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Traditional knowledge of fire use by the Confederated Tribes of Warm Springs in the eastside Cascades of Oregon

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ABSTRACT

We examined traditional knowledge of fire use by the Ichishikin (Sahaptin), Kitsht Wasco (Wasco), and Numu (Northern Paiute) peoples (now Confederated Tribes of Warm Springs, CTWS) in the eastside Cascades of Oregon to generate insights for restoring conifer forest landscapes and enhancing culturally-valued resources. We examined qualitative and geospatial data derived from oral history interviews, participatory GIS focus groups, archival records, and historical forest surveys to characterize cultural fire regimes (CFRs) –an element of historical fire regimes– of moist mixed conifer (MMC), dry mixed conifer (DMC), and shrub-grassland (SG) zones. Our ethnohistorical evidence indicated a pronounced cultural fire regime in the MMC zone, but not in the two drier zones. The CFR of the MMC zone was characterized by frequent (few-year recurrence), low-severity burns distributed in a shifting pattern. This regime helped to maintain forest openings created by previous ignitions, resulting from lightning or possibly human-set, that had burned large areas. The CFR was influenced by the CTWS traditional knowledge system, which consisted of four elements: fire use and associated resource tending practices, tribal ecological principles, the seasonal round (the migratory pattern to fulfill resource needs), and culture. Thinleaf huckleberry (*Vaccinium membranaceum*), a cultural keystone species, occurs primarily in the MMC zone and was a principle focus of traditional fire use of the CTWS peoples. Fire was deployed to maintain shrub productivity and site access for harvesting. Cessation of fire use by ~1940 has caused a decline in huckleberry productivity throughout much of the historical harvest zone. Our findings about CFR scale show how a nested, multi-level framework (patch- and landscape-levels) may be employed to reintroduce fire and thereby promote forest restoration and enhance culturally-valued resources. Our findings also highlight the utility of engaging the communities that hold traditional knowledge in the forest management and planning process.

1. Introduction

Millions of hectares of forest in the eastside Cascades of Oregon and Washington have accumulated excessive fuel and undergone stand structural alteration over the past century, priming them for uncharacteristically severe wildfire and insect outbreak (Stine et al., 2014). Public land management agencies and American Indian tribes seek to restore resilience to natural disturbances in these altered forest landscapes given climate change and human development stressors (Lake and Long, 2014; Hessburg et al., 2015). Investigations of historical fire regimes have revealed knowledge to guide forest restoration in Pacific Northwest forests (Cissel et al., 1999; Hessburg et al., 2005; Stine et al., 2014). Historical fire regime metrics including frequency, severity, and patch size, can point to ecological targets for restoration. To date, there is limited understanding of the influence of traditional fire use on historical fire regimes and forest structure of specific ecological zones within a landscape (however, see Boyd, 1999; Turner and Peacock, 2005; Lake, 2007; Turner et al., 2011).

There is growing recognition that American Indians influenced historical fire regimes and forest landscape structure during the Holocene (e.g., Anderson and Moratto, 1996; Agee, 1993; Crawford et al., 2015; Lake et al., 2017). Fire use varied geographically (Crawford et al., 2015), sparking scientific debate about the magnitude of this influence (Denevan, 1992; Vale, 2002). Despite such debate, investigations of traditional fire use have generated restoration applications, such as restoration conceptual models and prescribed fire strategies (Kimmerer and Lake, 2001; Anderson and Barbour, 2003; Senos et al., 2006). In addition, for American Indian tribes, knowledge of fire use can guide restoration practice to promote diverse landscape values, including community identity, intergenerational cohesion, economic benefits, and ecological functions (Lake and Long, 2014; Long et al., 2015; LeCompte, 2018).

Here we focus on the "cultural fire regime" (CFR), meaning the characteristic pattern of managing fuels and ignitions of a particular plant community that a society uses to promote desired natural resources and ecological conditions (Bonnicksen et al., 1999; Lewis and Anderson, 2002; Senos et al., 2006; Lake, 2007; Lake et al., 2017). In combination, the pattern of natural ignitions (e.g., lightning-ignited fires) and that of the

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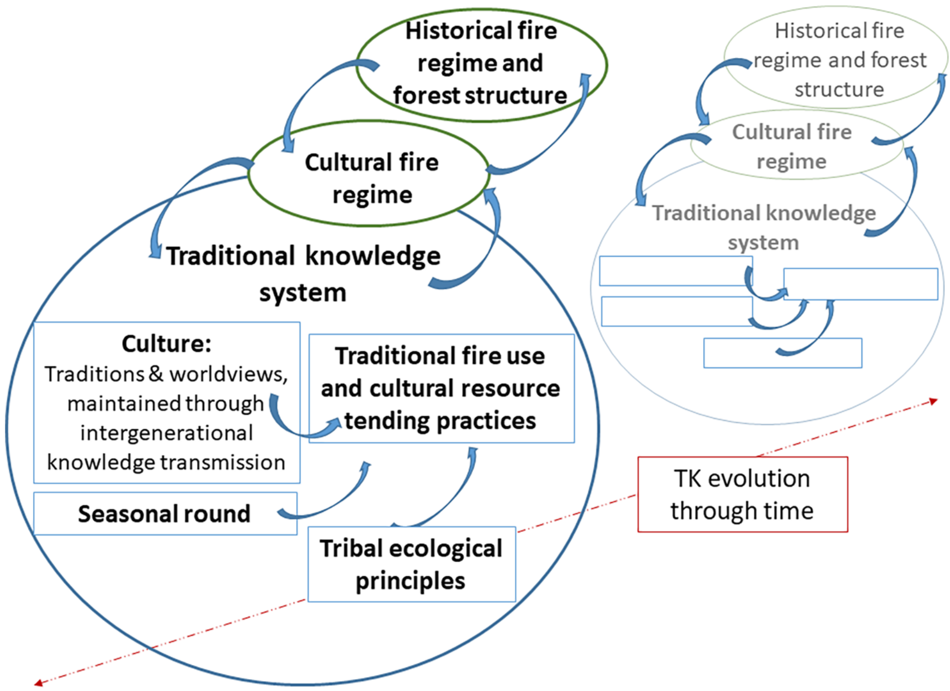

Fig. 1. Conceptual diagram of the traditional knowledge system in relation to the cultural fire regime.

CFR constituted an ecosystem's historical fire regime (Agee 1993; Lake, 2007). This said, the CFR is not necessarily in conjunction with natural fires, e.g., in the eastern U.S., where lightning ignitions are rare (Bonnicksen et al., 1999). CFRs are not well understood, particularly CFR variability across ecological zones, such as those of the eastside Cascades of Oregon (Senos et al., 2006; Lake, 2007; Lake et al., 2017). CFRs are distinct from natural fire regimes in several respects: (1) seasonality; (2) frequency; (3) severity and effects; (4) spatial scale and burn site; (5) ignition strategies; and (6) controls on fire spread, e.g., development of fuel breaks, appropriate timing of fire use (Bonnicksen et al., 1999; Kimmerer and Lake, 2001; Lake, 2007; Lake et al., 2017).

The CFR was structured by the traditional knowledge system of the inhabitant tribal group. In this paper, we use the term traditional knowledge to refer to the body of place-specific knowledge, practices, and beliefs that a society has developed over time to bring about desired ecological conditions, structure, and function (Berkes et al., 1995; Turner et al., 2000). The fire use practices that tribes historically applied to the eastside Cascades landscape were one element of a multi-themed traditional knowledge system (Turner et al., 2000): (1) traditional fire use and associated resource tending practices; (2) tribal ecological principles (understandings about the effects of tending practices on resource productivity and site access); (3) the seasonal round (the migratory pattern to fulfill resource needs); and (4) culture (traditions, ceremonies, and worldviews maintained through intergenerational communication) (Fig. 1). The traditional knowledge system, CFRs, and historical landscape structure were linked through a coevolutionary process of knowledge accumulation and adaptation in response to ecological change (Durham, 1991).

Our focus here is on the CFRs maintained by the Confederated Tribes of Warm Springs (CTWS). The CTWS are three tribal groups who historically inhabited and / or migratorily occupied sites in the eastside Cascades: the Ichishikin- (or Sahaptin) speaking tribes, including the Warm Springs, Tenino, and Dog River bands; the Kitsht Wasco (Wasco); and the Numu (Northern Paiute) peoples (Murdock, 1980; Hunn, 1990; Aguilar, 2005).[1] Our primary research goal was to generate knowledge about traditional fire use and CFRs in the three main ecological zones of the eastside Cascades—the moist mixed conifer (MMC), dry mixed conifer (DMC), and shrub-grassland (SG) zones—and thereby generate applications to forest restoration. Second, we aimed to expand understanding of the CTWS traditional knowledge system and its influence on CFRs. We examined two questions:

(1) How did the CTWS peoples traditionally use fire in the MMC, DMC, and SG zones, and thereby create and maintain CFRs?
(2) How was the CTWS traditional knowledge system structured, and how did fire use fit into this system?

One approach to understanding a society's traditional fire use is to examine which resources it relies on for subsistence and other purposes, including its cultural keystone species – the particular species that "form the contextual underpinnings of a culture" by fulfilling both a key material resource need, and an iconic cultural role as reflected in important ceremonies or narratives (Garibaldi and Turner, 2004; see also, Turner et al., 2011; Long et al., 2015). Western red cedar (*Thuja plicata*) is a cultural keystone species of Northwest coastal peoples of North America, for instance. Keystone species are often intensively managed, as guided by traditional practices and rules. For the CTWS, thinleaf huckleberry (*Vaccinium membranaceum)* (elsewhere, big-leaf huckleberry (Helliwell, 1987), big huckleberry (Minore, 1984; Anzinger, 2002), mountain huckleberry (Richards and Alexander, 2006)) — one of six huckleberry species that grow on the Warm Springs Reservation (Marsh et al., 1987) — is a cultural keystone species because of its importance as a traditional food, for food gatherers, for an annual ceremonial feast, and for wildlife hunted as game (Hunn, 1990; Aguilar, 2005). One CTWS management objective is enhancement of this species, due to its cultural importance (CTWSRO, 1992; Jimenez, 2002). In the broader scope, treaty rights and U.S. government trust responsibility to American Indians (i.e., federal legal obligations to tribes) direct that the area's tribes continue to have access to this species, including on off-reservation sites (primarily on US Forest Service lands), as they have had historically (Goschke 2016; see also, Pitt, 2015). Legal scholarship has advanced the case for co-management of the resource to maintain and/ or restore huckleberry field size and productivity

[1] However historically the Numu people occupied areas outside of the eastside Cascades, in southeastern Oregon (CTWS, 2016).

(Goschke, 2016). We found that traditional knowledge about thinleaf huckleberry (French, 1965; Anzinger, 2002), provided insight into the CFRs of the eastside Cascades.

Lacking in the literature are landscape-level, geographically-explicit analyses of CFR variability across multiple ecological zones of a landscape. This is because much of the research to date has examined fire use of individual ecological zones, resulting in knowledge about CFRs that has been assembled from disparate studies. This situation yields a fragmentary, geographically imprecise understanding of CFR variability across the ecological zones of a tribe's seasonal round and landscape. Moreover, landscape ecological data (e.g., spatial extent, patch size) relevant to our current understanding of historical fire regimes are lacking. Another area that is not well understood is the structure of traditional knowledge systems that maintained CFRs. We address these gaps by conducting a geographical analysis of CTWS burning practices across three ecological zones of the eastside Cascades, and examining the traditional knowledge system in which these practices were rooted. Knowledge about historical fire use may highlight priority zones where reintroducing traditional knowledge-based restoration strategies may have the most impact.

After describing the study area, we review the literature pertaining to historical natural resource use by the CTWS, and traditional fire use in the eastside Cascades. We then describe the mix of qualitative and geospatial methods used in this study. Our presentation of results associated with the research questions is followed by a discussion of their contributions to the literature and application to forest restoration, particularly thinleaf huckleberry restoration. We conclude by summarizing our key findings.

1.1. Study landscape and community

The Greater Warm Springs Reservation Area (GWSRA), the study landscape, spans MMC, DMC, and SG zones in the eastside Cascades (Fig. 2). We primarily employed ecological subregions (ESRs), (Hessburg et al., 2000) to delineate the three zones. In addition, in response to emergent data about resource sites, we expanded the initial MMC zone to include the area along the Cascades crest (Kuchler, 1964; USDA Forest Service ECOMAP Team, 2017).

The GWSRA consists of the Warm Springs Reservation and adjacent forest and shrub-grassland areas within which the CTWS tribes traditionally harvested culturally-valued resources (Hunn, 1990; Aguilar, 2005), including "cultural foods" – foods harvested or gathered by tribal members that have social and historical significance—as defined by the tribes' Integrated Resources Management Plan (CTWSRO, 1992). The CTWS lands currently include the Warm Springs Reservation (259,000 ha), and treaty-ceded lands (approximately 4 million ha) where the CTWS have reserved rights (WSGVCRD, n.d.). Reserved rights sites in this study were limited to those that lie within the eastside Cascades and adjoining Cascades crest. The Ichishikin-speaking (Sahaptin) people fulfilled their food, household, and cultural needs by harvesting plant and wildlife resources found in the eastside Cascades (Hunn, 1990). The Kitsht Wasco (Wasco) also developed traditional knowledge about the area, as did the Numu (Northern Paiute), who were resettled to the Warm Springs Reservation in 1879 (Aguilar, 2005; CTWS, 2016). After reservation establishment (1855), the knowledge systems of the three tribal groups intermingled (tribal elder informants, personal communication).

2. Seasonal rounds, traditional fire use, and cultural fire regimes of the eastside Cascades

2.1. Seasonal rounds of the CTWS

At the landscape-level, the seasonal round of American Indians set the fundamental migratory spatial and temporal pattern of fire use (Turner et al., 2000), and in turn CFRs (Lake et al., 2017). "Seasonal round" means the pattern of annual migration across an area's ecological zones to secure the variety of food and household goods that fulfill social-economic and cultural needs. Traditional fire use, as a seasonal round practice, was applied on a consistent return interval at the landscape-level (Hunn, 1990; Senos et al., 2006; Turner et al., 2011). Fire use was also applied at smaller, nested scales, specifically the habitat-scale (e.g., creating canopy openings to maintain productivity of species associated with a specific seral stage), and the population-scale (e.g., practices to maintain a particular patch) (Turner et al., 2000). Fire use was one of a variety of horticultural techniques American Indians used to maintain the composition, distribution, and spatial extent of plant communities (Anderson and Moratto, 1996; Bonnicksen et al., 1999). Others included tree girdling, pruning plants of unproductive branches, and weeding. In combination, these techniques encouraged site conditions that promoted culturally-valued resources.

Since at least 9000 years ago, when fishing settlements were inhabited near present-day The Dalles, Oregon along the Columbia River (Hunn, 1990), eastside Cascades tribes sustained themselves through a migratory seasonal round of gathering and fishing, supplemented by hunting. In addition to their dependence on the abundant salmon runs of the Columbia River system, tribes tended and gathered hundreds (or more) of forest plant species, spanning four plant categories: trees, shrubs, forbs and ferns, and grasses and grass-like plants (Marsh et al., 1987; Helliwell, 1987). The sequence of resource ripening and availability, influenced by phenological, wildlife ecological, and other seasonal factors, as well as annual climatic variability, structured the burning and tending pattern. Each of the three CTWS tribes had its own seasonal round, as structured by their territory and the distribution of culturally-valued resources (Murdock, 1980; Hunn, 1990; Aguilar, 2005).

For the Ichishkin- (Sahaptin) speaking bands, such as the Warm Springs band, dietary staples consisted of roots, especially of the *Lomatium* genus (Hunn and French, 1981), and fish, particularly salmon (Hunn, 1990). Beginning in the early spring, harvesters dug the roots and stems of plants that occur on low elevation, dry sites, particularly on dry rocky hillsides and flats, especially bitterroot (*Lewisia rediviva*), Canby's biscuitroot (*Lomatium canbyi*), and Indian celery (*Lomatium grayi*). The round proceeded upslope as spring progressed (Hunn, 1990; Aguilar, 2005). Harvest of montane roots such as western springbeauty (*Claytonia lanceolatata* pursh) began soon after snowmelt (French, 1965). During the summer, the harvest focused on foothill species, including chokecherry (*Prunus virginiana*) and serviceberry *(Amelanchier alnifolia)*. In summer and early fall, the harvest transitioned to higher elevation forest sites, often based from encampments (French, 1965; Murdock, 1980; Hunn, 1990; Williams, 2000). For dietary and cultural reasons, thinleaf huckleberry ("We woo no Wash"), the focus of an annual ceremonial feast, was particularly important (Hunn, 1990; Pitt, 2015). The Sahaptin social-economic system also featured fibrous plants, which were used to make mats, clothing, and baskets for food gathering (Hunn, 1990).

The Wasco resided along a stretch of the Columbia River that was prime for trading, near The Dalles (Aguilar, 2005; CTWS, 2016). Celilo Village, located near the now-submerged Celilo Falls, was a main settlement. This Chinookan tribe developed a culture that resembled the Northwest Coast people. The Wasco seasonal round focused on fish (trout, pike, sturgeon, salmon, smelt, and eels)—the staple food and a trade good—, which was supplemented by roots, berries, game, and materials for household goods (Knudson, 1980; Aguilar, 2005). Gathered foods included wild potatoes, onions, hazelnuts, acorns, and huckleberries. Baskets were made of bark or grass; spoons, ladles and bowls were carved of wood.

The Numu (Northern Paiute) people inhabited the western part of the Great Basin (Fowler, 2000). Their territory extended from northern California and western Nevada into south-central and southeastern Oregon, particularly the area between the eastern Cascades and the southern Blue Mountains (Voegelin, 1955; Zucker, 1983; Couture et al.,

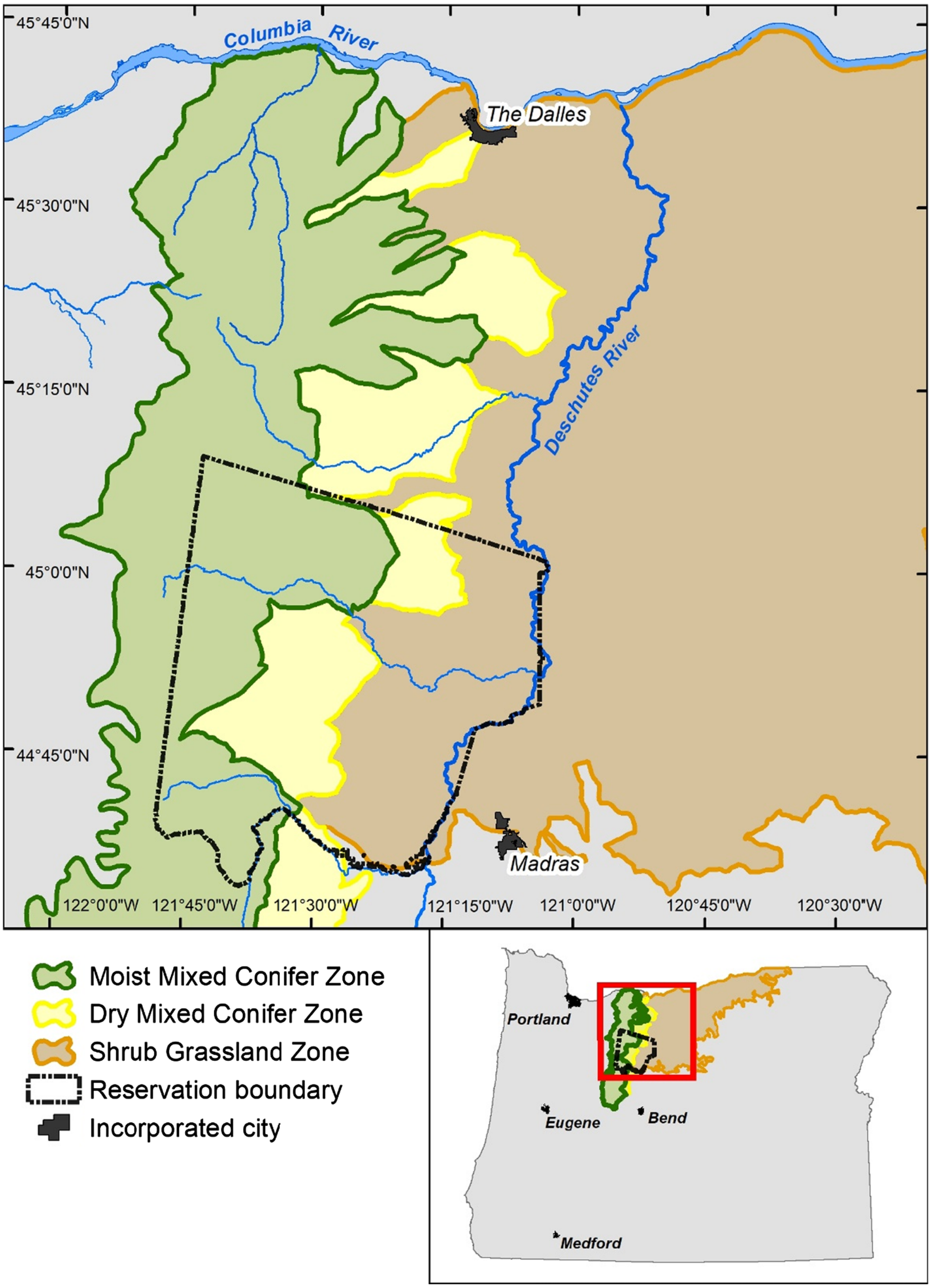

Fig. 2. Greater Warm Springs Reservation Area of the eastside Cascades of Oregon. Ecological zones are delineated mainly from ecological subregions (ESRs, Hessburg et al., 2000), with supplementation of potential natural vegetation geography (USDA Forest Service ECOMAP Team, 2017). MMC zone: ESR 4, ESR 5, and Cascades Crest (Kuchler). DMC zone: ESR 11, ESR 41, and ESR 46. SG zone: ESR 7, ESR 9, ESR 10, and ESR 45.

1986). The Numu seasonal round was adapted to the arid, drought-prone, sparsely vegetated Great Basin environment through its expansive area and "broad-spectrum" hunting and gathering (Fowler, 2000) of a large diversity of plants and animals. The family foraging group resided in temporary camps that moved in response to resource availability. Key plant resources included seed-bearing grasses for consumption, including Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Agropryon spicatum*) (Marsh et al., 1987), and at least for tribes of northern California, grasses for basketry construction and herbs for cordage (Anderson and Moratto, 1996; see also, Fowler, 2000).

2.2. Cultural fire regimes of the eastside Cascades of Oregon

In the U.S. Pacific Northwest, CFRs fall into three broad categories, generally spanning a west-to-east geography (Agee, 1993; see also Kimmerer and Lake, 2001). (1) West of the Cascade Range, the Kalapuya Indians frequently burned prairies, e.g., the Willamette Valley, and adjacent dry Douglas-fir forest. (2) In drier coastal and montane areas, including the eastside Cascades, tribal burning maintained meadow openings to promote desired plant resources and game. (3) In the inland Pacific Northwest, tribes broadcast burned grasslands and shrub-steppe regions (Shinn, 1980). Fire use varied ecologically and culturally (Boyd, 1999). In the wet conifer zone of the northern

Table 1
Ecological characteristics of ecological zones of the Greater Warm Springs Study Area, in the eastside Cascades of Oregon.

	Moist mixed conifer zone	Dry mixed conifer zone	Shrub-grassland zone
Key forest/woodland species	Grand fir (*Abies grandis*) White fir (*Abies concolor*) Douglas fir (*Pseudotseuga menziesii*) Western hemlock (*Tsuga heterophylla)* Lodgepole pine (*Pinus contorta*)	Ponderosa pine (*Pinus ponderosa*) Douglas fir (*Pseudotseuga menziesii*)	Western juniper (*Juniperus occidentalis*)
Elevation (m)[1]	820–2100	640–1100	300–700
Physiography	Deep U-shaped valleys, steep to gentle slopes, dissected ridges	Gentle to moderate slopes	Low-elevation plateau, level to gentle slopes, broken by steep V-shaped valleys
Historical fire regime	Variable regimes[2]: Mixed-severity fire/Frequent to moderately frequent intervals (< 20–50 years) Mixed severity, 50–100 year-interval High severity fire (rare)	Variable regimes[3]: PP: Low severity/1–10 year interval DF-OR: Mixed severity/ 10–25 year interval (approximately)	Variable regimes[4]: Grasslands: Low severity/very frequent (< 10 year) Shrublands: Mixed- and high-severity (25–35 year- (occasionally 50 year-) interval

[1] Marsh et al. (1987). Elevation data are approximate. Elevation ranges of zones are not mutually exclusive, due to variability in aspect and other ecological factors.
[2] "Mixed-severity": both low- and high-severity patches occur. Sources: Perry et al. (2011); Stine et al. (2014). "Low severity" = < 20% overstory trees or basal area affected. "Mixed severity" = 20–70% overstory trees or basal area affected.
[3] Sources: Hessburg et al. (2007); Perry et al. (2011); Stine et al. (2014). PP = ponderosa pine; DF-OR = Douglas fir-Oregon.
[4] The confidence of the estimated fire return interval is lower for this ecological zone than forest zones, due to limited fire scar data. Fire interval estimate based primarily on shrub and grassland species, which were historically predominant in the GWSRA; present-day prevalence of western juniper has expanded since the mid-19th century (Miller, 2005). Sources: Morgan et al. (1996); Baker and Shinneman (2004); Stine et al. (2014).

Cascades, fires were typically large and severe, potentially displacing tribes and damaging valued resources, suggesting less prevalent burning, if at all (Agee, 1993). There is evidence of Indian burning in the Oregon coast range, however (Zybach, 2003). The traditional fire use and CFRs of the eastside Oregon Cascades, where the CTWS reside today, lie within this regional context. Below, we present what is known about fire use and CFRs of the MMC, DMC, and SG zones. Table 1 presents the historical fire regimes and related ecological characteristics of these zones.

2.2.1. Moist mixed conifer zone

The CFR of the MMC zone of the eastside Cascades was characterized by small patch, low-severity burns, which maintained meadows and glades (Hunn, 1990; Agee, 1993; Williams, 2000; see also, Kimmerer and Lake, 2001). These openings dotted the matrix and edges of the true fir, Douglas fir, and other conifer communities (Agee, 1993). These openings improved the productivity of berry-producing shrub fields, including thinleaf huckleberry, grouseberry (*V. scoparium*) and blueberry (*V. caepitosum*) (Hunn, 1990; French, 1999), and increased populations of game species, such as deer and elk (Agee, 1993; Williams, 2000). Similarly, on mountain slopes of British Columbia, Canada, tribes burned to enhance berry-producing shrubs (e.g., thinleaf huckleberry, blackcap raspberry [*Rubus leucodermis*]), starch-rich roots (e.g., avalanche lily, *Erythronium grandiflorum*), and nuts (e.g., hazelnut, *Corylus cornuta*) (Gottesfeld, 1994; Turner, 1999; Turner et al., 2011).

Two factors, burn frequency and timing, controlled burn patch size and severity. Ignitions were applied to berry patches every several years. This interval is the sweet spot in which there is adequate fuel to carry a light surface burn, yet not so much fuel that the fire burns hot and creates a large patch. One Oregon Cascades settler observed, "The Indian method was to burn the old burns about every three years or as soon as there was growth enough to make a good fire" (Pioneer of 1847, in Williams, 2000:15). In general however, the burn interval may have been longer than that noted in the settler's account, due to the > 7-year period required for abundant berry production (Minore, 1984; Anzinger, 2002). Burns were timed to coincide with early autumn rain events, or in the early summer before forest fuels became dry, which moderated flammability (Hunn, 1990; Williams, 2000).

2.2.2. Dry mixed conifer zone

Forest characteristics relevant to the historical fire regime of the DMC zone are the historical presence of grasses; a well-developed understory vegetation component; and in ponderosa pine-dominant forests, a diverse age class structure due to susceptibility of older and/or scorched trees to native bark beetle-caused mortality (*Dendroctonus ponderosae; D. brevicomus*) (Agee, 1993). A frequent (approx. 10–25 year), low-severity historical fire regime promoted these vegetation and forest structural characteristics (Agee, 1993; Hessburg et al., 2007; Stine et al., 2014). Evidence of traditional fire use in the DMC zone in the eastside Cascades is sparse. For the northern Rockies however, there is suggestive evidence of widespread Indian burning of DMC forests and grasslands (Barrett and Arno, 1982).

2.2.3. Shrub-grassland zone

Tribal groups may have applied broadcast, low-severity fire to the SG zone, though the paucity of historical ecological records (e.g., fire scars) limits the certainty of conclusions (Agee, 1993). Immediately to east of the SG zone of this study, in the east-central rangelands of Oregon, the Paiute burned in late summer and early fall (Shinn, 1980). For instance, in September 1826, a Hudson's Bay Company explorer traveling east of the Deschutes River noted recently burned-over land, consistent with practices elsewhere, such as the Snake River (Shinn, 1980; Agee, 1993). In less remote places, there is suggestive evidence that tribes broadcast burned large areas frequently (perhaps even annually) (Shinn, 1980). Fire use frequency probably varied widely in association with human population density, as well as social-cultural motivations, specifically signal fires, insect gathering, and hunting (Agee, 1993).

3. Materials and methods

3.1. Approach

To answer our research questions we undertook three main steps. First, we identified culturally-valued resources for the Warm Springs Reservation and located their occurrence by ecological zone. Second, we investigated whether and how fire was used to manage these resources. We sought to understand fire use within the context of the CTWS traditional knowledge system. Third, we sought evidence of how CFRs affected historical fire regimes.

As noted, a major challenge of conducting research on CFRs is the fragmentary record and sparse geospatial data regarding traditional fire use by specific tribes (Turner, 1999; Williams, 2000). We addressed this challenge by developing an anthropological-landscape ecological GIS framework and a traditional knowledge database. We constructed the integrative GIS framework in steps. (1) We delineated the seasonal round area of the CTWS peoples, based on secondary literature (e.g., French, 1965; Murdock, 1980; Hunn, 1990). (2) We divided this area into its constituent ecological zones (MMC, DMC, SG) constructed from biophysically modeled ecological subregions (Hessburg et al., 2000) and potential natural vegetation (Kuchler, 1964; USDA Forest Service ECOMAP Team, 2017). (3) Historical resource use sites and migration features (trails, settlements) were entered into the GIS. (4) We analyzed the elements of the traditional knowledge database by ecological zone. This approach revealed insights into geographical variation of traditional fire use and CFRs.

3.2. Materials and data processing

3.2.1. Qualitative analysis of traditional knowledge

We constructed a traditional knowledge database, featuring qualitative data, from three sources: oral history interviews, a participatory GIS (PGIS)-based workshop, and archival records (McBride et al., 2017). Where needed, CTWS ethnobotanical and forest ecological sources served as a data cross-reference (e.g., French, 1965; Marsh et al., 1987; Helliwell, 1987; Jimenez, 2002). The oral history interviews (n = 14), conducted with key informants in 2014–2015, employed a semi-structured protocol (Patton, 2002). Interview guide topics were traditional fire use of various ecological zones and influences on fire use. The PGIS workshop, conducted in November 2017, generated focus group-based oral histories (3 focus groups, 32 participants) and geographical data about the interview guide topics. Standard PGIS techniques consist of participant mapping of features relevant to community knowledge and/or values (Besser et al., 2014; McBride et al., 2016). We developed a novel PGIS technique that was adapted to the CTWS community. We supplemented maps with ethnohistorical photographs that depicted activities, places, and people familiar to CTWS participants. We also used base map features that included historical village sites and trail networks derived from a federal survey conducted in 1922–1926, and botanical zones containing culturally-important resources derived from primary and secondary sources (Marsh et al., 1987; Helliwell, 1987; Jimenez, 2002; UWLSC, 2008). These photographs and base map features elicited interactive oral histories associated with each ecological zone. To protect sensitive cultural data, all place-specific data were aggregated by ecological zone. We also extracted data from archival resources (ethnographic records, survey maps) collected from the David H. and Kathrine S. French Papers and the Eugene Hunn Papers, held by the University of Washington and Reed College.

Interviews and the PGIS workshop were recorded and the recordings transcribed. We analyzed the qualitative data using a coding scheme developed through a grounded theory approach (Patton, 2002). We identified emergent themes from the data, which we related to *a priori* themes from the literature. This process generated the four traditional knowledge system elements (Fig. 1) that structured the coding scheme and was applied to the transcribed data. Inter-coder reliability procedures consisted of examining data examples as a team to assess and refine the coding scheme.

3.2.2. Geographical characterization of traditional fire use and burn land-cover

Geographical characterization of traditional fire use and burn land-cover was derived from the Cascade Range Forest Reserve inventory conducted by the U.S. Geological Survey, in 1901 (Langille et al., 1903); ethnohistorical slide imagery of cultural food harvest sites, 1952–1954 (UWLSC, 2008); and oral history interviews. We also quantified the historical village site and trail network data from the PGIS base maps by ecological zone to improve understanding of where human activity was concentrated.

Historical burn land-cover polygons, acquired from the Cascade Range Forest Reserve inventory, were processed using ArcMap 10.3.1. The purpose was to develop baseline data of historical burn geography as a potential influence on subsequent fire use, regardless of ignition source (lightning vs. anthropogenic). We derived data for two variables, burn land-cover area and patch size, from this inventory. Limitations are noted: (i) DMC forest burns are potentially under-represented because surveyors tended to focus on high-severity fire (Langille et al., 1903); (ii) paucity of ignition source information (natural vs. anthropogenic); and (iii) an absence of data for the SG zone, which was outside the inventory area.

The ecological conditions of cultural food sites were derived from the ethnohistorical imagery of D.H. and K.S. French. These anthropologists conducted field work on the CTWS peoples in the mid-20th century, particularly 1949–1956 (UWLSC, 2008). Site locations of the images were identified and entered into the project GIS using U.S. Geographical Survey (USGS) 7.5 min topo-quadrangle maps in consultation with forest managers (CTWS Branch of Natural Resources, Mt. Hood National Forest) and tribal informants.

Spatial data about fire use were gleaned from the PGIS workshop-based oral histories (conducted in 2017) and oral history interviews (2014–2015). Our interview protocol elicited information about the location, timing, severity, and patch size of anthropogenic fire. We elicited data about reference forest structure conditions using imagery from two sources: historical photographs of the study area showing forest type and successional stage, and stand simulations of forest type and successional stage, constructed from Visual Nature Studio software (USDA Forest Service, n.d.).

4. Results

4.1. CFRs among ecological zones of the GWSRA

Evidence from the oral history interviews, participatory GIS, archival data, and spatial analysis revealed that the CTWS peoples deployed fire to increase the ecological productivity of, and access to, certain disturbance-dependent culturally-valued resources in the east-side Cascades. However, fire use varied among ecological zones (Table 2). We found evidence of traditional fire use in the MMC zone, and an absence of such evidence in the DMC and SG zones, which we interpreted to mean that the CTWS peoples maintained a CFR in the MMC zone only. Diverse cultural foods of the seasonal round were tended historically in all three zones (Fig. 3). The ecological utility of burning apparently varied, however, which contributed to fire use variability among ecological zones. In addition, analysis of the historical travel network revealed that trail length was concentrated in the MMC zone (59.0%), compared to the DMC zone (31.8%) and SG zone (9.2%). Settlements were primarily located in the SG zone (80%) and DMC zone (20%). The dense trail network into MMC forests from lower-elevation SG zone settlements supported an overall picture of migratory burning and tending in this zone (e.g., based from encampments).

In the MMC zone, the CFR consisted of low severity, frequent (every few years), small-scale ignitions applied to existing huckleberry shrub sites according to most, but not all, informants. The main reasons to burn were to clear away competing vegetation from the thinleaf huckleberry shrubs and maintain access. If left unchecked, competing vegetation would likely have reduced huckleberry productivity owing to the combination of moist growing conditions and fire recurrence interval variability. Besides burning, other practices to maintain productivity were harvesting and girdling trees, which maintained canopy openings, and possibly weeding out competing shrubs.

In the DMC zone, culturally-important resources included roots (e.g., wild carrot (“saw-wickt”, *Periderida gairdneri*)); bulbs (e.g., blue camas (“wa-ka-mo”, *Camassia quamash*), which occurred in meadows); and chokecherry, a berry-producing shrub. Thinleaf huckleberry also occurred in the DMC zone of the GWSRA, though with lower productivity than in the MMC zone (Jimenez, 2002; USDA Forest Service,

Table 2
Cultural fire regime and traditional knowledge across ecological zones of the Greater Warm Springs Study Area.

	Moist mixed conifer zone	Dry mixed conifer zone	Shrub-grassland zone
Cultural fire regime	Low severity, frequent ignitions applied to specific plant resources	Fire use not reported	Fire use not reported; natural ignitions perceived as beneficial
Tribal ecological principles	Burning promotes ecological functions that maintain huckleberry productivity (control of competing vegetation and insects, soil replenishment) and resource access	None reported	Fire replenishes productivity of edible roots
Key resources	– Bear grass – Mountain ash berries – Pine nuts[1] – Thin-leaf huckleberry – Western red cedar	– Black lichen – Blue camas – Chokecherry – Thin-leaf huckleberry[2] – Wild carrot	– Biscuitroot – Bitterroot – Desert parsley – Indian celery
Cultural relevance	Huckleberry feast ceremony	None reported	Root feast ceremony
Seasonal round mode[3]	Large, extended family group, long duration	None reported	Individual/small group, short duration
Trail distribution (% length in zone)	59.0	31.8	9.2
Village distribution (% in zone)	0.0	20.0	80.0

[1] White bark pine (*Pinus albicaulis*) may be the species of the pine nuts historically gathered in the MMC zone, as indicated by several sources: Keane, R.E., Tomback, D.F., Aubry, C.A., Bower, A.D., Campbell, E.M., Cripps, C.L., Jenkins, M.B., Mahalovich, M.F., Manning, M., McKinney, S.T. and Murray, M.P., 2012, A range-wide restoration strategy for whitebark pine (Pinus albicaulis), Gen. Tech. Rep. RMRS-GTR-279, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO,108 pp.; US Forest Service, 1977, Draft Environmental Statement, Badger-Jordan Planning Unit of Mt. Hood National Forest, Portland, OR, 219 pp.; Hayes, H.E. and Pague, B.S. 1891. Biennial Report of the Oregon Weather Bureau, Frank C. Baker, State Printer, Salem, Oregon; Lang, F.A. 2019. Whitebark pine, The Oregon Encyclopedia, https://oregonencyclopedia.org/articles/whitebark_pine/#.XQk0dYhKh9N, last accessed 6/17/19.

[2] Occurrence is occasional in this zone (Marsh et al., 1987).

[3] Sources: Zucker (1983); ethnohistorical records, D.H. and K.S. French papers, Special Collections, University of Washington.

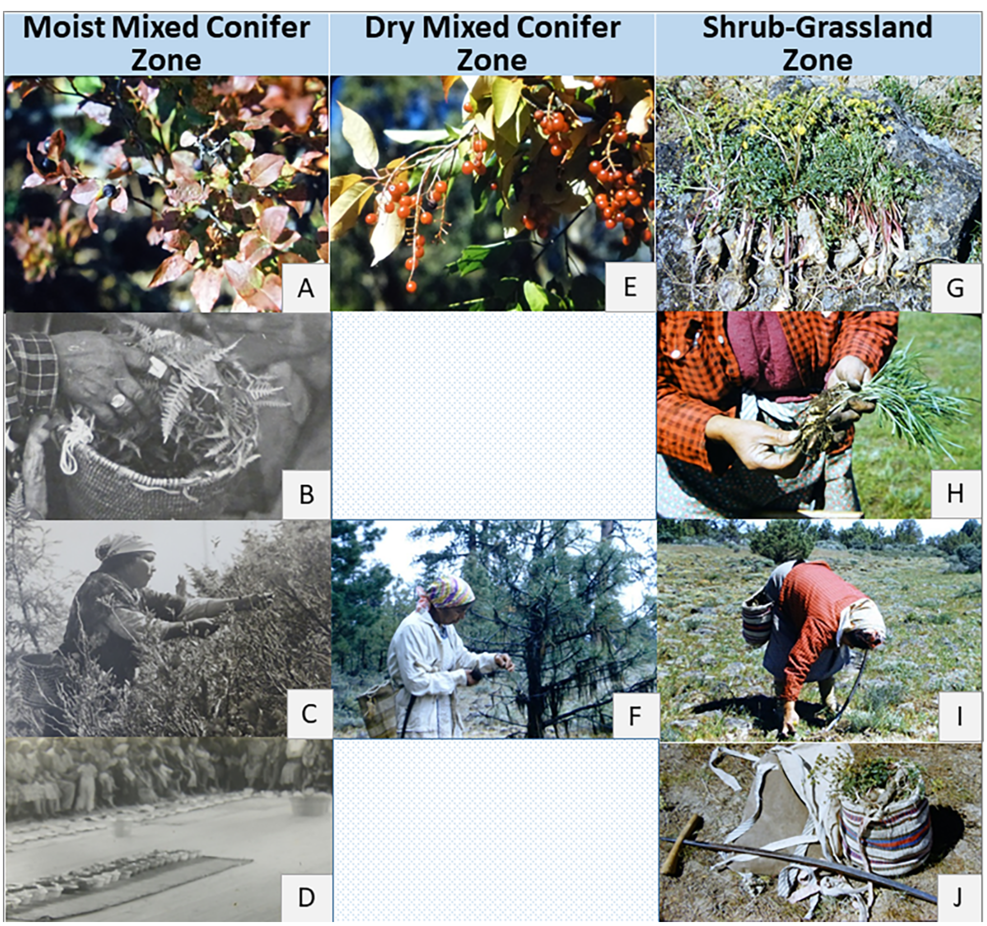

Fig. 3. Example resources maintained by traditional knowledge in ecological zones of the Greater Warm Springs Study Area. Moist mixed conifer zone: big-leaf huckleberry, Mt. Hood area (A); harvest, preserved with fern fronds (B, UW negative 38663); huckleberry picking (C, UW negative 38875); huckleberry feast ceremony (D). Dry mixed conifer zone: chokecherries, Shitike Creek area, Warm Springs Reservation (E); "kunc", a confection derived from black lichen (F). Shrub-grassland zone: biscuit root (G, H, I, J). Image dates: 1951–1955. Images are derived from the University of Washington Libraries, Special Collections, David H. and Kathrine S. French papers, Accession 5496-001, Box 54. (Slide images not assigned a UW negative number unless otherwise stated.)

Table 3
Historical (1901) burn land-cover pattern in the eastside Cascades of Oregon, Greater Warm Springs Study Area.

Ecological zone	Ecological subregion (ESR)[1]	Percentage of area in burn land-cover	Burn land-cover patch, mean (ha)
Moist mixed conifer zone	All ESRs of zone	12.3	406.7
	Ecological subregion 4	16.6	280.0
	Ecological subregion 5	9.9	363.3
	Cascades Crest (Kuchler)[2]	12.8	738.2
Dry mixed conifer zone	All ESRs of zone	1.7	107.0
	Ecological subregion 11	2.4	60.6
	Ecological subregion 41	2.6	223.0
	Ecological subregion 46	0.0	0.0
Shrub-grassland zone	n.a.	no data	no data

[1] Names corresponding with ESR numbers are of the form: ESR number = Bailey's ecoregion – Dominant Precipitation Class(es) – Dominant Potential Vegetation Group(s) – Dominant Solar Radiation Class(es) (Hessburg et al., 2000). 4 = M242C – Wet – Warm – MFCF – Low Solar; 5 = M242C – Moist – Warm – MF/CF – Mod Solar; 11 = 200/300 – Dry Moist – Warm – MF/DF – Mod Solar; 41 = M242C – Moist – Warm – MF/DF/CF – High Solar; 46 = M242C – Moist – Warm – DF – High Solar. M242C = Eastern Cascades Section. 200/300 = Okanogan Highlands - Eastern Cascades Sections.

[2] The area of this ecological unit lies outside the geographical extent of the ESR framework (Hessburg et al., 2000). Thus, this unit is derived from the potential natural vegetation framework (Kuchler, 1964; USDA Forest Service ECOMAP Team, 2017).

2010). Our informants reported an absence of burning in this drier zone—a surprising result, given evidence elsewhere that demonstrates burning to promote geophytes (Anderson, 1997, Anderson and Lake, 2016). Lower precipitation and a comparatively frequent natural fire return interval may have constituted an ecological combination that posed less need for fire use in the eastside Cascades.

Edible roots were (and are) the primary cultural food of the SG zone. Staple roots included biscuitroot ("coush", *Lomatium cous*) and bitterroot ("Piyati", *Lewisia rediviva*). The cultural importance of these starch-rich foods was manifested in the root feast, an annual ceremony. These foods were tended through digging practices of the seasonal round. Apparently, fire was not employed by the CTWS to promote resource productivity in this zone, according to tribal informants. However, informants noted increased resource productivity in the years after a natural fire burned over gathering sites; such ignitions were spoken of as a positive event. In this arid zone, the need to control competing vegetation and improve resource access may have been minimal.

Our analysis of historical burn land-cover data provided a landscape-scale context for assessing the role of CFRs in historical fire regimes. The burn area distribution was disproportionately high in the MMC zone (12.3% of zone area) compared to the DMC zone (1.7% of zone area); (SG: no data), (Table 3, Fig. 4). Variability in burn severity, persistence, and cumulative fire scar area may have contributed to the magnitude of difference in burn area among zones, however. The forest inventory (Langille et al., 1903) indicates that burn openings were prevalent in the MMC zone, regardless of initial ignition source (e.g., lightning, settler burns), which traditional fire use appears to have subsequently maintained. Within the MMC zone, burn land-cover was prevalent in the ecological subregions where huckleberry fields were maintained, particularly the Cascades Crest Forest (12.8%). Burn patch size was comparatively large in the MMC zone (406.7 ha) relative to the DMC zone (107.0 ha).

The CFR of MMC forests contributed to the maintenance of openings in mid- and high-elevation montane sites according to ethnohistorical slide imagery and oral history data (Fig. 5). The CTWS applied frequent, low-severity burns on an as-needed basis to maintain openings apparently initially created by large conflagrations. Ignitions were applied to targeted shrub patches, thereby tending to maintain and/ or expand existing openings, estimated at tens to hundreds of hectares (based on historical inventory data), rather than create new openings. This practice resulted in a shifting anthropogenic disturbance pattern across an area that spanned an estimated 220,000 ha across 24 cultural food resource sites on the mid- and upper-elevations of mountain slopes (Mt. Hood, Mt. Jefferson) and buttes of the eastside Cascades and Cascades crest.

4.2. *Traditional fire use of thinleaf huckleberry in the CTWS traditional knowledge system*

Traditional fire use by the CTWS focused on thinleaf huckleberry. Further analysis revealed that fire use was maintained by a traditional knowledge system composed of four interconnected elements: (i) resource tending practices; (ii) tribal ecological principles; (iii) the seasonal round; and (iv) culture (see Appendix A).

4.2.1. *Resource tending practices*

Most informants were told by their elders, or had seen as a child, that burning was intentionally used to manage huckleberries. However, one participant reported that tribal members relied on lightning-ignited fires, yet indicated that humans promoted ignitions by preparing site conditions, such as concentrating flammable material (e.g., conifer needles), then praying for lightning strikes. Ignition sites occurred in the MMC zone on Mount Hood and Mount Jefferson, particularly along the Cascades crest. Huckleberry patches were described as having sparsely distributed, small-diameter, short trees, a dense field structure of huckleberry shrubs, and few other understory plants. Huckleberries were also harvested at lower elevation DMC sites. However, informants reported that fire was not used to manage berry patches in the DMC zone. Fire does not appear to have been used extensively, if at all, to manage other resources, such as edible roots, lichen, and medicinal plants in this zone. This said, one interviewee reported that the Paiute used fire to manage roots and possibly oak in lower elevations east of the reservation. All other informants reported that fire was not used to manage roots, although several had observed an increase in root productivity on some sites after burn exposure.

Participants described a rotational system in which different areas were burned each year. One informant reported a 7-year rotation interval. Fires were typically set in the fall at the end of the berry season when temperatures were lower, at precipitation onset, thereby promoting low-severity burns. Occasionally fires were set in late spring but not in the summer because they would be too difficult to control. Small (e.g., < 1 ha), low-intensity burns were designed to control competing underbrush (e.g., snowbrush (*Ceanothus velutinus*)) while not damaging the berry bushes. Fire control practices consisted of clearing flammable material (needles, small branches) from the target area and stationing fire guards. Rather than burn one large area simultaneously, a series of micro-fires (~1 m in diameter) were set. Several informants reported that rituals and prayers were used to bring rain to control the burns.

Fire specialists determined when ecological conditions were appropriate for burning. Fire specialists were older males who had been trained from an early age and had accrued knowledge to determine

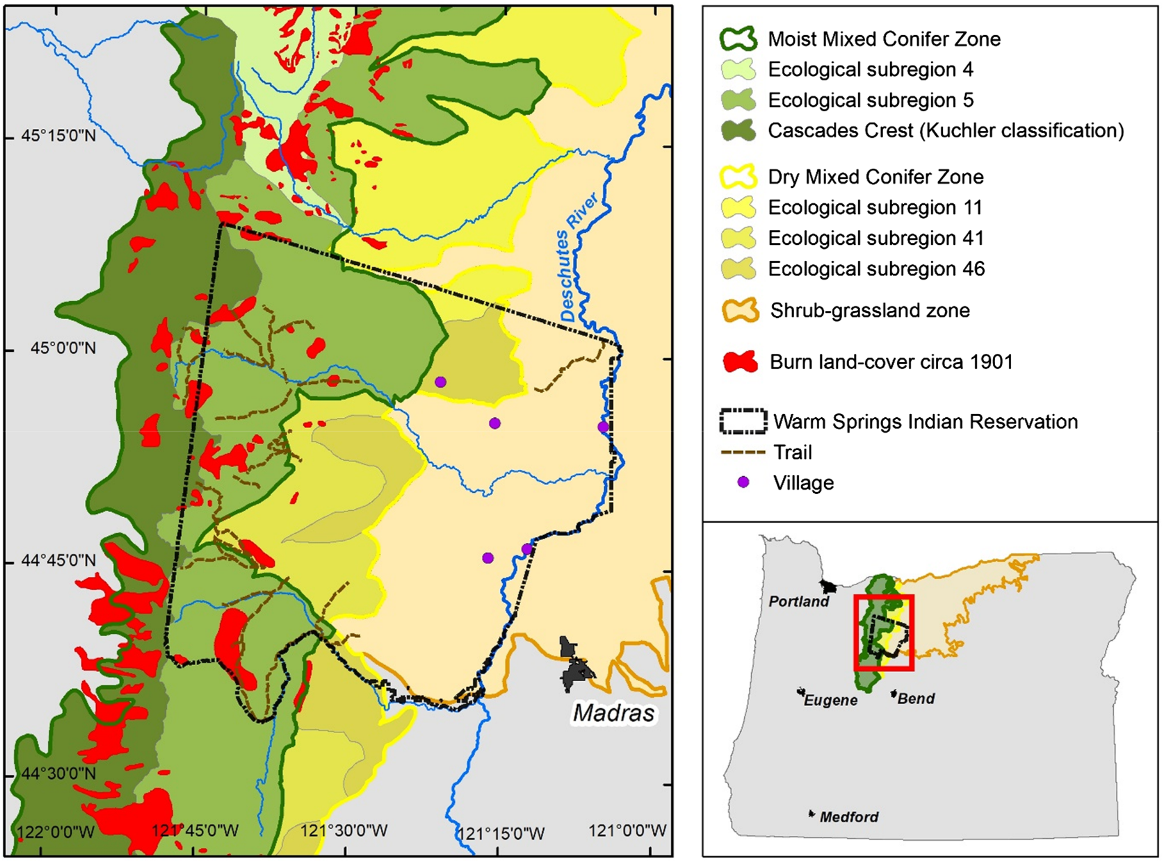

Fig. 4. Historical (1901) landscape pattern of burn land-cover, Greater Warm Springs Study Area. Land-cover data: Langille et al. 1903. Trail and village data: federal survey of Warm Springs Reservation, 1922–1926. For ecological zone details, see Table 3.

when weather conditions were conducive to controlled burns. Internal regulation of fire use by the community has been observed elsewhere (Huffman 2013). Huckleberry resource management was a collective endeavor rather than an individually-organized practice, as described by tribal informants.

4.2.2. Tribal ecological principles

Controlled burns were based on a set of tribal ecological principles and aimed to fulfill several purposes: insect control, reduction of understory vegetation and downed debris, control of tree encroachment, huckleberry patch expansion, stimulation of new plant growth, and soil fertility replenishment. Burn practices were designed to produce stand structure conditions that promoted huckleberry productivity, consistent with previous findings (French, 1999). Target conditions included open sites with scatterings of small diameter trees within the berry fields, relatively little underbrush, few downed logs, and large, densely concentrated huckleberry bushes. Removal of competing understory vegetation improved ecological productivity (e.g., of berries) and facilitated traversing of the fields by harvesters. These cultural site characteristics are also important to beargrass (*Xerophyllum tenax*), which sometimes occurs intermixed with huckleberry shrubs (Hummel and Lake, 2014).

4.2.3. Seasonal round

Fire use was integrated into the seasonal round. In late summer and early fall, tribal members traveled from villages, primarily located in the low elevation SG zone up into the MMC zone to access high country berry fields, deer and elk hunting grounds, and other resources. Base camps near the berry fields, where multiple extended families camped, functioned as an important social structure of the seasonal round. Women and children did most of the berry picking; men handled the packhorses and hunted for deer and elk. The volume of annual huckleberry harvest was substantial (2.5–8 gallons (estimated)/harvester/day).

4.2.4. Culture

The use of fire for huckleberry management was strongly associated with CTWS culture, particularly prayers and rituals. The huckleberry feast, held in early August, was (and remains) an important annual ritual in honor of the huckleberries. A number of participants attributed the poor present-day condition of berry fields to failure by tribal members to properly honor the huckleberries. They highlighted the importance of treating the plants that sustain the tribes with respect; otherwise, ecological productivity would be reduced.

Community cohesion embodied in the intergenerational and interfamilial gifting of huckleberries was a primary tending motivation. A rite of passage for CTWS adolescent girls—a counterpart to a hunting rite for adolescent boys—was a girl's first harvest, which culminated in gifting.[2] Similarly, the huckleberry feast functioned as a ceremonial expression of the longhouse religion, and included ritualized food songs, speeches, and reciprocal gifting. The ceremony brought together the community in sacred thanksgiving.

A worldview of human-nature interdependence also governed fire use and associated practices among the CTWS: if people take care of nature, nature will provide. Linked to this worldview is the belief that plants will reduce productivity if people neglect to tend them. Harvesting berries and edible roots was viewed also as benefitting and thereby honoring these cultural foods.

[2] University of Washington Libraries, Special Collections, David H. and Kathrine S. French papers, Accession 5496-001, Box 16.

Fig. 5. Historical reference conditions of sites traditionally tended for big-leaf huckleberry, in the moist mixed conifer zone, Greater Warm Springs Study Area. Fire use was applied into the late 1920s-/early 1940s. Mt. Hood area resource site, 1953, depicting upslope and downslope views (A, B). Multorpor Mountain berry picking area, western slope, 1952; Multorpor Mountain is a small volcanic cone on the southern slope of Mt. Hood (C, UW negative 38660). Mt. Hood area from Multorpor Mountain berry picking area, 1952 (D, UW negative 38662). *Wasquapam satas*, loosely translated as "site where the Wasco harvest", Warm Springs Reservation, 1954 (E, F). Images are derived from the University of Washington Libraries, Special Collections, David H. and Kathrine S. French Papers, Accession 5496-001, Box 54. (Slide images not assigned a UW negative number unless otherwise stated.)

The intergenerational transmission of traditional knowledge was largely field-based and informal, with children expected to learn by watching and imitating their elders. For specialized knowledge such as fire prayers and practices, knowledge was passed on to someone who was recognized by the elders as having a gift for being a "seer". The longhouse ceremonies, such as the huckleberry feast, were key occasions during which cultural knowledge was transmitted to tribal youth.

4.3. Social and ecological ramifications of the disruption of traditional fire use

Traditional fire use on the GWSRA continued on some sites into the late 1920s/early 1940s, according to most tribal participants, although one informant observed that burning had stopped by the late 1800 s. It may be that burning continued into the 20th century on sites where enforcement was limited. The cessation of traditional burning was due in part to the emergence of fire suppression policies of forest land management agencies, as occurred for the Karuk of northern California (Norgaard, 2014), and the Klamath (Turner, 2011). One example policy may have been the US Forest Service – state Cooperative Forest Fire Prevention Campaign of the early 1940s to protect wartime timber supply (Williams, 2009). Another potential factor in fire use disruption may have been escaped burns. One participant noted a large fire that took place in 1938 near Mount Hood—attributed to tribal members burning their huckleberry fields—as a key turning point in burning prohibition. This fire burned the same year that a fire (40,000 ha) occurred in the SG zone of the Warm Springs Reservation (Logan, 1982). Finally, fire use cessation was attributed to the younger generation of men not acquiring the necessary knowledge or skills during the post-World War II era, when they began shifting into new occupations. This combination of change in forest policy, social conditions, and fire events may have increased pressure on CTWS members to curtail burning practices.

The disruption of traditional fire use has contributed to an array of social ramifications (Table 4). One, tribal youth reportedly have experienced a loss of traditional knowledge of burning techniques, a diminished interest in food gathering, and an erosion of tribal language fluency. In response, the Warm Springs community—as one of thirteen tribes operating within the U.S. Fire Learning Network—has worked to recover and rejuvenate this traditional knowledge, including tribal languages, by engaging tribal youth in traditional burning practices (Huffman, 2013). Two, the overall community has reportedly experienced a weakening of traditional beliefs, the traditional relationship with the natural world, and community cohesion.

Fire use disruption also brought about ecological change (Table 4). All of the study participants described the present-day montane huckleberry fields where they had picked as youth as "overgrown," resulting in decreased patch area and productivity, and impeding access due to dense undergrowth. Key ecological changes included an increase in competing vegetation and tree size, resulting in more shade, smaller berry shrubs, and smaller patches. An implication of the understory vegetation accumulation is an increase in fuel loading and potential fire risk and severity if and when wildfires burn after a long absence. Additionally, informants reported the incursion of "non-traditional" plants and willows and more downed wood, further inhibiting access.

Table 4
Social and ecological changes and ramifications of disruption of traditional fire use.

Category	Changes	Ramifications
Social	Loss of ecological knowledge of traditional fire use practices and gathering site locations	– Diminished interest among youth in traditional food gathering and tending – Reduced fluency of language associated with traditional food gathering
	Weakening of traditional beliefs	– Huckleberry plants no longer honored; consequently, the resource is making itself less available for harvest, as perceived by traditional food gatherers – Harvest for huckleberry feast sometimes occurs outside the tribes' traditional territory – Huckleberry fields neglected, due to lack of harvest (harvest perceived by traditional gatherers as a fundamental mechanism of resource tending) – Some tribal members sell huckleberries –a departure from the traditional view that surplus berries should be given to elders and others who aren't physically able to gather them
	Weakening of community cohesion	– Fewer tribal members respect traditional beliefs, behaviors, and spiritual practices
Ecological	Forest encroachment into huckleberry patches	– Decline in huckleberry productivity and area
	Increased density of understory species other than huckleberry plants	– Increased competition for sunlight and soil nutrients, decreased size and productivity of berry bushes, and impeded access to and within berry fields
	Increased fuel loading of downed woody debris	– Impeded access to and within berry fields – Increased fire risk and susceptibility to higher severity, more damaging fires, especially under extreme conditions (e.g., summer drought)

5. Discussion

5.1. Fire use in the eastside Cascades in relation to CTWS traditional knowledge

Our analysis revealed that the distribution of fire use across ecological zones of the eastside Cascades was maintained by the CTWS traditional knowledge system, which was comprised of four interrelated elements: resource tending practices, tribal ecological principles, the seasonal round, and culture. These findings expand upon the existing understanding that fire use is a part of the traditional knowledge system (Turner et al., 2000; Lewis and Anderson, 2002; Stewart, 2009; Huffman, 2013; Lake and Long, 2014) in that we relate fire use to a landscape ecological framework. The seasonal round provided valuable insight into the spatial and temporal pattern of fire use. This factor is associated with data about the biogeographical distribution of culturally-valued plant resources, and by extension the spatial pattern of practices to enhance and access such resources. In addition, the seasonal round denoted data about an array of factors influential to fire use (e.g., encampment duration, encampment group size, harvest volume, preservation techniques). For instance during dry, windy periods, the escaped embers of fires set to dry and preserve the harvest may have augmented intentional burning (Minore et al., 1979). Finally, an aspect of the seasonal round that provided insight into the spatial pattern of fire use was quantification of the trail network. We found that the zone with the highest density of trails, indicating prevalent tribal activity, was associated with fire use. Similarly in the western Klamath Mountains, a relationship has been detected between the spatial patterns of the trail network and settlements and traditional fire use (Lake, 2013). These findings demonstrate how the seasonal round —a type of cultural geographical variable— can reveal historical linkages between tribal societies and landscapes, thereby guiding current restoration.

Our data also highlighted the role of culture in fire use pattern. Culture includes the traditions (e.g., ritualized ceremonies) and social roles (fire specialists; determinants of the start of the huckleberry harvest) through which fire use and other tending knowledge was maintained over generations. For instance, huckleberry traditional knowledge was stewarded by small, designated groups of men and women; in time, these groups transmitted this knowledge to the next generation through a deliberate process of designating specific tribal youth to learn and steward the traditional knowledge. Huckleberry ("We woo no Wash") drew together the tribal community through intergenerational and interfamilial gift-giving, the longhouse religion, as well as gathering by family groups at seasonal encampments, making it a cultural keystone species. When considered in light of previous studies (Berkes et al., 1995; French, 1999; Turner, 1999; Stewart, 2009; Long et al., 2015), we conclude that CTWS traditional burning in MMC forests of the eastside Cascades was purposeful, systematically deployed, intergenerationally maintained, guided by a highly valued knowledge system, and understood as a spiritual obligation and a stewardship responsibility.

Our results also highlight the ramifications of the disruption of traditional fire use on the CTWS community and resources, as has been documented elsewhere in the Pacific Northwest (Turner, 1999; Senos et al., 2006; LeCompte, 2018, and the Inland Northwest (Carroll et al., 2010)). By the late 1920s/early 1940s—about eight decades after the 1855 Treaty with the Tribes of Middle Oregon and roughly contemporaneous with the onset of commercial forestry on the Warm Springs Reservation (Logan, 1982) –fire use had been largely discontinued. Traditional knowledge must be applied if it is to persist and flourish (Charnley et al., 2007; Huffman, 2013; Lake et al., 2017). We found that traditional knowledge has a community basis. An implication of this finding is that unless the community is engaged, traditional knowledge risks deterioration (LeCompte, 2018).

5.2. CFRs of eastside Cascades ecological zones

Our analysis of the MMC zone of the eastside Cascades revealed a CFR characterized by a shifting rotation of frequent, low-severity, small-scale burns at targeted huckleberry patch sites. These results correspond with those of montane areas elsewhere in the Pacific Northwest, including of the Stl'atl'imx (Lillooet) peoples of the Pemberton Valley, B.C., Canada who deployed fire to tend berries and montane roots (*Erythronium, Lilium*) (Turner, 1999), and the Gitksan and Wet-suwet'en peoples of northwestern B.C., who tended mid-elevation *Vaccinium* berry patches (Gottesfeld, 1994). Oral histories have produced evidence of a several-year, rotational fire use pattern in montane areas of B.C. and ecological reasoning that corresponds with the results of this study: "when it got [too] bushy" (Turner, 1999:189), individuals burned one hillside area, then redirected harvesting to an unburnt area. In combination, these findings provide evidence that tribal peoples maintained a CFR in MMC forests of the Pacific Northwest.

Our findings also provide insight into how the CFR of MMC forests may have influenced the zone's historical fire regime and landscape structure. Our results correspond with the evolving picture of MMC zone dynamics that large fires accounted for the most area burned, yet small and medium fires were the most numerous (Stine et al., 2014). The CTWS apparently contributed to fire frequency by applying frequent, low-severity burns on an as-needed basis to maintain openings initially created by large conflagrations, as indicated in the 1901 forest inventory. This finding also expands upon previous research (French,

1999) by identifying geographical evidence that sites traditionally maintained for huckleberry tended to occur on or near large burn scars. This result suggests that the CFR may have contributed to the variability of the mixed severity fire regime, as occurs in the Pacific Northwest (Perry et al., 2011). That is, CTWS ignitions may have intermixed frequent, low-severity fire with the comparatively infrequent, natural ignitions that initially created large openings. The resulting patchwork of burn openings and fuels distribution may have increased historical forest resilience to wildfire (Stine et al., 2014; Hessburg et al., 2015).

At the landscape level, our results show evidence of variability in the eastside Cascades CFRs. We found that traditional fire use was pronounced in mid- to high-elevation MMC forests, but unpronounced for the DMC and SG zones. This result suggests that the CTWS varied ignitions in response to the practical need and appropriateness in different ecological zones and associated natural fire regimes. For certain roots harvested by the CTWS in the SG zone, our results differ from existing studies. For geophyte food plants such as Indian carrot, CTWS informants reported that fire was not purposefully applied, although natural ignitions were perceived to be beneficial. This result contrasts with that of many Sierra Nevada tribes (e.g., Sierra Miwok , North Fork Mono, and others), who reported burning, along with tilling, to promote this species (Anderson, 1997; Anderson and Lake, 2016). For the CTWS, this species tends to grow on low elevation meadows (Marsh et al., 1987), which may be slightly drier and less prone to competing vegetation than those of the Sierra Nevada. Similarly, the absence of CTWS fire use to promote camas contrasts with that reported for the Salish of southern Vancouver Island (Turner, 1999; Turner and Peacock, 2005). Camas harvested by the CTWS tends to grow in meadows (Marsh et al., 1987), whereas that harvested by the Salish occurred on Gerry Oak savannah within the Western Hemlock Biogeoclimatic zone, which is thought to be prone to afforestation. These contrasting findings may be due to regional differences in fire utility. We conclude that fire use variability in the eastside Cascades was driven by its relative ecological appropriateness for maintaining culturally-important resources, as has been shown in Pacific coastal North America (Turner et al., 2011).

5.3. Applications

5.3.1. Applications to thinleaf huckleberry enhancement and forest restoration

Our analysis revealed that the cessation of fire use (by the 1920s-1940s) contributed to reduced productivity and trail navigability of thinleaf huckleberry patches, despite the persistence of this understory shrub (USDA Forest Service, 2010). Informants cite two main causes of this ecological change. First, little sunlight reaches the shrub patches, due to canopy closure and encroachment by trees and competing undesired shrubs—a finding that corresponds with other studies of the eastside Cascades (Senos et al., 2006; USDA Forest Service, 2010; LeCompte, 2018), and B.C., Canada (Turner, 1999). Second, on commercial forest management units, trampling by equipment, vehicles, and yarding can damage shrub patches in the short-term; in addition, logging appears to promote weedy annuals and biennials (Anzinger, 2002). However, foresters note that these impacts subside over time. Soil moisture loss is a compounding factor on sites prone to evaporation and drainage (CTWS Branch of Natural Resources, personal communication). These findings highlight the need for huckleberry restoration prescriptions.

In response, natural resource managers of the GWSRA have adopted huckleberry enhancement prescriptions (Jimenez, 2002; USDA Forest Service, 2010). These prescriptions address objectives to enhance cultural foods for use by tribal members while fulfilling forest stand growth and yield targets, as directed by the agency's forest plan (CTWSRO, 1992). Huckleberry treatments strive to balance appropriate levels of sunlight and shade by retaining a partial overstory (canopy closure target: 30–50% (CTWS personal communication)). CTWS managers are implementing a variety of treatments, which range from commercial thin (70–110 trees per acre (tpa)), to "landscape" intermediate thin (50–70 tpa), to shelterwood (15–25 tpa), and "shelterwood – light" (10–15 tpa) on selected commercial harvest units in the MMC zone (management groups: grand fir; western hemlock-beargrass; mountain hemlock-lodgepole pine, and Pacific silver fir). These harvest modifications constitute an initial transition away from the intensive timber management of the 1960s-1970s, which featured even-aged harvests (clear-cut and plantation) (Logan, 1982). Such harvest modifications are notable, given the constraints posed by long-term management plan harvest commitments (CTWSRO, 1992; CTWSRO, 2012), forest operations, and restoration funding limitations. Managers report that huckleberry treatments allow sunlight to reach understory vegetation and reduce soil water loss, resulting in improved huckleberry productivity. In addition, a snowpack logging prescription (snowpack minimum: 0.9 m to 1.5 m) protects understory vegetation. Finally, CTWS managers have adopted road-edge vegetation retention, which reduces the deposition of detrimental roadbed dust onto huckleberry shrubs.

Although silviculture proxy fire treatments reportedly promote the objectives of forest growth and resource enhancement, such proxy treatments fall short of replicating the ecological benefits of traditional fire use. At the Big Huckleberry Summit (2007), Muckleshoot, Nisqually, Umatilla, and Warm Springs participants reported that fire performs many ecological functions, including nutrient cycling, reinvigoration of plant sprouting, and control of detrimental insects and diseases (LeCompte, 2018). This finding highlights the utility of fire reintroduction on sites where silvicultural objectives allow.

Our results about CFR scale suggest how a nested, multi-level framework, spanning patch- ("landscapes within landscapes") and landscape-levels (Hessburg et al., 2015:1089; see also, Stine et al., 2014) may be employed to reintroduce fire. At the finer-scale, our analysis revealed that the CTWS historically used fire in a rotational pattern to maintain patch openings in the MMC zone (Fig. 5). This finding suggests that one approach to restoration is a multi-stage fire reintroduction process. First, low severity fire initially could expand (or create) forest openings. Second, on-going, shifting application of frequent fire or proxy treatments around the management unit could maintain openings.

At the landscape-level, our analysis revealed that the spatial extent of the CFR (~220,000 ha) spanned an area that currently includes multiple ownerships—the Warm Springs Reservation and the Mt. Hood National Forest. This finding suggests that coordinated planning across ownerships is important to manager capacity to restore forest resilience and enhance cultural food resources. Incident management teams could allow wildfire use in areas that promote desired resources, provided that they do not pose a threat to life and property (Wildland Fire Decision Support System, 2018). However, many reservations, as well as private owners, have tended to favor fire suppression to protect timber resources, due to an array of social-economic and cultural constraints (Steen-Adams et al., 2017). Thus, efforts toward landscape-level, coordinated restoration may require dialogue both within tribal communities and across tribal and nontribal communities about acceptable trade-offs of reintroducing traditional fire as a management tool.

5.3.2. Applications to community engagement

Our research has applications for engaging communities who hold traditional knowledge. Our team's interactions with the CTWS revealed protocols that can promote productive collaboration between forest scientists, tribal communities, and tribal natural resource managers. Traditional knowledge is sacred knowledge (Berkes et al., 1995), some of which may be appropriately known only within the tribal community (Lake et al., 2017). Also, holders of traditional knowledge are unlikely to engage with scientists and managers unless they perceive an opportunity to advance their goals (Charnley et al., 2007) and the research framework accommodates both traditional and western knowledge (Lake et al., 2017). This said, many tribal elders, young adults, and managers are eager to participate in traditional knowledge documentation activities (e.g., PGIS workshops, interviews). Our team found that the following research design elements promoted successful collaboration: (i) dialogue to elicit tribal community goals and potential concerns about proposed forest science research; (ii) a protocol for protecting culturally-sensitive data (e.g., a non-disclosure agreement); (iii) an oral history approach to knowledge sharing, particularly featuring visual aids (e.g., archival photographs, maps); (iv) opportunities to engage tribal youth in the transmission and documentation of traditional knowledge (e.g., PGIS trainings). Such protocols can promote the revitalization of traditional knowledge, engagement of knowledge holders, and restoration of forests and culturally-important resources in and beyond the eastside Cascades of the Pacific Northwest.

6. Conclusion

This study was motivated by calls for research that integrates traditional knowledge into the understanding of forest ecology and restoration (Turner et al., 2000; Hessburg and Agee, 2003; Charnley et al., 2007; Lake et al., 2017). Eastside Cascades forests, which have been altered by utilitarian forestry practices and the interruption of historical fire regimes (Stine et al., 2014; Hessburg et al., 2015), have been our focus. We endeavored to generate insights by examining traditional knowledge of fire use from a perspective that integrated anthropology and landscape ecology. This approach revealed a pronounced CFR in the MMC zone, but not in the drier DMC and SG zones. This approach also highlighted the interrelated influences of culture, tribal ecological principles, the seasonal round, and fire use practices on the CFR. Our results suggest that the CTWS used fire in the zone that was appropriate to this combination of factors, but not in the drier zones due to comparatively less vegetative competition with cultural foods, and generally more frequent fire recurrence intervals. Another conclusion generated by our integrative approach is that the role of the CFR in the MMC zone was to maintain openings initially created by large conflagrations and that this regime operated at the landscape-level, spanning multiple mountains and buttes of the eastside Cascades. An application of this finding is that the MMC zone may be a priority area for traditional knowledge-based restoration, owing to the disruption of the CFR, in combination with wildfire suppression policies of the past century.

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Appendix A. CTWS traditional knowledge (TK) regarding thin-leaf huckleberry resource

TK major category	TK specific category	Data
Traditional fire use	Spatial extent of cultural fire regime (CFR) in moist mixed conifer zone	~220,000 hectares (estimated)
		CFR area spanned 2 Cascade Range mountains (Mt. Hood, Mt. Jefferson) and several buttes
		24 (at least) huckleberry resource sites
	Historical forest structure, as influenced by CFR	Forest matrix included sizable openings
		Openings characterized by minimal canopy cover, minimal competing understory vegetation, and scattered, small-diameter conifers
	Burn timing and frequency	Early fall (generally)
		Several-year recurrence interval: ignitions rotated around resource area
	Burn severity	Low severity
	Burn patch	Small, controllable patch size (a "section" of resource area), < 1 hectare (estimated)
	Fire control techniques	Burning timed to occur with precipitation events
		Clearance of flammable litter, collected in part to dry huckleberries, thereby controlling fuel load
		Fire guards encircled burn area
		Sparks extinguished by wet materials (e.g., gunnysacks)
		Belief in seers' ability to forecast precipitation onset
		Belief that the Creator would control fire spread
	TK practices other than fire use	Tree girdling
		Rotational harvest of huckleberry sites across resource area
		Respect for appropriate harvest start time: wait until berries are mature
		Exercise attention in traversing resource area to avoid damaging plants
	Demographic characteristics of designated fire specialists	"Scouts" or "seers" (older men) determined appropriate ignition conditions and timing
		Men primarily responsible for fire control; women assisted
	Recentness of fire use	Late 1920s to early 1940s
Tribal ecological principles	Target conditions	Relatively open sites with scattered, small-diameter conifers
		Traversable harvest areas: sparse downed woody debris, due to fuel gathering to dry huckleberries
		Minimal competing understory vegetation
		Field structure: Dense occurrence of huckleberry plants
	Reasons for burning	Control competing understory vegetation
		Maintain and/ or expand canopy openings
		Removal of debris to facilitate navigability for harvesters
		Stimulate sprouting of new huckleberry plant growth
		Replenish soil fertility; "cleanse soil"
		Control insect populations

Seasonal round	Socio-economic and cultural utility of huckleberries	Important dietary resource
		Tea ingredient (huckleberry leaves)
		Trade good
		Focus of ceremonial feast
		Interfamilial and intergenerational ceremonial gifting
	Harvest volume	2.5 - 8 gallons (estimated) / harvester/ day
	Preservation techniques	Air drying
		Fire /smoke augmented air drying, when cold or cloudy
		Canning (after 1940s)
	Encampment group size and demographics	Variable group size
		Multi-family groups, often spanning the three CTWS tribes
		Intergenerational group composition
		Mixed gender group composition (women and men)
	Mode of travel to encampment site	Horseback and horse-drawn wagons (until 1940s)
		Truck or car (post-World War II)
	Encampment duration	Variable encampment duration: some families stayed at a single base camp for the entire harvest season; others migrated among multiple sites
		Duration of entire harvest season: Several days to several weeks
	Encampment activities	Men handled pack horses and hunted game (deer, elk)
		Women and children harvested and processed berries
		Resources harvested other than huckleberries: other berry species, medicinal plants, basketry materials, game
	Land tenure	Harvest and encampment rights not exclusive to specific groups
		Cultural/language groups intermixed and circulated among gathering sites
Culture	Ceremonial huckleberry feast and associated multi-day festival	Event involved ritualistic blessings, songs, and festivities
		Ceremony honored the huckleberry plant and women gatherers
		Prior to the feast, designated women scouted the berry fields to assess ripeness; their return signaled the start of the feast
		Ceremony signaled the start of the harvest season
	Worldview and beliefs	Worldview of human-earth interdependence
		Harvest activities benefit the plants (e.g., resource productivity)
	Gender and generational aspects of TK	Older, designated men determined when and where to burn
		Women determined when to begin harvest
		Grandparents key to transmitting traditional knowledge to youth
	Intergenerational transmission of TK	Informal mode of transmission largely employed
		Children learned by watching and imitating their elders
		Elders sought and identified youth with a gift for TK, as basis for transmitting fire prayers and related knowledge
		Fasting rituals believed to be a mechanism for the Creator to reveal TK

References

Agee, J.K., 1993. Fire ecology of Pacific Northwest Forests. Island Press, Washington DC.

Aguilar, G.W., 2005. When the River Ran Wild! Indian Traditions on the Mid-Columbia and the Warm Springs Reservation. Oregon Historical Society Press in association with University of Washington Press, Portland, OR.

Anderson, M.K., Moratto, M.J., 1996. Native American land-use practices and ecological impacts. In: Sierra Nevada ecosystem project: final report to Congress Vol. 2. University of California Center for Water and Wildland Resources, Davis, CA, pp. 187–206.

Anderson, M.K., 1997. From tillage to table: The indigenous cultivation of geophytes for food in California. J. Ethnobiol. 17 (2), 149–169.

Anderson, M.K., Barbour, M.G., 2003. Simulated indigenous management: a new model for ecological restoration in national parks. Ecol. Restoration 21 (4), 269–277.

Anderson, M.K., Lake, F.K., 2016. Beauty, bounty, and biodiversity: the story of California Indian's relationship with edible native geophytes. Fremontia 44 (3), 44–51.

Anzinger, D.L., 2002. Big huckleberry (Vaccinium membranaceum) ecology and forest succession, Mt. Hood National Forest and Warm Springs Indian Reservation, Oregon, M.S. Thesis. Oregon State University, Corvallis.

Baker, W.L., Shinneman, D.J., 2004. Fire and restoration of pinon–juniper woodlands in the western United States: A review. For. Ecol. Manage. 189 (1–3), 1–21.

Barrett, S.W., Arno, S.F., 1982. Indian fires as an ecological influence in the northern Rockies. J. For. 80 (10), 647–651.

Berkes, F., Folke, C., Gadgil, M., 1995. Traditional ecological knowledge, biodiversity, resilience, and sustainability. In: Perrings, C.A. (Ed.), Biodiversity Conservation: Problems and Policies. Kluwer Academic Publishers, Dordrecht, pp. 281–287.

Besser, D.T., McLain, R., Cerveny, L.K., Biedenweg, K., Banis, D., 2014. Mapping landscape values: issues, challenges and lessons learned from fieldwork on the Olympic Peninsula, Washington. Environ. Pract. 16 (2), 138–150.

Bonnicksen, T.M., Anderson, M.K., Lewis, H.T., Kay, C.E., Knudson, R., 1999. Native American influences on the development of forest ecosystems. In: Sexton, W., Malk, A., Szaro, R., Johnson, N. Ecological stewardship: a common reference for ecosystem management, vol. II, pp. 439–470.

Boyd, R., 1999. Indians, Fire, and the Land in the Pacific Northwest. Oregon State University Press, Corvallis, OR.

Carroll, M.S., Cohn, P.J., Paveglio, T.B., Drader, D.R., Jakes, P.J., 2010. Fire burners to firefighters: the Nez Perce and fire. J. For. 108 (2), 71–76.

Charnley, S., Fischer, A.P., Jones, E.T., 2007. Integrating traditional ecological knowledge into forest biodiversity conservation in the Pacific Northwest. For. Ecol. Manage. 246 (1), 14–28.

Cissel, J.H., Swanson, F.J., Weisberg, P.J., 1999. Landscape management using historical fire regimes: Blue River. Oregon. Ecol. Appl. 9 (4), 1217–1231.

Confederated Tribes of Warm Springs Reservation of Oregon (CTWSRO), 1992. Integrated Resources Management Plan: Warm Springs Reservation, 1992-2001. Confederated Tribes of Warm Springs Reservation, Warm Springs, OR.

Confederated Tribes of Warm Springs Reservation of Oregon (CTWSRO), 2012. Integrated Resources Management Plan: Warm Springs Reservation. Confederated Tribes of Warm Springs Reservation, Warm Springs, OR.

Confederated Tribes of Warm Springs (CTWS), 2016. History, https://warmsprings-nsn.gov/history/ (accessed 12/28/18).

Couture, M.D., Ricks, M.F., Housley, L., 1986. Foraging behavior of a contemporary northern Great Basin population. J. California Great Basin Anthropol. 8 (2), 150–160.

Crawford, J.N., Mensing, S.A., Lake, F.K., Zimmerman, S.R., 2015. Late Holocene fire and vegetation reconstruction from the western Klamath Mountains, California, USA: A multi-disciplinary approach for examining potential human land-use impacts. Holocene 25 (8), 1341–1357.

Denevan, W.M., 1992. The pristine myth: The landscape of the Americas in 1492. Ann. Assoc. Am. Geograph. 82 (3), 369–385.

Durham, W.H., 1991. Coevolution: Genes, Culture, and Human Diversity. Stanford University Press, Stanford, CA.

Folwer, C.S., 2000. "We Live by Them" Native Knowledge of Biodiversity in the Great Basin of Western North America. In: Minnis, P.E., Elisens, W.J. (Eds.), Biodiversity and Native America. University of Oklahoma Press, Norman, OK, pp. 99–132.

French, D.H., 1957 (1999). Aboriginal control of huckleberry yield in the Northwest, in: Boyd, R. (Ed.), Indians, Fire, and the Land. Oregon State University Press, Corvallis, OR, pp. 31–35.

French, D.H., 1965. Ethnobotany of the Pacific Northwest Indian. Econ. Bot. 19 (4), 378–382.

Garibaldi, A., Turner, N., 2004. Cultural keystone species: implications for ecological conservation and restoration. Ecol. Soc. 9 (3). https://www.ecologyandsociety.org/vol9/iss3/art1/.

Goschke, L., 2016. Tribes, treaties, and the trust responsibility: a call for co-management of huckleberries in the Northwest. Colo. Nat. Resour. Energy Envtl. L. Rev. 27 (2), 315–360.

Gottesfeld, L.M.J., 1994. Aboriginal burning for vegetation management in northwest British Columbia. Hum. Ecol. 22 (2), 171–188.

Helliwell, R., 1987. Forest Plants of the Warm Springs Indian Reservation, Branch of Natural Resources, Confederated Tribes of Warm Springs, OR. Bureau of Indian

Affairs, Warm Springs Agency, Warm Springs, OR.
Hessburg, P.F., Salter, R.B., Richmond, M.B., Smith, B.G., 2000. Ecological subregions of the Interior Columbia Basin, USA. Appl. Vegetation Sci. 3 (2), 163–180.
Hessburg, P.F., Agee, J.K., 2003. An environmental narrative of Inland Northwest US forests, 1800–2000. For. Ecol. Manage. 178 (1–2), 23–59.
Hessburg, P.F., Agee, J.K., Franklin, J.F., 2005. Dry forests and wildland fires of the inland Northwest USA: contrasting the landscape ecology of the pre-settlement and modern eras. For. Ecol. Manage. 211 (1–2), 117–139.
Hessburg, P.F., Salter, R.B., James, K.M., 2007. Re-examining fire severity relations in pre-management era mixed conifer forests: inferences from landscape patterns of forest structure. Landscape Ecol. 22 (1), 5–24.
Hessburg, P.F., Churchill, D.J., Larson, A.J., Haugo, R.D., Miller, C., Spies, T.A., North, M.P., Povak, N.A., Belote, R.T., Singleton, P.H., Gaines, W.L., 2015. Restoring fire-prone Inland Pacific landscapes: seven core principles. Landscape Ecol. 30 (10), 1805–1835.
Huffman, M.R., 2013. The many elements of traditional fire knowledge: synthesis, classification, and aids to cross-cultural problem solving in fire-dependent systems around the world. Ecol. Soc. 18 (4). https://www.ecologyandsociety.org/vol18/iss4/art3/.
Hummel, S., Lake, F.K., 2014. Forest site classification for cultural plant harvest by tribal weavers can inform management. J. For. 113 (1), 30–39.
Hunn, E.S., French, D.H., 1981. Lomatium: a key resource for Columbia Plateau native subsistence. Northwest Sci. 55 (2), 87–94.
Hunn, E.S., 1990. Nch'i-Wana, "The Big River:" Mid-Columbia Indians and Their Land. University of Washington Press, Seattle, WA.
Jimenez, M., 2002. Management Considerations Focusing on Big-Leaf Huckleberry, Vaccinium membranaceum, Confederated Tribes of Warm Springs, Warm Springs, OR.
Knudson, R., 1980. Fish, roots, game, and trade in the Columbia Plateau. J. For. 78 (9), 542–556.
Kuchler, A.W., 1964. Potential natural vegetation of the conterminous United States. Manual to accompany the map (No. 36). American Geographical Society.
Kimmerer, R.W., Lake, F.K., 2001. The role of indigenous burning in land management. J. For. 99 (11), 36–41.
Lake, F.K., 2007. Traditional ecological knowledge to develop and maintain fire regimes in northwestern California, Klamath-Siskiyou bioregion: Management and restoration of culturally significant habitats, Doctoral dissertation. Oregon State University.
Lake, F.K., 2013. Historical and cultural fires, tribal management and research issues in Northern California: trails, fires and tribulations. Occ.: Interdiscipl. Stud. Human. 5, 1–22. http://occasion.stanford.edu/node/121.
Lake, F.K., Long, J.W., 2014. Fire and tribal cultural resources. In: Long, J.W., Quinn-Davidson, L., Skinner, C.N., (Eds.), Science Synthesis to Support Socioecological Resilience in the Sierra Nevada and Southern Cascade Range. Gen. Tech. Rep. PSW-GTR-247. U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Albany, CA, pp. 173–186.
Lake, F.K., Wright, V., Morgan, P., McFadzen, M., McWethy, D., Stevens-Rumann, C., 2017. Returning fire to the land: celebrating traditional knowledge and fire. J. For. 115 (5), 343–353.
Langille, H.D., Plummer, F.G., Dodwell, A., Rixon, T.F., Leiberg, J.B., 1903. Historical conditions of the Cascade Range Forest Reserve, Oregon. U.S. Geological Survey, Professional Paper No. 9, Government Printing Office, Washington DC.
LeCompte, J.K., 2018. Restoration, Risk, and the (Non) Reintroduction of Coast Salish Fire Ecologies in Washington State. In: Fowler, C.T., Welch, J.R. (Eds.), Fire Otherwise: Ethnobiology of Burning for a Changing World. University of Utah Press, Salt Lake City, UT, pp. 128–150.
Lewis, H.T., Anderson, K., 2002. Omer Stewart's legacy of fire: anthropological and ecological contexts, in: Stewart, O.C., with Lewis H.T., Anderson, K. (Eds.), Forgotten Fires: Native American Burning of Prairies, Shrublands and Forests. University of Oklahoma Press, Norman, OK. pp. 3–16.
Logan, R., 1982. Historical Perspectives: The Warm Springs Forest through 1980. Warm Springs Reservation, Warm Springs, OR.
Long, J.W., Quinn-Davidson, L., Goode, R.W., Lake, F.K., Skinner, C.N., 2015. Restoring California black oak to support tribal values and wildlife, in: Standiford, R.B., Purcell, K.L. (Eds.), Proceedings of the Seventh California Oak Symposium: Managing Oak Woodlands in a Dynamic World. Gen. Tech. Rep. PSW-GTR-251. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Berkeley, CA, pp. 113–122.
Marsh, F., Helliwell, R., Rodgers, J., 1987. Plant Association Guide for the Commercial Forest of the Warm Springs Indian Reservation. Bureau of Indian Affairs, Warm Springs Agency, OR.
McBride, B.B., Sanchez-Trigueros, F., Carver, S.J., Watson, A.E., Stumpff, L.M., Matt, R., Borrie, W.T., 2016. Participatory geographic information systems as an organizational platform for the integration of traditional and scientific knowledge in contemporary fire and fuels management. J. For. 115 (1), 43–50.
Miller, R., Bates, J., Svejcar, A., Pierson, F., Eddleman, L., 2005. Biology, ecology, and management of western juniper (Juniperus occidentalis). Oregon State University Agricultural Experiment Station, Technical Bulletin 152, Corvallis, OR.
Minore, D., Smart, A.W., Dubrasich, M.B., 1979. Huckleberry and Ecology Management Research in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-093. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 60 pp.
Minore, D., 1984. *Vaccinium membranaceum* berry production seven years after treatment to reduce overstory tree canopies. Northwest Sci. 58 (3), 208–212.
Morgan, P., Bunting, S.C., Black, A.E., Merrill, T., Barrett, S., 1996. Fire regimes in the Interior Columbia River Basin: past and present. USDA Forest Service, Rocky Mountain Research Station Final Report for RJVA-INT-94913. Fire Sciences Laboratory, Missoula, MT.
Murdock, G.P., 1980. The Tenino Indians. Ethnology 19 (2), 129–149.
Norgaard, K.M., 2014. The politics of fire and the social impacts of fire exclusion on the klamath. Humboldt J. Soc. Relations 36 (1), 73–97.
Patton, M.Q., 2002. Qualitative Evaluation and Research Methods. SAGE Publications, Thousand Oaks, CA.
Perry, D.A., Hessburg, P.F., Skinner, C.N., Spies, T.A., Stephens, S.L., Taylor, A.H., Franklin, J.F., McComb, B., Riegel, G., 2011. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. For. Ecol. Manage. 262 (5), 703–717.
Pitt, P.E., 2015. Addressing food sovereignty through access to Wi'wnu (Huckleberries): A case study of the Warm Springs Indian Reservation, M.S. thesis. The Evergreen State College.
Richards, R.T., Alexander, S.J., 2006. A Social History of Wild Huckleberry Harvesting in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-657. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 113 pp.
Senos, R., Lake, F.K., Turner, N., Martinez, D., 2006. Traditional ecological knowledge and restoration practice. In: Apostol, D., Sinclair, M. (Eds.), Restoring the Pacific Northwest: The Art and Science of Ecological Restoration in Cascadia. Island Press, Washington, DC, pp. 393–426.
Shinn, D.A., 1980. Historical perspectives on range burning in the Inland Pacific Northwest. J. Range Manage. 33 (6), 41–423.
Steen-Adams, M., Charnley, S., Adams, M., 2017. Historical perspective on the influence of wildfire policy, law, and informal institutions on management and forest resilience in a multiownership, frequent-fire, coupled human and natural system in Oregon, USA. Ecol. Soc. 22 (3). https://www.ecologyandsociety.org/vol22/iss3/art23/.
Stewart, O.C., 2009. Forgotten Fires: Native Americans and the Transient Wilderness. University of Oklahoma Press, Norman, OK.
Stine, P., Hessburg, P., Spies, T., Kramer, M., Fettig, C.J., Hansen, A., Lehmkuhl, J., O'Hara, K., Polivka, K., Singleton, P., Charnley, S., Merschel, A., White, R., 2014. The Ecology and Management of Moist Mixed Conifer Forests in Eastside Oregon and Washington: A Synthesis of the Relevant Biophysical Science and Implications for Future Land Management. Gen. Tech. Rep. GTR-PNW-897. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.
Turner, N.J., 1999. "Time to Burn:" Traditional use of fire to enhance resource production by aboriginal peoples in British Columbia. In: Boyd, R. (Ed.), Indians, Fire, and the Land in the Pacific Northwest. Oregon State University Press, Corvallis, OR, pp. 185–218.
Turner, N.J., Ignace, M.B., Ignace, R., 2000. Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. Ecol. Appl. 10 (5), 1275–1287.
Turner, N.J., Peacock, S., 2005. Solving the perennial paradox: ethnobotanical evidence for plant resource management on the Northwest Coast. In: Deur, D., Turner, N.J. (Eds.) Keeping It living: Traditions of plant use and cultivation on the Northwest Coast of North America, pp. 101–50.
Turner, N.J., Deur, D., Mellott, C.R., 2011. "Up On the Mountain": Ethnobotanical Importance of Montane Sites In Pacific Coastal North America. J. Ethnobiol. (1), 4–44.
University of Washington Libraries, Special Collections (UWLSC), 2008. David H. and Katherine S. French papers, 1916-2006, http://archiveswest.orbiscascade.org/ark:/80444/xv30429/op = fstyle.aspx?t = k&q = DH + French (accessed 12/18/18).
USDA Forest Service, 2010. Preliminary Assessment: Huckleberry Enhancement. Mt. Hood National Forest, Estacada, OR.
USDA Forest Service, n.d.. Program Areas, Landscape Simulations. https://www.fs.fed.us/t-d/programs/forest_mgmt/projects/landscapesim/software.shtml (accessed 12/19/18).
USDA Forest Service ECOMAP Team, 2017. Kuchler Sections. https://data.fs.usda.gov/geodata/edw/edw_resources/meta/S_USA.PNV_KuchlerSections.xml (accessed 12/18/18).
Vale, T., 2002. Fire, Native Peoples, and the Natural Landscape. Island Press, Washington DC.
Voegelin, E.W., 1955. The Northern Paiute of Central Oregon: A Chapter in Treaty-Making Part 1. Ethnohistory 2 (2), 95–132.
Warm Springs Geo Visions' Cultural Resources Division (WSGVCRD), n.d. https://wsgeov.com/ceded-lands-map/ (accessed 12/18/18).
Wildland Fire Decision Support System (WFDSS), 2018, https://wfdss.usgs.gov/wfdss/WFDSS_Home.shtml (accessed 5/13/19).
Williams, G.W., 2000. Early fire use in Oregon. Fire Manage. Today 60 (3), 13–20.
Williams, G.W., 2009. The US Forest Service in the Pacific Northwest: A History. Oregon State University Press.
Zucker, J., Hummel, K., Høgfoss, B., Penniman, J.F., 1983. Oregon Indians: Culture, History and Current Affairs: An Atlas and Introduction. Oregon Historical Society Press, Portland, OR.
Zybach, B., 2003. The great fires: Indian burning and catastrophic forest fire patterns of the Oregon Coast Range, 1491–1951, Doctoral dissertation. Oregon State University.