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Effects of understory fire management treatments on California Hazelnut, an ecocultural resource of the Karuk and Yurok Indians in the Pacific Northwest

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ABSTRACT

Before widespread fire exclusion policies, American Indians used broadcast understory fires or cultural burns to enhance resources integral for their livelihood and cultural practices. To restore ecocultural resources depleted from decades of fire exclusion and to reduce wildfire risks, the Karuk and the Yurok Tribes of Northwest California are leading regional collaborative efforts to expand broadcast fires and fuel reduction treatments on public, private, and Tribal lands in their ancestral territories. Through collaboration with Karuk and Yurok Tribal members and basketweavers, we evaluated the effects of broadcast fires and three fire proxy treatments on California hazelnut shrubs (*Corylus cornuta* var. *californica*) that produce highly valued ecocultural resources for basketry materials. Across a 10 ha Douglas-fir and mixed hardwood forest (500 m a.s.l.) in the Klamath mountains, we established 27 stratified blocks (16 m^2) and within each block applied three fire proxy treatments designed and used by Tribal members with an untreated control. These treatments involved manual hazelnut stem cutting, directly blistering hazelnut stems via propane torch, and igniting surface fuels piled within hazelnut shrubs to top-kill stems. Broadcast fire was applied to 12 separate blocks. After a full growing season (12–18 months post-treatment/burn), shrubs were re-measured. We then harvested these stems (n = 604; 50 shrubs) across treatments and compared results with stems gathered independently by two experienced Karuk/Yurok basketweavers (n = 396 and n = 73) from an adjacent broadcast burned site. Compared to the untreated shrubs, pile burning, propane torching, and broadcast burning increased basketry stem production by 7–10 fold ($p < 0.001$), while the cutting treatment increased production by 4-fold ($p = 0.006$). Shrubs with relatively greater access to sunlight (southern aspect, ≥51% and < 70% canopy cover) produced fewer quality stems when compared to shrubs with an eastern aspect ($p < 0.01$) and ≥70% canopy cover ($p < 0.05$). Harvested stems across all treatments displayed similar stem length distributions to those gathered by one of the two basketweavers ($p > 0.05$). Our results demonstrate that these fire-proxy methods are an effective means to increase the production and quality of basketry materials. Expanding the area and frequency of targeted understory fire-based forest treatments on private, public and Tribal lands in California and the Pacific Northwest would substantially increase the availability of these fire-enhanced ecocultural resources that are currently limited in supply and in high demand.

1. Introduction

As a result of historic fire exclusion policies in the American West, American Indian communities have sought to re-integrate prescribed fire and other fuel reduction treatments to decrease wildfire risks on Tribal lands and across other jurisdictions within their ancestral territories (Carroll et al., 2010; Kolden, 2019; Long and Lake, 2018). Tribes have expressed strong interest to use prescribed fire to improve the density and availability of culturally and economically important plants, fungi, and animals, referred to as 'ecocultural resources' (Anderson, 2018; Carroll et al., 2004; Lake et al., 2017; Long and Lake, 2018). Although ecocultural resources are similar to nontimber forest products (Chamberlain et al., 2018; Charnley et al., 2007; Jones and Lynch, 2007), ecocultural resources are also integral to Indigenous identity (Kimmerer, 2011; Long et al., 2018).

Co-management agreements between Tribes and public land

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agencies, such as the United States Department of Agriculture (USDA) Forest Service, reflect recent efforts to integrate Tribal ecocultural resource objectives into management plans (Bussey et al., 2015; Carroll et al., 2010; Catton, 2016; Diver, 2016; Dockry et al., 2017; Donoghue et al., 2010; Jurney et al., 2017; Long and Lake, 2018). Although numerous studies exist on the effects of prescribed fire, along with manual, mechanical, and pile burning fuel reduction treatments on fire severity (Kalies and Kent, 2016), only a few studies in North America examine the effects of such treatments on ecocultural resources (Halpern, 2016; Hankins, 2013; Lake, 2007; Lathrop and Martin, 1982; Peter et al., 2017; Shebitz et al., 2009; Wynecoop et al., 2019). Given that pre-colonial Indigenous burning, coppicing, transplanting, and harvesting sought to enhance ecocultural resources, specifically examining how such treatments affect these resources may provide useful information to support the objectives of Tribes and land management agencies involved in ecological restoration, socio-economic development, and wildfire risk reduction (Anderson, 2018; Charnley et al., 2018; Kalies and Kent, 2016; Senos et al., 2006).

After several decades of limited fuel treatments, the Karuk and the Yurok Tribes in Northwest California are leading regional efforts to expand fuel reduction treatments and prescribed fires on public, private, and tribal reservation lands in their ancestral territories to protect structures and to restore ecocultural resources (Fig. 1A; Diver, 2016; Harling, 2015; Long et al., 2018; Robbins et al., 2016). Fire-enhanced ecocultural resources (e.g., acorns, berries, basketry materials, and wildlife) are integral to the Karuk and Yurok Tribes (Baldy, 2013; Harrington, 1932; Heffner, 1984; Huntsinger and McCaffrey, 1995; Norgaard, 2014). In Karuk and Yurok territory, and elsewhere in California, American Indians refer to their prescribed fires as 'cultural burns', because the burns aim to improve the qualities and densities of ecocultural resources central to subsistence and ceremonial practices (Aldern and Goode, 2014; Long et al., 2018). Cultural burning is a critical component of 'ecocultural revitalization' efforts in Northwest California given the centrality of fire-enhanced resources to cultural practices. Cultural burning distinguishes these fires from the fuel reduction-focused prescribed burns of public land agencies whose primary objective is to reduce fuel loads, and thus, moderate wildfire intensity (Collins et al., 2010; Schwilk et al., 2009).

Since the early 1990s, forest management in the Pacific Northwest and Tribal consultation policies have undergone several major conceptual and programmatic changes coupled with legislation (Thomas et al., 2006; Vinyeta and Lynn, 2015). American Indian political organizing resulted in the passage of legislation to reform the National Historic Preservation Act in 1992 that required US governmental consultation with Tribes surrounding cultural resources in their ancestral territories (Stapp and Burney, 2002). In 1994 and 2000, US President Clinton issued executive orders that expanded consultation requirements to all decisions that had implications for Tribes (Clinton, 2000, 1994). These executive orders along with other internal actions of USDA Forest Service staff catalyzed the hiring of Tribal liaisons and the formation of the Office of Tribal Relations (Catton, 2016). Consequently, to meet these treaty and federal Indian trust obligations, collaborations among Tribes and public land agencies became increasingly formalized (Lake et al., 2018; Long et al., 2018).

With the implementation of the Northwest Forest Plan (NWFP) in the 1990s (Fig. 1B), forest management on public lands in Karuk and Yurok ancestral territories shifted from timber extraction toward ecological restoration and endangered species conservation (e.g., Northern Spotted Owl, *Strix occidentalis*) dependent upon old-growth forests (Thomas et al., 2006). The NWFP also precipitated the development of

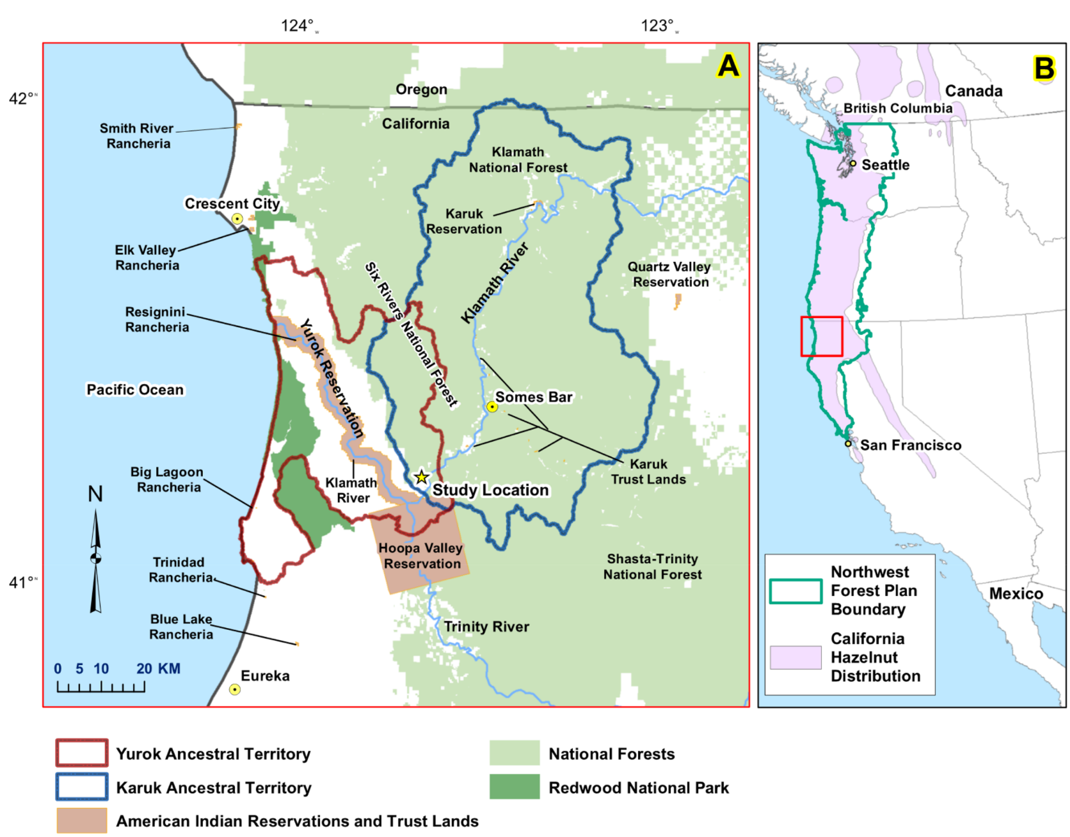

Fig. 1. (A) Study region with federal jurisdictional boundaries and Karuk and Yurok territories. Ancestral territory boundaries, provided by the Karuk and Yurok Tribes, represent reconstructions, but currently are not fixed or rigid boundaries. Ancestral lands of other Northwest California Tribes (e.g., Tolowa, Wiyot, Hupa, Shasta) are not included here, but note that their ancestral lands may partially overlap with the boundaries rendered here (Baumhoff, 1963). (B) Western region of the United States of America, including California hazelnut (*Corylus cornuta* var. *californica*) distribution derived from the *Atlas of US Trees* (Little Jr, 1971) as well as the area encompassed under the Northwest Forest Plan (2002). The study region is depicted by the red square.

Fig. 2. Hopper basket (center) used to pound acorns with unpeeled (left) and peeled (right) hazelnut basketry stems. This basket is composed of peeled hazelnut stems similar to those shown along with other materials. [Photo: Frank K. Lake, USDA Forest Service and Karuk Tribe]

new National Forest plans and established regular federal monitoring of Tribal consultation processes that created opportunities for the Karuk Tribe to influence forest policy and resource management within their ancestral territory (Diver, 2016; Long et al., 2018; Senos et al., 2006; Vinyeta and Lynn, 2015). These policy changes as well as the 2001 National Fire Plan and the 2003 Healthy Forests Restoration Act (PL 108-148) established benchmarks and best practices coupled with earmarked funds for fuel reduction treatments, and supported collaborative projects to manage fire in Karuk and Yurok ancestral lands (Lake, 2011). In California and the Pacific Northwest, the USDA Forest Service annually treats more area with understory mechanical thinning than prescribed fire to reduce forest surface fuels (Vaillant and Reinhardt, 2017). Impediments to prescribed fire and fuel reduction include seasonal restrictions on fuel reduction activities for threatened and endangered wildlife, staff reductions associated with the decrease in timber receipts from NWFP mandates, burn restrictions during major wildfire events, and air quality regulations that constrain available burn days (Calkin et al., 2015; Quinn-Davidson and Varner, 2012; Schultz et al., 2018; Stephens et al., 2016; Williams, 2009). However, recent efforts within the USDA Forest Service to increase cross-jurisdictional landscape-scale treatments, known as the 'Shared Stewardship' initiative seek to address several of these constraints (USDA Forest Service, 2018).

Despite these challenges, the Karuk and Yurok Tribes collaborate with the Fire Learning Network (FLN) and other agencies to host annual prescribed fire training exchanges (TREX: Butler and Goldstein, 2010; Harling, 2015; Long et al., 2018; Robbins et al., 2016; Spencer et al., 2015). The FLN is an effort by the USDA Forest Service, US Department of the Interior, and The Nature Conservancy to restore fire-dependent landscapes by engaging in collaborative, community-based planning. On the Yurok reservation, the Cultural Fire Management Council (CFMC) leads efforts to expand cultural burning in partnership with the Yurok Tribe and the California Department of Forestry and Fire Protection (Yurok Tribe, 2015). CFMC is a community-based organization led by Yurok Tribal members that support private and Tribal landowners who seek to conduct cultural burns on their properties by sharing equipment, providing necessary personnel, and submitting permits. The Karuk Tribe is collaborating with the USDA Forest Service, the Orleans-Somes Bar Fire Safe Council, and other community organizations to initiate fuel reduction and cultural burn treatments in their territory through the Western Klamath Restoration Partnership (WKRP; Lake et al., 2018; Long et al., 2018; USDA Forest Service PSW Region, 2018; Vinyeta and Lynn, 2015). The WKRP is composed of NGOs, Tribes, and government agencies that have initiated a pilot project near Somes Bar, CA to apply mechanical and prescribed fire treatments in fire excluded forests. Upon completion, they have proposed to expand these fire treatments across 480,000 ha. (Lake et al., 2018; Long et al., 2018; USDA Forest Service PSW Region, 2018).

Substantial ethnohistorical information exists on the effects of fire on ecocultural resources worldwide (Scherjon et al., 2015; Trauernicht et al., 2015) and in the Pacific Northwest, and California, in particular (Anderson, 2005; Blackburn and Anderson, 1993; Boyd, 1999; Lewis, 1993). However, empirical ecological effects of contemporary fuel reduction treatments on ecocultural resources are not well known, and such studies may serve to inform adaptive and collaborative management projects in American Indian territories (Anderson, 2002; Berkes et al., 2000; Long et al., 2018; Wynecoop et al., 2019). Species-specific studies have demonstrated that prescribed burning improves the densities of blueberries (*Vaccinium* spp., Duchesne and Wetzel, 2004) and reduces insect infestation in tanoak acorns (*Notholithocarpus densiflorus*, Halpern, 2016). Fire has been shown to increase the density and enhance the quality of several plant species (e.g., *Xerophyllum tenax* beargrass, *Muhlenbergia rignes* deergrass, *Anthoxanthum nitens* sweetgrass) used for American Indian basketry resources (Anderson, 1999; Gagnon and Platt, 2008; Griffith et al., 2007; Hart-Fredeluces and Ticktin, 2019; Lathrop and Martin, 1982; Peter et al., 2017; Shebitz et al., 2009; Shebitz and Kimmerer, 2005).

California hazelnut (*Corylus cornuta* Marsh. var. *californica*) is a critically important ecocultural resource for Karuk and Yurok Tribal members. California hazelnut ranges from British Columbia to the southern Sierra Nevada and central coastal mountains of California and extends over ~76% (180,471 km^2) of the NWFP area (Fig. 1B; Little Jr, 1971; Thompson et al., 2015). California hazelnut is a deciduous, multi-stemmed shrub that resprouts vegetatively after disturbance, similar to *Corylus americana* and *Corylus cornuta* var. *cornuta* in central and eastern North America (Buckman, 1964; Pelc et al., 2011). Throughout California hazelnut's range, the nuts are consumed by American Indians (Armstrong et al., 2018; Cuthrell, 2013; Fine et al., 2013; LaLande and Pullen, 1999; Thompson, 1991). Across the Pacific Northwest, California hazelnut stems continue to be used by American Indians for basketry and material culture (Mason and Coville, 1904; Moerman, 1998; Turner, 1998; Zobel, 2002) with similar uses of *Corylus* spp. persisting throughout Europe (Batsatsashvili et al., 2017; Bichard, 2008). The straight and unbranched stems of recently burned hazelnut shrubs are in high demand by California Indians to produce baskets for diverse uses (Fig. 2, Anderson, 1999; Bibby, 2004; Harrington, 1932; Heffner, 1984; Hunter, 1988; Johnson and Marks, 1997; Kallenbach, 2009; Levy, 2005; Mathewson, 2007; O'Neale, 1932; Ortiz, 1998, 1993; Salberg, 2005; Shanks, 2006; Thompson, 1991; Underwood et al., 2003). In 2017, basketweavers reported hazelnut stems selling for $1 per stem, indicating their socio-economic value (T. Marks-Block, *pers. obs.*, 2018). Moreover, the diverse products constructed from these materials reflect their artistry skills, cultural significance, and ancestral history and identity as well as bestow respect for these talented basketweavers (Bibby, 2012; Johnson and Marks, 1997; Mathewson, 1998). One type of basket in high demand is the baby cradle as these cradles remain a central component of child rearing in Northwest California Indian culture (Bibby, 2004). These baskets often require ~300 hazelnut stems to produce and then may be sold for ~$800 dollars (T. Marks-Block *pers. obs.*, 2018).

Based on ethnographic studies, Northwest California Indians such as the Karuk and Yurok reportedly initiated relatively small (< 4 ha) understory broadcast fires in the summer and fall months every 2–5 years in hazelnut groves to increase concentrations and quality of basketry stems (Anderson, 2005; Busam, 2006; Harrington, 1932; Huntsinger and McCaffrey, 1995; LaLande and Pullen, 1999; Stewart, 2002; Thompson, 1991). As cultural burning diminished due to the enforcement of fire exclusion policies, basketry stems reportedly became scarce because only poor quality gathering areas remained that, in turn, highly constrained basketry production (Bright, 1957; Heffner, 1984; Huntsinger and McCaffrey, 1995; Levy, 2005; Norgaard, 2014; O'Neale, 1932). For example, based upon 43 interviews with basketweavers in 1929, anthropologist Lila O'Neale reported that:

> "Hazel sticks are conceded by the women of both tribes [Yurok and Karok] to be the best, but the most difficult to procure nowadays. New little shoots from a ground recently burned over are ideal. This statement is followed, however, by the lament that fires cannot be set as they used to be by the old-time weavers, and by the regret that accidental burnings occur seldom in places where they do basket makers any good" (O'Neale 1932:15).

Because of these resource availability challenges, basketweavers and stem gatherers have used permitted techniques to generate hazelnut re-sprouting that serve as substitutes or proxies for cultural burns (F. Lake, *pers obs*; Hunter, 1988).

To evaluate these techniques for potential inclusion into larger-scale fuel reduction management areas, we collaboratively designed a field experiment to compare the efficacy of four practices (Fig. 3) used by Yurok and Karuk Tribal members to increase hazelnut stems for basketry: (1) cutting or the manual coppicing of hazelnut shrubs (Hunter, 1988); (2) pile burning of surface fuels including needle/leaf litter and 1-hour (0.00–0.64 cm diameter) and 10-hour (0.64–2.54 cm diameter) fuels within individual hazelnut shrubs; (3) propane torch burning of individual hazelnut shrubs (Ortiz, 1998); and, (4) prescribed cultural burns set to broadcast, or move through the understory, to top-kill multiple hazelnut shrubs. Among these treatments, we compare and contrast the production of suitable shoots: straight, unbranched basal re-sprouts of hazelnut shrubs (Fig. 2). Then we evaluate if canopy cover, aspect, and the presence of deer browse influence the productivity of basketry stems. Basketry stems were harvested post-treatment and compared and then contrasted by length and diameter with stems harvested independently by two experienced Karuk/Yurok basketweavers from an adjacent broadcast burned site.

Fig. 3. Four hazelnut shrub treatments. (A) Pre- and post-cut treatment. All stems in each shrub were cut to ground level (< 5 cm) to stimulate coppicing, and to mimic mechanical understory clearing and piling for fuel reduction. (B) Pile burn treatment during combustion. Surface fuels (primarily 1-h, 10-h fuels, and surface litter comprised of conifer needles and hardwood/shrub leaves) were placed between hazelnut stems within a shrub to form a burn pile (< 25 cm height). (C) Propane torch burn treatment. Hazelnut shrub stems were burned at ground level to cause bark blistering and stem mortality. (D) Broadcast burn treatment. A fire was set with drip torches to back down-hill and allowed to spread to kill above-ground hazelnut stems.

These treatments and measures were conducted in direct collaboration with Karuk and Yurok basketweavers whose ecological knowledge and harvesting practices informed this study and sampling design (Lake, 2013; McLaughlin and Glaze, 2008). Basketweavers have observed that hazelnut shrubs that grow in areas with relatively greater sun exposure produce extensive lateral branching, thus reducing viable basketry stems post-treatment (Johnson and Marks, 1997; Mathewson, 1998; Ortiz, 1998), but may increase nut production. Basketweavers also report that stem sprouts from coppiced hazelnut are not as pliable as stem sprouts that emerge from burned hazelnut (F. Lake and T. Marks-Block, *pers obs*). While we did not evaluate this stem characteristic, Rentz (2003) demonstrated that burned hazelnut stems contained a greater wood-to-pith ratio than unburned, coppiced hazelnut stems, lending empirical support to basketweavers' observations. Because basketweavers and managers have also reported that deer and elk browse may negatively affect basketry production (Underwood et al., 2003), we also included the presence of this activity in our observations.

Our study combines Indigenous ecocultural and 'western' scientific epistemologies to monitor and manage forests as advocated by American Indian fire and forest managers (Lake et al., 2017; Mason et al., 2012; Mazzocchi, 2006). This integrated participatory approach seeks to identify effective practices for improved ecocultural resource management, such as enhancing both the density and quality of basketry materials (Bussey et al., 2015; Emery et al., 2014; Hummel and Lake, 2015; Mockta et al., 2018).

2. Methods

2.1. Social science methods

To develop an ecological research project focused upon an Indigenous ecocultural resource, we initially drew from Indigenous and anthropological research methods such as participatory and reciprocal study design and observations that serve to foster relationships of trust among academics, Indigenous scientists, and cultural practitioners (Bernard, 2011; Lake et al., 2017; Smith, 1999; Wilson, 2008). We worked with Tribal cultural practitioners and Tribal government staff over several years to integrate ecocultural resource objectives into land management plans. This investment and participation in the community generated trust and led to accountability, reciprocity, and collaboration among researchers and Tribal members (Lake, 2013). The collection of qualitative and quantitative social science data was developed and reviewed iteratively by as the Karuk and Yurok Tribes, who have their own independent research review processes to generate accountability and collaboration with researchers (Karuk Tribe et al., 2017; Sarna-Wojcicki, 2014). These proposals then received approval by our institutional human subject review boards at the Oregon State University and Stanford University.

Sampling design and implementation initially was informed by semi-structured interviews, participant observations and collaborative field work with Karuk and Yurok basketweavers and cultural practitioners conducted by Lake (2002–2008; Lake, 2007; McLaughlin and Glaze, 2008). Initially, Lake worked closely with key basketweavers to develop research objectives and accountability. Building on collaborations established by Lake, Marks-Block conducted ecological field measurements from 2014 to 2019 of cultural burns (n = 15) for hazelnut stem production supplemented by additional interviews and direct observation of basketry stem gathering with basketweavers (n = 44) that informed the analyses and interpretation of the treatment data.

Our interviews and interactions with basketweavers corroborated that suitable basketry stems were scarce due to fire exclusion (Heffner, 1984; Hunter, 1988; Ortiz, 1998). Interviews also confirmed that in the absence of broadcast burning, basketweavers and friends gathered hazelnut stems from shrubs treated using the three fire treatment proxies (Fig. 3), although the relative efficacy of these treatments remained unclear. Basketweavers also consistently recalled that the departure of supportive USDA Forest Service managers created major set-backs, because they had to re-establish lines of communication with new staff and inform them about their basketry materials and fire treatment needs. Hence, as the National Fire Plan (2001) and the Healthy Forests Restoration Act of 2003 (P.L. 108-148) initiated increased fuel reduction treatments throughout this region (Schoennagel et al., 2009), basketweavers and Tribal members often were not informed about the schedules or locations of understory mechanical treatments and broadcast burns, and thus they missed opportunities to gather hazelnut stems. As a result, basketweavers and collaborators believed that an empirical study on the effects of several fire treatments on hazelnut shrubs could assist managers in incorporating Indigenous resource objectives into their plans.

To evaluate what basketweavers consider to be stems of basketry quality, we attended over 50 basketry classes and workshops supported by the Karuk and Yurok Tribes where we received direct instruction from basketweavers. We also observed over 50 independent hazelnut stem gathering trips to describe stem gathering practices. In these settings, all basketweavers stated that stems must be straight, unbranched, and free of insect intrusions or bark blemishes. Moreover, a wide range of both stem lengths and diameters are used depending on the type and size of basket they are weaving. Stems having lengths (e.g., 10–50 cm) can be used to weave earrings, tobacco pouches, or baby rattles, whereas longer stems (e.g., 50–100 cm) are suitable for producing storage baskets or baby cradles. Small diameter stems (1–3 mm) are preferred by basketweavers conducting fine weaving, although the tapered tips of long stems with 4–12 mm diameters may be used for similar purposes. Other basketweavers may select wide stems (5–12 mm diameter) for fish traps, storage baskets, or baby cradles.

As participant observers in both material gathering and production, we documented basketweaver gathering site preferences and also constraints such as gathering in marginal locations (e.g., clear cuts and mechanically thinned roadsides). Basketweaver Mrs. Verna Reece stated: “it’s kind of hard to get burn[ing done]…When logging…they just burn [slash]…so it wasn’t that good of material…Out in the open…[hazel stems are] kinda stalky, fat. It’s different when you have…a canopy over it. It kind of reaches for the sun and kinda grows long, slender” (Lake, 2007: 600).

From these basketweaver observations, we then broadly defined suitable quality basketry stems, and focused our efforts on measuring the length and diameters of stems produced from multiple treatments under a suite of biophysical conditions. Hazelnut morphology, structural integrity, autecology, and basketry use criteria garnered from basketweavers informed the sampling design, treatments, and measurements used here (Fig. 4).

2.2. Experimental methods

2.2.1. Study area

Treatments were conducted on a 10 ha forest with abundant hazelnut shrubs on a privately owned parcel that adjoins the Orleans Ranger District of the Six Rivers National Forest in the Klamath River watershed. The study location is within the 1919 km^2 ancestral territory of the Yurok Tribe and the 2728 km^2 ancestral lands of the Karuk Tribe (Fig. 1A; Waterman 1920, Baumhoff 1963). In Karuk territory, the federal government did not establish a reservation, leaving merely 3.83 km^2 of Karuk trust lands in their ancestral territory, with the remainder largely under the jurisdiction of the Klamath and Six Rivers National Forests and scattered private homesteads (Fig. 1A; Davies and Frank, 1992; Norgaard, 2014; US Census Bureau, 2017). As a result, Karuk Tribal members and management agencies must navigate the USDA Forest Service claims on their ancestral territory and have limited options to expand their land base through the acquisition of private land holdings. In Yurok territory, multiple overlapping jurisdictions occur including Redwood National Park (192 km^2, Underwood et al., 2003) and Six Rivers National Forest (577 km^2) outside of the reservation established by the federal government. The reservation is located along a one mile buffer from the Klamath River’s estuary to ~80 km upriver (~225 km^2; Huntsinger and Diekmann, 2010). However, 106 km^2 (47%) of the reservation is under private timber company ownership (Yurok GIS Program, 2015). Consequently, the Yurok Tribe must either coordinate or interact with multiple actors within their ancestral territory, but they presently have greater options for acquiring private properties than the Karuk Tribe.

Fig. 4. Karuk basketweavers Ms. Janet Morehead (left) and Ms. Lillian Rentz (right), peeling and evaluating the quality of hazelnut stems gathered from the treatment area.

Douglas-fir (*Pseudotsuga menziesii*) and mixed hardwoods (e.g., *Arbutus menziesii*, *Quercus kelloggii*, *Notholithocarpus densiflorus*, *Acer macrophyllum* and *Umbellularia californica*) comprise the forest overstory at the study site. In California, hazelnut is an understory, multi-stemmed shrub (< 6 m ht in this study region) that typically occurs below 2,100 m above sea level on mesic sites with well-drained soils (Fryer, 2007). Relatively low-intensity fires that historically scarred canopy trees every 10–17 years (Crawford et al., 2015; Skinner et al., 2018; Taylor and Skinner, 1998; Wills and Stuart, 1994) often ‘top-kill’ understory hazelnut stems, which is when above-ground plant tissues are killed, while below-ground plant tissues remain alive (Anderson, 1999).

2.2.2. Fire proxy treatments and prescribed burning of hazelnut shrubs

We replicated fire proxy treatments used by Karuk and Yurok Tribal members to mimic prescribed fires that could be implemented by forest managers at fuel reduction sites with hazelnut shrubs. These fire proxy treatments were: (A) cutting all stems in each shrub to ground level (< 5 cm) as a means to stimulate coppicing, and to mimic mechanical understory clearing and piling for fuel reduction; (B) piling surface fuels

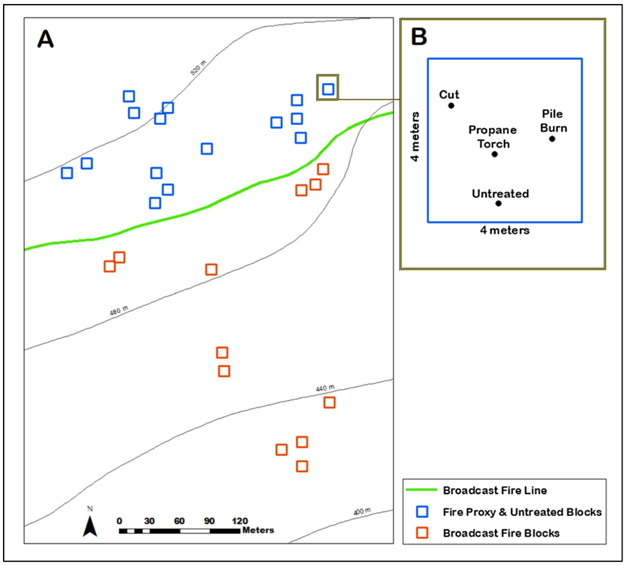

Fig. 5. Study site with treatment block design. (A) Spatial distribution of treatment blocks. The broadcast fire line divides the 15 fire proxy and untreated blocks from the 12 broadcast fire treated blocks. Contour lines depict the elevation and aspect at the site. (B) Schematic block (16 m^2) with four hazelnut shrubs (filled circles) that received fire proxy treatments.

(primarily 1-h, some 10-h fuels, and adjacent surface litter consisting of needles/leaves) between hazelnut stems to form a small pile (< 25 cm height) that was subsequently burned; and, (C) applying a propane torch flame near ground level to hazelnut shrub stems until stems blistered indicating stem mortality (Fig. 3). The prescribed fire treatment, referred to here as a 'broadcast' fire treatment, was allowed to spread across multiple hazelnut shrubs (Fig. 3D), while all other fire treatments were constrained to individually targeted shrubs.

We employed a randomized block design to establish 27 stratified blocks (block = 16 m^2) that included each treatment, except for the broadcast fire treatment (Fig. 5A). Blocks were selected if they contained at least four hazelnut shrubs spaced > 1–2 m apart with similar dimensions (e.g., shrub height, total stems, and stem diameter; Fig. 5B). Subsequently, total stems and the potential 'usable' basketry stems were counted within each hazelnut shrub and shrub height was measured over a 15 day period preceding the implementation of treatments on May 14, 2008. Based on basketweaver selection criteria, basketry stems were defined as straight stems > 10 cm long without branching. Shrub height as well as the slope, aspect, and canopy cover were recorded within each block. Slope was measured using a Suunto PM-5/360 PC Clinometer, aspect was recorded using a compass, and canopy cover was measured four times with a spherical concave densiometer at each cardinal direction above each shrub, to obtain a mean value (%) for each individual (Fiala et al., 2006; Lemmon, 1956). Aspects between 135° and 225° were classed as southern (n = 56) and aspects between 45° and 134° were classed as eastern (n = 49). Canopy cover ≤50% (n = 12) was categorized as 'low', cover ≥51% and < 70% as 'medium' (n = 63), and ≥70% as 'high' (n = 30). After our pre-treatment surveys, we randomly treated three of the shrubs within each block with a fire proxy and one shrub was designated as an untreated control (Fig. 5B).

Historically in Karuk and Yurok territory, cultural burns primarily were applied in the fall months (Harrington, 1932; O'Neale, 1932; Stewart, 2002; Thompson, 1991) with some occurring in spring months (Halpern, 2016; Lake, 2007). Given the unpredictable availability of broadcast burn conditions, the experimental and sampling design was conservative with all three fire proxy treatments and controls replicated as we were unsure whether broadcast burns could be included in this study. Fortunately, suitable prescribed fire conditions occurred on October 28, 2008 and a broadcast burn was applied to ~5 ha affecting 12 of the 27 treatment blocks (Fig. 5A). Fire lines were established to preserve ~50% of the previously treated blocks in order to compare the intact fire proxy treatments to the broadcast burn treatment (Fig. 5A). A backing fire with strip ignitions (3–5 m apart) was set with drip torches, and the fire burned from 14:20 to 16:30 h (Fig. 3D). Temperature ranged from 69.5° F to 75.0° F, relative humidity spanned 39.5–48.0% and the Yurok RAWS station (9 km from site) recorded fuel moistures between 7.4% and 12.3%. The fifteen blocks with three fire proxy treatments and a control that were not affected by the prescribed broadcast fire were then re-surveyed the following year (May 2009) when stems were suitable for harvest (n = 60 shrubs). Only one of the fifteen pile burned shrubs died. After a full growing season (18 months post-burn; April 2010), we re-surveyed 45 out of 48 shrubs in the 12 broadcast burned blocks as three tagged shrubs could not be re-located. Post-treatment measurements included the density of basketry stems, total live stems, and the presence of deer browse within each shrub.

2.2.3. *Hazelnut stem measurements*

On May 8, 2009, we harvested basketry stems (n = 604) produced from 50 shrubs in the cut (n = 233), propane (n = 205), pile burn (n = 148), and control (n = 18) treatments. Stems were cut < 5 cm from the ground, labeled, and then bark was removed to prepare the stem for weaving. Stem diameter was measured with a digital caliper and stem length with a meter tape. These stems harvested from the fire proxy treatments were then compared to hazelnut stem collections gathered on May 3, 2008 by two experienced Karuk/Yurok basketweavers (n = 396 and n = 73) from an earlier prescribed broadcast burn (October 2006) adjacent to the experimental study site.

2.2.4. *Data analyses*

To evaluate the production of post-treatment basketry stems in each shrub among the different treatments, we developed a negative-binomial generalized linear mixed model (GLMM) using the glmmTMB package in R (Magnusson et al., 2017; R Core Team, 2014). Block was set as a random effect, and treatment, aspect class, slope, the presence of deer browse, pre-treatment total stems, and canopy cover classes were included as covariate fixed effects. Pre-treatment total stems were also included as a fixed effect to evaluate if shrub size affected the quantity of post-treatment basketry stems. We used Type III Wald Chi Square tests to perform backwards selection to find the model of best fit. To analyze the differences within categorical variables that showed significance in the GLMM, we generated Estimated Marginal Means (EMMs) to address imbalances in the study design (e.g., 45 broadcast shrubs versus 15 pile burned shrubs) using the emmeans package and compared 95% confidence intervals using the Tukey and Dunnett methods (Lenth, 2018).

To analyze the length and diameter of stems gathered from the fire proxy treated and control shrubs, we developed two gamma distributed GLMMs using the glmmTMB package. Each shrub was set as a random effect in the model, and treatment, pre-treatment shrub height, aspect class, and canopy cover class were treated as covariate fixed effects. We generated models of best fit using backwards selection with Type III Wald Chi Square tests, and produced EMMs to analyze differences in stem lengths and diameters within categorical variables using the Tukey method. Stem length and diameter distributions from our treatment samples were compared with the collections of two basketweavers using a multiple comparison Wilcoxon Rank Sum test (Kabacoff, 2015).

3. Results

The 86 treated hazelnut shrubs produced a total of 923 basketry stems (10.73 per shrub ± 1.02), whereas the 19 control shrubs produced only 20 basketry quality stems (1.05 per shrub ± 0.45). Within the broadcast burned blocks, six shrubs had died while four shrubs were

Table 1
Effects of the fire proxy and broadcast burn treatments (e.g., cut, pile burn, propane, broadcast) on hazelnut basketry stem production compared with the untreated control. Estimated Marginal Mean (EMM) is back-transformed from the log scale and averaged over the values of aspect and canopy classes. The contrast to control ratio is the treatment EMM to untreated control EMM (1.54, SE = 0.60). The confidence intervals, *t*-statistic and *p*-values were generated using the Dunnett method.

Treatment	n	EMM	Contrast to control ratio	Contrast SE	CI	*t* ratio	*p* value
Cut	15	6.45	4.19	1.87	1.38–12.7	3.22	0.0066
Pile Burn	15	10.98	7.13	3.05	2.46–20.7	4.59	0.0001
Propane	15	15.45	10.05	4.16	3.57–28.2	5.57	< 0.0001
Broadcast	41	11.54	7.50	3.07	2.70–20.9	4.92	< 0.0001

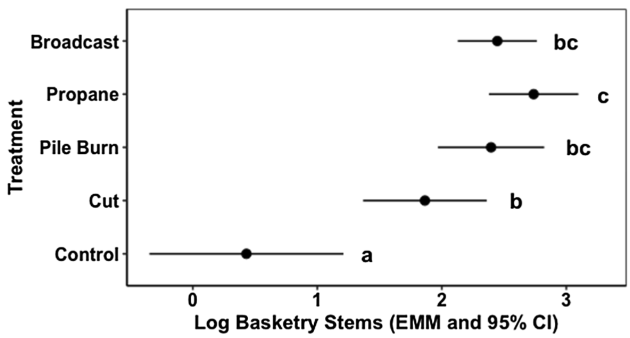

Fig. 6. Fire proxy treatment, broadcast burn, and untreated control effects on hazelnut basketry stem production. Estimated marginal means (EMM) of basketry stems with 95% confidence intervals (log scale) within the control and four fire proxy treatments. Letters indicate significant differences between treatments ($p < 0.05$).

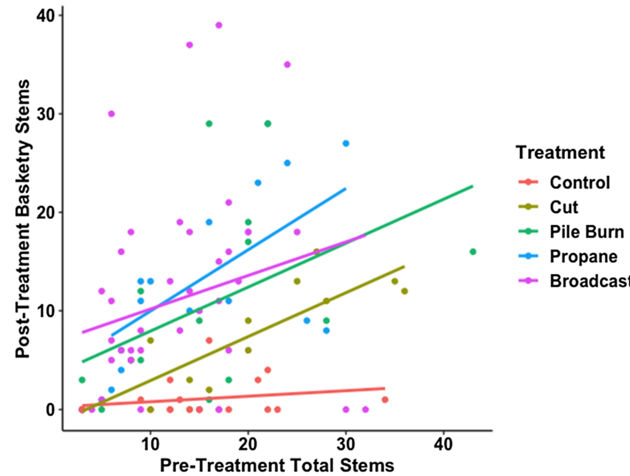

Fig. 7. Pre-treatment total stems (shrub size) positively affect post-treatment basketry stem production. Pre-treatment total stems and post-treatment basketry stems are plotted by treatment with lines of best fit determined by ordinary least squares regression.

unburned and were then included in the untreated (control). All hazelnut shrubs that were treated with either pile burning, propane torching, and, or a prescribed broadcast burn increased the production of basketry stems from 7 to 10-fold in comparison with the shrubs in the untreated controls ($p < 0.001$, Table 1, Fig. 6). However, the quantity of basketry stems per shrub produced by the cut treatment (EMM = 6.5, SE = 1.61) was only 4-fold greater than the untreated controls (EMM = 1.54, SE = 0.60, $p = 0.006$, Table 1). The EMM of the cut treatment was reduced significantly when compared with the EMM of the propane treatment (EMM = 15.45, SE = 2.79, $p = 0.025$, Fig. 6). Basketry stems among the propane, pile burn (EMM = 10.98, SE = 2.36), and broadcast (EMM = 11.54, SE = 1.84) treatments did not exhibit significant differences (all = $p > 0.25$, Fig. 6).

Pre-treatment total stems ($p < 0.001$), aspect class ($p < 0.01$), and canopy cover class ($p < 0.05$) imparted significant effects on basketry stem production in hazelnut shrubs (Wald Type III Chi Square test; Table 2). Shrub size (pre-treatment total stems) and basketry stem production exhibited a strong positive relationship ($p < 0.001$, Fig. 7).

Table 2
Variables affecting basketry stems within study blocks. Results of a Wald Type III Chi Square test on the significance of the treatments (control, cut, pile burn, propane, broadcast), pre-treatment total stems, aspect class, and canopy class on basketry stems generated from a negative-binomial generalized linear mixed model (GLMM). Aspects between 135° and 225° were classed as southern ($n = 56$) and aspects between 45° and 134° were classed as eastern ($n = 49$). Canopy cover ≤50% ($n = 12$) was categorized as 'low', cover ≥51% and < 70% as 'medium' ($n = 63$), and ≥70% as 'high' ($n = 30$). Two additional biophysical variables (deer browse, slope) did not exhibit strong effects on basketry stems ($p > 0.05$) and were removed from the model. Hazelnut shrub blocks ($n = 27$; 16 m^2) are set as random effects.

Fixed effect	χ^2	Df	$p(>\|\chi^2\|)$
Treatment	35.38	4	< 0.001
Pre-treatment total stems	23.11	1	< 0.001
Aspect class	6.99	1	0.008
Canopy class	7.14	2	0.028

Shrubs within eastern aspect classes produced 1.73-fold more basketry stems ($n = 49$, EMM = 9.48, SE = 1.18) than those in southern aspect classes ($n = 56$, EMM = 5.47, SE = 1.19, $p < 0.01$). Within the canopy cover classes, the shrubs within the medium canopy cover class ($n = 63$) produced a 5.08 EMM (SE = 0.86) of basketry stems, whereas shrubs within the high canopy cover class ($n = 30$) produced 1.84-fold greater basketry stems (9.36 EMM, SE = 1.75, $p = 0.03$) than the medium canopy cover class. Shrubs within the low canopy class ($n = 12$) had a 7.87 EMM (SE = 2.00) and did not differ significantly from shrubs in the high ($p = 0.83$) or medium canopy cover classes ($p = 0.27$). Within the initial negative-binomial GLMM, deer browse and slope did not impart significant effects on basketry stem production ($p > 0.05$).

Basketry stem lengths gathered from the treated and control shrubs ranged from 11.00 to 118.60 cm (μ = 43.24, SE = 0.83) and stem diameters ranged from 0.53 to 5.76 mm (μ = 2.30, SE = 0.04, Fig. 8). Basketweaver1 gathered stem lengths ranging 14.10–81.20 cm (μ = 38.97, SE = 0.58), and Basketweaver2 gathered stem lengths ranging 27.80–73.40 cm (μ = 47.76, SE = 1.29, Fig. 8B). From basketweavers' sourced materials, stem diameter ranged from 0.96 to 4.11 mm (μ = 2.13, SE = 0.03) and 1.64–4.45 cm (μ = 2.89, SE = 0.07), respectively (Fig. 8A). The distribution of basketry stem lengths and stem diameters gathered by Basketweaver2 were greater than those gathered by Basketweaver1 as well as those stems harvested from the fire proxy treatment blocks and broadcast burn (Wilcoxon rank sum; $p < 0.001$, Fig. 8). However, similar stem length and diameter distributions were recorded from stems harvested in the fire proxy treatment blocks and broadcast burn as well as those gathered by Basketweaver1 ($p > 0.05$).

Results from the gamma GLMMs showed that pre-treatment shrub heights and aspect classes had a significant affect on basketry stem lengths and diameters from treated and control shrubs. A strong positive relationship was detected between pre-treatment shrub height and

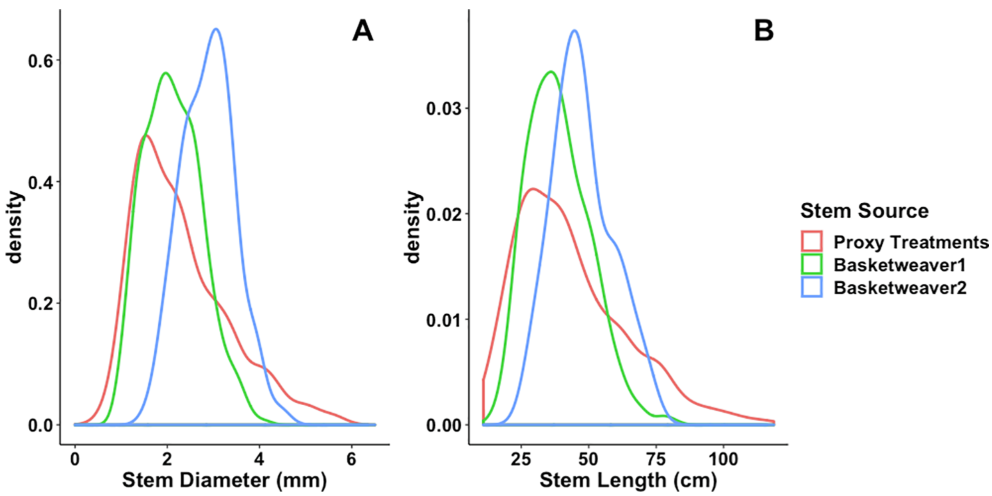

Fig. 8. Treatment effects on hazelnut basketry stem size distributions compared with basketweavers' harvests. Samples were gathered from 46 treated and 4 untreated shrubs (n = 604), and collected by Basketweaver1 (n = 396) and Basketweaver2 (n = 73). Fire proxy treatment and control stem size distributions did not differ significantly from the distributions gathered by Basketweaver1 (Wilcoxon Rank Sum; p = 0.5). However, the stem size distributions from Basketweaver2 differed significantly from all treatments and Basketweaver1, but based on a relatively small sample size (Wilcoxon Rank Sum; p < 0.001). (A) Stem diameter (mm) and (B) stem length (cm). Distributions shown as kernel density plots.

post-treatment stem lengths and diameters (p < 0.001). Shrubs within the southern aspect class produced both shorter length (EMM = 34.4 cm, SE = 1.62) and smaller diameter (EMM = 1.87 mm, SE = 0.08) stems post-treatment than eastern aspects (diameter EMM = 2.52 mm, SE = 0.15; length EMM = 47.6 cm, SE = 2.79, p < 0.001). Between the treated and control shrubs, basketry stem length did not differ significantly. However, the stem diameters harvested from the pile burn (EMM = 2.00 mm, SE = 0.12) and cut (EMM = 2.49 mm, SE = 0.127) treatments were significantly different (p = 0.02). Propane treated stem diameters (EMM = 2.14, SE = 0.11) were nonsignificant in the model (p = 0.15). No discernable effects of canopy cover classes on stem diameter or length were detected.

4. Discussion

The application of three fire proxy treatments and a prescribed broadcast fire treatment indicate that all treatments generated 4–10-fold increases in basketry quality hazelnut stems when compared with the untreated hazelnut shrubs. Untreated (control) hazelnut shrubs contained only 1.54 ± 0.60 basketry stems per shrub, and thus, are deemed marginal, or too limited in value for California Indian basketweavers (Anderson, 1999). Thus, broadcast fires or substitute treatments are required to generate basketry quality stems.

Basketweavers prefer cultural burns to treat hazelnut shrubs for basketry because they efficiently top-kill many hazelnut shrubs relatively rapidly, and thus, create improved gathering rates for basketweavers. Cultural burns also may have positive effects upon additional ecocultural species and may reduce understory fuels. Although our broadcast burn treatment was effective at producing basketry stems, ~15% of broadcast burned hazelnut shrubs died, and thus reduced the basketry stems expected from this treatment. While we did not assess pre-burn surface fuel loads before ignition, the landowner had not previously conducted fire treatments in the broadcast burn area, suggesting that surface fuel loads may have been relatively higher than in a historically, and thus, more frequently burned forest. Decades of fire exclusion increase surface fuel loadings that generate increased fire intensities and shrub mortality during prescribed burns (Kauffman and Martin, 1990; Thaxton and Platt, 2006). In the absence of broadcast burns, pile burning and propane torch burning treatments also are effective methods to top-kill hazelnut shrubs. When creating piles within hazelnut shrubs practitioners may avoid piles with high fuel loads and inordinate fire residence time to prevent shrub mortality resulting from excessive direct heat (Siefkin et al., 2002). Only ~7% of monitored shrubs died from our surface fuel piles when they were composed of 1-h, 10-h, and surface litter fuels with height limited to < 25 cm, but establishing fuel load and fire residence time limits or guidelines through additional research would be useful especially when expanding these applications over large areas.

In contrast to our cutting treatment that focused solely of hazelnut stems, mechanical cutting is widely used by agencies and landowners to create shaded fuel breaks (65–400 m wide) and is typically paired with the pile burning of cut woody debris (Agee et al., 2000; Rhoades and Fornwalt, 2015; Vaillant and Reinhardt, 2017). When burned hazelnut shrubs are unavailable or insufficient basketweavers will gather basketry stems opportunistically within these mechanically created fuel breaks if suitable coppiced hazelnut shrubs occur. However, basketweavers report reduced stem strength or pliability from mechanical treatments compared to burn treatments, which is supported by lower wood-to-pith ratios in these stems (Rentz, 2003). The lower stem quality and reduced expected stem density from cut treatments considerably reduces basketweavers' preference for this treatment.

The four environmental variables we measured (e.g., slope, deer browse, canopy cover, and aspect) appear to explain some of the variation observed in hazelnut basketry stems production. Deer browse occurred on only five of the 105 hazelnut shrubs measured, and thus, in this particular case deer browse was inconsequential. Yet, deer herbivory typically occurs at the axil tip of new basal shoots. Subsequently, the hazelnut shrub typically produces two or more lateral branches below where the apical bud and leaves were eaten, producing an unsuitable basketry stem. Thus, if deer or other ungulate browsers are abundant (e.g., at sites further from private residences), browse could become a major factor in the reduction of basketry stems.

Hazelnut shrubs in the 'high' canopy cover class produced 1.84-fold more basketry stems than those in the 'medium' canopy cover class. These results support Karuk and Yurok basketweavers' experience and observations. Areas with relatively low canopy cover (i.e., 0–20%) and increased light conditions stimulate lateral branching within hazelnut basal resprouts, reducing the potential density of basketry quality stems (Johnson and Marks, 1997; Lake, 2007; Ortiz, 1998). However, the shrubs within the 'low' canopy cover class produced highly variable basketry stems whose EMM was 1.55-fold greater than shrubs in the 'medium' canopy cover class although the EMM did not differ significantly. Only four shrubs in the low canopy cover class had 30% cover, and the remaining eight shrubs in that class were 50% cover, which reflects limitations in both our sampling effort and truncated range of measured canopy cover (30–85%) within a 10 ha sampled area. Given that southern aspects in the northern hemisphere are exposed to additional solar radiation than eastern aspects, shrubs with southern exposures (EMM = 5.48) produced significantly fewer basketry stems than those in eastern aspects (EMM = 9.48, Barbour et al., 1987: 341). Overall, additional sampling of shrub responses to treatments across the full aspect range would improve these analyses and our understanding.

Plant branching and architectural responses to sunlight are exceptionally diverse and show phenotypic plasticity (Valladares and Niinemets, 2007). In unburned and non-coppiced temperate deciduous understory trees and shrubs, lateral branching can be stimulated by increased light conditions (Bonser and Aarssen, 1994; Canham, 1988; Charles-Dominique et al., 2012; Hamelin et al., 2015; Pickett and Kempf, 1980). California hazelnut appears to change its plant architecture from a sympodial form in full sun to a monopodial form under forest canopies much like the multi-stemmed shrub, *Rhamnus cathartica* (Charles-Dominique et al., 2012). However, more detailed morphological measurements are required to confirm these hazelnut architecture forms.

Aspect class also affected stem length and diameter in the GLMMs analyses. Stems measured from eastern aspects were 1.38-fold longer and 1.35-fold wider compared with those in southern aspects. These results align with basketweaver knowledge that shrubs with full sun exposure produce shorter stems than those under canopy cover. Similarly, the Mediterranean shrub *Arbutus unedo* has been shown to produce taller resprouts post-fire when growing in northern and eastern aspects compared to southern and western aspects (Konstantinidis et al., 2006). However, our observed decrease in viable basketry stems in southern aspects and medium canopy cover should not be misconstrued to suggest that burning should be limited under these site conditions because shrubs under these conditions still produce at least a 5-fold increase in basketry stems as untreated shrubs.

Treatments did not have a detected effect on stem length. However, the cut treatment produced 1.25-fold greater stem diameters than the pile burn treatment. Cut treatments may not induce as much physiological stress or loss of stored energy as compared with burning treatments, and thus, the shrub may have sufficient resources to produce more robust stems with greater diameter. Several studies have found that high severity fires reduce shrub resprouting vigor and biomass compared with low severity fires and cutting treatments (Clarke et al., 2013; Fernández et al., 2013a; Keeley, 2006; Lloret and López-Soria, 1993), however other studies have found that severity does not correlate with resprout vigor in other shrub species (Drewa et al., 2002; Fernández et al., 2013b; Keeley et al., 2008).

Stem diameter and stem length distributions harvested from the treated and control shrubs ($n = 604$), were similar to those harvested from a broadcast burn by Basketweaver1 ($n = 396$). Thus, our fire proxy and broadcast burn treatments appeared to produce stem qualities that are preferred by basketweavers. However, Basketweaver2 harvested a distinctive set of stems. Admittedly, this stem sample from Basketweaver2 is relatively limited ($n = 73$) when contrasted with our treatments and Basketweaver1. Most importantly, basketweavers reported that some basketry projects may require different sets of stem diameters and lengths. Therefore, basketweavers' aims must be considered when comparing hazelnut stem harvesting activities.

Our results demonstrate that expanding the area and frequency of targeted understory fire-based forest treatments on private, public and Tribal lands in the Pacific Northwest and California would generate greater availability and distribution of basketry hazelnut stems that are currently limited in supply and in high demand (Baldy, 2013; Long and Lake, 2018; Ortiz, 1993). Small-scale (≤10 ha) application of these fire proxy treatments appears quite feasible both for private landholders or on public lands that would require minimal permitting as well as limited labor and low material costs. The constraints associated with prescribed and cultural burns, such as the limited burning season and increased liability concerns in close proximity to residences within the Wildland Urban Interface, do not necessarily apply to these fire proxy treatments because they can be conducted when prescribed burning conditions are risky or biophysically not possible (e.g., either elevated or low dead surface fuel moisture). Due to these and other constraints, the USDA Forest Service currently is able to implement understory mechanical fuel reduction treatments across a greater area than broadcast burning to reduce fuels in California and the Pacific Northwest (Vaillant and Reinhardt, 2017). Yet, the three fire proxy practices examined here appear to be highly compatible for integration into larger-scale USDA Forest Service, or other fuel treatment programs (≥10 ha), and likely would require only minor adjustments to current understory mechanical fuel reduction practices to meet these additional Tribal ecocultural objectives. For example, if the woody debris from these understory mechanical treatments are pile burned, hazelnut burn piles (< 25 cm) or propane torching could be incorporated into this fuel reduction activity, increasing hazelnut stem productivity. Further, hazelnut stems could be included for removal in mechanical understory thinning treatments, if they were initially excluded from the prescription. While Tribal members prefer broadcast burning for ecocultural resource production, they recognize that mechanical understory treatments are necessary to address decades of fire exclusion, and prepare sites for broadcast burning in the near future (USDA Forest Service PSW Region, 2018). If areas of high hazelnut shrub densities are either known or identified in consultation with Tribes and basketweavers, and align with fuel reduction objectives, the subsequent production of basketry stems from mechanical treatments would provide additional benefits to the fuel reduction value of this treatment. Given that hazelnut is distributed across 75% of the NWFP area, limited efforts are required to identify these suitable areas (Long et al., 2018).

Policies that support Tribal consultation within public land agencies offer effective opportunities for increased and effective collaborations and communication in forest management (Bussey et al., 2015; Dockry et al., 2017; Donoghue et al., 2010; Lake et al., 2017). Since this initial experimental study was conducted, prescribed burning and fuel treatments have expanded throughout northwest California, largely as a result of inter-governmental and community partnerships that aim to manage public, Tribal, and private lands (Harling, 2015; Long et al., 2018; USDA Forest Service PSW Region, 2018; Yurok Tribe, 2015).

Throughout this study, we sought to incorporate Indigenous knowledge and participation with 'western' scientific approaches to support these expanding collaborative efforts among Tribal governments and public land agencies. Fire exclusion policies forced California Indian communities and forest managers to curtail their routine cultural and prescribed burning practices. Despite these policies, Karuk and Yurok basketweavers retained their knowledge, maintained their practices and, most importantly, developed several innovative techniques to replicate fire's effects on hazelnut to produce essential basketry materials. To support their efforts, we quantified their hazelnut fire treatment outcomes with the aim to inform managers of their efficacy and material importance, to facilitate increased forest access, and to reduce bureaucratic processes required for Tribal members who seek to employ these fire proxy treatment methods and broadcast burns. Moreover, we encourage efforts to explore creative applications that aim to incorporate these hazelnut fire proxy practices within government-led understory mechanical fuel thinning and large-pile burning treatments. Through such collaborative processes, basketweavers and Tribes may be able to receive financial and logistical support, and, most importantly, recognition and respect for their priorities and experience in managing hazelnut as well as other critical ecocultural resources.

Declaration of Competing Interest

The authors declare no competing interests.

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