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Pre-contact Indigenous fire stewardship: a research framework and application to a Pacific Northwest temperate rainforest

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Fire is a key disturbance process that shapes the structure and function of montane temperate rainforest in the Pacific Northwest (PNW). Recent research is revealing more frequent historical fire activity in the western central Cascades than expected by conventional theory. Indigenous peoples have lived in the PNW for millennia. However, Indigenous people's roles in shaping vegetation mosaics in montane temperate forests of the PNW has been overlooked, despite archaeological evidence of long-term, continuous human use of these landscapes. In this paper, we present a generalizable research framework for overcoming biases often inherent in historical fire research. The framework centers Indigenous perspectives and ethnohistory, leveraging theory in human ecology and archaeology to interpret fire histories. We apply this framework to place-based, empirical evidence of Indigenous land use and dendroecological fire history. Our framework leads us to conclude that the most parsimonious explanation for the occurrence of historical high fire frequency in the western Cascades is Indigenous fire stewardship. Further, our case study makes apparent that scholars can no longer ignore the role of Indigenous people in driving montane forest dynamics in the PNW.

KEYWORDS
historical ecology, anthropogenic fire, traditional fire use, cultural burning, dendroecology, Oregon Cascades

1 Introduction

Fire is a key disturbance process that shapes the structure and function of North American Pacific Northwest (PNW) forested landscapes (Agee, 1993). Indigenous people in the PNW successfully coexisted with the region's fire regimes for thousands of years and, in some landscapes, they exerted considerable control over those fire regimes through intentional timing and location of ignitions over millennia of resource use and stewardship. Historical documentation of Indigenous fire use in the Willamette Valley, Puget Sound Basin, and seasonally dry forests of southern Oregon (Johannessen et al., 1971; Boyd, 1999) leaves little doubt that Indigenous people used fire to favor and enhance economically important resources in a wide variety of ecological contexts in the PNW. Conceptually these findings about Indigenous fire use in the PNW are relatively uncontroversial among archaeologists and others in the social sciences and humanities (e.g., Tveskov, 2007; Deur, 2009; Aikens et al., 2011; Turner et al., 2011).

Despite this consensus in the social sciences, theory and interpretive frameworks in the biophysical sciences continue to approach the question of the significance of Indigenous peoples' historical influence the region's fire regimes with caution. Indeed, regionally focused paleoecological evidence points toward climate rather than humanity as the dominant driver of fire regimes in the PNW (Whitlock and Knox, 2002; Whitlock, 2008; Oswald et al., 2023). While climate drivers are undoubtedly important, research in New England has used similar results to claim that the dominance of regional climate on fire regimes renders past Indigenous stewardship irrelevant for contemporary restoration and management (Oswald et al., 2020a,b). This argument has recently been extended to the PNW (Oswald et al., 2023), based on work that suggests potential human influences on landscapes were "local" and constrained to lower elevation coastal areas and inland valleys, such as the Willamette Valley, where historical Euro-American documentation of fire use is given more credence (Walsh et al., 2015; Whitlock et al., 2015).

These narratives coupled with iconic images of giant trees and the relative absence of wildfire during the tenure of US Forest Service management (ca. 1893 CE to present) have led many observers to conclude that Indigenous deployment of low-severity cultural fires would have had little impact on forest structure in the highly productive temperate rainforests of the western Cascades. This general sentiment is echoed in recent scholarship that suggests management interventions that reduce fuel loads, such as prescribed fires (similar to Indigenous cultural fire), will not increase resilience to wildfire in the western Cascades (Halofsky et al., 2018; Reilly et al., 2022).

Roos (2020) and others (Leonard et al., 2020) have pointed out that much of the disagreement over the impacts of cultural fire relates to the scale of inquiry and the methods employed to arrive at regionally valid conclusions, both of which may preclude accurate representations of Indigenous fire signals within long-term fire histories. We concede that historical Indigenous fire stewardship in the PNW may not have significantly altered forest successional trajectories at a regional level—or at least that it did not alter them ubiquitously or homogenously throughout the region. It remains important to empirically define the character and scale of historical Indigenous fire stewardship before dismissing its relevancy to contemporary land management. In other words, if the consequences of Indigenous fire stewardship were simply "local," we should define what "local" means in this context, specifically in terms of its ecological effects, spatial footprint, patch size, and distribution of locations across the region. Nevertheless, we also acknowledge that conceptual, methodological, and data-related challenges remain in the effort to link human agency to long-term fire histories at any scale.

In this paper, we briefly review current theory on the fire ecology of temperate rainforests of the western Cascades and highlight some reasons for how and why the question of Indigenous fire stewardship should receive more attention. We then propose a transdisciplinary research framework for overcoming previously intractable research questions about Indigenous fire stewardship in highly productive montane forest settings. We further describe our application of this framework to the Middle Fork study area on national forest land in the western Oregon Cascades where recent dendroecological research (Johnston et al., 2023) reveals far more frequent fire than predicted by theory. Although our framework has been tailored to the PNW and, further, to the empirical context of our study area, we suggest that the overarching approach is broadly generalizable and the methods for operationalizing these hypotheses may have applicability elsewhere around the globe.

2 Temperate rainforests, fire, and humans in the PNW

2.1 Forest and fire ecology

Temperate rainforests of the PNW are typically characterized as highly productive, closed canopy coniferous forests with coastal Douglas-fir (*Pseudotsuga menziesii var. menziesii*) often dominating the overstory. Contemporary ecological theory asserts that outside of human interventions, forest succession in Douglas-fir forests in this region is uninterrupted by fire for centuries (Agee, 1993; Franklin et al., 2002). In this theory, long fire-free periods are punctuated by large stand-replacing fires burning during periods of anomalously dry and windy conditions. Much of the ecological knowledge produced on the temperate rainforests of the PNW comes from studies conducted at the H.J. Andrews Experimental Forest and Long-Term Ecological Research (LTER) Site (Turner et al., 2003), a research area that was specifically located in steep, rugged terrain with dense, mesic old growth forest to increase efficiencies for logging old growth trees in difficult-to-access areas (Robbins, 2020). The high density of biomass and structural complexity of these and other old growth forests in the PNW are assumed to be evidence for the near complete absence of pre-Euro-American human intervention (Whitlock et al., 2015).

Vast portions of old growth Douglas fir forests in the PNW were logged between the early 1950s and late 1980s (Clary, 1986). In reaction to habitat destruction caused by logging, public and policy-maker attention has more recently focused on creation of wilderness areas and habitat reserves[1] designed with the explicit assumption that complex late-successional forests originated in the absence of past human agency and can best be maintained in the absence of future human intervention (Thomas et al., 2006). As a result, large portions of PNW forests have been virtually unmanaged since the mid-1990s (Franklin and Norman Johnson, 2014).

2.2 Changing forests and Indigenous occupation and removal

High-severity, stand-replacing fires are a significant and recurrent component of the region's ecosystems and the susceptibility of PNW forests to severe wildfires is increasing (Davis et al., 2017). Recent research has attributed this increase

1 For example, since 1994, the Northwest Forest Plan which applies to national forests in northern California, western Oregon and Washington, strictly limits active management across large areas designated as Late Successional Reserves in addition to officially designated wilderness areas.

in severe wildfire to the volatile combination of changing climate and forest management including a century of fire suppression, legacies of industrial timber extraction, and a recent decline in the management capacities of federal forest management agencies (Halofsky et al., 2020; Hessburg et al., 2022). As has recently been observed for forests in southeastern Australia (Fletcher et al., 2021), a less discussed and poorly understood additional factor potentially contributing to increased high-severity wildfire is the forced removal of Indigenous people from their traditional territories. This removal resulted in a near complete reduction of cultural stewardship activities, curtailing millennia of resource use and stewardship.

The absence of Indigenous removal in the analysis of Cascadian forest history is not due to the lack of evidence for human occupation of the region. Indigenous oral traditions attest to the fact that humans have lived in the PNW since "time immemorial" and are supported by multiple archaeological datasets. Radiocarbon dated materials from Cooper's Ferry site (10IH73) in western Idaho confirm human occupation of the region by at least 16,000 years ago (Davis et al., 2022), and material from Rimrock Draw Rockshelter (35HA3855) in eastern Oregon extends that date to 18,250 years ago (O'Grady, 2022). Within the Cascades themselves, finds at Cascadia Cave (35LIN11) in the central western portion of the range, have been radiocarbon dated to 9,450 calibrated years before present (cal BP)[2] (Baxter, 2023). Archaeological evidence from Cascadia Cave suggests that upland areas functioned as generalized hunting and gathering stations for highly mobile groups (Baxter, 2023). Regional-level archaeological and ethnohistorical summaries (Minor and Pecor, 1977; Aikens et al., 2011) point to long-term, persistent use of the Cascades by Indigenous hunter-gatherers from at least 10,000 years ago through the Euro-American Contact era.

Although the long tenure of Indigenous occupation of the Cascades was not static or unchanging, significant and relatively rapid changes to Indigenous populations and their practices began in the late 18th century CE if not earlier due to the adoption of horses, engagements with the European fur trade, and impacts of European-born epidemics (Boyd, 1999; Sobel, 2012). Beginning in the 1840s Euro-American settlement caused the dispossession of Indigenous peoples from their traditional lands. In the immediate years following epidemics and in the 1850s with federal policies restricting Indigenous peoples to reservations, far fewer people were making their annual seasonal rounds into the forest. The long history of successful Indigenous occupation of the Cascades juxtaposed with the recent increase in wildfire severity, point to a significant need to improve our understanding of the historical relationships between people, forest conditions, and fire as well as the implications of Indigenous removal on the landscapes of the Cascades.

2 In this paper we reference time in the past using Before Present (BP) for Pre-Contact Era archaeological data and Common Era (CE) Contact Era archaeology, history, and dendrochronological data. We note that 0 BP is defined as 1950 CE.

3 Reframing research priorities for historical Indigenous fire stewardship in the PNW

We submit that a decisive role for human agency in fire regimes of the highly productive forests of western Oregon and Washington is not exclusive of the persistence of complex old-growth habitat or strong, regional climate controls on broad-scale fire activity. In our theoretical schema, fire occurrence is influenced by variability in climate, but climate influence on fire and vegetation feedback is modulated by thoughtfully timed and placed human ignitions.

Our transdisciplinary research framework (Figure 1) consists of three components:

- Engaging descendant communities and their perspectives.
- Employing a place-based, human-ecology-centered approach that prioritizes research in locations and at scales most likely to yield evidence for human-fire interactions.
- Developing testable hypotheses and selecting appropriate methods to address them by synthesizing Indigenous perspectives, ethnohistory, and existing empirical evidence of ecological and archaeological landscape legacies.

The interdisciplinarity of our research team and our dialogue with Indigenous communities enhances our abilities to ask the right questions. A purposive, place-based sampling strategy allows us to empirically address hypotheses about human fire-interaction that derive from theory in human ecology, fire ecology, and Indigenous oral traditions. Lastly, we leverage our collaboration and multi-proxy data to improve our inferential abilities and to enhance the accuracy of our synthetic interpretations.

3.1 Co-production with descendant communities and Indigenous scholars

The investigation of past use of fire by Indigenous peoples requires multiple perspectives and diverse sources of evidence. In landscapes where descendant communities persist, it is fundamental to build collaborative relationships with those communities (Lake, 2021; Steen-Adams et al., 2023) as early in the research development process as possible. In addition to ethical considerations of including Indigenous peoples in this type of research, Indigenous knowledge and perspectives provide critical contributions because they often include nuanced, site-specific insights that encode long-term observations and experiences with place-based socioecological phenomena. However, collaboration is not exclusively about the incorporation of traditional ecological knowledge into interpretive frameworks. In some cases, Indigenous communities and their cultural heritage has been lost or severely diminished due to decades or centuries of colonial violence and oppression. In other cases, generations of colonial repression and exploitation mean collection and public dissemination of this information can be problematic in ways non-Indigenous people rarely consider. Descendant communities are often cautious about sharing their knowledge because it is considered privileged and sacred and because those communities want to retain ownership

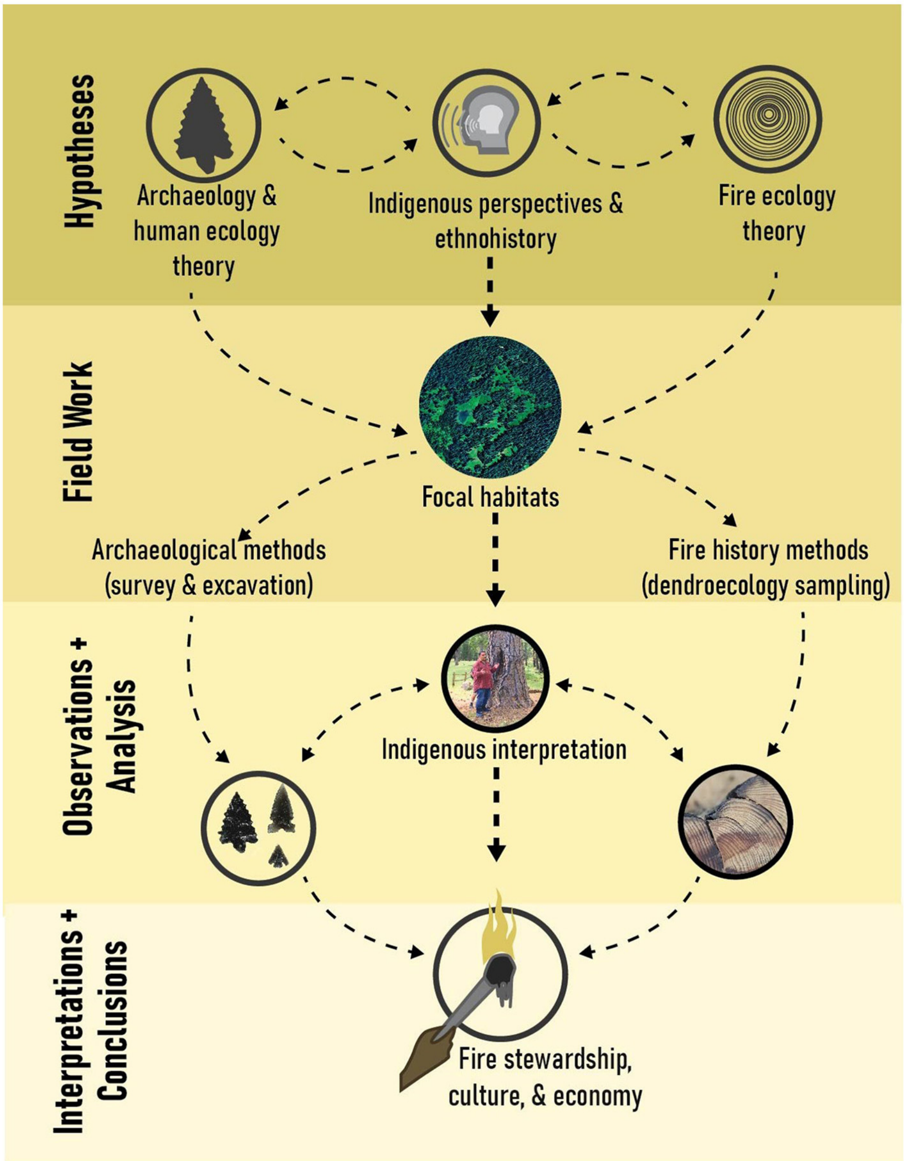

FIGURE 1
Research framework showing relationship of concepts, including Indigenous perspectives, across the various stages of the research process.

to avoid misappropriation and potential harms that sharing information could cause (Lake, 2021).

Our framework aims to integrate Indigenous perspectives and interests, with the goal of working closely with descendant communities (Native American Tribes in the case of the US PNW) to co-produce research that is non-extractive, respectful, congruent with community values, and advances community interests and priorities. In the PNW, this is a challenging task given the need to work with multiple Tribes with complex histories tied to early colonial conflicts, broken treaties and agreements, confinement to reservations, and Tribal termination and restoration. These histories document on-going inequities between Tribes and neighboring communities and institutions. Tribes in the state of Oregon have rightful, overlapping claims to traditional territories. Some Tribes have limited resources available to allocate to research activities. Despite these issues, we suggest it is crucial to engage descendant communities, to develop mutually beneficial relationships, and where appropriate, to make explicit agreements about data sovereignty and the dissemination of results. The results of collaboration may not always manifest as formal agreements or novel interpretations of scientific inquiry but may instead guide the types of questions asked and methods employed. We do not view collaboration with Indigenous communities as a specific tangible research result, although that can be one kind of outcome. Rather, we view it as an ongoing process integral to the overall effort of knowledge production.

For many Indigenous communities in the PNW and elsewhere, a basic component of traditional lifeways concerns the use of fire to steward successional pathways of traditional landscapes in ways that enhanced predictability and productivity of the resource base.

Among some Indigenous communities, the traditional practice of fire stewardship has continued and in other cases it is currently being rekindled as part of cultural revitalization initiatives. This type of fire use is known in the anthropological literature as the *"firestick farming"* hypothesis (Lewis, 1972; Bliege Bird et al., 2008; Jones, 2012) and is well supported within a multitude of Indigenous oral traditions as "fire stewardship" and "cultural fire" (Kimmerer and Lake, 2001; Lake et al., 2017). Rather than viewing human ignitions as a "black box" of decisions and accidents by a fire-wielding species, this conception of anthropogenic fire suggests that the use of broadcast fire by hunter-gatherers was a purposive resource management strategy employed to facilitate hunting and gathering, and to maintain, improve, and expand focal resources over generational timeframes.

Conventional approaches to establishing an "anthropogenic" signal in a fire regime presume that the natural ignitions (such as lightning) must first be rejected as an explanation for observed fire frequency (Allen, 2002). This conventional approach suggests that human ignitions must be shown to have clearly diverged from expectations of fire under a climate-driven lightning regime. These assumptions do not align with the logic of Indigenous fire stewardship where cultural fire is specifically aimed at "influencing and diversifying" a variety of different aspects of the fire regime (Lake et al., 2017), not simply increasing fire frequencies. Increased fire frequency may be a sufficient condition to invoke an anthropogenic signal, but since cultural fire does not necessarily result in significantly augmented fire frequencies, it is not a necessary one. Our framework flips this conventional approach on its head. We suggest that Indigenous oral tradition (supplemented by ethnohistorical documentation) should drive our inquiry and help shape our research design. The concept of Indigenous fire stewardship is one of reciprocal relationships which contrasts starkly with dominant Western notions of opposition and control (e.g. the mentality of fire suppression and agency-led prescribed fire) (Eriksen and Hankins, 2014; Coughlan et al., 2023). Consequently, research should seek to uncover empirical relationships between the historical fire regime and evidence for settlement and the subsistence activities that oral traditions reference. Once the spatial and temporal relationships between fire and human behavior are established, interpretations should rely on Indigenous oral traditions and theory in human ecology to explicate patterns of fire use.

3.2 Place-based research and focal habitats

Through our framework, we seek to identify the different spatial and temporal domains across which people used fire to steward their resource base, to improve productivity and to attenuate the potential impacts of unmanaged wildfires. In the PNW, we are fortunate to have Indigenous knowledge and ethnohistorical information that can inform on the types of habitats where Indigenous fire was applied. Based on this information, we suggest that it is crucial to purposively sample—at the landscape scale—places with a higher probability for long-term and more intensive human use and occupation. Such landscapes typically remain important to Indigenous peoples' cultural identity and shared memories, they often exhibit a high density of archaeological materials evidencing long term, persistent occupation, and they often retain high densities of culturally important plants, animals, or other resources (Lepofsky et al., 2017).

Cascadian landscapes were never homogeneous stands of closed canopy forest or their successional antecedents. They historically contained montane grasslands and more open, grass and shrub dominated forest structures such as glades and savannas as well as wet meadows and open areas along the edges of ponds and lakes. These places and their resources are frequently referenced by Indigenous oral traditions and continue to be highly valued by descendant communities (Deur, 2002, 2009; Turner et al., 2011; Steen-Adams et al., 2019). These types of habitats are also most closely associated with archaeological evidence of Indigenous upland resource use in the Cascades (Kelly, 2001; Carloni, 2005). However, ecological investigations of Cascade montane grasslands have focused primarily on subalpine meadows—often within wilderness areas—rather than the full range of high-elevations, mid-mountain slopes, and river bottoms. Subalpine meadow infill by conifers has been documented as occurring anywhere from ca. 200 years ago to as late as the mid-1900s (Haugo and Halpern, 2007; Halpern et al., 2010). The causes of infill have been primarily attributed to landform, changing fire regimes, removal of European grazers (cattle and sheep) and climate change (Haugo and Halpern, 2007; Halpern et al., 2010; Zald et al., 2012; Cansler et al., 2016). The paucity of studies on lower-elevation montane grasslands may be in substantial part due to their advanced stage of forest infill compared to the edge infill of large subalpine and ridgetop meadows. Again, the loss of Indigenous fire stewardship is rarely mentioned in relation to this infill and when it is, it is given little discussion (Haugo and Halpern, 2007; Takaoka and Swanson, 2008; Halpern et al., 2010; Hagedorn and Flower, 2021).

3.3 Human-ecology and Indigenous knowledge informed hypotheses for human-fire interaction

The economies of Late Holocene, Pre-Contact-era peoples of western Oregon are characterized as "collector" (Binford, 1980) or "delayed return" hunter-gatherer systems (Woodburn, 1982). Juxtaposed to immediate return economies, where people consume foods as they procure them, delayed return hunter-gatherers organize their economies around the storage of seasonally available food surplus. These delayed return economies were tied to semi-sedentary settlement strategies involving seasonal aggregation at lower elevation winter villages and dispersal of smaller family groups in spring-summer-fall to higher elevation, distant logistical camps (Minor and Pecor, 1977; Beckham et al., 1981). Reliance on storable plant foods was essential for surviving winters. Edible geophytes (roots, bulbs, tubers), nuts (acorns, hazelnuts), seeds (pine nuts, tarweed), berries, and the inner bark of ponderosa pine (*Pinus ponderosa*) were storable staple foods that provided dietary complements to anadromous and freshwater fish, deer, elk, waterfowl, and other small game.

The preparation and storage of foods by delayed return hunter-gatherers was intensive work (Fulkerson and Tushingham, 2021). Those who were willing to put in the work required to store foods would also have been interested in minimizing the uncertainties of their procurement. Indigenous forest stewardship techniques would have contributed to this goal by enhancing productivity, creating seasonally reliable food patches, and expanding the habitat of focal plant and animal resources, a type of tradeoff common to Pre-Contact Indigenous populations of the PNW (Tushingham and Bettinger, 2018). While the labor investments involved in some forest stewardship activities may have decreased the overall efficiency of procurement, "broadcast" burning[3] increased efficiencies in the capture of game, the collection of edible insects, grass seeds, and acorns (Kimmerer and Lake, 2001). Indeed, the availability and procurement of most Indigenous food resources—even fish (see David et al., 2018)—may have benefitted directly or indirectly from the frequent, seasonally-timed application of low severity fire (LaLande and Pullen, 1999; Connolly, 2000; Peacock and Turner, 2000; Kimmerer and Lake, 2001; Stewart, 2002; Anderson, 2005).

3.4 Hypotheses

Given this theoretical and empirical context, we hypothesize the following for the Middle Fork study area:

(H1) *Pyrodiversity and Settlement*: the landscape's pyrodiversity—the heterogeneity of characteristics such as fire severity and fire return interval—is spatially aligned with variability in human settlement and behavioral patterns as evidenced by archaeological remains and ethnohistorical accounts of land use.

(H2) *Cultural fire regime*: Ethnohistorical and Indigenous oral accounts of cultural fire use provide a more parsimonious explanation for the historical fire regime of specific focal habitats than climate or lightning alone.

(H3) *Indigenous removal and fire*: Removal of Indigenous peoples from Cascadian temperate rainforests had significant impacts on the fire regime and the successional trajectories of the landscape.

(H4) *Indigenous removal and focal habitats:* The implications of Indigenous removal on forest succession will be more evident within the focal habitats of Indigenous resource use.

4 Case study: Middle Fork Willamette study area

The Middle Fork study area is a forested landscape (ca. 25,000 ha) at the southern end of the Willamette National Forest on the west slope and central portion of the Oregon Cascades ecoregion (Omernik and Griffith, 2014). Elevations range from 1,750 m (above mean sea level) at the top of Warner Mountain to 475 m along the banks of the Middle Fork Willamette River (Figure 2). Winters are cool and extremely moist while summers are warm and dry. Precipitation varies with elevation from 1,300 to 2,700 mm annually, most of which falls as rain year-round at lower elevations and as snow at higher elevations between October and April (PRISM Climate Group, 2022). Relatively warm winters and exceptionally high winter and spring precipitation result in one of the most productive landscapes in the world, with some of the highest total terrestrial biomass accumulation on Earth (Graumlich et al., 1989; Smithwick et al., 2002). Our study area and the surrounding forest landscape are sparsely populated today, although small rural communities in the immediate vicinity have been assessed as being at very high risk from wildfires (Dye et al., 2021; McEvoy et al., 2021). We selected the Middle Fork study area for three main reasons:

- It retains significant focal habitats (legacy oak and pine trees, wet and dry meadows) that are the current focus of ecological restoration activities by the US Forest Service (Jankowski, 2022), including a class of montane savanna grassland, that may bear more in common with the oak-pine savannas found of Willamette valley floor, where Indigenous fire is better documented (Johannessen et al., 1971).
- It is known historically and through oral history as an important east-west Indigenous travel route (the "Klamath Trail") for traversing the Cascade range (Beckham et al., 1981; Kelly, 2001).
- It has a high density of previously recorded and excavated archaeological features (Baxter, 1986a; Winkler, 2005; Jankowski, 2022).

4.1 Middle Fork fire history

There are few cross-dated tree ring reconstructions of fire dynamics for PNW rainforests, although recent efforts in the central western Cascades have sought to fill this gap (Tepley et al., 2014; Merschel, 2021; Johnston et al., 2023). We created annually resolved fire histories at 16 sites systematically located approximately 4 km apart to form a 12 km by 12 km grid that provides an objective sample of variability in historical fire across the range of environmental conditions present across our study area. Tree species utilized to create cross-dated fire histories include Douglas-fir, ponderosa pine, noble fir (*Abies magnifica*), incense cedar (*Calocedrus decurrens*), mountain hemlock (*Tsuga mertensiana*), western red cedar (*Thuja plicata*), sugar pine (*Pinus lambertiana*), and western hemlock (*Tsuga heterophylla*). These fire histories extend back in time from between 1350 CE to 1700 CE depending on the site. More than 99% of reconstructed fires occurred prior to 1890 CE, after which management by the U.S. Forest Service emphasized "protection" of forests against fire (Graves, 1910; Johnston et al., 2023).

Five of the systematically located sites at middle to higher elevations (ca. 1,100 m–1,650 m) are characterized by a closed canopy forest structure and experienced relatively infrequent fire

3 The term "broadcast burning" signifies intentionally ignited fires intended to burn moderate to large areas at low intensity in mostly open-canopied vegetation (e.g., prairies, savanna grasslands or open woodlands) to revitalize an herbaceous ground layer and reduce fuels without causing substantial mortality to mature trees.

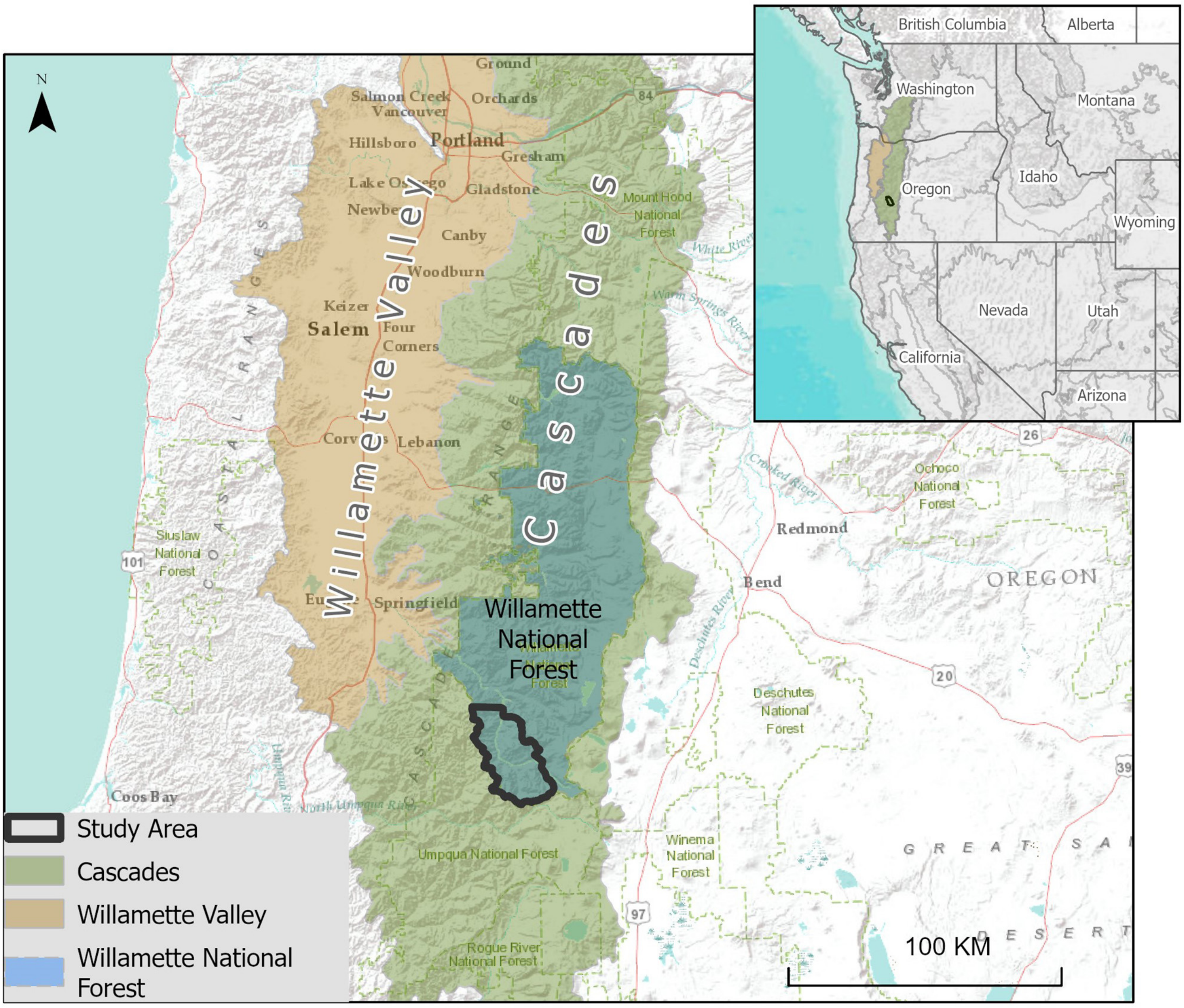

FIGURE 2
Map of the Middle Fork study area situated in the western Cascades.

(81–165 year mean fire return intervals), with one site lacking any fire records beyond extensive tree establishment following what we presume was a stand replacing fire in the early to mid 1700s. But other middle and all lower-elevation sites (550–1250 m) had much shorter fire return intervals. Fire occurred much more frequently in the lowest elevation forest stands found along the Middle Fork Willamette River than in typical fire prone eastern Oregon stands where conditions are drier, the summer fire season is longer, and lightning strikes are more frequent. Three sites experienced fire on average every 2–3 years for long periods circa 1600 to 1800 CE when multiple old trees sampled in close proximity allowed construction of well replicated composite fire histories (Figure 3).

Our data suggests the pre-contact fire regime was non-stationary through time and spatially heterogeneous, but some patterns have emerged. Although ecological theory of Douglas-fir dominated forests suggests that large, wind driven fires reset succession at coarse spatial scales (1,000–10,000 ha), our fire history reconstructions suggest that most pre-contact fires were much smaller than that. For example, most reconstructed historical fires were recorded at only one systematically located site–11% of fire years were recorded at more than two sites, and only 3% of fire years were recorded at more than three sites. Relatively infrequent fire at upper elevation sites was associated with drought, but there was no relationship between climate and fire occurrence across low and mid elevation sites suggesting that human influence was a primary driver of fire spread at those sites.

4.2 Middle Fork archaeology

Archaeological understanding of the Middle Fork study area is based on the results of cultural surveys (Winkler, 2005; Jankowski, 2022) with a few targeted subsurface investigations (Table 1). The oldest identified deposits in the Middle Fork study area were located in a rockshelter site (35LA39) between an undated volcanic tephra and charcoal radiocarbon dated to 2,357 cal. BP (Baxter,

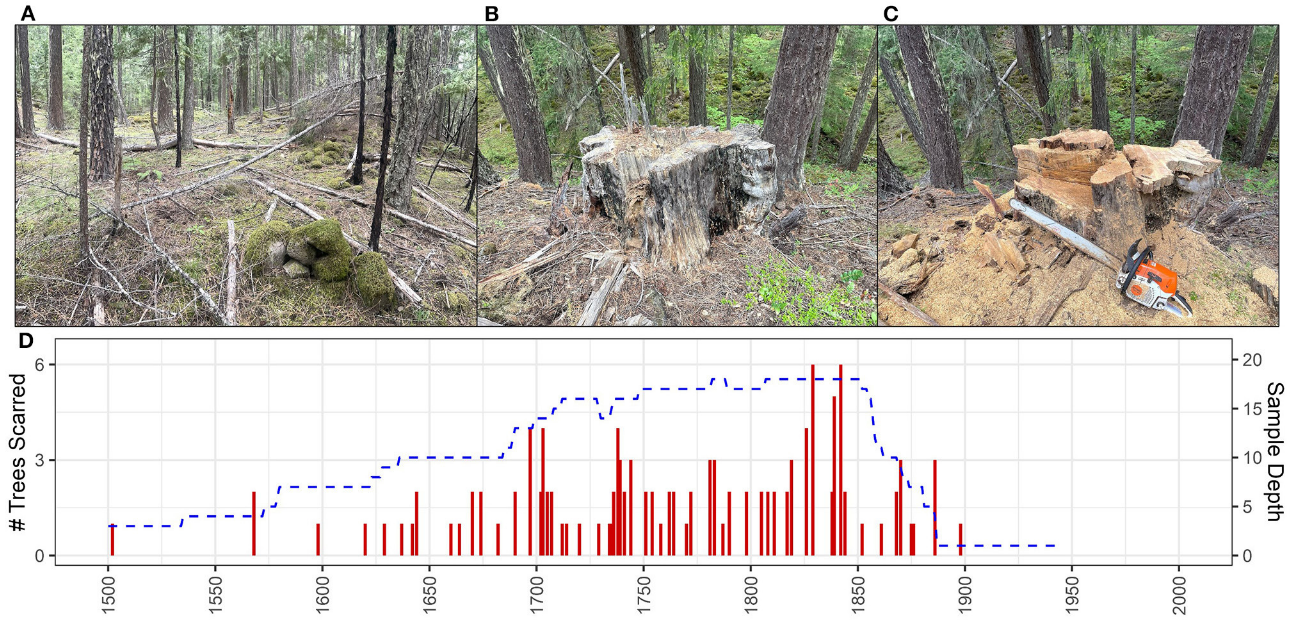

FIGURE 3
Dendroecological sampling and results at the Middle Fork study area. **(A)** Rock features showing evidence of past human use at frequent fire site, **(B)** Fire scarred stump at same site, **(C)** Sampling stump with a chainsaw, **(D)** Graph of cross dated fire history for the site with red bars indicating number of trees scared by year, dashed blue line showing sample depth (total number of recording trees within the sample). Note declining sample depth prior to 1700 CE suggests fires prior to 1700 CE may be underrepresented within the sample.

TABLE 1 Subsurface investigations in the Middle Fork study area.

Smithsonian trinomial	Site name	References
35LA39	Rigdon's Horse Pasture Cave	Baxter et al., 1983; Baxter, 1986a
35LA304	Vine Rock Shelter	Baxter and Connolly, 1985; Baxter, 1986a
35LA529	Saddle Site	Baxter, 1986a,b
35LA599	Colt Site	Baxter, 1986a,b
35LA656	Deadhorse Rock Shelter	Churchill, 1989
35LA727	Colt 85	Cox, 1985

1986a). The landscape was almost certainly used by people prior to that date and likely involved various phases of activity. However, we currently lack sufficient data to describe the full chronology of occupation (Table 2).

In terms of discrete archaeological finds, relatively large sites that likely served as seasonal base camps as well as numerous (ca. 300) culturally modified trees (CMTs) and rock cairn features occur along the river corridor below about 1,000 m in elevation. Smaller lithic scatters (concentrations of flaked stone produced during stone tool production) occur along the ridge tops and near bodies of water at higher elevation, but artifact densities are relatively low in those locations. Excavations at three rock shelter sites and three open-air artifact scatters at lower elevations provide additional insights into Pre-Contact land use activities (Table 1). Artifacts at these sites include hundreds of projectile points of diverse materials and styles indicating a long term, persistent focus on hunting. The collections also include flaked stone tools used for butchering animals or processing plant materials as well as hammer stones and ground stone (mortars, pestles, and slabs) used for grinding seeds, nuts, and berries. The numerous modifications on ponderosa pine CMTs resemble bark peels conducted by Klamath people to harvest cambium for food (Deur, 2009). However, some of these modifications appear to be "pitch wells,"—excavated cavities for harvesting pitch which was used as adhesive and also on "pitch-stick" torches for setting cultural fires (David Harrelson, Confederated Tribes of Grand Ronde, personal communications, 2024).

The densest cluster of these archaeological features occurs at a bend in the river where the river turns from an east-west to a south-north course (Figure 4). At this point, on the southern bank of the river, major south-north running trails intersect with the east-west Klamath Trail to provide connections from the river corridor to the Calapooya Divide which provides shorter access points to the North Umpqua Valley and the Row River in the southern Willamette Valley (the traditional territory of the Yoncalla Kalapuya) (Lewis, 2023a).

4.3 Ethnohistory

Historical sources suggest that at the time of Euro-American contact (ca.1820–1830 CE), the Middle Fork Willamette River watershed was broadly occupied by the Molala people, a Penutian speaking group with no close linguistic relatives but with close

TABLE 2 Radiocarbon dates (^{14}C) from excavated rock shelter sites in the Middle Fork study area.

Site	Sample	Material	^{14}C years BP	Cal years BP	
				From	To
35LA39	BETA-4263	Charcoal	2,450 ± 60	2,710	2,357
35LA656	Beta-15274	Charcoal	1,570 ± 70	1,574	1,305
35LA656	Beta-29430	Charcoal	860 ± 70	914	676
35LA39	Unknown	Bone	590 ± 80	675	502
35LA304	Beta-12472	Charcoal	530 ± 70	664	466
35LA304	Beta-12468	Charcoal	390 ± 90	625	153
35LA39	Beta-4262	Charcoal	190 ± 50	309	Out of range
35LA39	Beta-4261	Charcoal	130 ± 0	264	Out of range

Dates calibrated November 2023 using OxCal version 4.4.4 and the IntCal20 ^{14}C calibration curve.

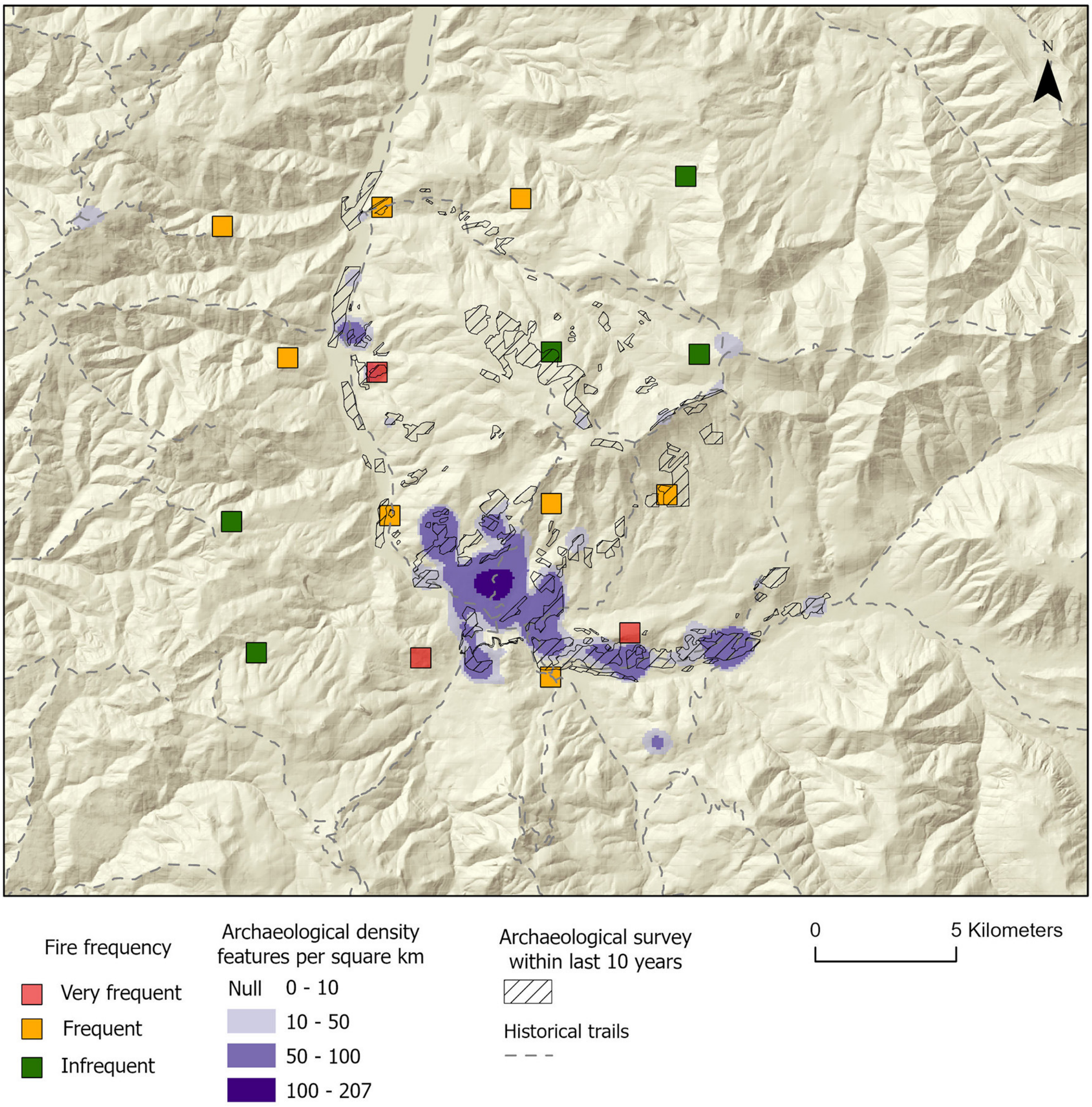

FIGURE 4
Map showing density of archaeological features in relation to fire frequency of dendroecological sample sites, archaeological survey, and historical trails within the Middle Fork study area.

social and cultural ties to the Klamath people who lived south and east of the Cascades in the Klamath Basin (Lewis, 2023b). However, the Klamath, Paiute, Kalapuya, Wasco, and Cayuse, also used the Middle Fork Willamette River corridor as a travel route to visit and trade with communities on either side of the Cascades (Baxter, 1986a). They also likely hunted and gathered along the way as different groups were known to have done historically (Bergland, 1992; Lewis, 2023b).

Molala people established winter villages at lower elevations (i.e. the western foothills of the Cascades) and dispersed into smaller groups for resource specific hunting and gathering in the higher Cascades in the spring and summer (Jacobs, 1945; Zenk, 1998). Molala were known for trading huckleberries, smoke-dried meat, and buckskins (Spier, 1930; Zenk, 1976). Historical observations and oral traditions document fire use by Molala and Klamath alike to improve game range and huckleberry production (Minto, 1908; Deur, 2009). Fire was also used to drive game in "circle hunts" (Teensma, 1987; LaLande and Pullen, 1999). Toward the end of summer or early fall, following the huckleberry harvest at higher elevations, people descended to harvest acorns and other seeds before returning to winter villages (Zenk, 1976). Small fires were set underneath individual oaks just prior to harvesting to make it easier to see and collect acorns in harvest and to kill pests. Trees that were masting were preferred candidates for pre-harvest burn management. These fires preceded broadcast burning of oak groves following the acorn harvest and served to protect focal oak trees from the later, landscape fire (David Harrelson, Confederated Tribes of Grand Ronde, personal communications, 2024). Oral traditions further suggest that smoke from cultural burning stimulates masting 2–3 years following a fire (Joe Scott, Confederated Tribes of the Siletz, personal communication, 2023).

4.4 Case study synthesis

A synthesis of archaeological and dendrochronological data suggests several key insights in relation to our hypotheses.

4.4.1 H1: Pyrodiversity and settlement

The most frequent fire sites (shortest fire-return intervals) occurred in the middle to low elevation zones where the highest density of archaeological features occur (Figure 4). This frequent fire zone includes all the seasonal base camp sites that have been located in the Middle Fork study area. These lower elevation archaeological sites are mostly found in association with focal habitats such as legacy oaks, springs or streams, patches of camas, and other important Indigenous foods. Ground stone is much more abundant in these sites, suggesting that the sites involved acorn and hazel nut processing, among other traditional plant foods. As mentioned above, cultural burning is commonly associated with oak and hazel stewardship in PNW Indigenous oral traditions and ethnohistorical sources (Gould, 1975; Anderson, 2005).

Fire-return intervals lengthened with distance from areas of oak and pine, but do not begin to match the region-wide expectations of long fire-return intervals except at the highest elevation sites most distant from archaeological sites (Johnston et al., 2023). The least frequent fire sites (longest fire return intervals) were in closed canopy forest stands at the highest elevations with the lowest density of archaeological sites. Although the one dendroecology sample site within the Middle Fork study area without any fire scars is located within 1.5 km of 10 smaller lithic scatters dispersed along adjacent ridgetops, these artifacts are clearly associated ridgeline meadow clearings that likely served as travelways and huckleberry gathering sites. Fire regimes along these ridgeline sites may have had shorter fire return intervals than the adjacent closed canopy forests stands, but we currently lack evidence to test that hypothesis.

4.4.2 H2 Cultural fire regime

While fire years correlated with aridity at most of the dendrochronological sample sites within the Middle Fork study area, the year in which a fire occurred was not significantly drier than usual at the most frequent fire sites suggesting that Indigenous burning may have overridden fire-climate relationships in those locations. These results are similar to those of Roos et al. (2022) who found that in Arizona and New Mexico, where fire years are normally associated with drier than usual conditions, weaker than expected relationships between fire and climate are indicative of the influence of anthropogenic ignitions. Wetter years constrain the fire season because there are fewer days where fuels are dry enough to burn. Unlike lightning, people have agency. Cultural fire ignitions are specifically timed and placed to take advantage of fire weather and landscape conditions most suitable to achieving specific goals (Coughlan and Petty, 2012).

Our fire history reconstruction also shows that fires were relatively small compared to most contemporary fire perimeters with few fires recorded at more than one of the systematically located sites separated by ∼4 km (Johnston et al., 2023). Perhaps most remarkable, despite the fact that we've documented fires at lower elevations (<1,000 m) in nearly every calendar year from 1693 through 1895 (with multi-year gaps noted after the 1850s), there is little evidence that these fires resulted in large or severe events. Similar to research findings in Australia (Bliege Bird et al., 2012; Bird et al., 2016), it seems that cultural fire in the Middle Fork buffered climate-driven fire size and severity.

4.4.3 H3: Indigenous removal and fire

Fire activity at most sites slowed significantly after the 1850s with few fires recorded between 1861 and 1871 CE. This decrease in fire is coincident with the removal of Indigenous people from their ancestral homes. Following the "Molala War," (1848 CE) and the "Rogue Wars," (1855–56 CE), many Indigenous survivors on the west side of the Cascades were forced from their lands by the federal officials and the US Army and removed to reservations at the Coast and Grand Ronde reservations (Beckham, 1977). As for Indigenous peoples from east of the Cascades, people from the Klamath Reservation and others from the Warm Springs Reservation continued traditional hunting and gathering activities in the Cascades during the later 19th and early 20th century. These activities included tree modification, if not burning, as these Tribal communities supplemented their diets with hunting and gathering, often during downtime between itinerant off-reservation agricultural and forestry work (Bergland, 1992; Lewis, 2023b).

Renewed Indigenous use of the area could explain a brief increase of fire in the Middle Fork study area ca.1870s, although Euro-American colonists may also be responsible, perhaps burning the landscape to improve grazing for sheep. By the 1890s, the USFS appears to have successfully enforced its policy of fire exclusion.

4.4.4 H4: Indigenous removal and successional dynamics of focal habitats

Extensive dendroecological data from living trees, logs, and snags at Jim's Creek (a nearly 250 ha area within the Middle Fork study area) show that until the mid-1800s, the site was dominated by scattered, open-grown oaks, pines, and Douglas-fir with a grassland ground layer. Phytolith assessment suggests a long grassland history (Kirchholtes et al., 2015). Notably, this site is among those documented for its presence of archaeological artifacts, an extremely high density of culturally modified trees, and an historical fire return interval comparable to the most frequent sampled in the area, in the range of every 2–6 years. Importantly, fires at this site appear to be low-severity fires that retained the large savanna trees, rather than stand-replacing events. However, beginning in the mid-1800s, a 75-year period of high tree recruitment converted all but a few areas of xeric, shallow-soiled grassland into closed canopy forest and dense woodland (Day, 2005; Sonnenblick, 2006).

5 Discussion and conclusions

Research synthesized here for the Middle Fork study area indicates that the climate-dominated, long fire-return model may not hold for at least some landscapes in the western Oregon Cascades. Instead, the available evidence supports our hypothesis that Indigenous peoples significantly influenced the fire regime on the Middle Fork study area. Further, removal of Indigenous people preceded a decline in fire frequency and triggered a conversion from grass, pine, and oak dominated open savanna forest to closed canopy Douglas fir. Given evidence for millennia of Indigenous land use and well-established land stewardship practices, it seems almost unimaginable that the removal of Indigenous peoples from their lands by Euro-American settlers and the United States government, and the on-going suppression of their traditional stewardship practices, did not precipitate significant environmental changes in many other areas of the PNW. Our interdisciplinary case study presents a significant opportunity to document historical fire stewardship by hunter-gatherers as well as to understand the long-term, landscape-level ecological consequences of colonial contact, genocide, and dispossession of Indigenous peoples.

Past research on historical fire disturbance in the PNW has overwhelmingly been directed toward understanding non-human factors influencing fire regimes and forest succession. Our framework helps fill a gap by taking a purposive and focused approach toward understanding long term human-fire interactions in an upland, temperate rainforest environment. In addition to shedding light on the past, we suggest that our study of Indigenous fire may provide relevant lessons for contemporary land management.

Today, the majority of Oregon residents live in cities just west of the Cascades, and the state is largely dependent on Cascadian watersheds (for water and electrical power) now threatened by increasingly frequent and extreme wildfires (Bladon, 2018). Although wildfire regimes in the western Cascades are often attributed to regional drivers that cause infrequent, large stand-replacing events, evidence from the 2020 Oregon megafires suggests that local controls, including vegetation structure and topography, are important regulators of the resultant patterns of burn severity (Evers et al., 2022). Further, recent research points to the importance of open habitats in the western Cascades for biodiversity conservation, fire risk mitigation, and other ecosystems services (Long et al., 2021; Hessburg et al., 2022). Consequently, understanding how Indigenous peoples interacted with, and sustainably inhabited, highly productive rainforests characterized by infrequent but large, high-severity wildfires is a critical challenge with present-day implications (Hoffman et al., 2021). Information about Indigenous fire stewardship will make an important contribution to future forest planning efforts that seek to balance climate change adaptation, conservation of threatened and endangered species, cultural values and legacies, and efforts to protect human communities and other sensitive resources from fire and other perturbations.

Lastly, our research framework, and the inquiry it engenders, is transferable to the investigation of geographies where historical, resilience-based management by small-scale societies remains obscured by empirically weak narratives that do not include Indigenous perspectives. Our approach seeks to move such research beyond the pitfalls of polemics and colonial mentalities to evaluate the empirical evidence of Indigenous fire stewardship and its implications for socioecological resilience-based management by merging scientific and Indigenous perspectives on past human behavior and their legacies. We use the power of multiple lines of evidence to argue that hunter-gatherer societies managed high-productivity Cascadian landscapes that, in the absence of Indigenous cultural fire, quickly became closed canopy forest with diminished social and ecological resilience to wildfire.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MC: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. JJ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. KD: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Writing – review & editing. DL: Conceptualization, Data curation, Funding acquisition, Investigation, Writing – review & editing. BJ: Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

KD was employed by the company Historical Research Associates, Inc (HRA). However, her contributions to this manuscript were not completed in relation to her employment with HRA.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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