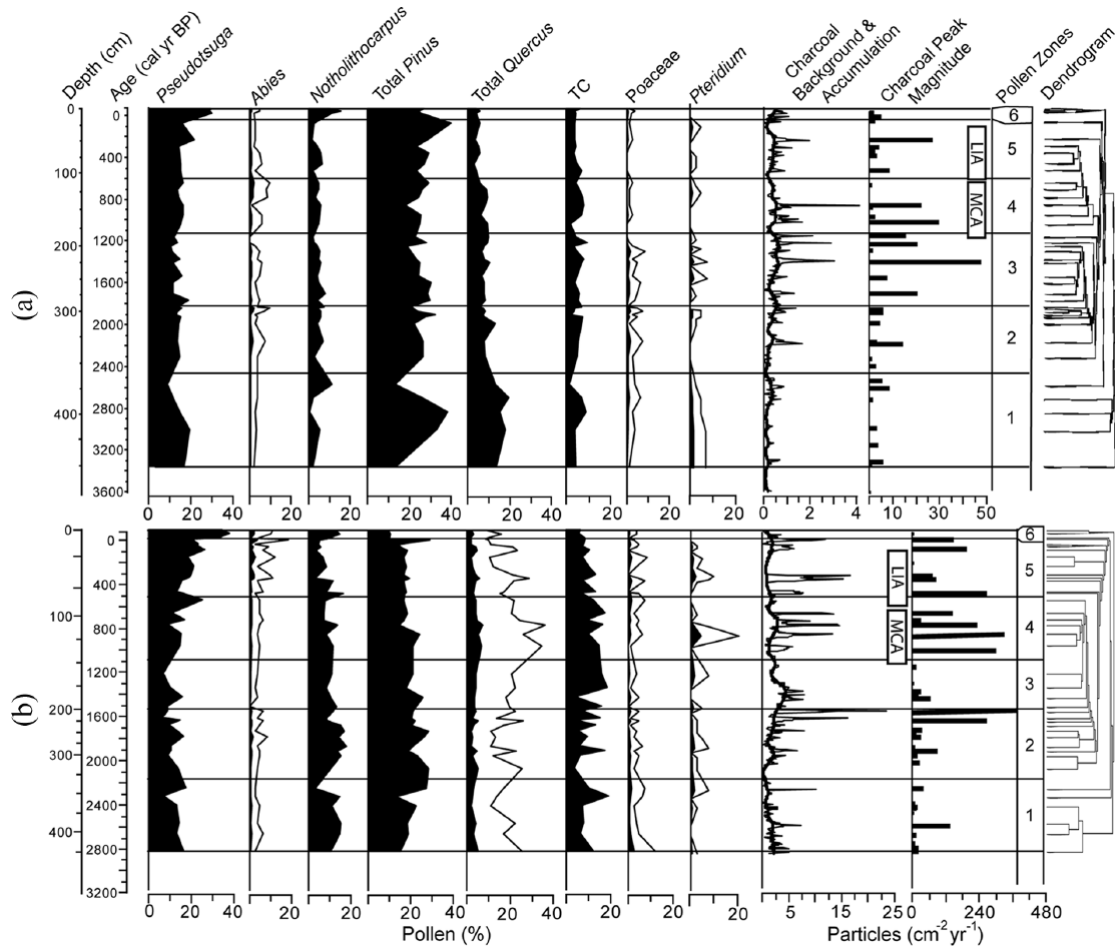
Figure 3. Pollen percentages of selected taxa, fire history reconstruction, pollen zones, and cluster analysis results for (a) Lake Ogaromtoc and (b) Fish Lake. TC represents the difficult to differentiate pollen of Taxodiaceae and Cupressaceae. Unshaded areas represent a 3× exaggeration. Fire history results include background charcoal (smoothed black line), charcoal accumulation rates (thinner black line), and peak magnitudes of each charcoal peak.

(Briles et al., 2008; Mohr et al., 2000). This followed a mid-Holocene regional cooling pattern inferred from an increase in shade-tolerant vegetation (*Abies* and *Pseudotsuga*) and a decrease in shade-intolerant vegetation (*Quercus* spp., *Calocedrus decurrens*, and Poaceae; Briles et al., 2005, 2011; Daniels et al., 2005; Mohr et al., 2000). These studies interpret the last ~2000–3000 cal. yr BP as one period characterized by similar vegetation and fire regimes.

The Lake Ogaromtoc pollen and charcoal record is largely consistent with a climatically controlled pattern of forest and fire dynamics, since shade-intolerant taxa are generally favored during warm periods with more active fire (such as the MCA), and shade-tolerant taxa are generally favored during cool periods with less fire indicated (such as the LIA). This is generally true until the historic forest zone (AD 1924–2009), at which point there is a clear deviation from climatic expectations, due to anthropogenic interference. In the early part of the record (2800–1000 cal. yr BP), forest closure is indicated, as expected, with shade-intolerant *Quercus* decreasing and shade-tolerant *Pseudotsuga* and *Abies* increasing (Figure 3). Closure continues slowly through the warmer and drier MCA, as shade-intolerant taxa and charcoal increase. During the LIA, fires decrease further and the forest closure accelerates as shade-intolerant taxa such as *Quercus* and Poaceae decline. At the end of the LIA, as climate began to warm, fires should increase and more open-forest structures should once

again begin to favor shade-intolerant species. However, with the significant decrease of Native Americans, reduction in tribal use of the landscape, and initiation of fire suppression, forest closure continued, leading to the highest percentages of *Pseudotsuga* taxa in the entire record and possibly a dominant Douglas-fir forest unlike any other period within the last 3000 years (Figure 3).

The vegetation and fire history reconstruction from Fish Lake is also initially consistent with a climatic explanation. Forest closure is indicated early on in the record in response to general cooling; however, an anomalous pattern appears between 1560 and 1110 cal. yr BP. This is a time of continued regional cooling which coincides with decreases in regional charcoal production (Briles et al., 2011; Mohr et al., 2000), but charcoal production at Fish Lake reaches its highest level while shade-intolerant taxa are increasing. During the MCA, pollen and charcoal are once again consistent with climate as shade-intolerant taxa and charcoal production increase.

A second anomaly can be seen during the LIA when opposite signals of forest closure (increases in shade-tolerant *Pseudotsuga* pollen – climatically expected) and forest opening (increases in shade-intolerant *Quercus* pollen – climatically anomalous) occur simultaneously. Although average *Quercus* percentages are less than during the MCA (Figure 3), PAR values (Figure 4) indicate expansion of *Quercus* by ~400 cal. yr BP to levels higher than at any time in Zone 4 (which encompasses the MCA). Finally, in the
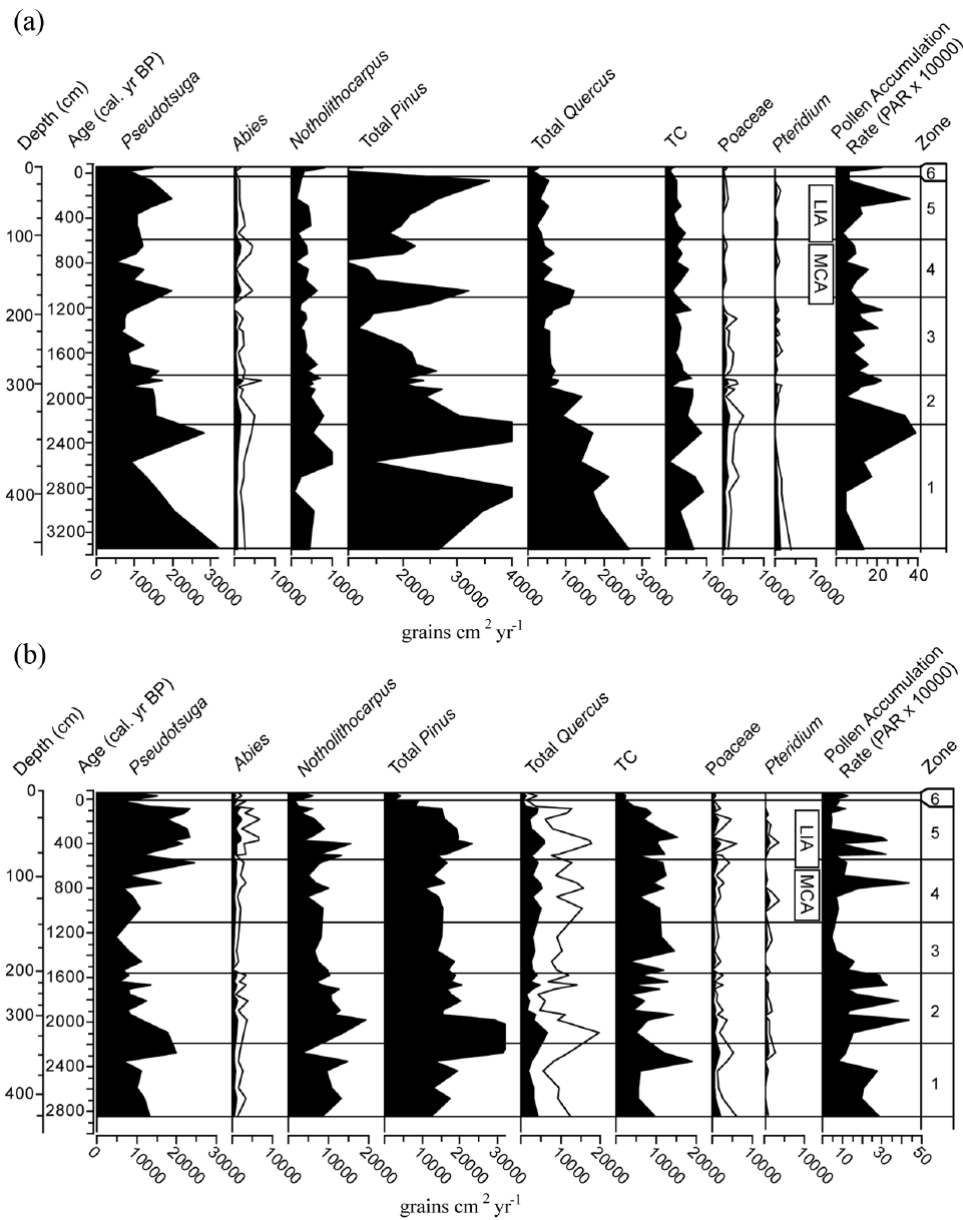
Figure 4. Pollen accumulation rates (PARs) for selected taxa at (a) Lake Ogaromtoc and (b) Fish Lake. Total PAR includes some taxa not displayed.

historic period, fires cease and shade-tolerant taxa such as *Pseudotsuga* and *Notholithocarpus* are favored as they reach their highest relative percent contribution in the Fish Lake record (Figure 3). This Zone 6 response is in contrast with expected climatic change but consistent with human impacts proposed at the Lake Ogaromtoc site, although potential alternative drivers of vegetation change will be considered below.

Prior to ~1500 cal. yr BP, both sites appear to respond to climate as their primary driver of fire and vegetation changes. After that period, at Fish Lake, we see patterns of pollen and charcoal that appear anomalous in comparison to regional climate trends. A number of factors may control vegetation and fire change. The synoptic scale patterns of El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) may cause local anomalies in comparison to regional climate reconstructions associated with short-term periodicities (Diaz and Markgraf, 2000; Mantua et al., 1997), but studies in the Southern Cascades region found

that ENSO was not a strong driver of fire at a regional scale (Taylor et al., 2008), and the influence of this system near the coast is weak (Trouet et al., 2010).

Shifts in the lightning regimes of the Klamath Mountains could also impact local fire dynamics. Currently, the western and lower elevation regions of the Klamath Mountains have low strike density (Rorig and Ferguson, 1999). Warmer temperatures can lead to increased convection and active transport of heat and moisture, resulting in more lightning strikes (Price and Rand, 1994). Thus, during warm periods, such as the MCA, lightning may have increased, but during cool periods, such as the LIA, lightning would likely have decreased.

Disturbances may also create forest change. In the Klamath Mountains, forest vegetation is largely dependent on the frequency and severity of landscape disturbances such as wind-throw and/or heavy snow events (Knapp and Hadley, 2011), insect outbreaks (Fettig et al., 2007), pathogen outbreaks (Zobel et al., 1985), and

fire (Halofsky et al., 2011). Certain regional vegetation types, such as oak woodlands, are dependent on frequent disturbance that removes competing vegetation that could eventually overtop
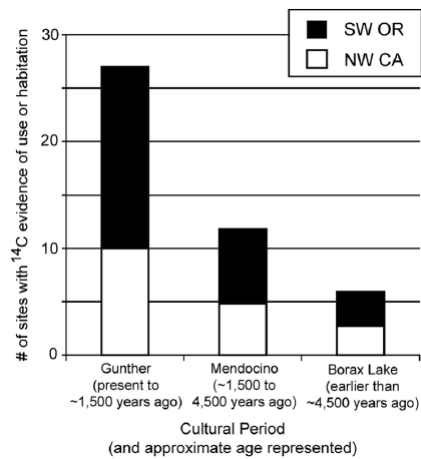

Figure 5. Radiocarbon evidence of habitation at archaeological sites in northwestern California (NW CA) and southwestern Oregon (SW OR). Dated sites are separated by cultural period and infer a pattern of regional population increases throughout the late Holocene.

shade-intolerant species (Hunter and Barbour, 2001). The most recent portion of the paleorecord at each study site offers a good example of these dynamics, as the removal of fire from around the study sites has caused a strong increase in shade-tolerant pollen percentages of *Pseudotsuga menziesii* at the expense of shade-intolerant taxa such as *Quercus* and *Pteridium*. Finally, humans can have a strong impact on forest change through use of fire and selective encouragement of certain species.

Anthropogenic impacts and forest structure in the historic period. The clearest evidence for anthropogenic impacts on vegetation and fire is illustrated in the historic period, a period for which we have a good understanding of both climate and human history. The LIA ended ~100 cal. yr BP. Since that time, climate has become warmer, and under these conditions, we would expect a greater number of fire events and more open-forest structure, but we see the opposite trends at both Fish Lake and Lake Ogaromtoc (Figure 6). Closed-forest indicators *Pseudotsuga* and *Notholithocarpus* occur at high levels at each site, and charcoal production and fire peak magnitudes drop to low levels. The last natural fire event in the fire-scar record at Fish Lake occurred in AD 1903 and at Lake Ogaromtoc in AD 1898 (Crawford, 2012). These vegetation and fire patterns do not match climatic expectations but are readily explained by recent anthropogenic impacts. Modern ethnographies document numerous uses of fire by California Native Americans to manipulate their environment. These include ensuring the availability of acorns (balanophagy) and

Table 3. Evidence of habitation by archaeological period.

Site ID	Radiocarbon date(s; cal. yr BP; with error)	Evidence of habitation			Source
		Gunther	Mendocino	Borax Lake	
CASIS326	400 ± 75; 510 ± 75	X			Mack (1989)
CADNO11	2260 ± 110	P	X		Gould (1972)
CAHUM129	215 ± 100; 1490 ± 100	X			Milburn et al. (1979)
CASIS331	690 ± 90	X			Mack (1989)
CASIS266	1235 ± 60	X			Mack (1989)
CASHA1176	1180 ± 80; 2160 ± 90; 2370 ± 70; 2530 ± 80	X	X		Basgall (1987)
CASHA1175	80 ± 50; 1810 ± 80; 3400 ± 180	X	X		Basgall (1987)
CASHA1169	940 ± 70; 2310 ± 90; 3330 ± 130; 5080 ± 180	X	X	X	Basgall (1987)
CASHA476	700 ± 60	X			Basgall (1987)
CASIS900	320 ± 60; 635 ± 30; 1080 ± 130; 1450 ± 130; 1530 ± 90; 2320 ± 185	X	X		Mack (1989)
CASHA475	1110 ± 390; 6530 ± 300	X	P	X	Clewett and Sundahl (1989)
CAHUM67	1050, ± unknown	X			Heizer and Elsasser (1964)
CAHUM573	7945 ± unknown		P	X	Hildebrandt and Hayes (1993)
35CU84	2810 ± 50; 8560 ± 190	P	X	X	Winthrop (1993)
JA21	1900 ± 90; 5310 ± 140		X	X	Winthrop (1993)
JA189	650 ± unknown; 1700 ± unknown	X	X		Winthrop (1993)
JA190	310 ± unknown; 750 ± unknown	X			Winthrop, 1993
JA100	50 ± 60; 1070 ± 110	X			Winthrop (1993)
JA6	550 ± 80	X			Winthrop (1993)
JA16	1120 ± 75; 1660 ± 80	X	X		Winthrop (1993)
JA19	1120 ± 75	X			Winthrop (1993)
JA23	260 ± 60	X			Winthrop (1993)
35KL18	564 ± 110	X			Mack (1983)
35KL16	580 ± 120; 970 ± 80	X			Mack (1983)
35KL20	100 ± 70	X			Mack (1991)
35KL19	210 ± 80; 230 ± 80; 580 ± 60	X			Mack (1991)
35KL26	330 ± 60; 380 ± 80; 400 ± 50	X			Mack (1991)
35CU62	3000 ± 90	P	X		Cressman (1977)
JO4	460 ± 90; 1150 ± 100; 1400 ± 80	X			Wilson (1979)

An 'X' indicates radiocarbon-dated material, while a 'P' indicates evidence of habitation during the period, but no radiocarbon date.
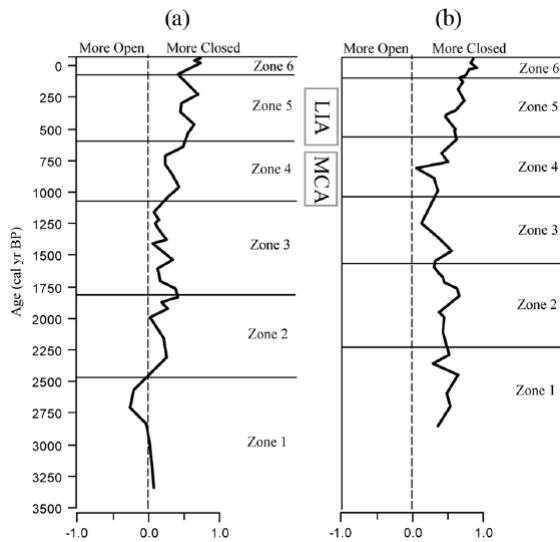
Figure 6. Comparison of normalized ratio between open-forest taxa (*Quercus, Pteridium*, and Poaceae) and closed-forest taxa (*Pseudotsuga* and *Abies*) at (a) Lake Ogaromtoc and (b) Fish Lake. The normalized ratio is calculated for each pollen level as: ((sum of closed-forest taxa percentages − sum of open-forest taxa percentages)/(sum of closed-forest taxa percentages + sum of open-forest taxa percentages)). Both sites demonstrate a trend toward more closed-forest structures over time, and the Medieval Climate Anomaly (MCA) and 'Little Ice Age' (LIA) are indicated with bars between (a) and (b).

basketry materials, clearing brush, encouraging browse for game, and reducing pests (Anderson, 2006; Kroeber, 1925 [1975]; Lake, 2013). With the arrival of European settlers, traditional Native American burning practices were disrupted and greatly reduced, and modern forest management enforced fire exclusion through suppression of both natural and human-caused fires (Busam, 2006). This has led to a greatly reduced occurrence of fire that is an important factor in shaping regional vegetation patterns (Halofsky et al., 2011), as shade-tolerant species less adapted to frequent fire events became more prevalent in the pollen record contrary to what is expected from a warmer and drier climate. This anthropogenically shaped modern forest system is evidence that human influences can be seen in pollen and fire records and is consistent with other studies that have detected anthropogenic influences elsewhere in North America (Allen et al., 2008; Anderson and Carpenter, 1991; Munoz and Gajewski, 2010). The real question becomes, can anthropogenic impacts be detected even farther back in the record, before Native American populations had been removed from the landscape and when modern fire suppression practices were not being applied?

Anthropogenic impacts and forest structure prior to the historic period

Of our two sites, Fish Lake offers the most compelling evidence for pre-European anthropogenic impacts. It is the site with the more complex cultural history, as it was along the border between traditional Yurok and Karuk Native American groups and was nearer to large Native American settlements (Kroeber, 1925 [1975], 1936). Fish Lake also has more complex vegetation and fire dynamics. With a stronger coastal influence than Lake Ogaromtoc, Fish Lake's cooler and wetter climate would lead to rapid forest closure without frequent fire.

The vegetation and fire record at Fish Lake prior to ~1560 cal. yr BP is largely climatically consistent. One of the more interesting

aspects of the early record is the large charcoal peak that occurs at ~1580 cal. yr BP. This event is approximately coincident with the onset of the Gunther period (Figure 7), when changes in new acorn processing, hunting, and fishing technology were brought into the region by Athabaskan- and Algic-speaking groups (Golla, 2007). Two explanations are most likely: (1) a natural fire event or (2) anthropogenic site clearing for subsistence and settlement by expanding regional tribal populations. This latter explanation is inferred from a synthesis of radiocarbon-dated archaeological sites in northwestern California and southwestern Oregon during the Gunther Period (post ~1500 cal. yr BP; Figure 5 and Table 3). There is insufficient evidence at this time to confirm either explanation.

Following the large fire event at Fish Lake, additional fire and vegetation anomalies occur from 1560 to 1110 cal. yr BP. Shade-intolerant constituents (*Quercus*, Poaceae, and *Pteridium*) all remain high, and shade-tolerant species (*Pseudotsuga* and *Abies*) percentages drop to low levels. This occurs during a period when continued cooling should lead to closing forest structure, but the opposite apparently occurred. Background charcoal also reaches its highest levels during this time, when cooler regional climate leads to lower pre-MCA charcoal levels at other regional sites (Briles et al., 2011; Daniels et al., 2005; Mohr et al., 2000). This anomalous increase in charcoal at Fish Lake occurs several hundred years before a MCA-related charcoal spike would be climatically expected from climatic evidence alone (Figure 7).

Anthropogenic drivers provide a possible explanation for these patterns. The Gunther cultural period population increases likely continued during this period. Larger local populations would require more resources for subsistence, and as demonstrated by ethnographic accounts, many subsistence resources (acorns, basketry materials, and cordage for fishing nets) were procured from fire-tended landscapes (Anderson, 2006; Lake, 2007, 2013). The increase in charcoal levels occurs in advance of expected change during the MCA and can be best explained by the clearing of local subsistence or habitation sites to accommodate an expanding local Native American population and meet their cultural needs.

The pollen and charcoal record during the MCA (~1050–600 cal. yr BP) is consistent with both an anthropogenic and climatic explanation and thus not particularly informative for distinguishing these influences. Native American subsistence practices encourage open-forest structure and shade-intolerant taxa through more frequent application of fire, similar to what would be expected in the warm and dry MCA. The similar nature of anthropogenic and climatic impacts makes interpreting any trends in this zone difficult at either site.

The LIA period at Fish Lake (540 cal. yr BP to AD 1936), presents an interesting vegetation and fire signal that shows increases in both shade-tolerant and shade-intolerant indicators. Cooler temperatures during the LIA should have promoted forest closure and decreases in fire occurrences as seen at sites across the western United States where charcoal levels decrease through this period (Marlon et al., 2012). The Fish Lake record shows increases in shade-tolerant *Pseudotsuga* and *Abies* percentages and declines in charcoal consistent with LIA climate change, but at the same time, shade-intolerant taxa such as *Quercus* remain high relative to the rest of the Fish Lake record (Figure 3). The opposite signal of closing forest structure combined with the maintenance of open-forest or shade-intolerant taxa during a cool, wet period suggests that there are more factors influencing regional forest composition and structure and fire dynamics than climate and natural fire alone.

Due to the important nature of *Quercus* as a food source for Native American tribes prior to European settlement (Anderson, 2006; Baumhoff, 1963), we argue that portions of the landscape were actively managed, using fire to retain these open-forest, shade-intolerant resources during a period of general forest closure. We envision Native Americans using fire to maintain oak
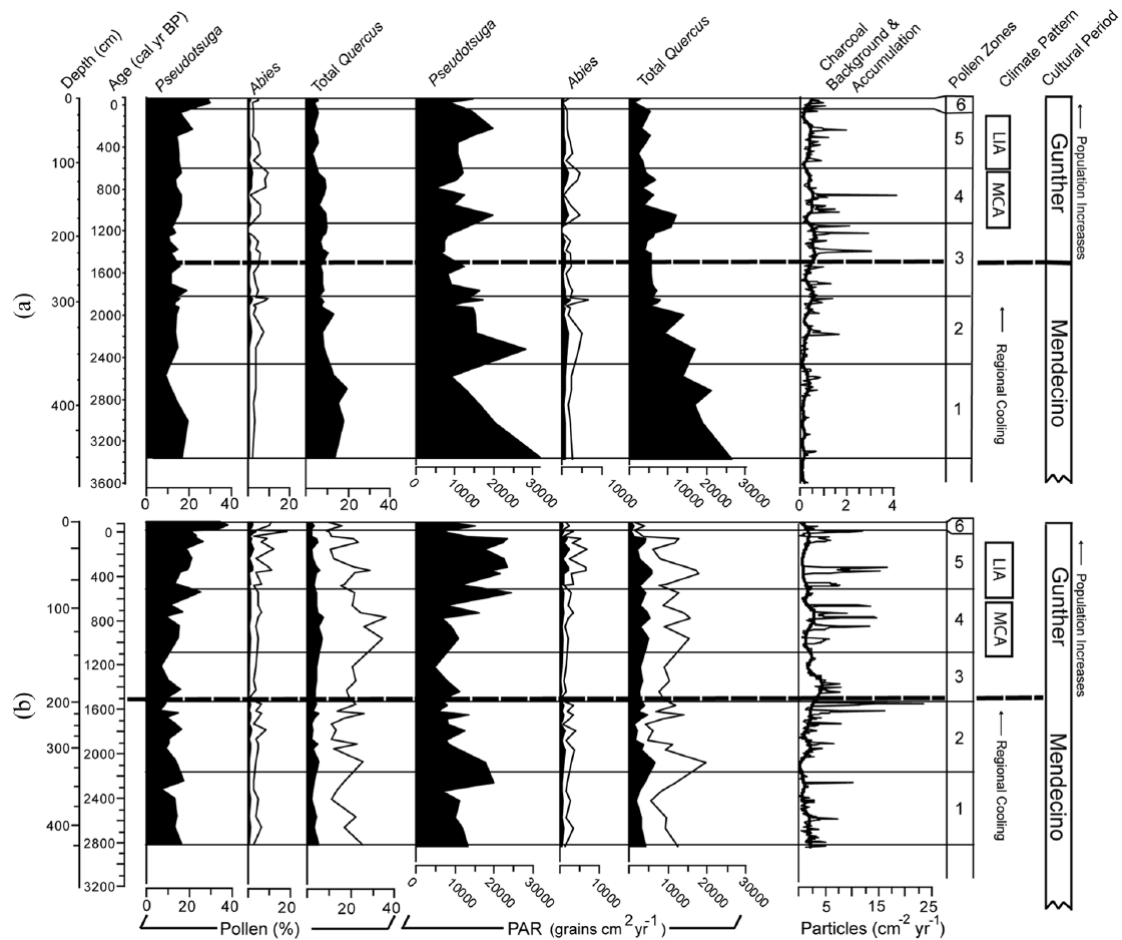
Figure 7. Pollen percentages and PAR of selected taxa, fire history reconstruction, pollen zones, general climate patterns, and cultural patterns for (a) Lake Ogaromtoc and (b) Fish Lake. This physical and cultural data summary allows comparisons of vegetation or fire or cultural changes over time for each site.

openings on rocky or south-facing slopes where it would be easier to inhibit forest succession even during a period of wetter cooler climate. Anthropogenic use of fire may have created a finer-scale landscape mosaic that produced a pollen signal with both increasing closed-canopy forest and continued high percentages of open-forest taxa. Such a mosaic is consistent with ethnographic descriptions of Native American land-use management for multiple resource types at the community and landscape scales (Anderson, 2006; Stewart, 2002).

Potential scale of Native American forest impacts. The evidence of increased fire activity prior to the MCA and the persistence of shade-intolerant vegetation during the LIA suggest that Native American impacts on forest and fire dynamics are present beyond the very local scale of villages, but in the Klamath region, there is no clear evidence for significant changes in forest structure at a regional scale. The resolution and accuracy of different methods to infer or detect tribal land-use practices may not be adequate (Lake, 2013). The role of site sensitivity may be important in identifying anomalous forest change patterns associated with human activity. Anthropogenic impacts are not as apparent at Lake Ogaromtoc (Figure 7), which is a warmer and drier site and was also less populated (Kroeber, 1936). Native Americans may not have needed to set fires more frequently than expected from the natural fire cycle in order to sustain resources, and thus, the ability to identify anomalous changes may be beyond detection of paleoecological or other methods (Lake, 2013; Whitlock et al., 2010).

There are two important points that become apparent when considering both anthropogenic and climatic considerations in our study. The first is that European anthropogenic impacts on modern forest composition are clearly discernible in both the pollen and fire dynamics at our study sites (Figure 7). The decrease in charcoal and the overall closure of forest structure at both sites strengthens the notion that anthropogenic impacts can be seen in paleoecological records. The second point is that paleoecological signals may be limited to areas where forest manipulation is necessary to keep forests open and subsistence resources available. This is demonstrated by contrasting our two sites. Lake Ogaromtoc, the drier site with a larger abundance of *Quercus*, does not present evidence of strong human manipulation when compared to the wetter, more coastal Fish Lake site. At Fish Lake, during periods of wet climate, greater effort would have been required to maintain an open woodland for collecting resources, producing a clearer human signature. This distinction underscores the challenge of distinguishing human impacts on forest change in California and suggests that while Native Americans may have used fire extensively, we are most likely to be able to find evidence at sites where more intense vegetation manipulation was necessary to acquire subsistence resources (Whitlock et al., 2010).

Conclusion

The results of this research indicate that while the fire and vegetation dynamics of the Klamath Mountain region of California are

often driven strongly by climate, there are anomalies in the paleo-ecological record that are inconsistent with climate as their primary cause. These anomalies are more pronounced at the Fish Lake site, where elevated pre-MCA charcoal levels and the increased presence of shade-intolerant taxa during the cool and wet LIA are not well explained by climatic conditions. Modern forest dynamics at both sites also indicate a more closed-forest structure and less fire than is expected under the recent warming climate.

In order to better explain the observed anomalies, a multidisciplinary methodology was employed that examined both the physical and cultural aspects of the study sites. Population increases and regional migration is indicated along the Klamath River in the last 1500 years, which corresponds to the anomalous pre-MCA charcoal increase. This charcoal increase is likely the result of use of previously lesser-used habitation and subsistence sites by new inhabitants to the region.

Population increases and subsistence strategies are also better explanations than climate for the increase in shade-intolerant taxa at Fish Lake during the LIA. This is particularly true for *Quercus*, which would be expected to decline under cooler and wetter conditions. Despite climatic pressures, *Quercus* was an important food source for expanding populations, and efforts would have been made to keep forests open and ensure a predictable supply of acorns.

The modern closed-forest structure and lack of fire are the clearest anthropogenic signals in the records at both sites. This is the result of post-European settlement bans on Native American burning practices and early 20th-century fire suppression policies that have removed an important determinant of ecosystem structure and composition in the Klamath Mountains. These 20th-century forest and fire regime changes have become the limited framework in which most management decisions are made, even though they only represent a small snapshot in time. These decisions are made with only an understanding of vegetation and fire dynamics over a matter of decades and take little consideration of human impacts much beyond European settlement. However, this type of multidisciplinary, long-term study that examines climate and human influences on vegetation and fire at a longer scale can more thoroughly define historic ecosystem dynamics. This can potentially provide a broader and more complete context for making wise management decisions in complex ecosystem such as the Klamath Mountains.

Native American impacts on forests appear to be present beyond the very local scale of villages, although there is no clear evidence from our study for significant changes in forest structure at a regional scale. Site selection is important when seeking to examine Native American landscape impacts. Increased collaboration between paleoecologists, archaeologists, and tribes would improve our ability to understand how the scale and proximity of prehistoric settlements would correlate with the spatial extent of Native American fire and vegetation impacts. While Native Americans may have used fire extensively, we are most likely to find evidence at marginal sites where resource acquisition and vegetation manipulation would have required greater effort.

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