Multi-disciplinary approach to identifying Native American impacts on Late Holocene forest dynamics in the southern Sierra Nevada range, California, USA

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1. Introduction

Fire is a natural disturbance component in many forests, especially in the western U.S. As climate changes, the frequency at which natural fires occur on the landscape also changes (Dale et al., 2001, 2000; Flannigan et al., 2000; Keeley et al., 2011; Swetnam, 1993), and succession theory predicts associated changes in forest composition. Cooler/wetter climates are associated with less frequent fires and more available soil moisture, with succession leading to closed forest canopies with more shade-tolerant/fire-sensitive taxa (*i.e.* increasing *Abies* spp. and *Calocedrus decurrens*) (Dale et al., 2001; Lenihan et al., 2003). Warmer/drier climates have less available soil moisture and greater fire occurrences, leading to the opening of forest canopies and more shade-intolerant/fire-adapted taxa (*i.e.* increasing *Pinus*, *Quercus*, Poaceae, and Rosaceae (Engber et al., 2011; Fites-Kaufman et al., 2007; Henne et al., 2012; Innes et al., 2006; Peterson and Hammer, 2001). The climate-driven model of forest succession (Figure 1a) assumes climate is the main driving force of forest structure and composition, and predicts that any variation in fire and vegetation as reconstructed from charcoal and pollen to be positively correlated to changes in independently derived climate reconstructions (*i.e.* drier climate = more charcoal and more shade-intolerant taxa). This model also predicts a positive correlation between vegetation and fire with regards to fire-sensitive/fire-adapted taxa (*i.e.* more fire-adapted taxa during periods of increased charcoal accumulation).

In the southern Sierra Nevada, *Abies concolor* (white fir) is a classic example of a very shade-tolerant/fire-sensitive species in mid-elevation, mixed-conifer forests. Saplings show high mortality when exposed to low-intensity fires (Kilgore, 1973). Further, fire suppression policies in the last 150 years have allowed documented expanded succession of *Abies* spp. (Franklin and Fralish, 2002; Kilgore, 1973). Conversely, *Quercus kelloggii* (California black oak) is fire-tolerant and drought-resistant. While *Quercus kelloggii* can tolerate some shade, it prefers open canopy and direct sunlight for best development (Franklin and Fralish, 2002). In cooler, wetter climates, or with less fire, *Abies* can

outcompete *Quercus* given its rapid growth habit; therefore, in a climate-driven regime (Figure 1a), we expect an inverse relationship between shade-tolerant/fire-sensitive *Abies* and shade-intolerant/fire-adapted *Quercus* spp. The role of fire in maintaining oak woodlands is widely recognized, where fire exclusion results in forest structure change to more fire-sensitive, shade-tolerant taxa (Bond and Keeley, 2005; Crawford et al., 2015; Engber et al., 2011; Higgins et al., 2000; Peterson and Hammer, 2001; Peterson and Reich, 2001), but climate is not the only source of fires. Native Americans have lived in California since the terminal Pleistocene, and their use of fire is extensively documented in the ethnographic record (Anderson and Moratto, 1996; Lewis, 1973; Voegelin, 1938). This situation elicits questions as to whether, when, and to what degree burning by Native Americans throughout the Anthropocene structured the region's biomes (Bowman et al., 2011). A human-influenced model (Figure 1b) may explain deviations from the expected climate-driven model (Figure 1a)

Fires were set by hunter-gatherers of prehistoric California to clear brush, drive game, facilitate hunting, promote seed germination, improve viewsheds, open travel corridors, and increase natural resource yields (Anderson and Moratto, 1996; Anderson, 1999; Coddington and Bird, 2013; Dincauze, 2000; Fowler, 2008; Gassaway, 2009; Lightfoot and Lopez, 2013; Lightfoot and Parrish, 2009; Lightfoot et al., 2013). Shade-intolerant/fire-adapted open canopy taxa provided important food supplies (e.g., acorns, a wide variety of small-seeded grasses and roots, and young, fresh browse for deer) for Native Americans in California, while shade-intolerant/fire-sensitive close canopy taxa typically did not (Jordan, 2003; Kroeber, 1925; Lewis, 1973; Lightfoot and Parrish, 2009). While it is clear from ethnographic records that such practices occurred regularly and were widespread (Gassaway, 2009; Jordan, 2003; Lewis, 1973; Stewart, 2014; Voegelin, 1938), the challenge is distinguishing human-induced changes in natural vegetation from climatically-induced changes in the absence of agricultural taxa such as *Zea mays* (Bowman et al., 2011).

We argue that anthropogenic burning was responsible for the persistence or pre-dominance of shade-intolerant/fire-adapted taxa, and that the pre-A.D. 1850 forest of California's Sierra Nevada range represented a human-influenced model of forest composition (Figure 1b). This influence will be most apparent during periods of cool and wet climate, such as the Little Ice Age (LIA; ~750-500 to 100 cal yr BP; Bowerman and Clark, 2011; Graumlich, 1993; Stine, 1994). Warm, dry periods such as the Medieval Climate Anomaly (MCA; 1000 to 750-500 cal yr BP; Bowerman and Clark, 2011; Graumlich, 1993; Stine, 1994) will obfuscate anthropogenic impacts of fire because any influence by Native Americans would be in-line with climatic changes (increased fire and open-canopy taxa).

Figure 1. Climate-driven model of forest succession (A) versus a human-influenced (B) model

Three lines of evidence are required to identify anthropogenic burning: (1) paleoenvironmental proxies demonstrating temporal change in fire and vegetation that (2) differ from expected climate-fire-vegetation relationships and (3) correlate temporally with changes in Native American activity (Bowman et al., 2011; Coddling and Bird, 2013). Archeological data that reconstruct changes in Native American activity in the southern Sierra Nevada range are still scarce, but research done throughout California shows relatively similar timing of cultural change with regard to Native American habitation, land-use intensification, tool use, and social structure (Beaton, 1991; Bowman et al., 2011; Gassaway, 2009; Hull, 2009, 2007; Jones and Schwitalla, 2008; Moratto, 1984; Morgan, 2009; Ramirez et al., 2010). We hypothesize that forest structure can be inferred from the relative prevalence of shade-tolerant/fire-

sensitive taxa to shade-intolerant/fire-adapted taxa. We also hypothesize that Native Americans had an identifiable impact on the forest structure of the southern Sierra Nevada, and that this impact is most evident during climatically cool, wet periods when Native American burning would have preserved shade-intolerant/fire-adapted taxa even while climate promoted succession of shade-tolerant species. The results of this research are significant because they examine the impacts Native Americans may have had on forest composition, and contribute to the debate regarding the scale and extent of Native American burning in California during the Anthropocene.

2. Study Area

Holey Meadow (HLY; 35° 57.319' N, 118° 36.925' W; elev. 1925 m) is a sedge meadow located within Sequoia National Monument at the southern end of the Sierra Nevada range (Figure 2). The Sierra Nevada range is a north-south trending mountain range that separates California's Central Valley to the west from the Great Basin to the east.). The Kern Plateau is an unglaciated high-elevation plateau in the southern Sierra Nevada range located in both Sequoia and Inyo National Forest-administered lands. From Yosemite National Park (YNP) to the southern tip of the range, exhibit similar hydroclimatic responses in relation to El Nino-Southern Oscillation variability (Wise, 2010). Elevation is highest in the south at Mt. Whitney (4420 m), decreasing northward. The climate is Mediterranean, with most precipitation from Pacific frontal storms in winter months. Topographic relief affects temperature and precipitation distribution throughout the range, with summer and fall lightning common in the southern Sierra Nevada and increasing with elevation (SNEP, 1996). Ecozones on the western slope are: oak woodlands/chaparral (up to ~1300 m elevation), montane/mixed conifer forests (1300–2200 m), and upper montane forests (>2200 m) (R.S. Anderson & Davis, 1988).

The main Native American tribes of the Kern Plateau and surrounding area are the Tübatulabal and Foothill Yokuts (Yokuts). The Tübatulabal are a branch of the Uto-Aztecan linguistic family and consider the Kern River Plateau their ancestral home (Voegelin, 1938). Linguists estimate the Tübatulabal's arrival in the Sierra Nevada, and subsequent linguistic divergence from other groups in their language family, ~4000–5000 years ago (Moratto, 1984). The Yokuts, constrained mainly to the lower-elevation oak woodland/chaparral ecozone, are more recently arrived to the Sierra Nevada foothills and thought to have migrated ~1000-2000 years ago (Gayton, 1948; Latta, 1977; Moratto, 1984).

The far southern Sierra Nevada is well-suited to this study given the presence of archaeological data, availability of paleoecologic sites, and independent paleoclimate records. Site selection for our paleoecologic reconstruction required three criteria: (1) deep sediments for palynological recovery, (2) proximity to a palynologically-sensitive ecotone, and (3) proximity to archaeological sites. HLY is located at the upper ecotone of *Quercus kelloggii*, a species highly prized by Native Americans for its acorns (Lightfoot and Parrish, 2009), and is near known archaeological sites, allowing us to better capture potential human influence on vegetation in the area.

While few archaeological excavations have been conducted in Sequoia National Forest-administered lands, there are considerable records of archaeological sites via surface artifacts, bedrock mortars, and bedrock basins. Unfortunately, while these data convey presence of Native Americans throughout the Sierran landscape, they do not provide a temporal context of land use/occupation.

Archaeological site CA-TUL-819 (Figure 2) is located 7 km (4.5 miles) east-northeast of HLY (Ramirez et al., 2010). CA-TUL-819 is interpreted as an autumn high-elevation Tübatulabal camp occupied intermittently from ~4500 BP through European contact (Ramirez et al., 2010). The site has evidence for acorn (*Quercus* spp.), *Hesperoyucca whipplei* (yucca), and *Distichlis spicata* (saltgrass) processing.

The ecoregion includes numerous edible plants such as *Chrysolepis sempervirens* (bush chinquapin), *Prunus virginiana* (western chokecherry), *Chenopodium fremontii* (Fremont's gooseberry), and *Q. kelloggii*. Surrounding modern tree species include *Pinus jeffreyi* (Jeffrey pine), *P. ponderosa* (ponderosa pine), *Abies concolor* (white fir), *Q. kelloggii*, *Calocedrus decurrens* (California incense-cedar), and *Sequoiadendron giganteum* (giant sequoia). Common shrub species include: *Chrysolepis sempervirens*; Rosaceae (rose family), including *Rosa woodsia* (Wood's rose), *Prunus virginiana* (chokecherry), and *Holodiscus discolor* (oceanspray); *Chenopodium fremontii* (Fremont's goosefoot), and *Ceanothus* spp. (California lilac), including Kern ceanothus (*C. pinetorum*), an endemic to the Kern plateau.

Figure 2. Study area showing paleoenvironmental reconstruction site (HLY) and nearby archaeological site CA-TUL-819. YNP: Yosemite National Park.

3. Methods

3.1 Sediment coring

The meadow was probed at several locations to determine the greatest depth of soft sediment with the least sand. Duplicate adjacent 4.95 m sediment cores (HLY-11-1 and HLY-11-2) were recovered in August 2011 using a 5-cm diameter modified Livingstone square rod piston corer. A separate 50 cm surface core (HLY-12-4) was extracted using a serrated blade due to the near impenetrable dense mat-like root structure of the peat. Cores were extruded in the field into pre-split plastic tubes and wrapped in plastic wrap before transport.

3.2 Sediment Analysis

For this paper we use 0-50cm of HLY-12-4 and 50-64cm from HLY-11-1 for sediment analysis, spanning the last 2000 years (additional depths were used to constrain the age model). Cores were photographed, described, and placed in cold storage at 4°C. Sediment type was described qualitatively by feel (sand, silt, clay). Eight samples (seed, charcoal, and plant material) were selected for AMS radiocarbon dating from 0-87 cm. Total organic matter (%TOM) was processed at continuous 1-cm samples using the loss-on-ignition method at 550°C (Dean, 1974). Magnetic susceptibility was measured using a ring magnetometer.

3.2.1 Pollen Analysis

Forty (40) samples were removed for pollen analysis (0.625 cm³). Samples were taken at a 55-year average interval (every 1-3cm; 21–74 years between sample) based on the age model (see Results). Pollen samples were prepared using standard chemical digestion methods (Faegri and Iverson, 1964).

Lycopodium spores, an exotic tracer, were added to samples during processing to calculate absolute pollen concentration and accumulation rate (Stockmarr, 1971). When necessary, samples were sieved through 180µm mesh to remove large fragments (generally peat, roots, or small gravel) following potassium hydroxide (KOH) digestion.

A minimum of 400 terrestrial pollen grains were counted at 400x magnification and identified to the lowest taxonomic level using reference guides (Kapp, 1969) and laboratory reference collections. We calculated pollen percentages based on the sum of terrestrial pollen, excluding wet meadow taxa such as Cyperaceae. Cluster analysis was created with CONISS, a stratigraphically-constrained incremental sum of squares cluster analysis, using the 'rioja' package in R (Grimm, 1987; Juggins, 2015).

Changes in percent pollen taxa through time are commonly interpreted as evidence for changes in the surrounding vegetation (Faegri and Iversen, 1964). Our understanding of the ecology of these taxa allows us to then infer ecologic change. When taxa respond inversely to climatic variability (e.g. moist vs. dry tolerant) palynologists have used this relationship to calculate the ratio (vegetation response index) of difference between the taxa to create a single variable that illustrates change more clearly than the plots of multiple individual taxa (Anderson et al., 2008b; Crawford et al., 2015; Mensing, 2001; Mensing et al., 2013, 2008, 2004). For example, this method has been used to create a moisture index to highlight potential hydrological changes (Anderson et al., 2008b). We use the relationship of *Abies* (shade-tolerant, fire-sensitive) to *Quercus* (shade-intolerant, fire-adapted) as a vegetation response index (VRI) based on the life history traits of these non-ambiguous pollen types.

In the western United States, we have observed that the exclusion of fire for the last 150 years has resulted in the encroachment of fire-sensitive taxa such as *Abies* into shade-intolerant *Quercus* woodlands (Engber et al., 2011; Peterson and Hammer, 2001). As stand density increases, understory composition further favors shade-tolerant taxa and alters fuelbed structure by decreasing fine fuels and

reducing the likelihood of low-intensity fires (Engber et al., 2011; Peterson and Hammer, 2001); therefore, during cooler, wetter periods when fire disturbance is less likely, we expect *Abies* to outcompete *Quercus*. Conversely, during warmer, drier climatic periods when fire disturbances are more likely, we expect an increased presence of *Quercus* to fire-sensitive *Abies*, resulting in a more open forest canopy structure (Bond and Keeley, 2005; Higgins et al., 2000; Peterson and Reich, 2001). We exclude *Pinus* spp. from the VRI because *Pinus* pollen tends to be overrepresented in the record due to prolific production and long-distance wind dispersal (Bradshaw and Webb, 1985). Thus VRI is calculated as $(Abies - Quercus) / (Abies + Quercus)$. A positive VRI indicates a greater proportion of *Abies* to *Quercus* pollen, which we infer as a more closed forest canopy. A negative VRI indicates a greater proportion of *Quercus* to *Abies* pollen, which we infer as a more open forest canopy. We use the VRI in comparison to both generally accepted climatic periods (MCA, LIA) and local independently-derived climate reconstructions for interpretation of forest structure change in relation to climate change.

3.2.2 Charcoal Analysis

Charcoal samples (1.25 cm³) were processed at continuous 1 cm intervals using sodium hexametaphosphate (5%) and stacked sieves of 500, 250, and 125µm mesh (Long et al., 1998). Charcoal larger than 125µm is thought to come from local fires rather than extra-local sources (Whitlock and Larsen, 2001). Because of the large quantity of charcoal recovered at these size fractions, only macroscopic charcoal fragments ≥250 µm were counted. Each charcoal sample was counted at 40x magnification by at least two trained technicians, and/or the authors, to within 10% or five piece tolerance. We did this to ensure inter-operator reliability and consistency. Charcoal was visually identified and tracked categorically as wood, grass, or other. Charred, but not fully combusted material, was tracked separately.

Charcoal accumulation rates (CHAR) and in/significant peaks were calculated using CharAnalysis 1.1 (Higuera et al., 2009) with 50-year interpolation and natural log transform. We used a Gaussian mixture model to determine charcoal peaks. Fire frequency and fire return intervals were smoothed over 1000 years. $C_{\text{background}}$ was transformed using a natural log and smoothed over 250 years.

3.3 Independent Climate Analysis

The only independent, annually-resolved climate reconstructions in the Sierra Nevada range spanning the last 2000 years come from tree-ring datasets analyzed and compiled into the North American Drought Atlas (NADA; Cook et al., 2009, 2008, 2004). The NADA is a gridded network (2.5° cells) using tree-ring reconstructions to calculate annual paleodrought conditions via the Palmer Drought Severity Index (PDSI). We use annually reconstructed PDSI values from grid cell 047 of the NADA as an independent measure of climate change at HLY.

We interpolated PDSI, VRI, and charcoal reconstructions every 50 years using a smooth spline to calculate correlations and explore relationships between all three proxies. Each splined reconstruction was standardized using $(x - \bar{x})/sd$, where x represents the value, $\bar{x}$ the mean of the reconstruction, and sd the standard deviation of the reconstruction, to allow for comparability between records.

Pearson's correlations were calculated at the 95% confidence interval. We further calculated a 50-year weighted moving average of PDSI (50yr WMA) to compare relative trends between non-standardized sedimentary proxy reconstructions, climate, and Native American activity.

4. Results

4.1 Chronology

Sediment spans the full Holocene, with a basal date of 13,100 cal yr BP. In total, 20 AMS radiocarbon (^{14}C) dates were obtained on plant macrofossils and charcoal from HLY-11-1 and HLY-12-4. Eight ^{14}C dates from the top 87cm span the last 2300 years (Table 1). Seven dates were used and calibrated using IntCal13 (Reimer et al., 2013) within the Bayesian age-model program Bacon v2.2 (Blaauw and Christen, 2011) to create the age model (Figure 3). Sample 168589 was determined to be an intrusive root and discarded from the age model.

Table 1. Holey Meadow radiocarbon dates. Shaded row discarded from the final age model. Weighted mean (wmean) calculated by Bacon (Blaauw and Christen, 2011).

Core	Depth (cm)	CAMS Lab #	^{14}C Age	cal yr B.P.			Material
				2 Σ min	wmean	2 Σ max	
HLY-12-4	11	168588	0 $\pm$ 35	50	230	280	Seed
HLY-11-1	13	157905	255 $\pm$ 40	110	290	400	Charcoal
HLY-12-4*	23	168589	95 $\pm$ 35	130	270	840	Intrusive root
HLY-11-1	26	156535	1070 $\pm$ 120	560	840	1150	Wood
HLY-12-4	46	164056	1710 $\pm$ 50	1400	1600	1710	Wood
HLY-11-1	49	168590	1705 $\pm$ 45	1540	1660	1770	Charcoal
HLY-11-1	68	168591	2120 $\pm$ 45	1950	2080	2250	Charred needles
HLY-11-1	87	164055	2315 $\pm$ 45	2250	2410	2710	Charcoal

* Not included in the age model because review of microscopy imagery taken before radiometric dating indicates the sample was root fiber and not leaf material

Figure 3. Bayesian age vs depth model for Holey Meadow. Grey cloud represents 95% confidence interval, blue bars represent calibrated radiocarbon ages at two sigma error calculated by Bacon 2.2 (Blaauw and Christen, 2011).

4.2 Sediment Analysis

Sediment is humified to well-humified peat throughout the core. No changes in magnetic susceptibility are observed. Changes in %TOM are discussed in relation to derived pollen zonation below.

4.3 Pollen and Charcoal Analysis

Thirty-one terrestrial pollen types, plus unknown and indeterminate grains, were identified. Pollen taxa with at least 1% sum are presented in Figure 4. We used CONISS (a stratigraphically-constrained cluster analysis) to identify five main zones of change. We recognize that in a full Holocene record we would not

identify five pollen zones within the last 2000 years; however, because we are interested in identifying periods of centennial change, and not millennial, we use a finer level of zonation identified by breaks in CONISS. These breaks independently conform to known climatic periods such as the MCA and LIA. Cyperaceae is not included in the statistical analyses or pollen accumulation rate, but is shown to demonstrate the site as a wet meadow throughout the time period. Statistical correlations between interpolated and standardized VRI, CHAR, and PDSI are based on pollen zones (Table 2 and Figure 5).

Figure 4. Pollen percentage diagram of selected taxa, pollen accumulation rate (Acc. Rate), total organic matter (%TOM), and charcoal accumulation rate (CHAR). Dots represent fire peaks (red significant, grey insignificant) calculated by CharAnalysis.

Table 2. Comparison of r^2 values between standardized sedimentary proxies and independent climate reconstructions interpolated at 50-year intervals using a smooth spline. Red indicates negative correlation values

Pollen zones	Zone 1	Zone 2a	Zone 2b	Zone 3	Zone 4	Zone 5	Zones 2-4
Cal yr BP	2000-1550	1550-1000	1000-750	750-500	500-100	100-A.D. 2003	1550-100
VRI v Charcoal	-0.47	^x -0.08	[*] 0.94	^{**} -0.98	^x -0.11	^x 0.57	-0.30
VRI v PDSI	[*] 0.69	^x -0.21	^{**} 0.94	[*] -0.89	^x -0.16	^x 0.57	^{**} -0.47
PDSI v Charcoal	^{**} -0.85	^{**} 0.93	[*] 0.83	^{**} 0.95	^{**} 0.99	^x -0.34	^{**} 0.84

^{*} p -value < 0.05
^{**} p -value < 0.01
^x p -value > 0.4

Figure 5. Vegetation Response Index (green), charcoal accumulation (orange), and PDSI (grey) standardized values interpolated at 50-year intervals using a smooth spline. Pollen zones are denoted by grey vertical lines.

Zone 1 (2000–1550 cal yr BP; 64–46 cm)

Zone 1 (Figure 4) has maxima for Poaceae, *C. sempervirens*, *Salix* spp., Apiaceae, Asteraceae, and Cyperaceae. This zone also has the highest pollen accumulation rate in this record. *Pinus* remains high (~50%) for the rest of the record until the historic period (100 cal yr BP; 1850 A.D.). The VRI is dominantly negative (interpreted as a more open canopy) during this period, indicating a higher proportion of shade-intolerant, fire-adapted *Quercus* (Figure 5). There is a weak negative statistical relationship between VRI and charcoal during this period ($r^2 = -0.47$; p -value = 0.20; Table 2), possibly

relating to environmental lag from two large fire events immediately preceding this study (data not shown; peaks at ~2200 and 2050 cal yr BP, but consistently high charcoal counts through this time). The highest levels of charcoal are also found in this period, with one significant fire peak ~1690 cal yr BP (Figure 4).

PDSI reconstructions indicate a variable climate oscillating between slightly wet (0.5) and slightly dry (-0.5) conditions based on the 50yr WMA (Figure 6). Climate has a strong negative correlation with charcoal ($r^2 = -0.85$; p-value = 0.004) and a moderate correlation with VRI ($r^2 = 0.69$; p-value=0.04; Table 2; Figure 5).

Zone 2 (1550 – 750 cal yr BP; 46-28 cm)

Zone 2 has high levels of Poaceae, and Apiaceae. Indeterminate pollen types (~5%) remain high from this point forward. Zone 2a (1550–1000 cal yr BP; 46-35 cm) has a greater %TOM than Zone 1, and the lowest prolonged pollen accumulation rates in the record (1400–1100 cal yr BP). *C. sempervirens* and *Salix* spp. reach maxima and maintain their highest levels throughout this subzone. Poaceae and Cyperaceae decrease from Zone 1 levels but remain relatively constant through the period. One insignificant fire peak occurs at ~1350 cal yr BP, and one significant fire peak at ~1050 cal yr BP. VRI and charcoal have no statistical relationship ($r^2 = -0.10$; p-value = 0.72) within this zone.

Zone 2a has both the wettest (0.7; wet) and driest (-1.8; drought) 50yr WMA PDSI in the entire record. There is no correlation between VRI and climate ($r^2 = -0.21$; p-value = 0.52) or VRI and fire ($r^2 = -0.08$; p-value = 0.81) during this period; however, there is a very strong positive relationship between fire and climate reconstructions ($r^2 = 0.93$; p-value < 0.001).

Zone 2b (1000–750 cal yr BP; 35–28 cm), which corresponds with the MCA, has the lowest %TOM in the last 2000 years. Pollen accumulation rate remains low. *Pinus* spp. decreases with a reciprocal increase in Cupressaceae. There is a general shift to positive VRI, indicating a more shade-tolerant, closed forest canopy (increased *Abies*). Charcoal levels also have a decreasing trend. There is a very strong positive relationship between VRI and charcoal in this subzone ($r^2 = 0.94$; p-value = 0.02). The %TOM is lowest in this zone with minima of 15%, while %TIC reaches a maxima of 4.4%.

There are also a strong positive correlations between VRI and climate ($r^2 = 0.94$, the strongest in the record; p-value = 0.02), and climate with fire ($r^2 = 0.83$; p-value = 0.08). This period is generally dry, experiencing pronounced drought except for a pluvial recorded by the 50yr WMA between 877–866 cal yr BP.

Zone 3 (750–500 cal yr BP; 28–21 cm)

Zone 3, transitioning between MCA and LIA, is marked as a whole by consistently low pollen accumulation and relatively stable pollen percentages and %TOM. *Pinus* recovers from lower levels during Zone 2b. Apiaceae is at maxima. *Quercus* percentages are variable while *Abies* remains relatively constant. *Fraxinus* reappears and remains present through the rest of the record. VRI is mostly positive during this time indicating a more closed, shade-tolerant forest cover, but demonstrates an consistent linear trend towards a more open canopy (-VRI). One significant charcoal peak is recorded ~750 cal yr BP, and one insignificant peak at ~600 cal yr BP. Unlike Zone 2b, Zone 3 has a very strong negative relationship between VRI and charcoal ($r^2 = -0.97$; p-value = 0.004).

This period has an overall trend towards slightly drier than “normal” climatic conditions, but generally wetter than Zone 2b. There is a very strong negative correlation between climate and VRI ($r^2 = -0.89$; p-value = 0.004), the strongest negative relationship between vegetation and climate in the record.

Conversely, there is a very strong positive relationship between climate and fire ($r^2 = 0.95$; p-value = 0.01).

Zone 4 (500–100 cal yr BP; 21–7 cm)

Zone 4, corresponding to the LIA, is marked by an increase in Rosaceae from its minima transitioning between Zones 3 and 4. *Quercus* and Poaceae demonstrate a generally increasing trend. *Fraxinus* reaches maxima, as does Cupressaceae. *Pinus* generally declines during this period, as do *Abies* and Asteraceae. VRI is almost entirely negative through this zone, indicating a prevalence of shade-intolerant *Quercus*. Charcoal levels decrease considerably, with only one insignificant fire peaks recorded at ~250 cal yr BP. There is no correlation between fire and VRI in this zone ($r^2 = -0.11$; p-value = 0.79).

The 50yr WMA for PDSI is effectively centered on “normal” conditions. Relatively wetter PDSI possibly has a very strong positive relationship with decreasing charcoal ($r^2 = 0.99$; p-value < 0.001). There is no relationship between climate and VRI ($r^2 = -0.17$; p-value = 0.69).

Zone 5 (100 cal yr BP–A.D. 2003; 7–0 cm)

Zone 5, the modern period, is marked by the greatest change in the last 2000 years. *Pinus* percentages drop markedly to almost half their percentage from maxima 2000 years ago. Both *Abies* and *Quercus* increase in unison, reaching their maxima by almost 10% more than previously in the record. VRI shows an abrupt increase in shade-tolerant taxa ~A.D. 1880, then another abrupt shift to shade-intolerant taxa around A.D. 1980. Charcoal levels are at their lowest in the entire record. There is no statistically significant relationship between fire and VRI ($r^2 = 0.57$; p-value = 0.61).

This period exhibits mild fluctuations in PDSI centered on “normal” conditions. There is no correlation between VRI and climate ($r^2 = 0.57$; p-value = 0.61) or climate and fire ($r^2 = -0.34$; p-value = 0.77).

5. Discussion

Human-influenced model supported for historic period

During the historic period (beginning ~ A.D. 1850) human impacts on the forest intensified through European immigration (A.D. 1854), establishment of the Tule River Indian Reservation (A.D. 1873), establishment of the Sierra Forest Reserve (A.D. 1893) and Sequoia National Forest (A.D. 1908), fire suppression policies (A.D. 1900), disease epidemics (A.D. 1900 and 1910), introduction of livestock grazing, and lumbering in the study area. We indeed observe no relationship between vegetation, fire, and climate in our sedimentary records, demonstrating that known anthropogenic influences are reflected in our proxy data and support a human-influenced model beginning at least 100 cal yr BP. We see a dramatic decline in *Pinus* (from 40–60% of the pollen signal to less than 30%) and synchronous increases in *Abies* (due to fire suppression) and *Quercus* (due to timber harvests creating open spaces in canopy). These results agree with a similar study in the Klamath Mountains of northern California (Crawford et al., 2015). Given this observation, we explore potential Native American sources of forest composition influence over the last 2000 years.

Radiocarbon dating from the closest archaeological site, CA-TUL-819, (Ramirez et al., 2010) suggests continuous site use over the last 2000 years. The number of artifacts recovered suggests possibly reduced site use between 1900–1650 cal yr BP, intensified site use around 1150 cal yr BP, and continued site use until the modern period.

Charcoal abundance during the last 2000 years is highly correlated with tree-ring PDSI reconstructions ($r^2 = 0.99$, $p\text{-value} < 0.001$; Table 2; Figure 6), suggesting climate (*i.e.* drought) appears to be the primary driving force of the regional fire regime at HLY. This result is supported by research that demonstrates regional fire regimes are climatically driven (Beaty and Taylor, 2009; Brunelle and Anderson, 2003; Hessl, 2011; Sherriff and Veblen, 2008; Swetnam, 1993; Swetnam et al., 1998), and that charcoal is likely produced under high and mixed-severity fire types. Low severity fires are often not captured in the charcoal record (Mohr et al., 2000; Whitlock and Anderson, 2003). Fire frequency in giant sequoia groves between ~1450–1150 cal yr BP (A.D. 500–800) is low, with a regional increase in fire frequency after 1150 cal yr BP (A.D. 800), and highest fire frequency between ~950–650 cal yr BP (A.D. 1000–1300) (Swetnam, 1993; Swetnam et al., 2009). Our charcoal accumulation rates are in agreement with Swetnam’s regional long-term fire history patterns over the last 1500 years. Few independent data points exist for fire and/or climate from 0–500 cal yr BP.

Vegetation change at HLY

2000–1550 cal yr BP and 1150–750 cal yr BP – Climate-driven model predominant

Charcoal accumulation between 2000 and 1550 cal yr BP exceeds what we expect based on climate reconstructions. Though VRI indicates more shade-intolerant taxa, changes in VRI are not quite synchronous with charcoal accumulation. This could be due to forest recovery from intense local and regional fires preceding this period (data not shown). Climate reconstructions by Moratto *et al.* (1978) indicate warm, dry conditions in the southern Sierra Nevada foothills from 2900–1700 cal yr BP, at odds with Cook’s PDSI calculations, but consistent with observations in charcoal and VRI. Current PDSI calculations for this period are based on very few tree-ring chronologies at higher elevations, making the point-by-point regression model of PDSI climate reconstructions weakest through this period. While the

possibility exists that the charcoal and VRI signal observed from 2000-1550 cal yr BP have an anthropogenic component, independent climate reconstructions to date are not robust enough for us to make a reasonable inference.

As expected, vegetation, fire, and climate are strongly, positively correlated during the Medieval Climate Anomaly (MCA; 1000–750 cal yr BP) – a period of increased fire and drought, also identified in the archaeological record as potentially resulting in a decline in the Native American population throughout California (Figure 6) (Hull, 2007; Jones and Schwitalla, 2008; Moratto, 1984). Trade routes appear to deteriorate among coastal and inland peoples between 950 and 650 cal yr BP (A.D. 1000–1300) (Jones et al., 1999). If population was not decreasing, there was likely a greater dispersal of people across the landscape such that large habitation centers were no longer the focus of occupation; population may have remained stable, but evidence for dispersal is difficult to identify. This period is when we hypothesize that if there were any anthropogenic alterations on the landscape, they would have produced the same ecological effects as a warmer climate and be indistinguishable from the climate-driven model.

1550–1150 cal yr BP – Ambiguous model dominance

Weak evidence for a human-influenced landscape exists from 1550–1150 cal yr BP. Native populations in California are thought to have dispersed, with only sporadic occupation of larger sites as drought conditions intensified over the period. The timing of Native American use of Sierran resources from 1550–1150 cal yr BP is variable, as the number of artifacts found in Yosemite declines through this time period while sites along marshy areas in the foothills and Central Valley indicate increased occupation (Dillon et al., 1991; Moratto et al., 1978). Because permanent habitation sites are more likely to be excavated and present in the archaeological record than smaller, more ephemeral sites, the timing and

spatial extent of Native American land use is presently ambiguous. Our VRI and charcoal reconstructions exhibits the same kind of variableness, but the causal relationship is ambiguous due to a lack of local archaeological data.

750–100 cal yr BP - Human influenced model predominant

Strong evidence for a Native American-influenced landscape occurs from 750–100 cal yr BP. Between 750–500 cal yr BP, there is a statistically significant negative relationship between vegetation and fire/climate (Table 2), possibly indicating that high-frequency/low-intensity fires, which are not captured in the charcoal record, are altering forest composition significantly from climatic expectations. During this period, Native Californians were intensifying resource procurement (Basgall, 1987; Beaton, 1991; Bettinger, 2015; Hull, 2009; Wohlgemuth, 1996). In California, this time also corresponds to increasing Native American population density (Hull, 2007; Moratto, 1984) during the onset of the Little Ice Age (LIA; 700–100 cal yr BP), and reoccupation of earlier village sites (Arnold et al., 2004). CA-TUL-819 was also occupied during this period (Ramirez et al., 2010). In Yosemite Valley, Anderson and Stillick (2013) find evidence for frequent surface fires between 650–400 cal yr BP, supporting previous work associated with Native American population expansion and fire (Anderson and Carpenter, 1991). Nearby, the Western Mono migrated to the Sierra Nevada just north of the Kern Plateau (in the San Joaquin, Kings, and Kaweah river watersheds) during the end of the Numic expansion, between 650 and 350 cal yr BP. This immigration could have conceivably increased population pressure due to the displacement of existing Sierra Nevadan peoples such as the proto-Yokuts and Miwok groups (Kroeber, 1925; Morgan, 2010; Powers, 1976). Changes in procurement strategies are evident, as bow technology became the dominant hunting weapon from ~750–550 BP (A.D. 1200–1400), with arrowheads dominating lithic assemblages throughout California from that point forward (Jones, 1995).

Figure 6. Environmental proxies compared against regional-to-local Native American habitation periods.

From 500–100 cal yr BP, as native populations and trade at village sites increased (Hull, 2009, 2005; Moratto, 1984), our proxy records show no statistical relationship between vegetation and either fire or climate (Table 2; Figure 6), supporting the human-influenced model. Our findings are supported by work in Yosemite Valley, where little decline in fire was observed during the LIA, as would be expected climatically (Anderson and Stillick, 2013). During the LIA climatic period, when we expect more shade-tolerant, fire-sensitive taxa, we instead observe an increase in the pollen of shade-intolerant/fire-adapted taxa. A similar phenomenon is observed in Yosemite Valley, where there is an abrupt shift to a higher ratio of *Quercus* to *Abies* pollen from 650–150 cal yr BP (Anderson and Carpenter, 1991). One possible explanation for both observations is that maintenance of a high-frequency/low-severity anthropogenic fire regime partially decoupled vegetation response to climate and produced an anthropogenic landscape as expected by our human-influenced model (Figure 1b). We can clearly observe disconnects between vegetation, fire, and climate response beginning ~100 cal yr BP with European settlement of the area (A.D. 1854), removal of Native Americans from the landscape, establishment of the Tule River Indian Reservation, fire suppression policy, and influenza epidemics. We suggest that frequent low-intensity human-set fires created a forest with higher than expected shade-intolerant fire adapted plants during the cool and wet LIA. Fire scar studies demonstrate that frequent, low-intensity fires were indeed common in the southern Sierra Nevada range, especially in the last 500 years (Gassaway, 2009; Swetnam, 1993; Swetnam et al., 2009; Taylor, n.d.). At two sites ~40 miles NNW of HLY, Swetnam et al. (2009) found mean fire return intervals (FRI) from 1750–250 cal yr BP (A.D. 200–1700) of 2.2 years (1–13 years) and 3.0 years (1–19 years) based on fire scars. The last two fire scar dates found were A.D. 1863 and 1915, coinciding with European migration and establishment of fire-suppression policies (Swetnam et al., 2009). A preliminary fire scar study in 2005 by Taylor (*unpub*)

~14 km NE from HLY at Freeman Creek Grove, Long Meadow, and near Route 190, has a chronology dating from 433 to -55 cal yr BP (A.D. 1517 to 2005). The composite record shows frequent scarring between A.D. 1660 and ~1865, with the last fire scar in A.D. 1910. The median fire return interval between the 3 locations is 3–6 years, with modal intervals between fires of 1.0, 1.8, and 0.68, respectively (Taylor, n.d.). The fire scars often occurred on an annual or biannual basis near HLY (Taylor, n.d.), as would be expected based on ethnographic records. These frequent fires likely explain the deviation in vegetation from climatic expectations; further strengthening the argument that Native Americans use of fire did indeed alter the forest structure surrounding HLY.

One explanation for the general disconnect between vegetation response and fire is that our charcoal reconstruction, while based on large charcoal fragments thought to be indicative of local fires, is still based on charcoal likely produced under high and mixed-severity fires. Low severity fires are often not captured in the charcoal record (Mohr et al., 2000; Whitlock and Anderson, 2003), but are, instead, captured through fire scars on witness trees.

Comparison with previous studies

A study using fine temporal resolution to explore Native American use of fire at two sites in the western Klamath Mountains of California shows a similar, albeit weaker, pattern (Crawford et al., 2015). That study found that vegetation, fire, and climate generally changed in a manner consistent with climate, except for two anomalous periods: 1560–1110 cal yr BP, and during the LIA. They observed an increase of shade-intolerant taxa, such as *Quercus*, even though these were periods of regional cooling in northern California. We observe the same phenomenon at HLY, of a more open than expected forest canopy during both these periods (corresponding to our Zone 2b and 4). This pattern has not specifically been noted in other pollen and charcoal studies in the central and southern Sierra Nevada (Anderson

and Carpenter, 1991; Anderson and Smith, 1994; Anderson and Stillick, 2013; Anderson, 1994; Anderson et al., 2008a, 2008b; Davis, 1992; Dull, 1999; Koehler and Anderson, 1994), however, we would note that the temporal resolution of earlier studies is typically not sufficiently high to confidently identify century-scale changes, and that the location of these studies may not have facilitated observation of this signal. Although Native Americans used fire for many purposes, natural fire is also common throughout mountain regions of California, and distinguishing a human impact is challenging. Previous work has found that it is critical to study sites located at ecotonal boundaries in a region of potential environmental stress to be able to observe the impacts of Native American use of fire on natural ecosystems (Crawford et al., 2015).

Beyond fire, possible confounding factors affecting forest composition include disturbances such as wind throw, pathogens, and insect outbreaks, all of which are part of forest ecosystem processes. The methods we use in reconstructing paleovegetation are incapable of detecting or reconstructing the precise nature of competitive dynamics and their mechanisms. Studies on southern Sierra Nevada forests have demonstrated that these types of disturbances affect already drought-stressed individuals (Ferrell, 1996) and have no significant difference in effect between shade-intolerant and shade-tolerant taxa (Fettig et al., 2007; Hilimire et al., 2013; Smith et al., 2005). These findings are similar to work done in the Klamath Mountains (Halofsky et al., 2011; Knapp and Hadley, 2011; Zobel et al., 1985).

Accordingly, we assume these disturbances to be effectively synchronous with external climate forces and thus indistinguishable in our sedimentary proxy records.

6. Conclusions

Fires are a frequent, natural disturbance in the western United States, and disentangling natural ignition sources from anthropogenic ones is a challenge. Using the knowledge that the frequency at which fires

naturally occur on the landscape changes with climate, we hypothesized that Native Americans had an identifiable impact on the forest structure of the southern Sierra Nevada, and that this impact is most readily identified through the preservation of shade-intolerant/fire-adapted taxa during climatically cool, wet periods through the use by Native Americans of frequent low-intensity fires

While HLY's sedimentary charcoal record has a strong correlation with regional fire reconstructions and climate, the pollen record demonstrates two pre-A.D. 1850 anomalies to forest structure change unexplained by either regional fires or independent climate reconstructions (1550–1150 cal yr BP, and 750–100 cal yr BP). We find strong support for a Native American-influenced landscape from 750–100 cal yr BP. We clearly see evidence of post-Contact settlement (100 cal yr BP–present), with forest dynamics showing the elimination of fire on the landscape and an increase in both *Quercus* and *Abies* taxa -- phenomenon unseen in the paleoenvironmental record, and one demonstrative of modern forest policies and management.

We temporally cross-referenced anomalous periods of VRI at HLY with available fire scar data, and found that frequent, low severity fires do not appear to be captured in the sedimentary charcoal record. Low frequency fires are abundant in at least the last 500 years. The archaeological record also supports more intensive land use and increasing/coalescing Native American populations during the LIA climatic period.

We find support for the human-influenced model (Figure 1b) of forest succession via changes in vegetation reconstruction unexplained by fire or climate and the timing of Native American population increase and intensification of resources near HLY and throughout California. This impact is most noticeable in the proxy record during the LIA.

Our finding supports previous paleoenvironmental work (Anderson and Carpenter, 1991; Anderson and Stillick, 2013; Crawford et al., 2015) and begin to suggest that the pattern of Native American influence

on forest structure is more widespread than just a single site. Additional paleoenvironmental sites throughout the Sierra Nevada range are necessary to test how widespread Native American impacts were on Sierran forests. Site selection is critical in assessing potential Native American impacts, and reconstructions must be performed at a fine, stratified temporal scale. Increased collaboration among archaeologists, paleoecologists, and tribal members, and the addition of co-situated archaeological excavations at sensitive, marginal sites would greatly improve our understanding of the scale, proximity, and spatial extent of past Native American landscape influences.

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