5 Indigenous Land Use and Fire Resilience of Southwest USA Ponderosa Pine Forests

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Introduction

Fire is a key ecosystem process in many environments (McLauchlan et al. 2020) and was particularly important in shaping the evolution and historical ecology of dry conifer forests in western North America that are dominated by ponderosa pine (*Pinus ponderosa*) and related species (Moore et al. 1999). Because fire has been historically ubiquitous in these forests, the relative contribution of Indigenous burning has often been unclear (Allen 2002). Nevertheless, the impacts of more recent human activities over the past 150 years have unquestionably reshaped the role of fire in these dry pine forests, especially in the southwest region of the United States of America. Overstocking of cattle and sheep beginning in the 1870s first removed grassy fine fuels, thus inhibiting fire spread before logging and active fire suppression in the early 20th century created multi-decadal fire-free periods in forests across the southwestern region of the United States (hereinafter "the Southwest").

The removal of fire by grazing, logging, and active suppression fundamentally reduced the fire resilience of these forests (Coop et al. 2020; Savage and Mast 2005). For these forests, the term "fire resilience" refers to the ability of forest stands to experience fire and maintain their basic structure, function, and ecosystem services while avoiding fire-induced ecological transformations into other biome types, such as grasslands or shrublands (Coop et al. 2020; Stephens et al. 2016). High-severity fires, in which there is a high degree of canopy mortality, create opportunities for such transformations to alternative vegetative states. However, low-severity surface fires are a keystone process in these forests, removing most young conifers and maintaining a widely spaced, open, elevated canopy that is resistant to generating crown fires. Surface fire regimes sustained high fire resilience by shaping fuel structure – it was difficult for fire to get into the canopy, or to travel very far when it did (Moore et al. 1999) (see Figure 5.2A–B). Without fire to remove young trees, the trees could infill and provide both vertical and horizontal continuity of canopy fuels, thus allowing crown fires to establish and propagate (Savage et al. 1996). This reduced the fire resilience of these forests and increased the likelihood of

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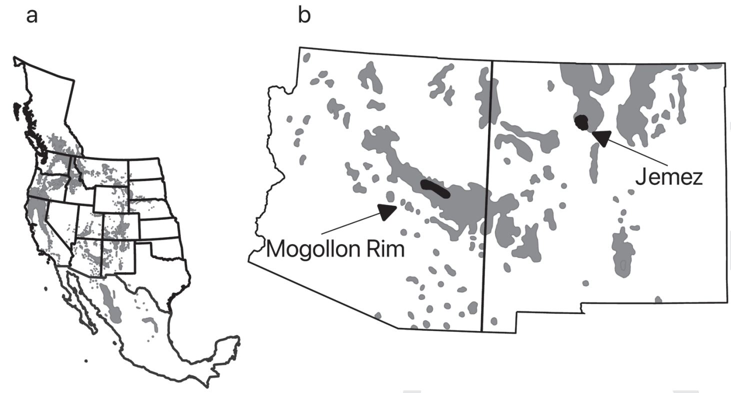

Figure 5.1A–B The distribution of ponderosa pine (gray areas) in western North America (Part A) and in the Southwest US (Part B). The location of the Mogollon Rim and Jemez study areas are indicated by black polygons (Part B).

transformations to alternative vegetative states (see Figure 5.2C–D), such as grasslands or shrubfields depending on the local seed sources, the rootstock of resprouters, and post-fire microclimates (Coop et al. 2020; Guiterman et al. 2018; Savage and Mast 2005; Savage et al. 2013).

Fuel-limited fire regimes such as those that characterized ~~by~~ the historical Southwest are potentially vulnerable to periods of reduced fire resilience due to climate-induced changes in ignitions or fuels (Whitlock et al. 2010). Historical surface fires had close relationships with interannual variability in precipitation because of the necessity for abundant and continuous surface fuels for surface fires to spread widely (Swetnam and Betancourt 1998; Swetnam et al. 2016). Years with widely spreading fires – those years when most of the cumulative area burned – tended to be dry years preceded by 1–3 wet years that produced abundant, continuous surface fuel to allow a limited number of ignitions to spread widely through those continuous surface fuels. This sub-decadal wet-dry switching was often associated with El Niño–Southern Oscillation and its influences on rainfall patterns (Kitzberger et al. 2007; Swetnam and Betancourt 1998). While much of the last 1,500 years had frequent wet-dry switching that favored widely spreading lightning fires at decadal timescales, there were periods in the transition from the Medieval Climate Anomaly (c. 900–1250 CE) to the Little Ice Age (c. 1400–1850 CE) (Mann et al. 2009) when such wet-dry switching was less frequent and lower magnitude (Roos and Swetnam 2012), potentially reducing surface fire spread and creating multi-decadal fire-free periods and reduced fire resilience in some Southwest forest stands.

Native American communities have lived in these forests for millennia but their long-term legacies on Southwest fire histories is debated. What were the

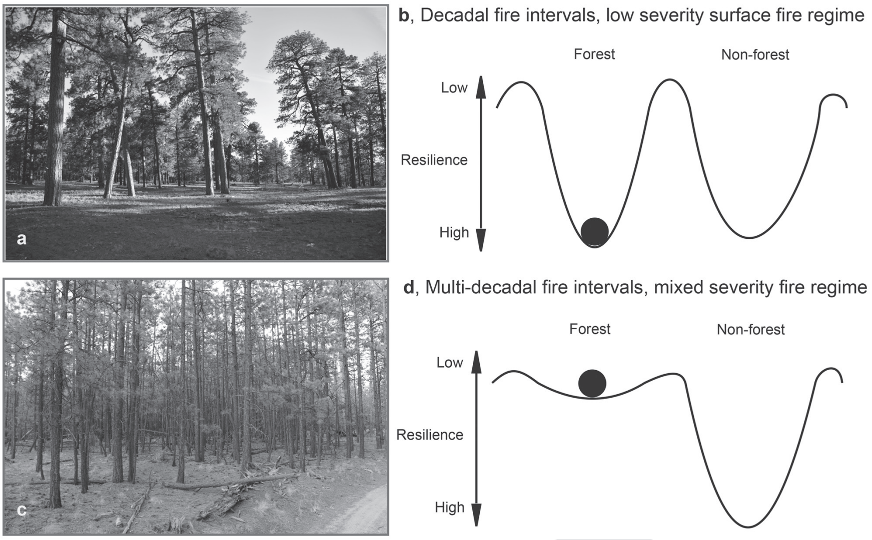

Figure 5.2A–D Illustrations of open-canopied ponderosa pine forest with grassy understory and elevated crown maintained by frequent surface fires (Part A) (Defiance Plateau, AZ. Photo: C. Guiterman), and a hyper dense "doghair thicket" created by a century of fire suppression (Part C) (Jemez Mountains, NM. Photo: C. Roos). Conceptual ball-in-basin diagrams illustrate how frequent surface fires act as a balancing feedback that removes small trees and maintains the open and elevated canopy that is resistant to drought and large hot fires (Part B). By contrast, without frequent surface fires as a key functional process, regeneration runs unchecked, reducing the fire resilience of pine stands and making them more vulnerable to crossing a threshold into an alternative vegetative state (e.g., shrubfields or grasslands/ meadows) when fire does return (Part D).

consequences of Indigenous land use and fire management on the fire resilience of these forests? Could the high-frequency, low-intensity Indigenous patch burning documented in the Southwest (Roos, Laluk, et al. 2022; Roos et al. 2021; Swetnam et al. 2016) and elsewhere (Bliege Bird et al. 2012) have improved the fire resilience of these forests in the context of climate variability even with abundant lightning (Allen 2002)? Here we combine archaeology, paleoecology, and paleoclimate reconstructions to show that fire use by Native American communities in ponderosa pine forests enhanced the fire resilience of occupied ponderosa pine forests by providing "response diversity" (Walker et al. 2006) with lightning ignitions. We follow Walker and colleagues in our use of "response diversity" to mean "diversity of responses to disturbance [or environmental change] among species or actors contributing to the same function in the social–ecological system" (Walker et al.

2006). We suggest that Indigenous burning contributed to response diversity and fire resilience in these fuel-limited forests because of their ability to overcome limitations of horizontal surface fuel continuity with more ignitions as climate patterns varied.

The modern wildfire problem in the Southwest is fundamentally a problem in historical ecology. Having been shaped by millennia of low-severity surface regimes, the last century of human land-use has led to a fundamental departure from this historical ecology. Restoration of frequent surface fire regimes in the Southwest is a classic example of applied historical ecology, wherein historical ecological information is applied to contemporary management and ecological restoration (Swetnam et al. 1999). Legacies of Indigenous use have often been left out of these applications, however, as the ambiguity of Indigenous fire management within histories of frequent fire presents interpretive challenges (Allen 2002). Here, we deliberately concentrate on the historical ecology of culturally and temporally variable Indigenous fire management to understand the consequences of Indigenous activities on the fire resilience to support an Indigenous applied historical ecology of Southwest forests.

Archaeological and Environmental Context

We concentrate on ponderosa pine forests in the Jemez Mountains of New Mexico and along the Mogollon Rim in east-central Arizona that were home to ancestors of Pueblo and Western Apache people (see Figure 5.1B). Southwestern ponderosa pine forests span elevations 1,700–2,300 masl and are dominated by one canopy species, ponderosa pine, with rare contributions of piñon (*P. edulis*) and/or various juniper (*Juniperus* spp.) at lower elevations, and Douglas-fir (*Pseudotsuga menziesii*) and Southwestern white pine (*Pinus strobiformis*) at higher elevations. Historically, understory plant communities were dominated by bunchgrasses (especially *Festuca arizonica*), forbs (especially those in Asteraceae and Amaranthaceae), and some shrubs, including various species of oak (*Quercus* spp., which in the case of *Q. gambelii* can also grow in tree form as occasional co-dominants), sumac (*Rhus trilobata*), and manzanita (*Arctostaphylos* spp.). These forests are dotted by rare, small meadows (< 25 ha) with a similar composition of grasses and forbs as were present in the historical understory (Allen 2004; Kaldahl and Dean 1999).

Average annual precipitation in these forests ranges from 420–500 mm. Annual precipitation has strong bimodality of peak rainfall during the summer monsoon in July, August, and September and a second, smaller mode from cyclonic winter storms from the Pacific from October to March. April, May, and June are reliably dry, creating conditions each year when fires can ignite and spread. Average low temperatures are above freezing from April through October, the primary growing season for both wild plants and crops, although late (spring/summer) and early (summer/autumn) frosts are not uncommon (Kaldahl and Dean 1999).

Frequent, low-severity surface fires were historically ubiquitous in these dry conifer forests in the Southwest and across western North America (see Figure 5.1A) until livestock grazing, logging, and fire suppression led to a near total cessation of wildfires beginning in the late 19th century (Swetnam and Baisan 2003; Swetnam et al. 2016). Fire-scarred ponderosa pines can be tree-ring dated to the year and often to the portion of the growing season when the surface fires occurred (Dieterich and Swetnam 1984). From c. 1700–1900 CE (the period of greatest sample replication in the tree-ring fire-scar record) (Margolis et al. 2022), fires tended to occur in a stand once or twice per decade in surface fuels during the arid foresummer (April–June) or at the onset of the monsoon with dry lightning storms (July) (Fulé et al. 1997; Moore et al. 1999).

Native populations have been using the Mogollon Rim and Jemez Mountains for at least 12,000 years (Haury 1957; LeTourneau and Baker 2002), although long-term occupation of these areas did not begin until c. 200 CE in the Mogollon Rim region (Haury and Sayles 1985 [1947]) and 1100 CE in the Jemez area (Roos et al. 2020; Roos et al. 2021). Here, we concentrate on the perennial Ancestral Pueblo occupation in both areas after 1100 CE and the intensive Western Apache use of the Mogollon Rim by 1550 CE. Between roughly 1000 and 1275 CE, the Ancestral Pueblo archaeology of the Mogollon Rim was characterized by widely distributed small villages, hamlets, and farmsteads in the form of 5–30 room masonry pueblos (Herr 2001; Mills and Herr 1999; Mills et al. 1999). Although the settlements were small, this was the period of greatest population size in the region (Newcomb 1999) and community religious structures (Great Kivas) integrated dispersed communities (Herr 2001). Grinding stones to process maize (*Zea mays*) and paleoethnobotanical remains all indicate a dependence upon farming (Huckell 1999). By the late 1200s CE, populations coalesced into a few large pueblos separated by 20+ km. Ethnographically and archaeologically, we know that Pueblo people used fire for myriad purposes, including burning to establish and clean agricultural fields and irrigation ditches; to promote wild plant resources for food, medicine, and craft materials, as well as for promoting habitat for preferred game animals; and in religious pilgrimages and practices (Bohrer 1983; Gifford 1940; Roos et al. 2021; Sullivan and Mink 2018; White 1943).

The Mogollon Rim area was also home to Western Apaches, who were seasonally mobile forager-gardeners who lived in ponderosa pine forests and adjacent woodlands from spring through autumn as part of seasonal mobility patterns (Graves 1982). Apache Elders describe traditions of their presence in eastern Arizona since time immemorial (Welch and Riley 2001). Apache archaeology is notoriously challenging, but a combination of archaeology (Herr 2013), ethnohistory (Forbes 1960), and oral tradition (Basso 1983) highlight intensive Western Apache use in the Mogollon Rim region by 1550 CE. Western Apaches used fire in many activities, including those described for Ancestral Pueblo peoples (Buskirk 1986; Griffin et al. 1971).

Hemish Pueblo people maintain oral traditions about their migration to the southern Jemez Mountains (Tosa et al. 2019), a process that has now been dated to as early as 1100 CE (Roos et al. 2020; Roos et al. 2021). These were small farming groups. For the first couple of centuries, populations and settlements were relatively small – no more than several hundred people (Kulisheck 2005). By the early 1300s CE, a much larger wave of migration grew the population to several thousand, with much of the population concentrated in large, aggregated villages and towns that were the home settlements for an agricultural society (Liebmann et al. 2016). Early in the 17th century, Spanish missionaries forced Hemish people into the valley below the forested mesas and the Hemish population declined by more than 85% in a matter of decades. Hemish people maintain at least 27 uses for fire and wood (fuel) that vary from domestic, village, agricultural, and landscape contexts (Roos et al. 2021).

Historical Ecology, Climate, and Resilience

Most of the area burned in Southwest ponderosa pine forests happened in years with large, widely spreading surface fires (Swetnam and Betancourt 1998). Prior to livestock grazing, logging, and active fire suppression by government agencies, widely spreading fires occurred in these forests typically at decadal intervals. However, on millennial timescales, multi-decadal intervals between widely spreading fires sometimes occurred, and likely created areas of fire refugia, where fuels could accumulate and young trees could establish. This resulted in reduced fire resilience of particular forest stands when fire did return (see Figure 5.2C–D). Co-occurring wet periods, unusually long intervals between fires, and tree-recruitment events have been documented in multiple places in the Southwest, particularly for the early 1600s CE (Brown and Wu 2005; Swetnam and Brown 2011). Most fire-scar records, however, are not old enough to cover the period of interest here (i.e., the past millennium). Instead, we use a published regression model of past fire activity that calibrated tree-ring precipitation reconstructions to a regional network of 45 fire history sites and >700 fire-scarred trees across the southern Colorado Plateau that encompasses both of our study areas (Roos and Swetnam 2012). This 1,400-year reconstruction of climate-driven fire activity indicates that climate conditions potentially produced several multi-decadal intervals between years with widely spreading fires (see Figure 5.3D). This was especially the case before the period best documented in the fire scar record (i.e., 1700 CE to present). In addition to multiple 20+ year long periods between widely spread fires, there were four periods of 50+ years in the fire activity reconstruction wherein annual climate fluctuations were lower amplitude and fire-spread may have been limited. During those periods (1170–1226, 1255–1314, 1360–1454, and 1543–1622 CE), wet-dry switching may not have produced abundant and continuous surface fuels, or these fuels were too moist to allow fire to spread, and fire resilience declined in some stands.

As a result, those stands may have been vulnerable to high-severity fire and transformations to alternative vegetative states (Savage and Mast 2005).

Temperature and precipitation have also varied in ways that could influence fuel production, flammability, fire spread, and the potential for crown fires. Prolonged wet periods (pluvials) can reduce fire spread by making fuels too moist to burn and can increase germination and stand infilling by synchronizing recruitment during these pluvials (Brown and Wu 2005). Droughts can impact fire spread and crown fire potential by making fuels in mesic topographic positions more flammable (Margolis et al. 2017). The Medieval Climate Anomaly (MCA; c. 900–1250 CE) was characterized by multiple warm and dry episodes (see Figure 5.3B–C) when mesic forests would have been more vulnerable to crown fires (Cook et al. 2010; Salzer et al. 2014;

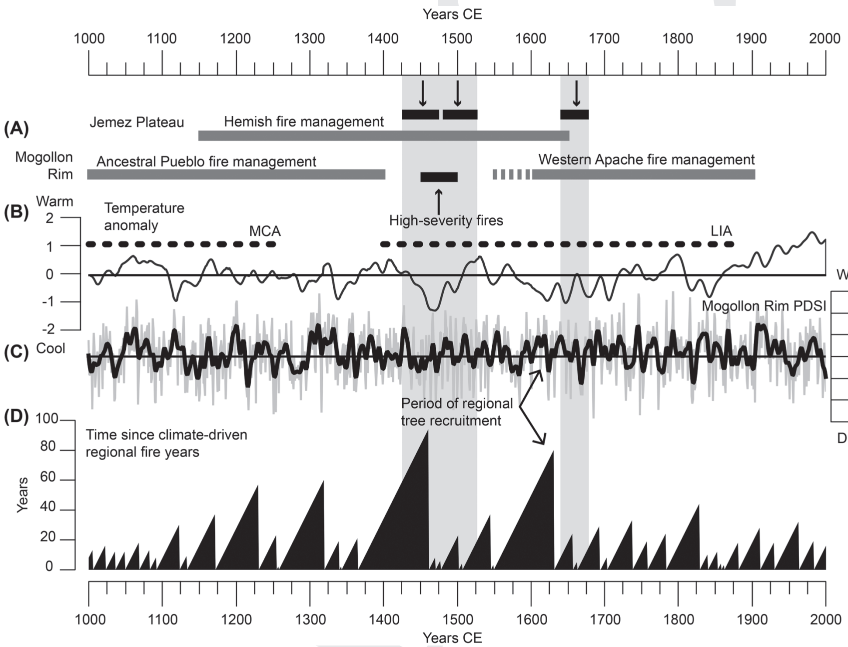

Figure 5.3A–D Synthesis of periods of Native American fire management (deliberate burning, wood harvesting; gray bars in Part A) and high severity fires (black bars in Part A indicated with arrows) in the Mogollon Rim (Roos et al. 2023) and Jemez Plateau areas (Roos et al. 2021) and temperature (Salzer et al. 2014) (Part B) and Palmer Drought Severity records (Cook et al. 2010; Williams et al. 2020) (Part C), and the cumulative duration since climate predicted fire years from Roos and Swetnam (2012) (Part D). Approximate boundaries for the Medieval Climate Anomaly (MCA) and the coldest period of the Little Ice Age (LIA) are marked (Part B). The early 17th century period of regional tree-recruitment associated with prolonged cool, wet conditions and longer fire-free periods is indicated (Part C) and (Part D).

Williams et al. 2020). Because they burned so frequently, drier forests would have required some combination of reduced fire spread and increased germination to build the vertical fuel continuity to become vulnerable to crown fires. Across the region, studies of buried strata in alluvial fans have identified periods of episodic high-severity fires in contexts with both semi-arid and mesic mixed-conifer forests. From Flagstaff, Arizona (Jenkins et al. 2011), Durango, Colorado (Bigio et al. 2017; Bigio et al. 2010), and both the Jemez (Fitch and Meyer 2016) and Sacramento Mountains (Frechette and Meyer 2009) of New Mexico, pyrogenic debris flows were most common during the warmer and drier MCA and in the periods of megadroughts in the 1400s and 1500s, or co-occur with reductions of fire spread predicted in the regional tree-ring model (Roos and Swetnam 2012). As significant as these high-severity fires could have been, during the past two millennia they probably burned much smaller patches when compared to modern high severity fires (Allen 2016; Bigio et al. 2010; Orem and Pelletier 2016).

In the eastern Mogollon Rim region, there is stratigraphic evidence of high-severity fire and post-fire erosion in the mid-1400s (see Figure 5.4D), but only in watersheds that were spatially distant from locations of intensive Native American settlement and land use (see Figure 5.3A) (Roos, Laluk, et al. 2022; Roos 2008). We lack evidence of high-severity fires during the MCA but cannot exclude that they occurred at a distance from Indigenous settlements but in occupied areas where periods of Indigenous patch burning bracketed a period of lighting-driven low-severity fires (see Figure 5.5A–B). High-severity fires during the mid-1400s are consistent with prolonged fire intervals between 1360 and 1454 CE in the fire-climate model, and warm and mild to wet periods between 1350 and 1425 CE, when increased germination of pines would have been likely (see Figure 5.3B–D), but it is notable that areas with Indigenous burning did not experience this because of the legacy of prior land-use.

In the Jemez Mountains, charcoal, pollen, and tree-ring records indicate that Ancestral Pueblo (Hemish) farmers managed woody fuel and fire for centuries between 1100 and 1650 CE (Roos et al. 2021; Swetnam et al. 2016) (see Figure 5.5D). Tree-ring records indicate that most of these fires were small and patchy, creating a fine mosaic of burned and unburned areas (see Figure 5.5C). As a result, fire-climate relationships were disrupted (Swetnam et al. 2016), further reducing the impact of multi-decadal climate variation on fire occurrence. Spatially distant from the areas of most intensive Hemish land use and burning, however, there is soil charcoal and tree-ring evidence for high-severity fire patches and the conversion of forests to alternative vegetative states (Guiterman et al. 2018; Roos and Guiterman 2021). For example, two large (100–300 ha) patches of Gambel oak (*Quercus gambelii*) shrubfields were established by high-severity fires in the 1400s and in 1522 CE (see Figure 5.4B–C). A third was established in 1664 CE within decades of the cessation of Hemish fire management (see Figure 5.4A). In all three cases, the pyrogenic transition to alternative states occurred within or shortly

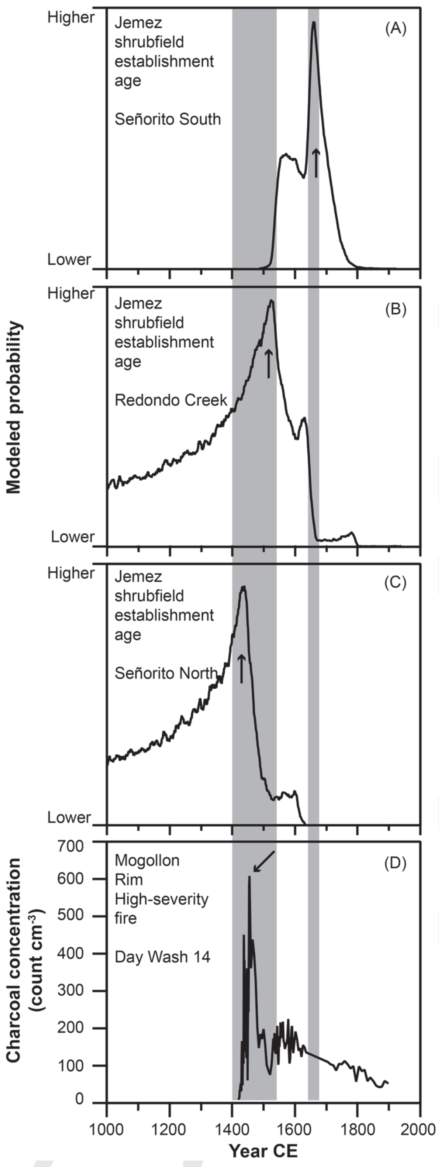

Figure 5.4 Evidence for the timing of high-severity fires (gray bars) at locations at a distance from Indigenous fire management in the Jemez Mountains (Parts A-C; Roos and Guiterman 2021), and in the Mogollon Rim area (Part D; Roos et al. 2023). Parts A-C are the modeled probability of the pyrogenic establishment of permanent shrubfields (an alternative stable state to pine forests). Part D is charcoal concentration from sediments that match modern analog samples from high-severity fires. Arrows indicate high severity fire dates for each location.

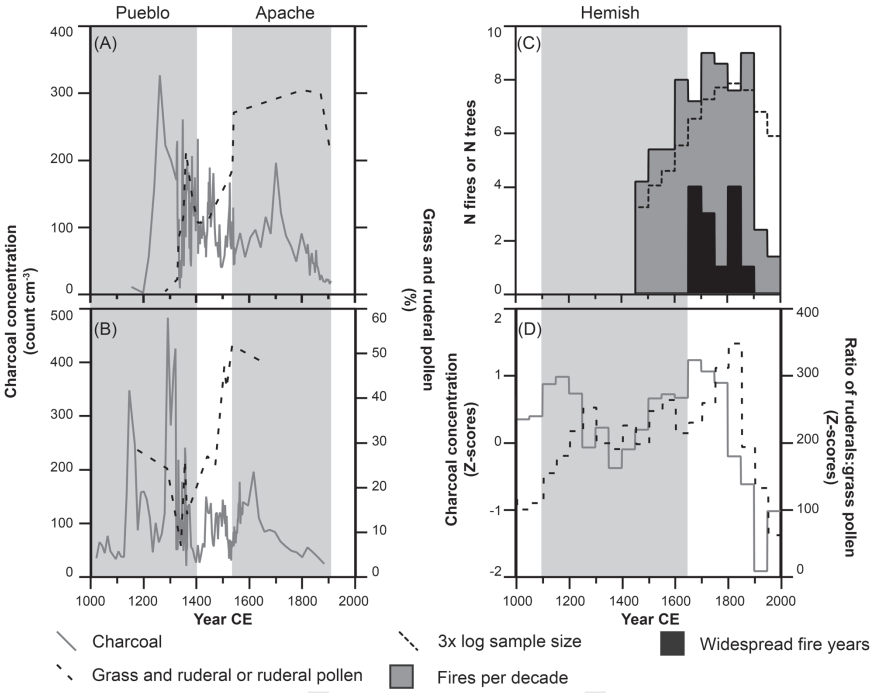

Figure 5.5A–D Charcoal concentrations and pollen of disturbance-loving plants for the Forestdale Valley 6 (Part A) and 10 (Part B) on the Mogollon Rim (Roos et al. 2023), and the Jemez Plateau (Part D) (Roos et al. 2021). Tree-ring based frequencies of all fires (gray) and widespread fires (>25% trees scarred, black; Part C), and sample depth (dashed line). These illustrate elevated charcoal concentrations at both during Ancestral Pueblo occupations of the Mogollon Rim (1100–1400 CE) and Jemez Plateau (1100–1650 CE). Apache burning produced lower charcoal because of repeated patch burning in fine fuels (grasses and ruderals) that produce less charcoal when they burn.

after periods of reduced fire spread in drier contexts and wet and warm or very wet periods conducive to germination and stand infilling (see Figure 5.3). Shrubfields are much rarer in the Ancestral Jemez landscape (2.2% of forest area) than the larger landscape (5.1% of forest area) and those shrubfields in the Hemish landscape may post-date the period of intensive occupation indicating that transitions to alternative vegetative states due to high-severity fire were rare or absent in the most intensively used cultural landscape (Roos et al. 2021).

In the Southwest, recent high severity fires and transitions to alternative vegetative states began in the 1950s, after 50–80 years of fire exclusion (Cooper 1960; Savage and Mast 2005). Four such periods of 50+ years between 1170 and 1622 CE (Roos and Swetnam 2012), when climate drivers of fuel production were infrequent, indicate that forests were equally vulnerable to fire during geographically and culturally variable Indigenous occupations of the Southwest. In the Mogollon Rim region, in areas that were never perennially occupied or were depopulated by 1325 CE, stratigraphic evidence indicates that high severity fires or pyrogenic transitions to alternative vegetative states happened between 1360 and 1450 CE, the longest period of reduced fire spread in the fire–climate model and following a warm and wet period that would have supported stand infilling (Roos, Laluk, et al. 2022; Roos 2008). By contrast, in areas where Indigenous burning persisted until at least 1400 CE there is no evidence for high severity fires or state transitions. These patterns of Indigenous moderation of fire severity are replicated in the Jemez Mountains. In both cases, the long fire-free interval from the fire–climate reconstruction coincided with warm and wet periods that would have facilitated synchronous germination and recruitment of young conifers (Brown and Wu 2005; Swetnam and Brown 2011), potentially reducing the fire resilience of some stands where fire was limited.

Discussion

Small patch burning produces pyrodiversity that can have important ecological consequences. Differences in the spatial pattern of fire can allow fire sensitive taxa to coexist with flammable ones (Trauernicht et al. 2015). Even when fire frequencies are roughly similar between Indigenous and lightning-dominated fire regimes, cultural burning can modulate fire–climate relationships (Bliege Bird et al. 2012; Roos, Guiterman, et al. 2022; Swetnam et al. 2016; Taylor et al. 2016).

As demonstrated here, ancient landscapes that were subject to Native American fire management were more resilient to episodes when climate may have reduced fire spread than landscapes that were not intensively managed. One property that supports ecological resilience is the redundancy of species (or agents) within key functional groups (functional redundancy) (Walker et al. 2006). In this sense, Native American ignitions were "functionally redundant" with the primary non-human ignition source, lightning. This redundance has sometimes made it unclear just how important Indigenous burning was (Allen 2002). However, in this context, Native American burning also gives the system "response diversity" (i.e., redundant agents do not respond to change in the same way) (Walker et al. 2006), in that cultural ignitions do not respond to climatological, environmental, or social conditions the same way that lightning does (if lightning responds at all). When surface fuels are abundant, spatially continuous, and dry enough to burn, this may not matter for fire resilience because lightning ignitions can spread widely. During climate episodes when fire spread was limited by discontinuous surface fuels or fuel moisture then the response diversity provided by Native American burning could have been critical for maintaining fire resilience by keeping low-severity surface fires on landscapes where it otherwise may have been less frequent (see Figure 5.2).

This conclusion has implications for fire management today. Dry pine forests that had historical fire regimes dominated by frequent, low-intensity surface fires are widespread across western North America (see Figure 5.1A). These same forests are now fragmented by roads, fire breaks, and other human infrastructure, including homes in the wildland–urban interface, but more than a century of fire exclusion has made for an overabundance of fuels to carry fires into and through the forests and their canopies. Even as managers leverage natural ignitions for "wildland fire use" (van Wagtendonk 2007) and emphasize management for forest resilience (Stephens et al. 2016), Native American fire management has a lot to offer for ensuring that ecologically and culturally beneficial fires happen where and when they are needed, especially when lightning ignitions and fire spread are insufficient to support the same goals. The historical ecology of Indigenous fire management both supports calls for incorporating cultural burning (Lake et al. 2017) but also the more general call for more prescribed burning and even managing other human ignitions to support fire resilient forests in western North America (Kolden 2019), thus making the case for an Indigenous applied historical ecology of Southwest forests (Swetnam et al. 1999).

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References Cited

Allen, C.D. 2002 Lots of Lightning and Plenty of People: An Ecological History of Fire in the Upland Southwest. In *Fire, Native Peoples, and the Natural Landscape*, edited by T.R. Vale, pp. 143–193. Island Press, Washington DC.

———2004 Ecological Patterns and Environmental Change in the Bandelier Landscape. In *Archaeology of Bandelier National Monument: Village Formation on the Pajarito Plateau, New Mexico*, edited by T.A. Kohler, pp. 19–67. University of New Mexico Press, Albuquerque, NM.

———2016 Forest Ecosystem Reorganization Underway in the Southwestern US: A Preview of Widespread Forest Changes in the Anthropocene. In *Forest Conservation and Management in the Anthropocene: Conference Proceedings*, edited by V.A. Sample, and R.P. Bixler, pp. 103–122, U.S. Department of Agriculture: Rocky Mountain Research Station, general editor. U.S. Department of Agriculture: Rocky Mountain Research Station, Fort Collins.

Basso, K.H. 1983 Western Apache. In *Handbook of North American Indians*, Vol 10, Southwest, edited by A. Ortiz, pp. 462–488. Smithsonian Institution Press, Washington, D.C.

Bigio, E., T.W. Swetnam, and C.H. Baisan 2010 A Comparison and Integration of Tree-ring and Alluvial Records of Fire History at the Missionary Ridge Fire, Durango, Colorado, USA. *The Holocene* 20: 1047–1061.

Bigio, E.R., T.W. Swetnam, and P.A. Pearthree 2017 Late Holocene Fire–Climate Relationships of the Western San Juan Mountains, *Colorado. International Journal of Wildland Fire* 26: 944–962.

Bliege Bird, R., B.F. Codding, P.G. Kauhanen, and D.W. Bird. 2012 Aboriginal Hunting Buffers Climate-Driven Fire-Size Variability in Australia's Spinifex Grasslands. *Proceedings of the National Academy of Sciences* 109(26): 10287–10292.

Bohrer, V.L. 1983 New Life from Ashes: The Tale of the Burnt Bush (*Rhus trilobata*). *Desert Plants* 5(3): 122–125.

Brown, P.M., and R. Wu 2005 Climate and Disturbance Forcing of Episodic Tree Recruitment in a Southwestern Ponderosa Pine Landscape. *Ecology* 86(11): 3030–3038.

Buskirk, W. 1986 *The Western Apache: Living with the Land Before 1950*. University of Oklahoma Press, Norman, OK.

Cook, E.R., R. Seager, R.R. Heim, R.S. Vose, C. Herweijer and C. Woodhouse 2010 Megadroughts in North America: Placing IPCC Projections of Hydroclimatic Change in a Long-Term Palaeoclimate Context. *Journal of Quaternary Science* 25(1): 48–61.

Coop, J.D., S.A. Parks, C.S. Stevens-Rumann, S.D. Crausbay, P.E. Higuera, M.D. Hurteau, A. Tepley, E. Whitman, T. Assal, B.M. Collins, K.T. Davis, S. Dobrowski, D.A. Falk, P.J. Fornwalt, P.Z. Fulé, B.J. Harvey, V.R. Kane, C.E. Littlefield, E.Q. Margolis, M. North, M.A. Parisien, S. Prichard and K.C. Rodman 2020 Wildfire-Driven Forest Conversion in Western North American Landscapes. *BioScience* 70(8): 659–673.

Cooper, C.F. 1960 Changes in Vegetation, Structure, and Growth of Southwestern Pine Forests since White Settlement. *Ecological Monographs* 30(2): 130–164.

Dieterich, J.H., and T.W. Swetnam 1984 Dendrochronology of a Fire Scarred Ponderosa Pine. *Forest Science* 30: 238–247.

Fitch, E.P., and G.A. Meyer 2016 Temporal and Spatial Climatic Controls on Holocene Fire-Related Erosion and Sedimentation, Jemez Mountains, New Mexico. *Quaternary Research* 85(1): 75–86.

Forbes, J.D. 1960 *Apache, Navaho, and Spaniard*. University of Oklahoma Press, Norman, OK.

Frechette, J.D., and G.A. Meyer 2009 Holocene Fire-Related Alluvial-Fan Deposition and Climate in Ponderosa Pine and Mixed-Conifer Forests, Sacramento Mountains, New Mexico, USA. *The Holocene* 19(4): 639–651.

Fulé, P.Z., W.W. Covington, and M.M. Moore 1997 Determining Reference Conditions for Ecosystem Management of Southwestern Ponderosa Pine Forests. *Ecological Applications* 7: 895–908.

Gifford, E.W. 1940 *Apache-pueblo. Culture Element Distributions: XII* . University of California Press, Berkeley, CA.

Graves, M.W. 1982 Apache Adaptation to the Mountains. In *Cholla Project Archaeology*, Vol 3: the Q Ranch region, edited by J.J. Reid, pp. 193–215. Arizona State Museum Archaeological Series No. 161, Tucson, Arizona.

Griffin, P.B.., M.P. Leone, and K.H. Basso 1971 Western Apache Ecology: From Horticulture to agriculture. In *Apachean Culture History and Ethnology*, edited by K.H. Basso, and M.E. Opler, pp. 69–73. Anthropological Papers, Number 21, Vol. 21. University of Arizona Press, Tucson, AZ.

Guiterman, C.H., Ellis Q. Margolis, C.D. Allen, D.A. Falk, and T.W. Swetnam 2018 Long-Term Persistence and Fire Resilience of Oak Shrubfields in Dry Conifer Forests of Northern New Mexico. *Ecosystems* 21(5): 943–959.

Haury, E.W. 1957An Alluvial Site on the San Carlos Indian Reservation, Arizona. *American Antiquity* 23: 2–27.

Haury, E.W., and E.B. Sayles 1985 [1947] An Early Pit House Village of the Mogollon Culture, Forestdale Valley, Arizona. In *Mogollon Culture in the Forestdale Valley, East-Central Arizona*, pp. 220–371. University of Arizona Press, Tucson.

Herr, S.A. 2001 *Beyond Chaco: Great Kiva Communities on the Mogollon Rim Frontier*. Anthropological Papers of the University of Arizona, Number 66. University of Arizona Press, Tucson, AZ.

——— 2013 In Search of Lost Landscapes: The Pre-Reservation Western Apache Archaeology of Central Arizona. *American Antiquity* 78(4): 679–701.

Huckell, L.W. 1999 Paleoethnobotany. In *Living on the Edge of the Rim: Excavations and Analysis of the Silver Creek Archaeological Research Project 1993–1998*, Vol 2, edited by B.J. Mills, S.A. Herr, and S.V. Keuren, pp. 459–504. Arizona State Museum Archaeological Series 192. University of Arizona, Tucson, AZ.

Jenkins, S.E., C. Hull Sieg, D.E. Anderson, D.S. Kaufman, and P.A. Pearthree 2011 Late Holocene Geomorphic Record of Fire in Ponderosa Pine and Mixed-Conifer Forests, Kendrick Mountain, Northern Arizona, USA. *International Journal of Wildland Fire* 20(1): 125–141.

Kaldahl, E.J., and J.S. Dean 1999 Climate, Vegetation, and Dendrochronology. In *Living on the Edge of the Rim: Excavations and Analysis of the Silver Creek Archaeological Research Project 1993–1998*, edited by B.J. Mills, S.A. Herr, and S.V. Keuren. Archaeological Series No. 192. Arizona State Museum, Tucson, AZ.

Kitzberger, T., P.M. Brown, E.K. Heyerdahl, T.W. Swetnam, and T.T. Veblen 2007 Contingent Pacific-Atlantic Ocean Influence on Multicentury Wildfire Synchrony over Western North America. *Proceedings of the National Academy of Sciences* 104: 543–548.

Kolden, C.A. 2019 We're Not Doing Enough Prescribed Fire in the Western United States to Mitigate Wildfire Risk. *Fire* 2(2): 30.

Kulisheck, J. 2005 *The Archaeology of Pueblo Population Change on the Jemez Plateau, A.D. 1200 to 1700: The Effects of Spanish Contact and Conquest Unpublished PhD Dissertation*, Department of Anthropology, Southern Methodist University, Dallas, TX.

Lake, F.K., V. Wright, P. Morgan, M. McFadzen, D. McWethy and C. Stevens-Rumann 2017 Returning Fire to the Land: Celebrating Traditional Knowledge and Fire. *Journal of Forestry* 115(5): 343–353.

LeTourneau, P.D, and T. Baker 2002 The Role of Obsidian in Folsom Lithic Technology. In *Folsom Technology and Lifeways*, edited by J.E. Clarke, and M.B. Collins, pp. 31–45, Vol. Special Publications No. 4. University of Tulsa, Tulsa.

Liebmann, M.J., J. Farella, C.I. Roos, A. Stack, S. Martini and T.W. Swetna. 2016 Native American Depopulation, Reforestation, and Fire Regimes in the Southwest United States, 1492–1900 CE. *Proceedings of the National Academy of Sciences* 113(6): E696–E704.

Mann, M.E., Z. Zhang, S. Rutherford, R.S. Bradley, M.K. Hughes, D. Shindell, C. Ammann, G. Fuluvegi and F. Ni. 2009 Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly. *Science* 326: 1256–1260.

Margolis, E.Q., C.A. Woodhouse, and T.W. Swetnam 2017 Drought, Multi-Seasonal Climate, and Wildfire in Northern New Mexico. *Climatic Change* 142(3): 433–446.

Margolis, E.Q., C.H. Guiterman, R. Chavardès, J. Coop, K. Copes-Gerbitz, D. Dawe, D.A. Falk, J. Johnston, E.R. Larson, H. Li, J.M. Marschall, C. Naficy, A.T. Naito, M.A. Parisien, S.A. Parks, J. Portier, H.M. Poulos, K.M. Robertson, J. Speer, M.C. Stambaugh, T.W. Swetnam, A.J. Tepley, I. Thapa, C.D. Allen, Y. Bergeron, L. Daniels, P.Z. Fulé, D. Gervais, M.P. Girardin, G.L. Harley, J. Harvey, K. Hoffman, J. Huffman, M.D. Hurteau, L.B. Johnson, C.W. Lafon, M. Lopez, R.S. Maxwell, J. Meunier, M. North, M.T. Rother, M. Schmidt, R. Sherriff, L.A. Stachowiak, A. Taylor, E.J. Taylor, V. Trouet, M.Villarreal, L.L.Yocom, K. Arabas, A. Arizpe, D. Arseneault, A. Azpeleta Tarancón, C.H. Baisan, E. Bigio, F. Biondi, G. Cahalan, A.C. Caprio, J. Cerano-Paredes, B.M. Collins, D.C. Dey, I. Drobyshev, C. Farris, M. Fenwick, W. Flatley, M.L. Floyd, Z. Gedalof, A. Holz, L. Howard, D.W. Huffman, J.M. Iniguez, K.F. Kipfmueller, S.G. Kitchen, K. Lombardo, D. McKenzie, A. Merschel, K. Metlen, J. Minor, C.D. O'Connor, L. Platt, W.J. Platt, T. Saladyga, A.B. Stan, S.L. Stephens, C. Sutheimer, R. Touchan, and P.J. Weisberg. 2022 The North American Fire Scar Network. *Ecosphere* 13.

McLauchlan, K.K., P.E. Higuera, J. Miesel, B.M. Rogers, J. Schweitzer, J.K. Shuman, A.J. Tepley, J.M. Varner, T.T. Veblen, S.A. Adalsteinsson, J.K. Balch, P. Baker, E. Batllori, E. Bigio, P. Brando, M. Cattau, M.L. Chipman, J. Coen, R. Crandall, L. Daniels, N. Enright, W.S. Gross, B.J. Harvey, J.A. Hatten, S. Hermann, R.E. Hewitt, L.N. Kobziar, J.B. Landesmann, M.M. Loranty, S.Y. Maezumi, L. Mearns, M. Moritz, J.A. Myers, J.G. Pausas, A.F.A. Pellegrini, W.J. Platt, J. Roozeboom, H. Safford, F. Santos, R.M. Scheller, R.L. Sherriff, K.G. Smith, M.D. Smith, and A.C. Watts 2020 Fire as a Fundamental Ecological Process: Research Advances and Frontiers. *Journal of Ecology* 108(5): 2047–2069.

Mills, Barbara J., and S.A. Herr 1999 Chronology of the Mogollon Rim Region. In *Living on the Edge of the Rim: Excavations and Analysis of the Silver Creek Archaeological Research Project 1993–1998*, Vol 1, edited by B.J. Mills, S.A. Herr, and S.V. Keuren, pp. 269–293. *Arizona State Museum Archaeological Series 192*. University of Arizona, Tucson.

Mills, B.J., S.A. Herr, E.J. Kaldahl, J.M. Newcomb, C.R. Riggs and R.M. Van Dyke. 1999 Excavations at Pottery Hill. *Living on the Edge of the Rim: Excavations and Analysis of the Silver Creek Archaeological Research Project 1993–1998* 1: 117–148.

Moore, M.M., W.W. Covington, and P.Z. Fulé 1999 Reference Conditions and Ecological Restoration: A Southwestern Ponderosa Pine Perspective. *Ecological Applications* 9: 1266–1277.

Newcomb, J.M.1999 Silver Creek Settlement Patterns and Paleodemography. In *Living on the Edge of the Rim: Excavations and Analysis of the Silver Creek Archaeological Research Project 1993–1998*, Vol 1, edited by B.J. Mills, S.A. Herr, and S.V. Keuren, pp. 31–52. Arizona State Museum Archaeological Series 192. University of Arizona, Tucson.

Orem, C.A., and J.D. Pelletier 2016 The Predominance of Post-Wildfire Erosion in the Long-Term Denudation of the Valles Caldera, New Mexico. *Journal of Geophysical Research: Earth Surface* 121(5): 843–864.

Roos, C.I. 2008 Fire, Climate, and Social-Ecological Systems in the Ancient Southwest: Alluvial Geoarchaeology and Applied Historical Ecology. Ph.D. Unpublished Ph.D. Dissertation, Anthropology, University of Arizona, Tucson.

Roos, C.I., and C.H. Guiterman 2021 Dating the Origins of Persistent Oak Shrubfields in Northern New Mexico using Soil Charcoal and Dendrochronology. *The Holocene* 31(7): 1212–1220.
Roos, C.I, C.H. Guiterman, E.Q. Margolis, K.T. Thompson, N.C. Laluk, C. Toya, M. Kaib and T.W. 2023 Indigenous Fire Management and Cross-Scale Fire-Climate Relationships in the Southwest US from 1500–1900 CE. *Science Advances* 8: eabq3221.
Roos, C.I, N.C. Laluk, W.T. Reitze, and O.K. Davis 2022 Stratigraphic Evidence for Culturally Variable Indigenous Fire Regimes in Ponderosa Pine Forests of the Mogollon Rim Area, East-Central Arizona. *Quaternary Research* 113: 69–86.
Roos, C.I., T.M. Rittenour, T.W. Swetnam, R.A. Loehman, K.L. Hollenback, M.J. Liebmann, and D.D. Rosenstein 2020 Fire Suppression Impacts on Fuels and Fire Intensity in the Western U.S.: Insights from Archaeological Luminescence Dating in Northern New Mexico. *Fire* 3: 32.
Roos, C.I., and T.W. Swetnam 2012 1416-year Reconstruction of Annual, Multi-Decadal, and Centennial Variability in Area Burned for Ponderosa Pine Forests of the Southern Colorado Plateau Region, Southwest US. *The Holocene* 22: 281–290.
Roos, C.I., T.W. Swetnam, T.J. Ferguson, M.J. Liebmann, R.A. Loehman, J.R. Welch, E.Q. Margolis, C.H. Guiterman, W.C. Hockaday, M.J. Aiuvalasit, J. Battillo, J. Farella, and C.A. Kiahtipes. 2021 Native American Fire Management at an Ancient Wildland–Urban Interface in the Southwest United States. *Proceedings of the National Academy of Sciences* 118: e2018733118.
Salzer, M.W., A.G. Bunn, N.E. Graham, and M.K. Hughes 2014 Five Millennia of Paleotemperature from Tree-rings in the Great Basin, USA. *Climate Dynamics* 42(5): 1517–1526.
Savage, M., P.M. Brown, and J. Feddema 1996 The Role of Climate in a Pine Forest Regeneration Pulse in the Southwestern United States. *Ecoscience* 3: 310–318.
Savage, M. and J. Nystrom Mast 2005 How Resilient are Southwestern Ponderosa Pine Forests after Crown Fires? *Canadian Journal of Forest Research* 35(4): 967–977.
Savage, M., J.Nystrom Mast, and J.J. Feddema 2013 Double Whammy: High-severity Fire and Drought in Ponderosa Pine Forests of the Southwest. *Canadian Journal of Forest Research* 43(6): 570–583.
Stephens, Scott L., B.M. Collins, E. Biber, and P.Z. Fulé 2016 U.S. Federal Fire and Forest Policy: Emphasizing Resilience in Dry Forests. *Ecosphere* 7(11): e01584roos.
Sullivan, A.P. and P.B. Mink 2018 Theoretical and Socioecological Consequences of Fire Foodways. *American Antiquity* 83(4): 619–638.
Swetnam, T.W., C.D. Allen, and J.L. Betancourt 1999 Applied Historical Ecology: Using the Past to Manage for the Future. *Ecological Applications* 9: 1189–1206.
Swetnam, T.W., and C.H. Baisan 2003 Tree-ring Reconstructions of Fire and Climate History of the Sierra Nevada and Southwestern United States. In *Fire and Climate Change in Temperate Ecosystems of the Western Americas*, edited by T.T. Veblen, C.M. Baker, G. Montenegro, and T.W. Swetnam, pp. 158–195. Springer, New York, NY.
Swetnam, T.W. and J.L. Betancourt 1998 Mesoscale Disturbance and Ecological Response to Decadal Climatic Variability in the American Southwest. *Journal of Climate* 11: 3128–3147.
Swetnam, T.W. and P.M. Brown 2011 Climatic Inferences from Dendroecological Reconstructions. In *Dendroclimatology*, Vol 8, edited by M.K. Hughes, T.W.

Swetnam, and H.F. Diaz, pp. 263–295. *Developments in Paleoenvironmental Research*. Springer Netherlands.

Swetnam, T.W., J. Farella, C.I. Roos, M.J. Liebmann, D.A. Falk, and C.D. Allen 2016 Multiscale Perspectives of Fire, Climate and Humans in Western North America and the Jemez Mountains, USA. *Philosophical Transactions of the Royal Society B: Biological Sciences* 371(1696): 20150168.

Taylor, A.H., V. Trouet, C.N. Skinner, and S. Stephens 2016 Socioecological Transitions Trigger Fire Regime Shifts and Modulate Fire–Climate Interactions in the Sierra Nevada, USA, 1600–2015 CE. *Proceedings of the National Academy of Sciences* 113(48): 13684–13689.

Tosa, P., M.J. Liebmann, T.J. Fergusons, and J.R. Welch 2019 Movement Encased in Tradition and Stone: Hemish Migration, Land Use, and Identity. In *The Continuous Path: Pueblo Movement and the Archaeology of Becoming*, edited by S. Duwe, and R.W. Preucel, pp. 60–77. Amerind Foundation and University of Arizona Press, Tucson.

Trauernicht, C., B.W. Brook, B.P. Murphy, G.J. Williamson, and D.M.J.S. Bowman 2015 Local and Global Pyrogeographic Evidence that Indigenous Fire Management Creates Pyrodiversity. *Ecology and Evolution* 5(9): 1908–1918.

van Wagtendonk, J.W. 2007 The History and Evolution of Wildland Fire Use. *Fire Ecology* 3(2): 3–17.

Walker, B.H., L.H. Gunderson, A.P. Kinzig, C. Folke, S.R. Carpenter, and L. Schultz 2006 A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems. *Ecology and Society* 11(1): 13 [online].

Welch, J.R., and R. Riley 2001 Reclaiming Land and Spirit in the Western Apache Homeland. *American Indian quarterly* 25(1): 5–12.

White, L.A. 1943 *New material from Acoma. Bureau of American Ethnology Bulletin 136*. Smithsonian Institution, Washington, D.C.

Whitlock, C., P.E. Higuera, D.B. McWethy, and C.E. Briles 2010 Paleoecological Perspectives on Fire Ecology: Revisiting the Fire-Regime Concept. *The Open Ecology Journal* 3: 6–23.

Williams, A.P., E.R. Cook, J.E. Smerdon, B.I. Cook, J.T. Abatzoglou, K. Bolles, S.H. Baek, A.M. Badger, and B. Livneh 2020 Large Contribution from Anthropogenic Warming to an Emerging North American Megadrought. *Science* 368(6488): 314–318.