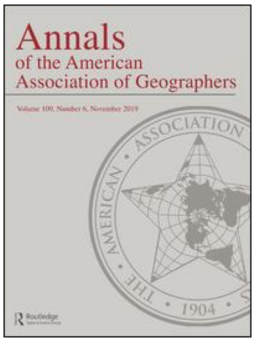

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Identifying a Pre-Columbian Anthropocene in California

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The beginning of the Anthropocene, a proposed geological epoch denoting human-caused changes to Earth's systems, and what metrics signify its onset is currently under debate. Proposed initiation points range from the beginning of the Atomic Age to the Industrial Revolution to the adoption of agriculture in the early Holocene. Most of the debate centers on the effects of modern industrially oriented technological and economic development. The effects of preindustrial and preagricultural populations on Earth's systems are less commonly evaluated. Because the utility of the Anthropocene concept is to denote measurable impacts of human activity on Earth's systems, we argue that focusing on an exact date or single event ignores time-transgressive, spatially variable processes of anthropogenic ecosystem engineering. We argue instead for a flexible, anthropologically and ecologically informed conceptualization of the Anthropocene—one that recognizes spatial, temporal, and scalar variability in the effects of humans on Earth systems. We present evidence in support of an ecologically informed pre-Columbian Anthropocene in California using a meta-analysis of sedimentological, palynological, and archaeological data sets from California mountains. We argue that use of fire for resource management by pre-Columbian populations was sufficiently frequent and extensive enough to result in widescale anthropogenic modification of California's biota and that an Anthropocene therefore began in California by at least 650 years ago, centuries before the arrival of Europeans. Recognizing a pre-Columbian Anthropocene in California constructively conceptualizes a marker for human economic–ecological intensification processes that could be more meaningful for policy, resource management, and research than focusing on any single historical event.
Key Words: Anthropocene, California, fire, Native Americans, Paleoecology.

The term Anthropocene refers to a proposed new geological epoch triggered by human-caused changes to the Earth's systems (Zalasiewicz et al. 2017). Defining the Anthropocene is contentious largely because there is no single agreed-on metric to mark its onset. Geoscientists, for example, use radionucelotides to argue that the Anthropocene began AD 1945 at the start of the Atomic Age (Zalasiewicz et al. 2015) or use evidence for the rapid accumulation of geochemicals such as carbon, nitrogen, and phosphorous in the lithosphere and atmosphere to argue that this new epoch began ca. AD 1800, at the start of the Industrial Revolution (Raupach and Canadell 2010; Steffen et al. 2011). Social scientists tend to argue for deeper time, pointing to long-term archaeological and ecological records for humans acting as land managers via agriculture and pastoralism (Ruddiman 2005; Ellis et al. 2016; L. Stephens et al. 2019). The Anthropocene's starting point consequently depends to a large degree on the characteristic used to identify it.

Because the utility of the Anthropocene concept is to denote human activity affecting Earth's systems to a measurable extent, we argue that focusing on the exact date for the beginning of the epoch discounts the profound effects of ecosystem engineering by nonindustrial or nonagrarian people (Ellis et al. 2016). Further, it ignores the fact that these events likely resulted from long-term processes of human economic and technological development in an ecological context, rather than any one event or set of events. Geographers recognize that space and place matter—that events do not unfold synchronously in all places and that impactful events can be time-transgressive. We consequently operate from the assumption that a flexible, anthropologically and ecologically informed conceptualization of the Anthropocene—one that recognizes spatial, temporal, and scalar variability in humankind's effect on biota—is a more useful approach than stricter geological conceptualizations (Ruddiman 2018). In this article we present evidence in support of an

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ecologically informed Anthropocene construct, demonstrating widespread human impacts via ecosystem engineering in California spanning at least 650 years. California represents an interesting challenge in identifying anthropogenic impacts because its pre-Columbian inhabitants were hunter-gatherers who used tools such as fire to manage natural resources.

Humans have potentially transformed their physical environments and affected ecosystem function and biodiversity patterns for thousands of years (Ruddiman 2005). Although fire occurs naturally, evidence suggests that it has also been used by humans for at least 400,000 years (Roebroeks and Vill 2011; Walker et al. 2016). By using fire, humans can alter fuels, creating large-scale successional shifts that affect ecosystem structure and buffer the effect of climate on fire size (Whitlock et al. 2010; Bliege Bird et al. 2012).

A recent global analysis found that hunter-gatherer groups living in wildfire-prone areas were more likely to use fire as a tool for ecological management precisely because the vegetation was adapted to frequent fires (Coughlan, Magi, and Derr 2018). The ethnographic record provides overwhelming evidence that low-intensity surface fires were ubiquitously set across California's predominately Mediterranean landscape to remove underbrush, clear travel corridors, facilitate hunting and drive game, promote seed germination, and generally increase yields of natural resources. Through historic photographs and written accounts, European explorers documented "park-like settings" free of underbrush with mixed-age and patchy tree cohorts (Muir 1894; Jepson 1923; Lewis 1973; Parker 2002). Fire scientists generally attribute such conditions to frequent low-intensity fires that consume shrubs and seedlings without damaging mature trees. These fire conditions are consistent with both frequent unsuppressed lightning-set fires and the pattern of Native Californian–set fires documented in ethnographies (M. K. Anderson and Moratto 1996; Codding and Bird 2013). The challenge in identifying a signal of anthropogenic fire becomes one of disentangling the effects of human ignitions from climatic ones. If evidence for anthropogenic fire can be consistently and unambiguously identified, then the argument can be made for the onset of an ecologically informed Anthropocene.

We use meta-analyses of available paleoecological and archaeological data sets to identify when a widespread signal of fire use affiliated with rapidly growing populations occurs within the ecological context of the mountains of California. We identify climate- versus human-driven environmental change with unambiguous pollen taxa that exhibit contrasting life history traits. Paleoecological studies based on pollen and sedimentary charcoal provide a biosphere record stored in a geologic context of sedimentary records. Radiocarbon dating of macrobotanical remains from these sedimentary records provides stratigraphically constrained timing of ecological change. Archaeological data sets provide insights into prehistoric population densities, traditional resource management practices, and natural resource use. Intensification-caused vegetation changes can be identified through reconstructions of vegetation history and timing of land use and occupancy (Munoz and Gajewski 2010; Crawford et al. 2015; Fulton and Yansa 2019).

We use the persistence of fire-adapted taxa and their associated systems during cool, wet periods when fire-sensitive taxa should dominate, coupled with evidence for increased human population densities and resource use, as an identifiable signal of a human-modified landscape. We challenge the assumption that the mountainous forests encountered by the first Europeans to reach California were created primarily by climatic conditions. We consequently argue that the process of large-scale anthropogenic modification of California's biota, and hence an Anthropocene, is identifiable in California at least 650 years ago, centuries before the arrival of Europeans.

Climate–Fire–Vegetation Dynamics

A warmer, drier climate is associated with more frequent fires due to less soil moisture and an increase in combustible fuels. These conditions lead to more open forest canopies and a greater prevalence of fire-tolerant and shade-intolerant taxa (Mohr, Whitlock, and Skinner 2000; Bond and Keeley 2005; Fites-Kaufman et al. 2007; Swetnam et al. 2009) such as oaks (*Quercus* spp.), pines (*Pinus* spp.), grasses (Poaceae), and bracken fern (*Pteridium aquilinum*). Fire-tolerant and open-canopy taxa provide important food sources for aboriginal Californians (acorns, pine nuts, seeds, shoots). Less frequent fire is typically associated with cooler, wetter climate, although large, high-severity fires might still occur. Greater availability of soil moisture and decreased fire frequency allow for the succession of

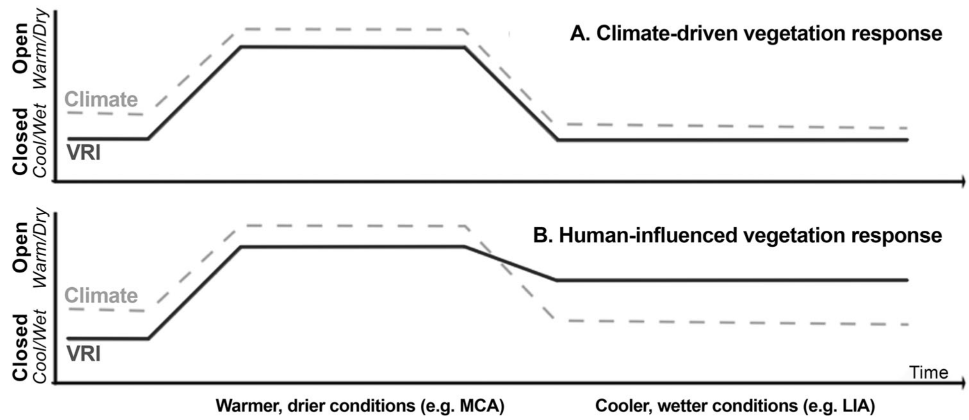

Figure 1. Conceptual model of forest canopy (open/closed) in relation to climate–fire–vegetation dynamics over time. (A) Expected forest canopy (solid dark gray line) driven by climate-only factors. (B) Expected forest canopy influenced by human behavior. Gray dashed line represents climate. VRI = vegetation response index; MCA = Medieval Climate Anomaly; LIA = Little Ice Age.

shade-tolerant and fire-sensitive taxa such as fir (*Abies*), incense cedar (*Calocedrus decurrens*), sedges (Cyperaceae), Douglas fir (*Pseudotsuga menziesii*), mountain hemlock (*Tsuga mertensiana*), and tanoak (*Notholithocarpus*; Swetnam 1993; Dale et al. 2001; Lenihan et al. 2003)

In the last 1,300 years, California has experienced multicentury periods of both warmer and drier and cooler and wetter conditions against which to test drivers of vegetation change. The Medieval Climate Anomaly (MCA), from ca. AD 900 to 1200, is regionally identified as a predominantly warmer and drier period with increased occurrences of regional fires. The Little Ice Age (LIA), from ca. AD 1200 to 1850, is identified broadly as a cooler and wetter period (Bowerman and Clark 2011), with a decrease in regional fires and a corresponding decrease in background charcoal accumulation (Swetnam 1993; Mohr, Whitlock, and Skinner 2000; Swetnam et al. 2009).

If climate and lightning-caused fires are the driving factors of vegetation response we expect more open-canopy and fire-tolerant taxa during warmer and drier climatic periods and more closed-canopy and fire-sensitive taxa during cooler and wetter climatic periods (Figure 1A). If human behavior and resource intensification are the driving factor, then we expect the persistence of open-canopy and fire-tolerant taxa even during suboptimal cooler and wetter periods (Figure 1B).

Paleoecological Evidence

Fires were ubiquitous throughout pre-Columbian California, with an estimated 6 to 16 percent (2–5 million ha) of nondesert land burned annually (Martin and Sapsis 1992). Pre-Columbian median fire return intervals are estimated in the range of five to ten years in oak woodlands and mixed conifer forests, twenty to thirty years in shrublands, and three years in grasslands, potentially a result of both lightning and human ignitions (S. L. Stephens, Martin, and Clinton 2007). Over the last century, vast portions of California have experienced no fire activity. Although large, severe fires occurred in the past, the paleoenvironmental record demonstrates a decrease in fire intensity over the last several hundred years, especially during the LIA (Swetnam 1993; Marlon et al. 2012).

Much paleoecological work in California has focused on vegetation change as a proxy for climate change (Davis et al. 1985; Edlund 1996; Mensing 2001; Barnosky et al. 2016). Only a handful of studies have focused on pre-Columbian anthropogenic influences with an emphasis on identifying human impact rather than climate proxies (e.g., Gassaway 2009; R. S. Anderson and Stillick 2013; Lightfoot et al. 2013; Ejarque et al. 2015). Even fewer data sets have been made publicly available.

We performed a meta-analysis of pollen-based paleoecological studies at five sites (R. S. Anderson and Carpenter 1991; Crawford et al. 2015; Klimaszewski-Patterson 2016; Klimaszewski-Patterson and Mensing 2016) from the Sierra Nevada and Klamath Ranges in California (Figure 2) to investigate an identifiable Anthropocene. Of the forty-five identified late- Holocene paleoecological sites reported throughout California's mountainous regions since AD 1980 (e.g., West 1982; Davis and

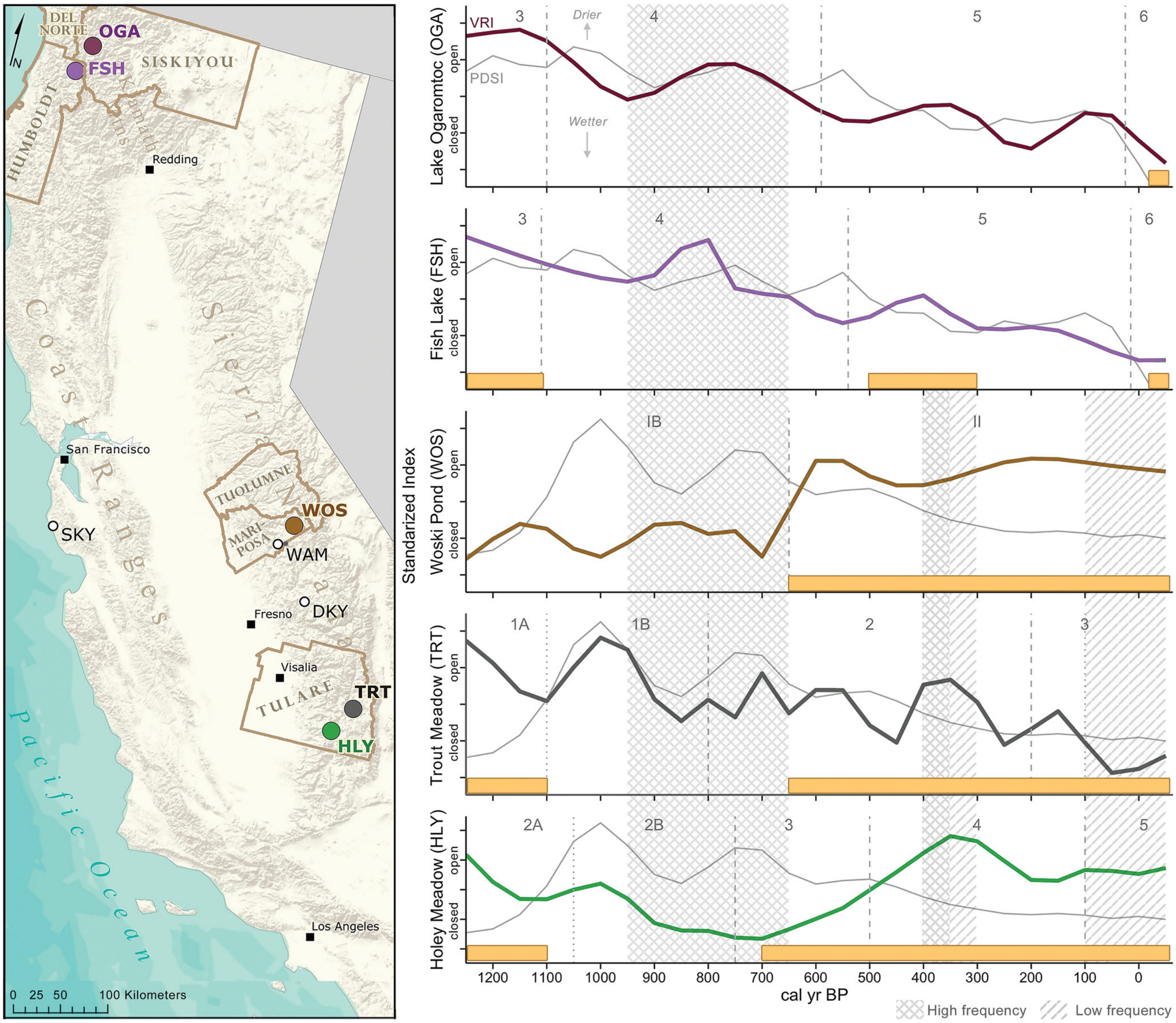

Figure 2. Thirteen thousand years of climate (gray line), vegetation (colored lines), and anthropogenic interpretations (by original authors; orange bars) from subcentennial sites in California mountains. Colored lines (matching colored circles, left) represent standardized vegetation response index of shade-tolerant and fire-sensitive (closed-canopy) versus shade-intolerant and fire-adapted (open-canopy) taxa. Gray line represents inferred climate from the North American Drought Atlas (E. R. Cook et al. 1999; E. R. Cook et al. 2004; E. R. Cook et al. 2008; Herweijer et al. 2007). Higher values indicate drier conditions; lower values indicate wetter conditions. Hashed shading represents regional fire scar studies (Swetnam, Touchan, and Baisan 1991; Swetnam and Anderson 2008). Double hash indicates high frequency of regional fires; single hash represents a low frequency. White dots represent other paleoecological sites discussed but not used in analysis. SKY = Skylark Pond; WAM = Wawona Meadow; DKY = Dinkey Meadow.

Moratto 1988; Edlund 1996; Wahl 2002; Wanket 2002), only these five published palynological studies meet all of the following criteria: (1) conducted at a subcentennial resolution, (2) for at least the last 1,300 years, (3) where identifiable life-history distinctions in vegetation changes could be identified, and (4) the data set was available for reanalysis.

At each of the five sites we calculated a vegetation response index (VRI; term coined in Klimaszewski-Patterson and Mensing 2016) between fire-sensitive or shade-tolerant (FSST) and fire-adapted or shade-intolerant (FASI) taxa. We used each study's identified nonambiguous FSST (e.g., *Abies*, *Pseudotsuga*) and FASI (e.g., *Quercus*, Poaceae) taxa to calculate VRI as (FSST – FASI)/(FSST + FASI). A negative VRI indicates more fire-adapted or shade-intolerant taxa and a positive VRI more fire-sensitive or shade-tolerant taxa. We then compared VRI changes

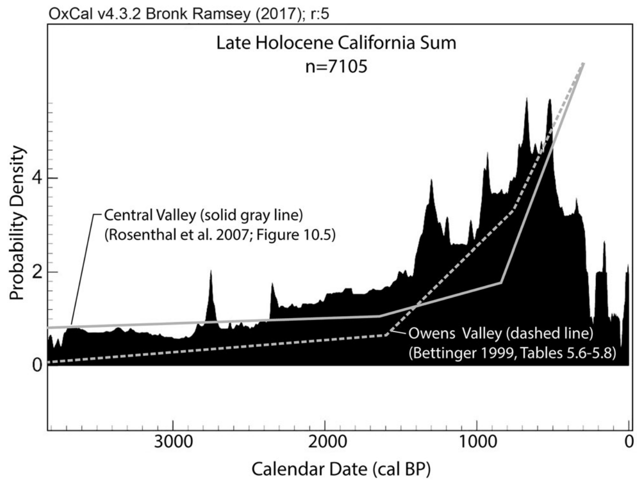

Figure 3. Population trajectories in Late Holocene aboriginal California. Radiocarbon summed probability distributions generated with normalized data from the CARD 2.1 data set (Martindale et al. 2016), using OxCal 4.3 (Bronk Ramsey 2009) and the Intcal 13 calibration curve (Reimer et al. 2013).

against a fifty-year smooth-spline climate reconstruction based on local, annually resolved tree-ring data (E. R. Cook et al. 1999; E. R. Cook et al. 2004; E. R. Cook et al. 2008; Herweijer et al. 2007). Our results demonstrate signals of anthropogenically altered landscapes by increases in fire-adapted or shade-intolerant taxa (e.g., *Quercus*) during cool, wet periods (LIA). Each site indicates periods of anthropogenic influence on the landscape, with Sierran sites Woski Pond (WOS; R. S. Anderson and Carpenter 1991) and Holey Meadow (HLY; Klimaszewski-Patterson and Mensing 2016) showing the strongest signals starting ca. 700 cal BP (Figure 2). Lake Ogaromtoc (OGA) and Fish Lake (FSH; Crawford et al. 2015) in the Klamath Mountains show the weakest signals, likely due to wetter conditions associated with their proximity to the Pacific Ocean. All five sites show anomalous changes in VRI compared to climatic expectations starting no later than 650 cal BP (AD 1300), 250 years prior to European contact.

Archaeological Evidence

Although there is little direct archaeological evidence for landscape-scale burning and other land management practices in California (see Cuthrell 2013; Lightfoot et al. 2013; M. K. Anderson and Rosenthal 2015), the ethnographic literature is replete with descriptions of managing wild plants through coppicing, pruning, or whipping (Fowler 2008); deliberately planting and tending tobacco (Todt 2007); irrigating wild plants to increase seed yield (Lawton et al. 1976); and especially deliberately setting fires (Jordan 2003). The benefits of the latter include marking territorial boundaries, increasing forage for game, clearing land for travel, producing better basketry material, and increasing annual yields of wild grasses, berries, and acorns (Lewis 1973; M. K. Anderson 2005). Fire was so important to aboriginal Californians that its use has been linked to the development of the complex sociopolitical organization (Bean and Lawton 1973).

When these deliberate fire practices began is unclear, but it seems reasonable to assume that their frequency increased in proportion to human population growth. Estimates for the number of people living in pre-Columbian California vary from 133,000 to 1.52 million (Merriam 1905; Kroeber 1925; Powers 1976), with most estimates hovering around 300,000 (Baumhoff 1963; S. F. Cook 1976). Although several researchers argue that these estimates are too low, because they are typically based on postcontact data (Preston 2002), many agree that population density in aboriginal California, a land of hunter-gatherers, rivaled or exceeded that of contemporaneous agriculturalists living in adjacent regions (Baumhoff 1963).

Several lines of archaeological evidence point to Late Holocene population growth in California. In Owens Valley, Bettinger (1999) identified exponential population increase after 1700 cal BP by tracking the frequency of time-sensitive projectile points. Rosenthal, White, and Sutton (2007) identified a similar pattern in their evaluation of the frequency of dated archaeological components in California's Central Valley. Arguably the most powerful indicator of population growth is radiocarbon data, the idea being that the probability of finding and dating cultural carbon increases with the frequency by which people generated cultural carbon in the past (Williams 2012). A summed probability distribution (SPD) generated from 7,105 radiocarbon dates (Martindale et al. 2016) from Late Holocene California (i.e., <3500 BP) generates a curve similar to those of Bettinger (1999) and Rosenthal, White, and Sutton (2007), with a marked increase in radiocarbon frequencies after 1500 cal BP and a peak from 800 to 500 cal BP (Figure 3).

In northwestern California, near OGA and FSH, ethnographic groups are the Yurok, Karok, and

Table 1. Demographic data for California ethnolinguistic groups at time of European contact

Ethnolinguistic group	Population[a]	Population density[a] (people per 100 km[b])	Associated paleoecological records
Yurok	2,500	131.00	Lake Ogaromtoc, Fish Lake
Karok	1,500	46.90	
Shasta	2,925	25.00	
Tubatulabal	1,000	17.20	Holey Meadow, Trout Meadow
Miwok	1,212	24.54	Woski Pond
California	91,364[b]	58.8 (avg.)	

[a]Data from Binford (2001, table 5.01).
[b]This number does not include all California ethnolinguistic groups.

Shasta, all of whom subsisted chiefly on anadromous fish (Tushingham and Bettinger 2013). Ethnographic sources indicate that these were among the largest and most densely packed pre-Columbian populations in California (Table 1). The radiocarbon SPD for counties containing or immediately adjacent to OGA and FSH suggest pronounced population growth after 1500 cal BP (and decline after 500 cal BP), but the VRI for both sites more closely correlates with climate than demography (Figures 2 and 4), possibly because as fishing-oriented groups they had far less incentive to manage terrestrial resources than groups in central and southern California. Lighting and managing the low-intensity fires required by indigenous traditional resource and environmental management (TREM) practices was also likely far less tenable in the moist coniferous forests of California's Pacific Northwest.

Like all Sierra Nevada groups, the Miwok, affiliated with the Yosemite region and the WOS site, were accomplished hunters and prodigious acorn storers, subsisting through the winter largely on acorns stored in granaries (Barrett and Gifford 1933; Bates 1983). Both hunting and an acorn-centered diet would have benefited from landscape management by fire. The Miwok also had some of the highest population densities in the Sierra Nevada at the time of European contact (Table 1), with SPD-derived population levels in the area peaking along with VRI ca. 500 cal BP. Population declines thereafter, inverse to the more open-canopy biota (likely the result of anthropogenic burning).

The Tubatulabal and Foothill Yokuts, of the HLY and Trout Meadow sites, had a subsistence economy similar to that of the Miwok (Harvey 2019). At the time of European contact, the Tubatulabal had among the lowest population density in California outside the Mojave Desert and the lowest in the Sierra Nevada (Binford 2001). Their SPD, however, suggests rapid population growth after 1000 cal BP and a peak in population ca. 600 cal BP (Figure 4). HLY indicates the most pronounced VRI signal, suggesting strong anthropogenic effects and the greatest deviation from climate from 350 to 200 cal BP. Trout Meadow demonstrates a more equivocal signal, with punctuated periods of inferred anthropogenic effects at ca. 650 to 550 cal BP, 450 to 300 cal BP, and 250 to 150 cal BP.

Discussion

The process of large-scale anthropogenic modification of California's biota, and hence an Anthropocene, is identifiable in the Sierra Nevada of California at least 650 years ago. In the Sierra Nevada, paleoecological records indicate a shift toward more open-canopy forests after 700 cal BP, when climate is modeled to have encouraged proliferation of closed-canopy coniferous forests. Although populations appear to decline after peaking ca. 500 cal BP, VRI data from at least two Sierran sites suggest that aboriginal burning continued unabated or even increased after this period of time. We speculate that growing populations between 1500 and 500 cal BP (roughly contemporaneous with the MCA) faced a new challenge during the LIA with the onset of pronounced climatic change and increased precipitation. Climate during the LIA ought to have favored the spread of *Abies* over *Quercus*. Nowhere would this have been more pronounced than in the Sierra Nevada. Given this predicament, perhaps aboriginal burning increased after 700 cal BP as a deliberate attempt to maintain MCA-type environments with abundant oak woodlands. We suggest that aboriginal inhabitants of the Sierra Nevada not only maintained their habitat through burning at scales recognizable in the

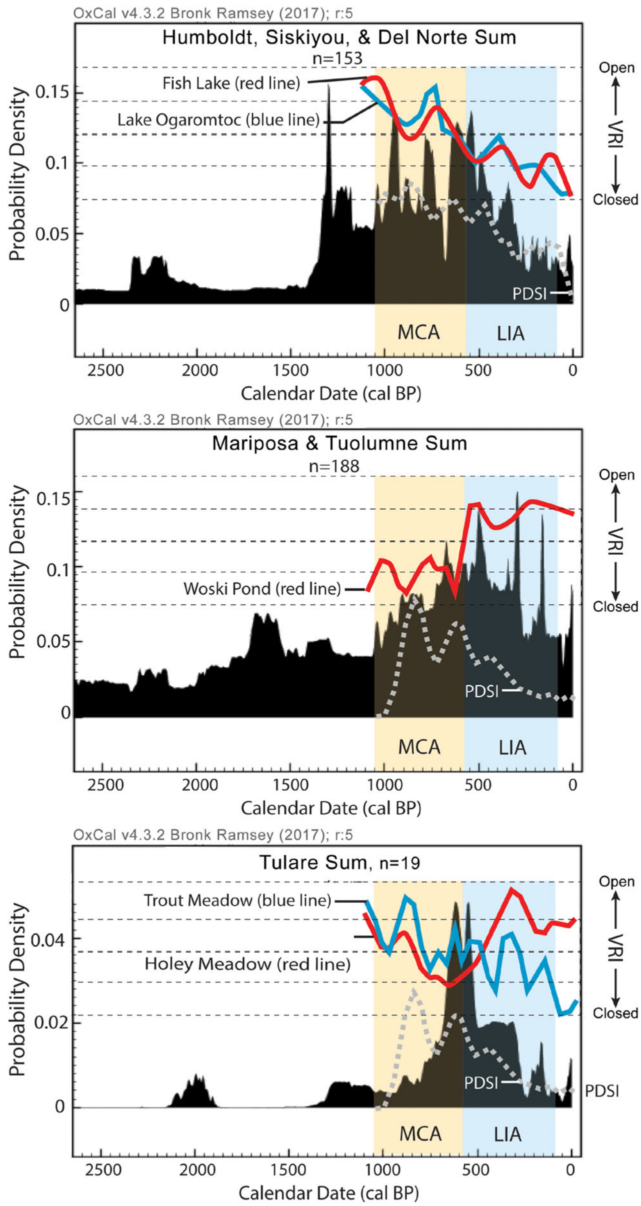

Figure 4. Radiocarbon (SPDs) and affiliated paleoclimatic and paleoenvironmental data for reviewed paleoecological and archaeological data sets. SPDs generated using normalized data from the CARD 2.1 data set (Martindale et al. 2016), using OxCal 4.3 (Bronk Ramsey 2009) and the Intcal 13 calibration curve (Reimer et al. 2013). MCA = Medieval Climate Anomaly; LIA = Little Ice Age; VRI = vegetation response index; PDSI = Palmer Drought Severity Index; SPD = summed probability distribution.

paleoecological record but they actively did so in response to altered paleoclimatic circumstances.

The argument for aboriginal burning maintaining oak woodlands is further supported by paleolandscape models reconstructing the last 1,100 years of forest succession at Holey Meadow (Klimaszewski-Patterson et al. 2018) and Trout Meadow (Klimaszewski-Patterson and Mensing 2020). Both studies analyzed various scenarios of climate-driven and human-influenced fire regimes to explore which models of forest succession best approximated the observed palynological record. Both studies indicate that the most likely fire regime to explain the empirical record is through the addition of TREM-like low-intensity surface fires. In short, climate alone could not reproduce the observed pollen record with statistical relevance, whereas the addition of TREM fires best approximated the observed record, with statistical significance. This ecosystem engineering is most noticeable at both sites during the LIA.

We recognize that of our five sites, the southern and central Sierra Nevada sites by far show the strongest support for a pre-Columbian ecological–Anthropocene signal, but other studies from the Sierra Nevada and coastal California also support identifiable pre-Columbian human impacts. At Wawona Meadow (R. S. Anderson and Stillick 2013) in Yosemite National Park (Figure 2), the authors indicate evidence for frequent surface fires starting ca. 650 cal BP (AD 1300). At Dinkey Meadow (Davis and Moratto 1988) in Sierra National Forest the published reconstructed pollen diagram shows a sharp decline in *Abies* throughout the LIA while *Quercus* remains steady. At Skylark Pond (Cowart and Byrne 2013) near Point Año Nuevo (Figure 2), the authors interpret evidence for nonclimatic fires starting no later than ca. 550 cal BP, possibly sooner. Additional well-dated, high-resolution palynological data sets are necessary throughout California to further refine onset of an Anthropocene. Given the spatial distribution of reanalyzed paleoecological sites from central-east to northwest California, we think a minimum date of 650 cal BP is reasonable, especially given that mountainous regions in the interior are thought to have had lower populations and less intense land use.

Aside from the Anthropocene, epochal boundaries have been retrospectively assigned based on extinction events identified from an incomplete fossil record. It remains to be seen whether the amalgamation of modern-day extinctions and radionucleotide markers is sufficiently concentrated in the geologic record to represent a distinguishable signal at the scale of geologic time. What is more important to the current debate is that the Anthropocene concept has greater value than a strictly defined point in time because the idea can help change thinking about the depth and extent of human impacts in the present day. Humans have clearly altered the biota and chemistry of Earth, and traces of these changes over thousands of years are evident in the geologic record. Traditional geologic methods never attempted to consider human impacts, and those impacts are time-transgressive and cumulative. People had an impact on Earth's systems prior to the Industrial Revolution or the Atomic Age. Adopting a flexible, ecologically informed approach to the question of an Anthropocene, as we have in pre-Columbian California, can have important consequences for how we conceptualize modern ecology and the long-term role of human manipulation of Earth systems. In the case of California, this way of thinking can potentially transform modern land use management and fire policy at a time when new approaches to fire ecology are desperately needed.

Conclusions

We propose that an Anthropocene began in present-day California no later than AD 1300 (650 cal BP), well before Europeans entered the western Americas. We base this conclusion on identifiable and quantifiable signals from independent paleoecological and archaeological evidence. We offer that intentionally set fires resulting in low-intensity burning by pre-Columbian Native Californian populations were responsible for altering forest structure in California such that open oak/mixed conifer forests persisted into and through the LIA instead of climatically expected closed coniferous forests. As per the Anthropocene concept, human modification of the environment is observable in the geologic sedimentary record and was spread throughout California by this date.

We argue that the term Anthropocene is more constructively conceptualized as a marker of the intensification of human economic–ecological processes rather than any one historical event. Identifying a signal of preindustrial, or even preagricultural, human behavior in the geologic record can be difficult, but the effort can be accomplished by employing a multidisciplinary and multiproxy approach focused on human behavior.

The onset of an Anthropocene will consequently not be contemporaneous in all locations, much in the same way that there are variations in timing or effect of climatic events (e.g., LIA, MCA); however, this does not make the construct any less valuable. Thinking of the term Anthropocene as a flexible concept expressed in the multitude of geophysical changes that people have caused across the globe, through the lenses of society, politics, and economics, is particularly useful in informing policy and management of natural resources. The debate will continue as to defining a formal geologic boundary. Given that such temporal boundaries are typically defined from an incomplete fossil record spanning millions of years, we argue that the consideration of the full record of human activity is an integral part of this debate.

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