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The importance of Indigenous cultural burning in forested regions of the Pacific West, USA

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ABSTRACT

Indigenous communities in the Pacific West of North America have long depended on fire to steward their environments, and they are increasingly asserting the importance of cultural burning to achieve goals for ecological and social restoration. We synthesized literature regarding objectives and effects of cultural burning in this region within an ecosystem services framework. Much scholarly literature focuses on why various species harvested from burned areas were important historically, while tribes and recent research increasingly stress a wide range of ecological and cultural benefits afforded by contemporary cultural burning. These tribal values generally align with broader ecological restoration objectives, although Indigenous practitioners espouse holistic views on the benefits of burning rather than focusing narrowly on fuel reduction and wildfire mitigation. While government agencies are motivated to treat more and larger areas to reduce fire risk (expanding pace and scale), tribal practitioners have tended to burn comparatively small areas at one time, and cumulatively due to various constraints. However, they would like to burn more widely and frequently to promote resilience to wildfire and drought; conserve biocultural diversity, maintain traditional knowledge and spiritual values; and provide material goods such as foods, medicines, and fiber materials. Much of the experimental research on the effects of cultural burning has been conducted as graduate research and has tended to look at single burns (sometimes agency prescribed burns or wildfires rather than tribally-led cultural burns) for short periods in very limited contexts. Such studies have found that treatments often promote desirable plant qualities, including reduced incidence of pests and structural qualities that facilitate weaving and other crafts. However, effects on understory plant diversity, wildlife, fruit production, parasites, and other key aspects of resource quality have been more difficult to evaluate due to complex interactions and scale considerations. Expanding long-term tribal collaboratives, including designating cultural management areas with frequent burning, would help to understand the potential to achieve ecocultural restoration objectives.

1. Introduction

Indigenous communities in the Pacific West of North America have long depended on fire to steward their environments (Boyd, 1999; Turner, 1999; Anderson, 2009; Lightfoot and Parrish, 2009; Anderson, 2018). Indigenous communities in this region have expressed their interest in reasserting their traditional fire stewardship practices (Goode et al., 2018; Clark et al., 2021). Federal and state agencies have sought to increase their engagement with tribes and other Indigenous organizations to support restoration, including collaboratives such as the Western Klamath Restoration Partnership (Kelly et al., 2019). Consequently, there is heightened interest in how Indigenous approaches to burning can integrate with broader ecosystem restoration policies and investments.

1.1. Calls for increased use of fire

Scientists and land managers have increasingly called for greater use of fire, including both prescribed and naturally-ignited fires, to expand the "pace and scale" of restoration and promote resilience of social-

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ecological systems (Kolden, 2019; McWethy et al., 2019; Spies et al., 2019). These calls have become stronger as uncharacteristically large and severe wildfires have become more common (Miller and Safford, 2012; Miller et al., 2012; Reilly et al., 2017) and more disruptive to ecological and social values, including public health (O'Dell et al., 2019) and cultural resources (Welch, 2012). National forests in this region have initiated the process of revising their land management plans to expand the role of intentional fire (Spies et al., 2019), while the State of California has committed to sweeping new initiatives (Forest Management Task Force, 2021) that include support for tribal cultural burning. However, significant policy obstacles, including liability concerns and air quality regulations, may hinder these efforts (Clark et al., 2021).

1.2. Intent and scope of this review

In this paper we review and synthesize publications about Indigenous use of fire in the Pacific West in the present-day United States to explain its importance to tribal communities, its utility in advancing social and ecological well-being now and in the future, and key implications for research and management. Our review concentrates on the forested regions of Northern California and southern Oregon, which represent a center of Indigenous burning, as the place where the Indigenous Peoples Burning Network (http://www.conservationgateway.org/ConservationPractices/FireLandscapes/Pages/IPBN.aspx) originated. However, we also reference studies from the wider regions of Western North America that are associated with frequent fire regimes.

We considered a variety of sources, including previously published review articles and synthesis reports, publications derived from social science research including interviews and ethnographies, articles and theses that report findings from monitoring/observational studies, as well as recent reports produced by and for tribal entities that have a policy orientation (Goode et al., 2018; Clark et al., 2021; Sloan and Hostler, 2014; Norgaard and Tripp, 2019). Older academic publications often focus on historical practices and intentions described by cultural practitioners to non-Indigenous researchers (e.g., Stewart 2002), while more recent documents help to understand contemporary needs and constraints often as part of tribal collaborative efforts. Our approach complements a recent review of Indigenous fire management across the globe that was limited to articles published in peer-reviewed journals since 2000 to reflect contemporary knowledge (Nikolakis and Roberts, 2020). Older literature and tribal reports can highlight objectives that are pertinent to our region, but which may not be well-represented in recent peer-reviewed articles.

We begin by briefly summarizing debates over the past importance of Indigenous burning and the implications for addressing contemporary challenges. Next, we consider how an ecosystem services framework can help to identify important benefits of cultural burning, while also acknowledging how such classification could also misrepresent more holistic tribal perspectives. We then consider implications for management and research. Throughout the paper, we include figures that illustrate examples of contemporary Indigenous burning and their associated targets.

1.3. Evolving debates over the past influence of Indigenous burning

After modern land management institutions in the USA were established over a century ago, some land managers decried Indigenous burning, then derided by some as "Paiute forestry", as harmful to forests (Harley, 1918; Greeley, 2000). Early U.S. Government records include derogatory references to "old superstitious Indians" (Crouse, 1902), "renegades" (Harley, 1918), and the "hand of the incendiary" with "selfish and malicious motives" (Lake, 2007) (p. 273). Over the past century, academics have debated the importance of Indigenous burning versus climate on fire regimes. Whitlock and Knox (2002) provided a review for the Pacific Northwest that considered paleoecological evidence over thousands of years and historical accounts and which highlighted the extensive influences in the Willamette Valley of Oregon. Focusing on ethnoecology research in the same region, Boyd (1999) highlighted regional features associated with fire use, including huckleberry patches, ponderosa pine forests, oak woodlands, and prairies. Other scientists have contended that the influence of Indigenous burning in the Pacific West was confined to localized areas around settlements (Vale, 2002). These claims have been challenged by researchers who have found evidence that changes in fire regimes coincide with interruption of Indigenous practices (Fry and Stephens, 2006; Skinner et al., 2009; Taylor et al., 2016; Metlen et al., 2018). They have also been challenged by other researchers who have engaged directly with Indigenous communities to document their use of fire (Anderson, 2009; Lake, 2013; Anderson, 2018). Recent research using paleoecological reconstruction and landscape modeling has found that Indigenous burning shaped the environment, including promoting oaks, over large areas around meadow sites in the southern Sierra Nevada (Klimaszewski-Patterson and Mensing, 2020).

Debates over the influence of Indigenous burning have occurred in other regions of North America, leading some scientists to note how conventional paleoecology approaches may fail to recognize the influence of Indigenous burning. For example, Oswald et al. (2020b) recently synthesized paleoecological research and historical documents and concluded that "Native people did not use fire to shape New England's landscape" (Oswald et al., 2020a) and that fire was not an appropriate management tool in that region. That work generated several responses that explained why the effects of Indigenous burning may be difficult to resolve at landscape scales and why it is important to carefully consider such evidence and Indigenous knowledge (Abrams and Nowacki, 2020; Leonard et al., 2020; Roos, 2020).

Recent studies in other regions, many of which have involved partnerships with tribes, have also documented legacies of Indigenous burning. In a study in the Northern Great Plans that involved the Blackfeet Nation, Roos et al. (2018) concluded that small groups of Indigenous bison hunters used fire in response to favorable climate conditions, thereby enhancing climate impacts in ways that might be difficult to distinguish from Indigenous burning. A study in the high plateaus of Utah using archaeological data and modeling found that fire activity was more strongly correlated with ancient Indigenous farming-foraging systems than the climate factors that dominate more recent wildfire activity (Carter et al., 2021). In the Jemez Mountains of the Southwest, a recent study by Roos et al. (2021), which involved several tribes in the region, documented the ecological influence of patchy Indigenous burning and wood collection around an ancestral Jemez community. This work added to research by Liebmann et al. (2016), who provided fine-grained evidence of the impacts of Spanish colonization on Native Jemez populations and the indirect changes on fire regimes and forest regeneration. These recent studies contrast with older ecological research in the Southwest that discounted Indigenous influence on fire regimes and instead emphasized the influence of lightning (Allen, 2002).

This evolving science demonstrates the importance of engaging with tribes to interpret records and understand implications of research. In many of the more recent publications that were informed by collaborations with Indigenous peoples, researchers have noted that methods need to be sensitive to the finer-scale, more subtle signatures of Indigenous burning (Lake, 2013; Roos et al., 2019). We return to research issues later in this paper, while turning our focus to understanding how and why Indigenous burning can help confront present and future social and ecological challenges.

1.4. Definition and objectives of cultural burning

Cultural burning has been recently defined by Clark et al. (2021) as the "purposeful use of fire by a cultural group (e.g., family unit, Tribe, clan/moiety, society) for a variety of purposes and outcomes" (p. 3). Other terms such as Indigenous fire management (Nikolakis and

Roberts, 2020), Indigenous burning, and Indigenous stewardship encompass cultural burning. Practitioners note that cultural burns are generally preceded by extensive site preparation and followed by monitoring and additional cultural practices as part of a land stewardship tradition. Agency-led prescribed burns may be informed by cultural practitioners to achieve cultural objectives (Fig. 1). However, cultural burners contend that typical agency-led prescribed burns tend to be more focused on reducing fuels and avoiding canopy mortality, while relying more on climatological metrics, constructed fire lines, and suppression technology (Marks-Block and Tripp, 2021).

Scholars have previously catalogued the many objectives of cultural burning (Table 1). Williams (2005) condensed 70 different reasons for Indigenous burning documented by Lewis (1973) into 11 categories. A recent review of international burning across temperate and tropical biomes around the work identified 18 categories of objectives (Trauernicht et al., 2015). Recent reviews from chaparral ecosystems in California (Anderson and Rosenthal, 2015; Anderson and Keeley, 2018) identify particular organisms that were targeted in Indigenous burning, while then explaining how those practices support social engagement and ecosystem-level functions.

1.5. Present-day priorities

Priorities for cultural burning have shifted in response to the present-day challenges facing tribal communities. A recent article reported that tribes in British Columbia had goals of strengthening cultural connection and well-being, restoring the health of the land, and respecting traditional laws (Nikolakis et al., 2020). Another recent review from British Columbia (Lewis et al., 2018) found that cultural burning continues to follow traditional rationales, but that debris control and hazard abatement have become more predominant while foodstuff amelioration has become less predominant. Recent reports in California directed toward policy change (Goode et al., 2018; Clark et al., 2021) focus on present-day needs and intentions that emphasize social values including the right to burn and cultural integrity, as well as material benefits and community safety. Such forward-looking approaches are an expression of tribal adaptive capacity and self-determination (Mauer, 2020).

2. Ecosystem services frameworks

2.1. Millenium ecosystem assessment framework and revisions

Ecosystem services are commonly defined as benefits that ecosystems provide to people, or more precisely as those *functions* of ecosystems that benefit humans (Kremen, 2005). Scholars have noted that humans have to make some investment (for example, harvest and processing) to convert the services into actual benefits (Willot et al., 2019). The United Nations' Millennium Ecosystem Assessment (MEA) featured a function-based typology that included "provisioning", "regulating", and "cultural" services that directly affect people, as well as the "supporting services" that maintain the system (Patterson, 2014). Scholars have tried to update these frameworks to avoid problems such as double counting by not using a supporting services category (Willot et al., 2019). Despite these issues, ecosystem services frameworks like the MEA are increasingly structuring agency land management planning, including revision of national forest plans in the U.S. (Armatas et al., 2018), as well as international vulnerability assessments of forest and communities (Paudyal et al., 2015; Long and Steel, 2020). Consequently, an ecosystem services framework may be useful in relating values important to tribes to these institutional processes. In Table 1, we crosswalk these categories to ones previously suggested in reviews of Indigenous burning with different spatial scopes, while acknowledging that objectives often relate to multiple kinds of services.

2.2. Services for ecosystems and other modifications to better reflect Indigenous worldviews

While applying an ecosystem services framework, we recognize that its utilitarian emphasis may conflict with worldviews commonly held by Indigenous people. Applications of the framework often emphasize services that are amenable to economic valuation (Binder et al., 2017); however, for many cultural ecosystem services, quantification and monetization may be difficult or objectionable (Fish et al., 2016). Indigenous communities often maintain more holistic, reciprocity-based philosophies, which reflect a deontological, or duty-based, framework

Fig. 1. A prescribed burn project led by a crew from Greenville Rancheria, with guidance from elders, to promote beargrass (*Xerophyllum tenax*) near Canyon Dam on the Plumas National Forest.
Photo by Reina Rogers.

Table 1
Services associated with Indigenous cultural burning in this study and others with different spatial scopes.

	Source and region			
Service category	Pacific West USA (this paper)	USA (Williams, 2005)	Global (Trauernicht et al., 2015), with numbers ranked from most frequent (1) to least frequent	California (Anderson, 2018; Anderson and Keeley, 2018)
Services for ecosystems	Duties to places and non-human relatives		15. Ownership/ responsibility	
Non-material cultural services	Maintenance of lifeways	Clearing areas for travel Clearing riparian areas Economic extortion Warfare & signaling	1. Clean/clear landscape 13. Communication 17. Warfare/conflict	Keeping the country open
	Transmission of knowledge			Retaining traditional knowledge
	Ceremonies and spiritual well-being		14. Ceremonial/medicinal	Ceremonial and medicinal purposes, including tobacco and wild celery
	Sense of place			
Material cultural-provisioning services	Foods, medicines, and materials from plants, fungi, and animals	Improve growth and yields Crop management	2. Manipulate plant traits 4. NTFP harvest 6. Cultivation	Creating plant material for the manufacture of baskets and other cultural items Enhancing food production (plants and fungi)
		Felling trees	10. Forest management 16. Firewood collection	Firewood and structures
		Hunting Insect gathering	3. Drive game animals 5. Attract game 18. Fishing 7. Pasture management 11. Animal safety 12. Animal gathering	Managing and hunting wildlife
Regulating and supporting services	Species biodiversity			Increased patchiness of plant populations Higher species diversity
	Ecosystem biodiversity			Increase landscape heterogeneity Expand special plant community types (e.g., ponds, marshes, meadows, and prairies)
	Pollination			Promote butterflies
	Regulating pests and diseases	Pest management	9. Pest management	Combat insects and diseases
	Soil health			Increase nutrient cycling and soil moisture
	Hydrology			Increase water resources, including spring flows
	Regulating wildfire	Fireproof areas	8. Prevent destructive fires	Reduce the chance of catastrophic fires

(Whyte, 2018). This philosophy of stewardship has been described as "reciprocal restoration" (Kimmerer, 2011), a "caretaker responsibility" (Deur, 2009), and "human services for ecosystems" (Lake, 2021). Members of Indigenous communities have emphasized both benefits and a sense of duty as motivations for cultural burning (Deur and Turner, 2005; Strass, 2010). Many Indigenous practitioners view cultural burning as fulfilling their stewardship responsibilities to the land, while suggesting that such practices will in turn benefit the people who depend on those ecosystems (Kimmerer and Lake, 2001). Therefore, frameworks that emphasize measurable goods and ends may reinforce consumerism and fail to appreciate the importance of maintaining proper ways of living and the well-being of whole systems to Indigenous peoples.

Researchers have proposed alternative frameworks for examining cultural services, especially to better integrate Indigenous perspectives (Fish et al., 2016). The MEA and other frameworks apply the term "cultural ecosystem services" only to *non-material* benefits, including aesthetic, spiritual and existence values, in contrast with more tangible services (Fish et al., 2016). However, associating cultural services only with intangible benefits is awkward because material provisions are so critical to maintaining Indigenous cultures. In response, Fish et al. (2016) (p. 212) instead defined cultural services as "contributions ecosystems make to human well-being in terms of the identities they help frame, the experiences they help enable and the capabilities they help equip."

2.3. Non-material cultural services

Non-material cultural services are one of the least studied dimensions of Indigenous fire stewardship, but they are particularly important in explaining why Indigenous people assert the need to conduct burning themselves. We discuss several examples of non-material cultural services, while noting that these benefits intersect synergistically with each other and with the physical effects that also support tribal cultures.

2.3.1. Maintenance of lifeways

After living in fire-prone landscapes for millennia, many tribes across the Pacific West have become culturally dependent on fires to obtain benefits from their ecosystems. They developed practices to modify fire regimes that responded to climate and other environmental factors (Anderson, 2005; Eriksen and Hankins, 2014; Lake, 2021). These relationships vary across and among tribes and at different levels of organization, including individuals, families, clans/groups, and villages/towns. Differences among practices are associated with gender, specialized trades (e.g., basketweaver, hunter, food gatherer, regalia maker), and cultural roles (e.g. ceremonial leader, defender of sacred areas) (Lake, 2021). Some uses of fire reported from historical literature (e.g., smoke signaling, felling trees, driving game, and economic warfare) have been displaced by adoption of alternative technologies and other social changes. As discussed further under provisioning services, to yield good returns on their investments of labor, Indigenous

practitioners target areas that are accessible and expected to be productive (Long et al., 2016). Burning remains important for clearing areas and enhancing resource quality in ways that make it sufficiently worthwhile to invest time in tending and harvest (Anderson, 2018; Long and Lake, 2018). Accounts from more than a century ago noted the lack of fire and effects of non-Indigenous forest practices were reducing opportunities for traditional harvest (Editor, 1916; Thompson, 1916).

2.3.2. Transmission of knowledge

Indigenous knowledge is derived from observations of the environment, ecological processes and species life histories and interactions; it is also taught continually as members engage in ritual, subsistence, and other domestic activities that provide opportunities for intergenerational exchange (Huffman, 2013). When environmental conditions deteriorate in ways that no longer support traditional lifeways, the associated knowledge and social structures are likely to erode (Willette et al., 2016; Norgaard et al., 2017; Long and Lake, 2018). Cultural burns are a mechanism for reversing this erosion, as they draw in members from many tribal communities who share their knowledge of using fire and tending resources while reaffirming shared obligations. Such burns are conducted to create more open and safer areas that facilitate access by elders and youth (Anderson and Rosenthal, 2015). Burning and associated stewardship practices maintain culturally important traditions including intergenerational learning and place-making (LeCompte-Mastenbrook, 2016; Norgaard, 2019).

2.3.3. Ceremonies and spiritual well-being

Cultural use of fire is important for sustaining Indigenous spiritual values, including fulfilling obligations in Tribal belief systems and practices (Eriksen and Hankins, 2014). For example, among the Southern Paiute, "oral history states that the Creator charged them with balancing the land, which is sentient and considered a close relative, at different points in time", and fire is one of the tools they are expected to use to maintain that balance (Spoon et al., 2015). Cultural burns are featured in ceremonies (Kimmerer and Lake, 2001), and they are typically conducted with offerings of ceremonial plants like tobacco (*Nicotiana* spp.), wild celery (*Lomatium* spp.) and sage (*Salvia* spp. and *Artemisia* spp.) and sharing of songs. Many Indigenous practitioners consider fire to be "medicine" for both humans and the land, and traditional medicine persons have a key role in using fire (Norgaard, 2019; Wynecoop et al., 2019; Lake, 2021). Some individuals received special training and acquired knowledge of fire, winds, and responses of dead and living plants to fire. Stewart (2002) described such a chosen individual among the Karuk Tribe as a "formulist": "When setting a fire, the fire setter said formula (made incantations?) for a big fire, yet one which would do no harm…. Then the formulist blows in all four directions to keep the fire from spreading. The formulist is a fire setter who knows the proper medicine" (p. 277). Today such individuals become recognized as cultural burning specialists and serve in roles comparable to a "burn boss" in agency-led prescribed burns.

Areas that have been used to manage wildfires are often located in places of ceremonial and spiritual importance. For example, fire lookout towers were placed upon sacred peaks, which are often used for making medicines and are associated with weather and fires (Norgaard, 2019), and culturally important plants and sites are located along trails and ridges that have been co-opted for agency wildfire management, chiefly suppression (Fig. 2). These places are culturally significant for many reasons, including having long been sites for gathering ceremonial and medicinal plants and instructing youth in the use of fire, as explained by Karuk Tribal member Charlie Thom: "When they [US Forest Service] first come to this country, they start putting lookouts all over… [Mountain peaks named]…I can't make Indian Doctors without [named Mountain peak]…that we go up there, [via] Indian trail, not other trail, but Indians" (p. 13). Failure to recognize the cultural significance of locations being used for wildfire control could reinforce negative impacts to tribal cultures.

2.3.4. Sense of place especially at gathering sites

Indigenous tending and gathering often occurs in places that have enduring organisms and cultural associations. Low-intensity fire regimes help ensure the survival of many legacy, "specimen", or "elder" trees that maintain a sense of place and community well-being (Figs. 3, 4, and 5). For many tribes in the Sierra Nevada and Klamath mountains, sugar pine (*Pinus lambertiana)* groves were managed as tribal family-owned resource sites: "the places where the sugar pines grow are owned by individuals. When it is time to gather the cones, each owner invites his family and friends to come with him, and then, when the cones are gathered, they are divided equally among the relatives and guests" (Schenck and Gifford, 1952)*(p. 378)*. Many open old-growth hardwood forests and woodlands support rare wildlife and distinctive architectures, including broad crowns and low branches (Fig. 4) (Long et al., 2016). Fire suppression has spurred conifer encroachment in these

Fig. 2. Historical tribal trail (upper right) along a ridge, which was maintained using bulldozers as a fire line within the Red-Salmon Complex, August 2020, Klamath National Forest, near Forks of Salmon, California, USA.
Photo by Frank Lake, USDA Forest Service.

Fig. 3. An elder sugar pine (*Pinus lambertiana*) provides special cultural values including sense of place in addition to producing edible seeds.
Photo by Frank Lake, USDA Forest Service.

areas, resulting in development of narrow-crowned trees with high branches that are less conducive for harvesting nuts (Fig. 5). These examples illustrate the difficulty in segregating cultural services from provisioning services.

2.4. Material cultural-provisioning services

2.4.1. Plants and fungi used for foods, medicines, and materials

Provision of material benefits, often summarized as foods, medicines, and fibers, remain central objectives of Indigenous burning. Several species of hardwood trees, including tanoak, California black oak (*Quercus kelloggii)*, and giant chinquapin (*Chrysolepis chrysophylla*) and some conifers such as sugar pine are associated with low-moderate fire regimes and yield staple foods for tribes throughout the region (Bowcutt, 2013; Long et al., 2018a). Many tribes rely upon cultural burning to stimulate production of berry-producing shrubs, including huckle-blue-bilberries (*Vaccinium* spp.); geophytes, also known as "root crops" or "Indian potatoes" that propagate from underground storage organs that are edible; and many seed-producing forbs and grasses (Anderson, 1997; Anderson and Rowney, 1999). Many foods, such as roots and berries, are also regarded as medicines (Lynn et al., 2013) and have prominent roles in ceremonies and celebrations of the annual return of "first foods" (Long et al., 2018b). Mushrooms are another tribal resource that may be promoted by cultural burning (Anderson and Lake, 2013). Some fungi including morels and cap mushrooms commonly produce fruiting bodies

Fig. 4. This elder canyon live oak tree (*Quercus chrysolepis*) has a distinctive, low-branching architecture growing within an area of Indigenous use that likely moderated fire regimes and facilitated its endurance.
Photo by Michael Hentz, Mid Klamath Watershed Council.

following disturbances that include fire, although only a few species appear to depend more exclusively on fire (Pilz et al., 2004; Larson et al., 2016). Declines in many of these species have been attributed to fire exclusion, lack of tribal cultivation, and associated growth of competing vegetation (Anderson and Rowney, 1999).

Tribes have long utilized wood for a variety of purposes, including fuel for heating and material for construction. Large trees, especially redwood (*Sequoia sempervirens*), have long been important for constructing structures, furnishings, and canoes (Thompson, 1916; Huntsinger et al., 1994). Frequent, low-intensity Indigenous burning may have promoted development and retention of old-growth redwood (Stephens and Fry, 2005) and therefore, promoted the supply of large logs needed to support tribal traditions. Access to such logs has made traditional canoes available for ceremonies and jumpstarted economic enterprises such as the Yurok Tribe's recently established redwood canoe tours.

Many plants utilized for weaving materials have traditionally been cultivated through burning and associated horticultural practices (Anderson, 1999, 2005; Lake and Long, 2014). Several kinds of plants have been the subjects of recent collaborative research on burning, including beargrass (*Xerophyllum tenax*) (Shebitz et al., 2009b; Hummel et al., 2012; Hart-Fredeluces et al., 2021), sandbar willow (*Salix exigua*) (Lake, 2007; Ross et al., 2008), and hazel (*Corylus cornuta* var. *californica*) (Marks-Block et al., 2019). Thompson (1916) described how Yurok people "take the greatest care of the hazel nut flats" (p. 29) using fire to stimulate nut production and the vast quantities of young shoots needed for baskets.

2.4.2. Harvest of animals

Cultural burning has long been used to facilitate harvest of wild animals, including large and small animals used for meat, tools, regalia,

Fig. 5. An elder tanoak (*Notholithocarpus densiflorus*) tree at a cultural heritage site in the Western Klamath Restoration Project area, where lack of fire and stand densification have accumulated surface fuels and resulted in a loss of lower tree limbs, both of which limit opportunities for gathering nuts. Photo by Kenny Sauve, Karuk Tribe.

and other material uses (Long and Lake, 2018). While diets in many communities have shown a reduction in the harvest of wild game (Kuhnlein and Receveur, 1996; Norgaard, 2019), burning to promote game animals remains an objective in tribal plans (Norgaard and Tripp, 2019). Burns were used both to facilitate hunting and to encourage important forage plants, including bracken fern (*Pteridium aquilinum*) relished by deer (*Odocoileus hemionus*) in prairies of the Olympic peninsula (Norton, 1979). Burning has also been important for harvest of small animals such as insects; for example, Anderson (1996) noted accounts of burning to harvest grasshoppers. A recent collaborative investigation with Northern Paiute Tribes indicated that bark charring encouraged egg deposition of the pandora moth (*Coloradia pandora*), the larvae of which remain a desired traditional food resource (Slaton et al., 2019). Burning was also important in maintaining accessibility for fishing, "Fishing in small streams possible formerly; now completely choked out by brush" (Stewart, 2002) (p. 282).

2.4.3. Multiple dimensions of material productivity

While material uses are considered more straightforward to observe and quantify than other services, measuring provisioning services associated with cultural burning can be very complex. Many products, including traditional foods, medicines, and regalia, may be passed down, traded or gifted rather than sold in markets; often, only finished products such as baskets are priced rather than the component materials harvested from the forest (Marks-Block et al., 2019). Furthermore, wild-harvested products are valued based upon multi-dimensional, non-standardized qualities that resist simple evaluation based upon quantity. For example, several studies have tried to quantify the criteria used by Indigenous basketweavers, who prize the long, pliable and defect-free shoots or leaves that grow after burns (Lake, 2007; Hummel et al., 2015; Marks-Block et al., 2019). While fruit size is not a common measurement in ecological studies, some practitioners suggest that burning could enhance the size of berries. For example, a cultural facilitator, Wally Morgan (Gitxsan) said, "this place was recently burned, that's why the berries are so juicy and the size of marbles" (Armstrong and Anderson, 2020). In a field study, Wynecoop et al. (2019) reported observing large huckleberries in burned plots. These examples illustrate why commonly measured metrics, such as plant canopy cover and frequency, may not capture the many benefits of cultural burning.

2.4.4. Non-substitutable effects of fire on provisioning services

While many of the species mentioned previously can also be promoted by non-fire disturbances, fire is considered both an efficient tool and one that is not well-substituted. For example, smoke can enhance germination of plants such as tobacco and beargrass (Preston and Baldwin, 1999; Shebitz et al., 2009a). Tobacco is a featured product of cultural burning in both historical literature and contemporary projects (Harrington, 1932; Boyd, 1999; Baldy, 2013; Tushingham et al., 2013; Aldern and Goode, 2014). In the Klamath region, tobacco has been sowed into burns by individual cultivators, as described by Lucy Thompson over a century ago (1916). As discussed further below, burning also has distinctive effects in regulating insect pests that reduce quality of forest foods and materials.

2.4.5. Managing fire frequency to enhance provisioning services

Indigenous practitioners have long managed the intensity, frequency, and spatial arrangement of fires to promote provisioning services. Indigenous peoples in the region have long considered how fire severity influences mushroom production and the relationships between fungi and host shrubs and trees of cultural importance (Anderson and Lake, 2013). Native Americans in southwest Oregon sometimes burned hazel shrubs at low intensity to "scorch" and "roast" the nuts on the bush as they were harvested (Pullen, 1996). Many roots crops and basketry plants, including those mentioned above and deergrass (*Muhlenbergia rigens*), were burned frequently (1 to 15 years, but often less than 5 years) to cultivate desired forms and to maintain their abundance in openings (Anderson, 1996). Recent burning is critical for maintaining the supply for weavers (Anderson, 1996). As one elder explained, "you find out the places that burned the year before, because that means next year there will be many good materials waiting for you" (Baldy, 2013). Similarly, groves of nut trees were also burned regularly to clear debris and make it easier to collect and separate good acorns from infertile or infested ones (Lake, 2019). Sierra mountain misery (*Chamaebatia foliolosa*) forms dense foliage that impedes acorn harvest (Anderson, 2005), and experimental research has shown the burning can temporarily reduce its abundance (Kauffman and Martin, 1985). Frequent burning to foster open understory forest conditions and grasslands facilitates the gathering of roots and bulbs (Anderson, 2005; Anderson and Lake, 2016). In a study of multiple prescribed burns in Washington State (Orr, 2014), camas (*Camassia quamash*), an important root crop, was more abundant in recently burned areas while strawberry (*Fragaria virginiana*) was more abundant in less recent burns. In response to such complex temporal dynamics, practitioners vary the timing of burns in forests and account for overstory tree cover to promote desired products. Hazel yields high quality basketry materials after recent burns under closed canopy conditions (Marks-Block et al., 2019), but hazel nut production requires more exposure to sun and longer time between fires. In addition to the frequency of burning, the seasonality of burning controls the quantity and quality of hazel shoots for weaving (Marks-Block et al., 2021).

2.5. Regulating and supporting services

We combine regulatory and supporting services because they are difficult to distinguish and both involve ecological processes such pollination, hydrology, and soil development. While anthropologists have long documented how tribes burned to promote species that afforded material and cultural benefits, the effects of cultural burning on ecosystem functions are not as well documented. One reason is that these broad-scale climate factors are likely to overwhelm the effects of small-scale cultural burns in many studies. Reflecting this challenge, the review by Anderson (2018) begins by detailing how Indigenous people have used fire to promote individual species and later considers the likely effects of burning on biodiversity, water, and fire regimes at a landscape scale. Some of these effects on ecological processes have also been suggested by field experiments and/or modeling of prescribed burns and wildfires as proxies for cultural burns.

2.5.1. Species biodiversity

Indigenous practitioners emphasize the importance of supporting the wide variety of species (including plants, animals, and fungi, and often described as "relations") that are connected through complex food webs and interconnected life cycles (Anderson and Lake, 2013; Long et al., 2016). Consistent with that perspective, Bowman and Legge (2016) asserted that restoration of degraded ecosystems needs to focus on the influence of fire management on food webs and biodiversity. Such expansive views contrast with management systems that focus heavily on conserving or mitigating impacts to rare and threatened species (Long et al., 2020).

Burning can enhance localized diversity, especially compared to areas that have been encroached by trees due to fire suppression. For example, Livingston et al. (2016) reported more understory species in sites within oak woodlands that had been treated with fire than in encroached sites. Studies of fall cultural burns in chaparral and oak woodlands reported greater abundance and diversity of herpetofauna and small mammals (Hankins, 2009; Hankins, 2013). Another study in blue oak (*Quercus douglasii*) woodland found an increase in native plant species cover, but not in an isolated valley oak (*Quercus lobata*) woodland surrounded by agricultural fields (Hankins, 2015).

Cultural burning practices may target relatively common resources to enhance their quality rather than to simply make them more abundant. They may focus on single species that dominate patches, including sedge (*Carex* spp.) beds, oatgrass (*Danthonia* spp.) meadows, and sandbar willow thickets (Fig. 6). Frequent burning may favor certain plant groups that have fire resistant and resilient traits, such as annual forbs, open bunchgrasses, and rhizomatous and resprouting perennials (Kerns and Day, 2018). Maintenance of fire regimes can also help some vegetation communities to resist invasion by non-native species, including Scotch broom (*Cytisus scoparius*), that can displace native plants (Hamman et al., 2011).

2.5.2. Ecosystem biodiversity

Cultural burning may augment the diversity of communities within a landscape (Anderson, 2018), particularly at a finer grain than occurs under wildfires (Bowman and Legge, 2016). Recent field studies of wildfires are finding evidence that a diversity of fire characteristics, or "pyrodiversity" supports plant and pollinator diversity by sustaining a wide variety of successional communities and associated nesting habitats (Ponisio et al., 2016). However, field studies of wildfires with varying severities may not account for the diversity associated with frequent, predominantly low-severity cultural burning. In the Pacific Northwest, cultural burning over time can enhance landscape diversity by maintaining rare species associated with open habitats such as prairies (Fig. 7), including western lily (*Lilium occidentale*) (Long et al., 2018b), Howell's triteleia (*Triteleia howellii*) (Douglas and Penny, 2004) and certain butterflies (Hamman et al., 2011). Frequent fires are important for curbing the encroachment of conifers (Engber et al., 2011) and shrubs into open, herbaceous-dominated or savanna communities. For example, one historical account described such conditions within an area in modern day Mendocino County in northern California (which was recently burned in the enormous August Complex of 2020) "Lassik burned a hell-of-a-lot. [Tribal] Informant said country was kept burned off completely—almost a prairie…. Did not harm oak trees. Kept brush

Fig. 6. A US Forest Service burner and Yurok tribal member (right), uses a propane torch to burn at sandbar willow at Tishunick, a Karuk village near Orleans, CA, with guidance from a Karuk/Yurok cultural adviser, Laverne Glaze.
Photo by Frank Lake, USDA Forest Service.

Fig. 7. Prescribed burn conducted by the Confederated Tribes of Grande Ronde at Champoeg Prairie to curb invasive plants and facilitate future harvest of camas, yampa, tarweed, and other culturally important plants.
Photo by Andy Neill, Institute for Applied Ecology.

from getting too thick or higher…Indians complain about modern [Government fire] restrictions." (Stewart, 2002) (p. 282). In the Yurok country, Thompson (1916) observed that "our Legends tell when they arrived in Klamath River country, that there were thousands of acres of prairie lands and with all the burning they could do the country has been growing up to timber more and more." (p. 31). Skinner (1995) also attributed the loss of forest openings in the Klamath mountains to fire exclusion, while Lake (2007, 2013) described the landscape as the product of tribally-mediated cultural fire regimes. Tribes today have highlighted the impacts of losing these open grasslands and associated biodiversity (Anderson, 2009; Norgaard and Tripp, 2019; Sloan and Hostler, 2014). Some initiatives, such as the prescribed burning program in Redwood National Park, reflect these concerns, with research suggesting that the savanna areas of the Little Bald Hills are the legacy of fire stewardship by the Tolowa people (Varner et al., 2012).

2.5.3. Pollination

Indigenous traditional knowledge and teachings often relate the interconnectedness between host plants, pollinators, and tribal uses (Charnley and Hummel, 2011; Underwood, 2020; Hill et al., 2019). Many pollinators, including hummingbirds, bees, and butterflies, depend upon resources found in recent fires, including plant flowers, exposed mineral soil patches, and dead wood that serves as nesting burrows. Fire diversity in forests managed with intentional fire can buffer pollinator communities against the scarcity of floral resources during droughts (Ponisio et al., 2016). Declines in several rare butterfly species have been linked to the combination of long-term declines in fire, loss of prairie habitat, and reductions in Indigenous stewardship such as tending of camas, which is an important nectar source (Schultz et al., 2011). The California tortoiseshell butterfly (*Nymphalis californica*) and ceanothus silk moth (*Hyalophora euryalus*) are examples of two culturally important pollinator species that may benefit from cultural burning of shrub areas (Anderson and Keeley, 2018). Some of the field studies of prescribed burns in butterfly habitat have revealed challenges in minimizing potential short-term negative impacts of prescribed burns while restoring the benefits of fire-maintained habitats (Trudeau, 1996; Schultz et al., 2011). Such findings point to the value of understanding how to use fires of different intensities and scales to promote multiple objectives.

2.5.4. Regulating pests and diseases

Indigenous people have long used fires to reduce the incidence of pests that degrade the quality of plant products for food and basketry materials (Anderson, 2005; Anderson and Rosenthal, 2015). This objective is prominent in early discussion of Indigenous burning in the region (Editor, 1916; Harley, 1918). These pests include filbertweevils (*Curculio* spp.) and filbertworms (*Cydia latiferreana*) in acorns, hazel, chinquapin, and other nuts (Anderson, 2005; Bowcutt, 2013; Halpern, 2016). Recent research has illustrated how burning can modulate insect levels in contemporary tanoak groves (Halpern, 2016). Indigenous burners have also asserted that burning can reduce mistletoe (*Phoradendron* spp.) infestations through smoke fumigation (Anderson, 2018), and some studies have shown such effects on dwarf mistletoe (*Arceuthobium* ssp.) in pines (Zimmerman and Laven, 1987; Harrington and Hawksworth, 1990). Research has also indicated that burning sandbar willow can reduce insects that render stems unsuitable for weaving (Lake, 2007). Although most of these examples refer to harvested species, pest control was related to general forest health. For example, one individual reported in 1933 that the "smoke kept the bugs down and kept the country healthy" (Stewart, 2002) (p. 283). In a more recent example, Earl Scrub Albury (a Karuk elder) explained that when fir trees were weeping pitch, that indicated a need to burn to rejuvenate the area (Lake, 2007). The introduced Sudden Oak Death pathogen (*Phytophthora ramorum*) has impacted fire-prone coastal forests, including many hardwoods of special cultural importance to tribes. Recent research has suggested that intense wildfires can reduce the incidence of that introduced disease, but with costs to healthy forests and other values (He et al., 2021). Researchers have begun to investigate

how tribal stewardship practices including prescribed burning and silviculture to promote large hardwoods may reduce spread of the disease and resulting tanoak mortality (Cobb et al., 2017).

2.5.5. Soil health

Similar to other Indigenous cultures around the world, the relationships among fires, soils, plants, and fungi are recognized by tribes of the Pacific West region (Sillitoe, 1998). The combination of burning and other horticultural practices can increase organic matter, promote soil fertility and aeration, facilitate nutrient cycling, maintain mycorrhizae networks, and generate biochar (a product of incomplete combustion of coarse woody material) (Norton, 1979; Anderson and Rowney, 1999; Anderson and Lake, 2013; Anderson and Lake, 2016). Burning can stimulate growth of various species that support nitrogen-fixation including deerbrush (*Ceanothus* spp.) and lupines (*Lupinus* spp.) (Story, 1974; Anderson and Keeley, 2018). Such plants are often important food sources for rare butterflies (Trudeau, 1996; Goergen and Chambers, 2009; Schultz et al., 2011). Biochar can enhance soil quality in ways that promote plant growth (Lehmann et al., 2006) and consumption of biochar by animals can improve their health (Schmidt et al., 2019). Authors Ron Goode and Frank Lake note that Indigenous practitioners incorporate charred material into the soil to enhance plant growth and have long observed that animals also use it to rid themselves of parasites.

2.5.6. Enhanced hydrology

Cultural burning has been practiced to reduce vegetation density and increase water availability. Tribes have recognized that burning can increase water levels in springs and meadows that favor many culturally important plants (Anderson and Rosenthal, 2015). Historical research documented an example of this intention on the Trinity River, "He [Indian informant circa 1933] told me that they [Indians] were sure that the burning made the springs run better" (Stewart, 2002) (p. 283). Such hydrologic effects of prescribed burning received attention by pioneering fire researcher Harold Biswell (1999). Research has documented increased water flows in a forested montane watershed that has been managed with extensive use of wildland fire (Boisramé et al., 2019). Furthermore, Indigenous burners indicated that smoke would benefit salmon and other fish by reducing summer water temperatures (Norgaard and Tripp, 2019). A recent study reported that wildfire smoke had such beneficial effects in the Klamath River valley (David et al., 2018).

2.5.7. Wildfire regulation

A recent global review found that intentional burning to protect resources by preventing high-intensity, destructive fires was common in both ethnographic studies (49%) and all studies (36%) in their analysis (Trauernicht et al., 2015). Within the past century in the Pacific West region, tribal members reported setting fires to inhibit spread of wildfires. For example, Johnny Bennett (Karuk, Forks of Salmon, 1977) said "when the lightning hit they [old Indians] never put it out, push them [fires] back, [Indians] make a fire line, let them go back up the mountain. Take sticks out there, burn up against it" (Karuk Tribe and Cultural Solutions, 1999) (p. 25). Indigenous burning was conducted to maintain open conditions around villages, harvesting sites, and processing sites, and other favored areas, and to facilitate travel along ridges, riparian areas, and trails between those locations (Boyd, 1999; Lake et al., 2018; Lake and Christianson, 2019) (Fig. 2). In the western Sierra Nevada foothills, such dispersed but spatially extensive burning by different tribal communities cultivated a mosaic of fuel conditions that would curtail large wildfires (Anderson and Rosenthal, 2015; Spoon et al., 2015; Anderson and Keeley, 2018), Furthermore, intensive fuelwood gathering, plant pruning and cleaning of areas used for gathering acorn and other resources would have reduced fuel amounts and continuity.

Researchers have used modeling and understanding of these spatial patterns to demonstrate that Indigenous burning was a major influence on fire regimes in areas such as the southern Sierra Nevada (Klimaszewski-Patterson et al., 2018). Fire ecology modeling has suggested that reducing fuels within relatively small portions of a landscape, such as 10–20% of a landscape per decade, can greatly moderate extreme fire outcomes in parts of our region (Finney et al., 2007; Collins et al., 2013). Finney et al. (2007) suggested that those effects would be achieved with some areas repeatedly treated and others left untreated, that patch size was generally not a key driver of outcomes, and that strategic placement would result in greater benefits. Analysis of historical photography had indicated that high heterogeneity, including areas of very open forests and low fuel continuity, promoted landscape resilience to severe fire (Lydersen and Collins, 2018). These findings suggest how widespread application of cultural burning would support wildfire mitigation efforts.

Many tribal resources including homes and infrastructure; ancestral villages, camps, petroglyphs, and sacred sites; and populations of plants used for a range of traditional purposes can be damaged by high-severity fire through both direct consumption and impacts from high heating (Ryan et al., 2012). However, high-severity burn patches were also essential to promoting tribal values, as they often become dominated by shrubs such as hazel, manzanita (*Arctostaphylos* spp.), deerbrush (*Ceanothus* spp.), and gooseberry (*Ribes* spp.) that provide food for wildlife and Indigenous people (Anderson, 2018).

Tribal practitioners emphasize that their treatments are not intended to stop fires with stark fuel breaks, but rather to facilitate control of fires and to moderate their intensity and severity. Treatments along ridgelines and in wildlife-urban interface areas have been designed to temper fires while supporting other values, including production of acorns (Harling and Tripp, 2014). This approach is relevant to the wildland fire management strategies of developing Potentially Operational

Fig. 8. This large tanoak tree featured an archaeological site along a historical trail being used as a containment line during the Somes Fire on the Six Rivers National Forest, near Somes Bar, California, USA.
Photo courtesy of USDA Forest Service.

Delineation Units (PODs), which are bounded by linear control features, such as trails (Fig. 8), within which fires can be managed (Wei et al., 2019).

3. Implications for management and research

3.1. Recognizing the many ecological and social benefits of cultural burning

Indigenous communities have repeatedly championed the importance of burning as a means of restoring ecosystems and revitalizing their cultures (Anderson, 2009; Goode et al., 2018; Norgaard and Tripp, 2019; Clark et al., 2021; Sloan and Hostler, 2014). A goal of restoring reference fire regimes, including Indigenous influence, is guiding prescribed burning programs (Thornburgh et al., 2000) and remains a topic of great importance for research (Varner and Jules, 2017). The ecosystem services framework may help to highlight the many positive aspects of fire in ways that can advance burgeoning forest restoration initiatives. Practitioners contrast their holistic approach with strategies that focus on reducing fuels and wildfire impacts. Cultural burning is intended to reduce fuels and rejuvenate and reconfigure shrubs and other understory plants, but not to eliminate those plants. Indigenous practitioners acknowledge both the benefits and risks associated with vegetation. Despite the salience of cultural burning to tribal communities and to broader restoration outcomes, recent strategy documents paid little attention to the subject. For example, the National Cohesive Wildland Fire Management Strategy does not specifically address tribal interests in using fire (Wildland Fire Leadership Council, 2014). Related academic works proposing strategies to promote more resilient socio-ecological systems (Abrams et al., 2015; Schoennagel et al., 2017) similarly do not discuss Indigenous fire stewardship. These omissions may in part reflect an ingrained emphasis on combating the negative, destructive aspects of wildfires, in contrast to more holistic tribal frameworks.

3.1.1. Holistic understanding of overlapping benefits for social-ecological well-being

Indigenous burners use fire with multiple, overlapping benefits in mind (Anderson and Keeley, 2018). For example, burning hazel underneath a canopy of hardwood trees may reduce nuisance diseases and pests, generate stems used for basketry or tools, stimulate flowering for pollinators, enhance nut quality and abundance, enhance browse and forage for game animals, increase hunting efficiency, and reduce risks of severe fire (Marks-Block et al., 2019). Tribal practitioners tune the tending and burning regimes to promote a desired mix of benefits. For example, the Karuk Tribe has prioritized treatments to reduce fuels and threats of wildfire in community areas, while promoting hazel sticks and retaining mature yew (*Taxus brevifolia*) and dogwood (*Cornus nuttallii*) (Diver, 2016; Norgaard and Tripp, 2019). Within California black oak groves, cultural burning similarly has a multiplicity of effects that promote conditions that support tribal harvest and many other ecosystem services (Fig. 9) (Long et al., 2016). Species like Pacific fisher (*Pekania pennanti*), California condor (*Gymnogyps californianus*), and pileated woodpecker (*Dryocopus pileatus*) are valued in terms of material uses of their fur or feathers, their supporting roles (e.g., predation, cavity excavation), and their roles in stories and ceremonies (Norgaard and Tripp, 2019; Jordan, 2015; Long and Lake, 2018). These multiple benefits cross ecosystem service categories and make it more challenging to evaluate the cumulative benefits of treatments because they involve many effects at different scales. Furthermore, categorizing services may obscure the conjoined nature of socio-ecological values. Previous scholars have noted that culture, ecology and place are inextricably woven together (Berkes, 2012), which complicates efforts to understand changes in community systems (Tremblay et al., 2020).

In the Klamath region, community-based research has revealed how suppression of cultural burning and other Indigenous stewardship practices has led to declines in diet and social well-being (Norgaard, 2019). Understanding how to use fire to restore culturally important resources helps young people to understand both the ecology of their homelands, and their own place within their communities (Norgaard et al., 2017; Norgaard, 2019). Such approaches could shift Indigenous practitioners from being considered “outlaws” or malicious arsonists

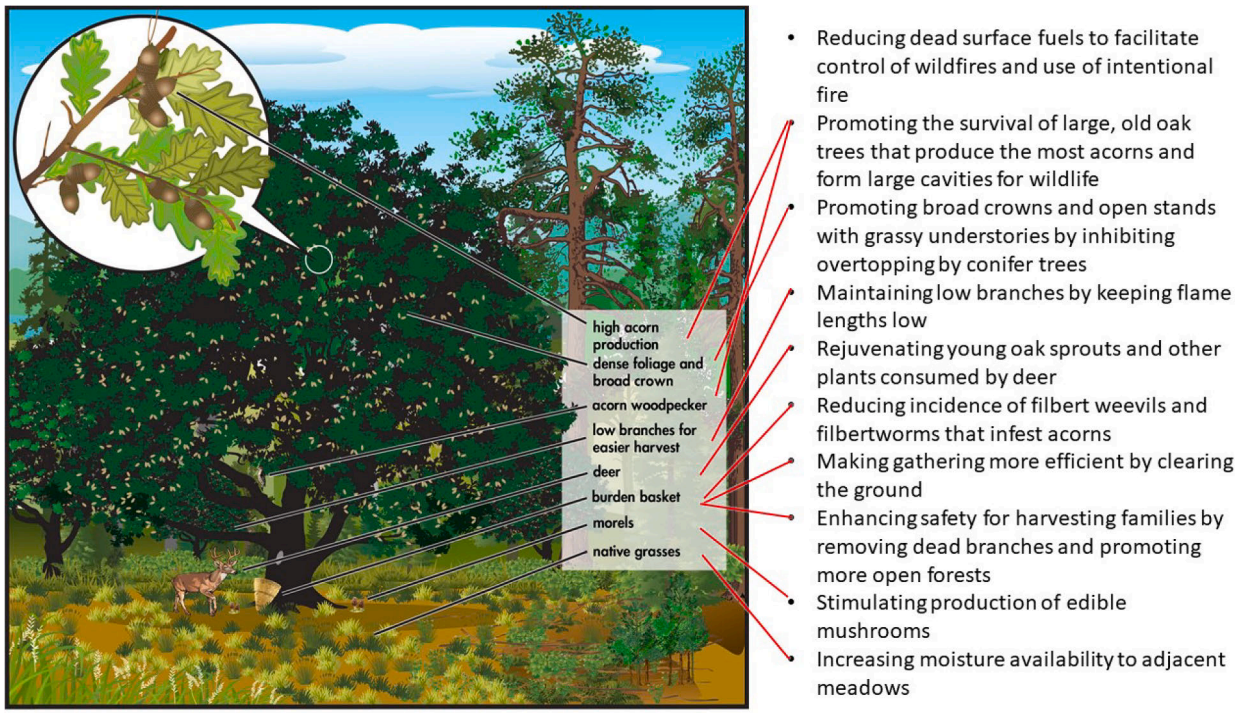

Fig. 9. Relationships between various objectives of cultural burning and conditions desired by tribes for black oak ecosystems.

and turn them into "valued food service employees" (Sowerwine et al., 2019). Such reframing moves the discussion about the need for cultural burning beyond narrow evaluations of ecological conditions and into a broader examination of socio-ecological well-being.

Indigenous peoples also burn to stimulate growth of various plants with medicinal values, although research on this topic is likely to be limited by concerns over protecting sensitive information regarding their use and location. An example of a medicinal plant appearing following a recent early spring cultural burn is Pacific sanicle (*Sanicula crassicaulis*) (Fig. 10). Researchers have reported on its historical use to treat snakebite (Barrett and Gifford, 1933), its use as food by Indigenous people (Anderson and Keeley, 2018), and its value for bees (Wray and Elle, 2017). The plant's ability to store energy in its taproot, intolerance of shade, and association with oak savannas are all traits that explain why it would respond favorably to cultural burning. Indeed, conservationists have identified a decline in Indigenous stewardship as one of the threats to a rare relative in Canada, snakeroot sanicle (*Sanicula arctopoides*) (Zevit and Fairbarns, 2010). Therefore, this plant represents just one of many opportunities to better appreciate the multifaceted effects of cultural burning.

3.1.2. Promoting diverse fire mosaics

Indigenous practitioners seek to cultivate a diversity of conditions within a patchy arrangement to ensure that surrounding lands maintain sustainable supplies for current and future needs. These arrangements consider ecological variation across large landscapes; for example, in the Klamath region, tribes cultivated huckleberries, bilberries, tanoaks, and black oaks in lower and mid-elevation forests, while relying on blueberries and acorns in more intermixed shrub-dominated patches following higher severity fire at higher elevations (Pullen, 1996). When staggered across watersheds, elevation ranges, and time, treatments promote food production, facilitate harvest, and enhance food security in the face of drought, wildfire, and other disturbances.

Fig. 10. Pacific sanicle (*Sanicula crassicaulis*) emerging between burned swaths in a March 2021 cultural burn near Mariposa, California, USA. Photo by Ron Goode.

A strategy that emphasizes cultural burning may contrast with ones that favor treating large areas in ambitious individual projects that require lengthy environmental reviews (or wildfires managed for resource objectives that are not governed by such reviews). It reflects the "small is beautiful" concept, which holds that small groups working locally can achieve better conservation outcomes than large corporate entities (Schumacher, 1973). This concept has been widely incorporated into natural resources management (Lovell et al., 2002). In addition to relying on smaller treatments, a strategy geared toward cultural burning would also require retreating sites more frequently than national forest managers in the Pacific West region have typically achieved (Kolden, 2019; North et al., 2021). In California, despite calls to rely on greater use of fire, there are few examples of restored fire regimes in frequent fire vegetation types outside of areas that have experienced managed wildfires for resource objectives (North et al., 2021). However, current tribal plans such as one advanced by the Western Klamath Restoration Partnership emphasize the role of cultural burning, along with greater use of managed wildfires, in protecting communities from the detrimental effects of uncharacteristically large and severe wildfires (Harling and Tripp, 2014). The intent is not to exclude fire from the landscape but to moderate wildfires so they will not damage vast areas and harm communities.

3.2. Addressing challenges between Indigenous objectives and government agency objectives

There appears to be strong alignment between the benefits of cultural burning and agency restoration strategies, but there are some challenges in implementing both and in making them mutually supportive.

3.2.1. Addressing policy constraints on cultural burning

Constraints on prescribed burning, such as air quality regulations and liability concerns, also have constrained cultural burning by Indigenous practitioners (Clark et al., 2021). Other constraints on restoration treatments include concerns for rare wildlife, including spotted owls (*Strix occidentalis*) and Pacific fisher, which have been translated into requirements to maintain higher levels of forest canopy cover than were historically widespread (Lydersen et al., 2019) and to avoid burning during especially sensitive denning, nesting, and breeding periods in the spring (Thompson and Purcell, 2016). Traditional burning was generally a fall or late winter activity, and tribes have sometimes expressed concerns that burning outside of those traditional seasons could be harmful to wildlife (Halpern, 2016). However, contemporary practitioners may desire flexibility to use fire to advance restoration objectives through an adaptive process.

3.2.2. Recognizing that thinning complements, but does not substitute for, cultural burning

Forest management intended to support tribal values has in many cases relied more on thinning than burning (LeCompte-Mastenbrook, 2016). Researchers have found that both tree cutting and fire will likely benefit both biodiversity conservation and fire management in current mixed conifer forests (Abella and Springer, 2015). However, field studies have found larger effects on plant communities from moderate- to high-severity fires than from low-severity prescribed burning (Kerns and Day, 2018), or from canopy thinning treatments followed by prescribed burns. Such responses are especially likely in forests that are highly departed from historical fire regimes—they may require greater and different forms of disturbance to reset their trajectories. However, even where thinning is effective in increasing light, nutrients, and water to understory plants, it may not accomplish other objectives such as pest reduction and desirable growth forms. Moreover, practitioners have reported contexts in which some traditional plants, such as huckleberry

and western redcedar (*Thuja plicata*), are favored by fire but not by mechanical thinning (Wynecoop et al., 2019).

3.2.3. Avoiding negative effects

Prescribed burning has potential for negative effects, and some of those risks could also apply to cultural burning. However, the likelihood of negative outcomes may be greatly reduced due to practices adhered to by cultural practitioners. Any kind of wildland fire has potential to result in other unintended and undesirable effects including escape, consumption of snag habitats, undesired mortality of large trees, and nuisance levels of smoke (Ryan et al., 2013). In general, however, cultural burns may have lower potential for such effects than other kinds of fire for several reasons. First, individual cultural burns are often intended to result in small, patchy, low-moderate severity burns. Second, cultural burning is often practiced as an intergenerational endeavor with both young people and elders. Burning and tending are often planned to enhance safety for family gatherings. When burners purposefully limit their operations to relatively traditional technologies, they have incentives to avoid conducting risky burns. Cultural practitioners tend their burns closely, with attention to effects on understory plants, wildlife, community health, and protecting legacy resources. The small, patchy scale of cultural burning is likely to inhibit the delivery of heavy smoke to large populations, especially as compared to wildfires (Long et al., 2018c). Furthermore, the preparation that precedes cultural burns reduces the likelihood that a fire escape or an infestation of invasive plants will occur.

Despite such precautions, reintroduction of indigenous burning may be complicated in areas that have undergone transformations resulting from Euro-American colonization, including invasion by non-native species and increases in accidental ignitions. In such systems, such as chaparral in southern California, some managers and ecologists are concerned that burning too frequently could negatively impact native vegetation (Keeley and McGinnis, 2007). In an extreme example, a study in Washington state found that five decades of annual burning resulting from artillery fire transformed the dominant vegetation in a prairie from native fescue to non-native grasses; in contrast, prescribed burning on a 3–5 year rotation for two decades reduced cover of most non-native species while inhibiting conifer encroachment on oaks (Tveten and Fonda, 1999). Potential for increases in non-native species following prescribed burning has been reported from a variety of vegetation types in the region, including chaparral and grasslands (Safford and Harrison, 2008), ponderosa pine forest (Keeley and McGinnis, 2007; Kerns and Day, 2018), and riparian areas (Hankins, 2013), although outcomes often vary greatly. The potential for undesirable increases in non-native species is often associated with the existing level of non-natives within or adjacent to the treatment areas. Research in Arizona forests showed that burning in an area with high levels of cheatgrass promoted the invasive, while burning in a native-dominated site did not (McGlone et al., 2012). Hankins, an Indigenous practitioner and scholar, observed a similar dynamic when comparing outcomes following burning in two oak-grassland sites in the north-central Sacramento Valley (Hankins, 2015). He speculated that reintroducing cultural burning over time could help to gradually restore the native composition.

3.2.4. Explaining the relevance of services

Different categories of services may be associated with different challenges and opportunities for advancing cultural burning. Many of the benefits of cultural burning may be devalued within market-based frameworks; however, the value of some provisioning services can be estimated. For example, researchers have estimated the volume of materials needed to produce products such as baskets that command high prices (Anderson, 2018; Marks-Block et al., 2021). Furthermore, provisioning services may be afforded special leverage where the federal government recognizes off-reservation tribal rights to gather, fish, and hunt, especially in Washington and Oregon (Bernholz and Weiner, 2008). Because the ability to exercise such rights depends on the availability of resources of suitable quality and quantity, those legal levers could support cultural burning. On the other hand, the effects of burning on provisioning services may be difficult to measure easily since resource quality of root crops, acorns, and shoots may be best evaluated upon harvest by tribal gatherers (Hummel et al., 2015).

Regulating and supporting systems including wildfire protection, water availability, pollination, food webs, biodiversity, carbon sequestration, and soil tilth, have all been a focus of management and research (Nikolakis and Roberts, 2020). However, quantifying such services can be challenging because of the broad spatial and temporal scales needed to understand them. Burning affects a tremendously wide variety of species and their interactions, including not only biomass removal but also more complex effects on air, soil, water, food webs, and parasitic and symbiotic associations. This complexity poses substantial challenges in selecting metrics and scales for evaluation. Cultural services are even more challenging to integrate into institutional processes since they tend to be non-quantified, non-fungible, less openly discussed, and yet more contested. For example, court decisions have often denied protection to tribal sacred sites on public lands (Carpenter, 2004). Resistance to formal co-management arrangements may impede the ability of Indigenous people to directly steward places on public lands. The concepts of cultural services and services for ecosystems elucidate why Indigenous people want to directly apply fire themselves.

An ecosystem services framework can help to integrate Indigenous perspectives more fully within planning frameworks (Armatas et al., 2018). Such approaches depart from past efforts that often focused on tribal concerns for archaeological sites (Long et al., 2020). Recognizing the interconnections between ecological and social services can help to identify opportunities to unravel persistent effects of colonialism (Long and Lake, 2018).

3.3. Addressing limitations of paleoecological research

As noted in the introduction, ecologists have explained that methods used to reconstruct environmental histories, including sampling of charcoal deposits in lakes and fire scars on trees, may have poor ability to detect Indigenous influences (Klimaszewski-Patterson et al., 2018; Abrams and Nowacki, 2020). This methodological challenge is acute in areas where fires would be naturally frequent in the absence of human influence (Roos et al., 2019). Tree rings can sometimes help to distinguish wildfires from Indigenous burning based upon time of year, but even they are likely to underrepresent light Indigenous burning (Whitlock et al., 2004). However, analysis of tree-ring records can also be modified to be more sensitive to patchy burning (Roos et al., 2019). Roos et al. (2018) explain that Indigenous burning may have either enhanced or buffered climate impacts on fire regimes at different scales, and it is difficult to separate those influences without considering multiple types of evidence. Responding to the exclusion of Indigenous values and knowledge in this field, researchers have called for more transdisciplinary efforts including collaborations with Indigenous experts to interpret paleoecological evidence and to inform contemporary forest management (Lake, 2013; Lightfoot et al., 2013; Leonard et al., 2020).

3.4. Addressing shortcomings of controlled experiments

Many experimental research studies on cultural burning have been set up as relatively short-term investigations, often as part of graduate studies, with limited resources to obtain environmental clearances needed for treatments. While many projects have been conducted in partnership with tribal practitioners (Shebitz, 2006; Lake, 2007; Shebitz et al., 2008; Hankins, 2013; Halpern, 2016), they may not have recreated traditional burning regimes due to such external constraints. For example, Halpern (2016) noted that practitioners wanted to study fall burning, but she had to examine spring burns to comply with federal and state prescribed burning regulations. Similarly, environmental review requirements initially constrained Lake (2007) to study relatively small

burns using propane torches to evaluate effects of burning on willow shoots (Fig. 6). He later was able to study a larger prescribed burn, which he found to be more effective in controlling insect pests. Meanwhile, a tribal-Forest Service collaborative research study (Wynecoop et al., 2019) considered how burning treatments could benefit culturally important plants by comparing areas burned in a wildfire, treated with a combination of mechanical thinning and prescribed fire, or not having been treated within 10 years. While these studies advance our knowledge, they reveal a lack of studies that explicitly incorporate cultural burning practices.

The complexity associated with scale and potential shadow effects of treatment are some of the challenges in delineating "treatment" and "control" units. Studies of single burns are not likely to be representative of cultural burning regimes for several reasons. First, the strong influence of precipitation on plant growth makes the effects of burning more difficult to resolve (Hankins, 2015). Second, single burns in long-unburned areas may be more intense than would be typical for cultural burns. For example, a recent study of ceramic sherds in an ancient village site in northern New Mexico found that a that a large prescribed burn during mild October weather, but following 119 years of fire exclusion, burned more intensively than any fires in the previous 900 years (Roos et al., 2020). Third, fire effects are likely to change as cultural burning is reintroduced, because consumption rates, fuels, and vegetation composition change with repeated burning (Levine et al., 2020). Establishment of long-term studies could address many of these shortcomings.

3.5. *Establishing long-term collaborative studies*

Indigenous peoples are rightfully concerned about potential for traditional ecological knowledge to be extracted and used by non-Indigenous contractors or scientists in ways that do not directly advance tribal stewardship and sovereignty (Klenk et al., 2017). Some collaboratives, such as the Western Klamath Restoration Partnership, have enjoyed success in fostering tribal engagement (Kelly et al., 2019). Tribal influence in other collaboratives, including the Dinkey Landscape Collaborative, is less apparent (Butler et al., 2015). Establishing longer-term experimental studies with Indigenous communities would help to better understand effects of cultural burning and other traditional stewardship practices. For example, a research study on former university lands in Missouri revealed how differences in forest composition and structure can develop under contrasting fire regimes, including frequent fires, over 60 years (Knapp et al., 2015). Tribes and land management agencies could similarly explore opportunities to establish stewardship areas that would support long-term investigations of cultural burning. Many research natural areas (and some wilderness areas) in California have experienced a shortage of fires, yet they also discourage "manipulative" vegetation treatments (Coppoletta et al., 2019). Nevertheless, a recent tribal-agency collaboration in the Indiana Summit Research Natural Area demonstrated how traditional practices and return of fire could safeguard cultural resources and facilitate tribal harvesting of pandora moth larvae (Slaton et al., 2019).

4. Conclusions

Rooted in historical practices and traditional values, tribal cultural burning continues to adapt to meet contemporary challenges. Indigenous people are asserting their rights and responsibilities to burn to maintain their well-being. The overlap between cultural burning and contemporary agency forest management can encourage mutually beneficial outcomes rather than perpetuating the harmful legacy of fire exclusion. The framework of ecosystem services can relate the goals of Indigenous practitioners to government management systems, while expanding awareness of the many diverse benefits of cultural burning beyond its potential to regulate wildfires. The many benefits of cultural burning are the results of a complex web of material/immaterial and direct/indirect effects. This understanding illustrates why the many benefits are difficult to quantify or evaluate with market-based systems. Nevertheless, scientific approaches can be adapted to better detect and measure many of the physical effects, and collaborative efforts can better reveal the benefits of restoring cultural burning to tribal communities and to wider society. Distinctive ecological communities that have evolved with Indigenous use of frequent fire in the Pacific West region are especially important to study at long-term and broader spatial scales. Expanding long-term tribal collaboratives, including designating Indigenous stewardship areas with frequent burning, would advance our understanding of restoration in forested landscapes.

CRediT authorship contribution statement

Jonathan W. Long: Conceptualization, Writing – review & editing. **Frank K. Lake:** Conceptualization, Writing – review & editing. **Ron W. Goode:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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