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Revitalized Karuk and Yurok cultural burning to enhance California hazelnut for basketweaving in northwestern California, USA

Tony Marks-Block^{1*} , Frank K. Lake², Rebecca Bliege Bird³ and Lisa M. Curran⁴

Abstract

Background: Karuk and Yurok tribes in northwestern California, USA, are revitalizing the practice of cultural burning, which is the use of prescribed burns to enhance culturally important species. These cultural burns are critical to the livelihoods of indigenous peoples, and were widespread prior to the establishment of fire exclusion policies. One of the major objectives of cultural burning is to enhance California hazelnut (*Corylus cornuta* Marsh var. *californica*) basketry stem production for Karuk and Yurok basketweavers. To evaluate cultural burning as a form of human ecosystem engineering, we monitored hazelnut basketry stem production, qualities, and shrub density in 48 plots (400 m²) within two prescribed and 19 cultural burn sites. Socio-ecological variables that were analyzed included burn frequency, burn season, overstory tree (≥ 10 cm diameter at breast height) basal area, ungulate browse, and aspect. We also observed basketry stem gathering to compare travel distances, gathering rates, and basketweaver preferences across sites with different fire histories and land tenure.

Results: Hazelnut shrubs, one growing season post burn, produced a 13-fold increase in basketry stems compared with shrubs growing at least three seasons post burn ($P < 0.0001$). Basketry stem production and stem length displayed negative relationships with overstory tree basal area ($P < 0.01$) and ungulate browse ($P < 0.0001$). Plots burned at high frequency (at least three burn events from 1989 to 2019) had 1.86-fold greater hazelnut shrubs than plots experiencing less than three burn events ($P < 0.0001$), and were all located on the Yurok Reservation where land tenure of indigenous people is comparatively stronger. Basketweavers travelled 3.8-fold greater distance to reach gathering sites burned by wildfires compared with those that were culturally burned ($P < 0.01$). At cultural burn sites, wildfire sites, and fire-excluded sites, mean gathering rates were 4.9, 1.6, and 0.5 stems per minute per individual, respectively.

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Conclusions: Karuk and Yurok cultural fire regimes with high burn frequencies (e.g., three to five years) promote high densities of hazelnut shrubs and increase hazelnut basketry stem production. This improves gathering efficiency and lowers travel costs to support the revitalization of a vital cultural practice. Our findings provide evidence of positive human ecosystem engineering, and show that increasing tribal sovereignty over fire management improves socio-economic well-being while at the same time supports measures of ecosystem structure and function.

Keywords: American Indians, basketry, California, *Corylus cornuta* var. *californica*, ecosystem engineering, indigenous peoples resource use, prescribed fire, resource management

Resumen

Antecedentes: Las tribus Karuk y Yurok del noroeste de California, EEUU, están revitalizando la práctica cultural de quemas, que es el uso del fuego prescrito para aumentar las especies culturalmente importantes. Estas quemas culturales son críticas para sustentar la vida de los pueblos indígenas, y fueron sumamente extendidas antes del establecimiento de las políticas de exclusión del fuego. Uno de los principales objetivos de las quemas culturales es aumentar la producción de tallos del avellano de California (*Corylus cornuta* Marsh var. *californica*) que es usado para la construcción de cestos por los fabricantes de cestos (cesteros) de las tribus Karuk y Yurok. Para evaluar las quemas culturales como una forma de ingeniería ecosistémica, monitoreamos la producción de cestos realizados con tallos de avellano, la calidad y densidad de esos tallos, en 48 parcelas (400 m²) dentro de dos quemas prescritas y en 19 lugares con quemas culturales. Las variables socio-ecológicas que fueron analizadas incluyeron la frecuencia de quemas, la estación de quemas, el área basal (≥ 10 cm de diámetro a la altura del pecho) de árboles del dosel superior, el ramoneo por ungulados, y la exposición. Observamos asimismo el lugar de colección de los tallos para comparar distancias recorridas, tasas de recolección, y las preferencias de quienes fabrican los cestos a través de sitios con diferentes historias de fuego y tenencia de la tierra.

Resultados: Una estación luego del fuego, los arbustos de avellano de California produjeron un incremento de 13 veces la producción de tallos factibles de ser usados en cestería comparados con arbustos creciendo al menos tres estaciones post fuego ($P < 0.0001$). La producción y el largo de los tallos desarrollaron relaciones negativas con el área basal de árboles del dosel superior ($P < 0.01$) y el ramoneo de ungulados ($P < 0.0001$). Las parcelas quemadas a alta frecuencia (al menos tres eventos de fuego de 1989 a 2019) tuvieron 1,86 veces más arbustos de avellano que aquellas parcelas que experimentaron menos de tres eventos de fuego ($P < 0.0001$), y fueron todos ubicados en la reservación de Yurok, donde la tenencia de la tierra por parte de la comunidad indígena es comparativamente más fuerte. Los fabricantes de cestos viajaron distancias 3,8 veces más largas para alcanzar lugares quemados por fuegos naturales comparados con aquellos que fueron sujetos a quemas culturales prescritas ($P < 0.01$). En los sitios quemados por prácticas culturales, por incendios naturales u aquellos lugares excluidos de fuegos, el tiempo promedio de recolección fue de 4,9, 1,6, y 0.5 tallos por minuto por individuo, respectivamente.

Conclusiones: Los regímenes de quemas culturales por parte de las tribus Karuk y Yurok con altas frecuencias de quema (e.g. de tres a cinco años), promueven una alta densidad de arbustos de avellano e incrementan la producción de tallos para cestería. Esto mejora la eficiencia en la recolección y reduce los costos del viaje, lo que ayuda a la revitalización de una práctica cultural vital. Nuestros hallazgos proveen evidencias positivas de ingeniería ecosistémica humana, y muestran que el incremento de la soberanía tribal sobre el manejo de fuego mejora las condiciones de bienestar socio-económico, mientras que al mismo tiempo aportan a la estructura y el funcionamiento del ecosistema.

Background

Across diverse ecosystems worldwide, prescribed burning by indigenous peoples, known colloquially as cultural burning, has been shown to impart positive effects on human and ungulate foraging returns, habitat diversity, and species abundance as well as the mitigation of wild-fire spread by reducing fuel loads and fire intensities

(Laris 2002; Bilbao et al. 2010; Bliege Bird et al. 2012; Fowler 2012; Seijo et al. 2015). Given the substantial shifts in ecosystem functioning generated by cultural burning practices of indigenous peoples, several authors have suggested that these practices provide critical ecosystem engineering functions that generate or maintain a distinctive suite of non-human species and

communities adapted to the pyrodiversity created by indigenous peoples' fire regimes (Jones et al. 1994; Smith 2011; Bliege Bird et al. 2013; Odling-Smee et al. 2013).

In California, USA, fire serves as a critical biophysical process (Sugihara et al. 2018). Preceding Spanish and American colonialism, fires set by California Indians imparted profound ecological effects by reducing fire severity and fuel continuity (Mallek et al. 2013; Taylor et al. 2016). These cultural fires enhanced California Indian subsistence and ceremonial resources and, thus, are integral to the culture and economy of California Indians (Lightfoot and Parrish 2009; Anderson 2018). However, in 1905, the USDA Forest Service initiated fire exclusion policies to protect timber commodities and built structures, and by the 1920s, these policies had solidified throughout the State of California to exclude cultural burning (Pinchot 1905; Ayres and Hutchinson 1931; Clar 1959; Cermak 2005). Fire exclusion policies reduced indigenous peoples' cultural burning practices and limited the availability of their key ecocultural resources (Huntsinger and McCaffrey 1995; Aldern and Goode 2014; Eriksen and Hankins 2014; Lake et al. 2017; Norgaard 2019). By the 1990s, US federal land management agencies revised their fire policies to recognize the potential benefits of prescribed fires as a management tool, generating opportunities to revive indigenous people's cultural burning practices (Butler and Goldstein 2010; Long and Lake 2018; Stephens and Sugihara 2018).

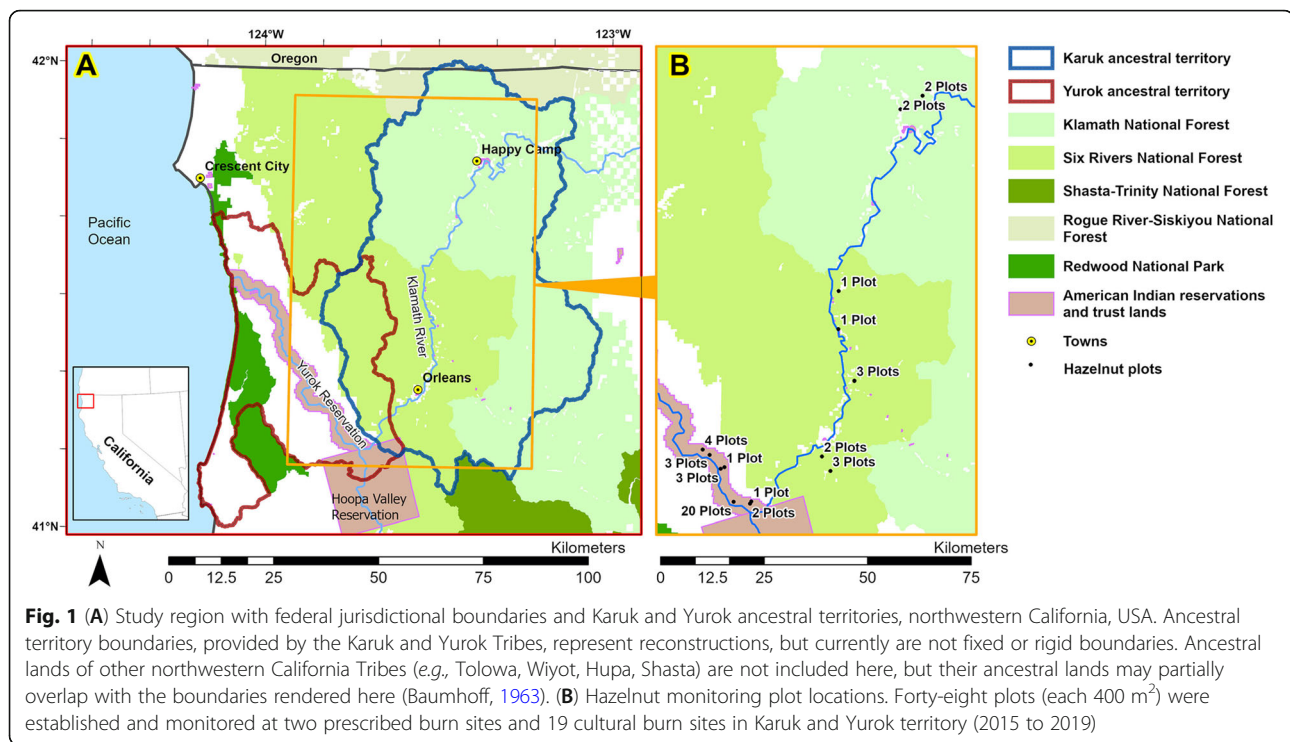
In northwestern California, indigenous peoples such as the Karuk, Yurok, and Hoopa Valley tribes (AKA Hupa), are leading efforts to re-introduce cultural burning by forming partnerships with public land and fire agencies as well as non-governmental organizations (Underwood et al. 2003; Levy 2005; Salberg 2005; Long and Lake 2018). In 2013, institutional support for cultural burning in northwestern California was initiated through the Prescribed Fire Training Exchanges (TREX; Terence 2016), and, in 2014, the Six Rivers National Forest began the Roots and Shoots project on the Lower Trinity, Orleans, and Ukonom ranger districts (Colegrove 2014). The TREX program falls under the Promoting Ecosystem Resilience and Fire Adapted Communities Together agreement between the USDA Forest Service and The Nature Conservancy that invests in cooperative and collaborative burning on private, tribal, and public lands across the United States (Butler and Goldstein 2010; Spencer et al. 2015). In Karuk and Yurok territory, TREX provides financial and logistical support to develop burn plans, process permits, supply equipment, and mobilize fire personnel to support inter-governmental, inter-agency, and civil society partnerships. (Harling 2015; Terence 2016). The Roots and Shoots project is a Six Rivers National Forest effort

developed by the USDA Forest Service and Tribal members to burn 176 acres within 25 forest areas containing ecocultural resources integral to indigenous peoples (Colegrove 2014).

While cultural burns are utilized in different seasons and at different scales and intensities for a wide range of ecocultural species (Hankins 2013), in recent decades, one of the major objectives for conducting cultural burns in Karuk and Yurok ancestral territories (Fig. 1) has been to enhance the production of basketry materials for indigenous basketweavers (Hunter 1988; Ortiz 1998; Senos et al. 2006). California Indians use baskets in a wide range of contexts: child-rearing; food harvesting, processing, and storage; for everyday clothing; and in ceremonies (Johnson and Marks 1997; Bibby 2004; Shanks 2006; Mathewson 2007). Baskets are also economically important, sold both within and outside the indigenous community to supplement income (Cohodas 1997; Smith 2016). In turn, baskets provide spiritual connections to land and ancestors, through the materials used as well as the form of the basket design (Lang 1994; Johnson and Marks 1997; Smith 2016). Northwestern California Indian basketweaving exists as one of many manifestations of socio-ecological relationships within this fire-dependent culture (Lang 1991; Hillman and Salter 1997; Buckley 2002; Smith 2016; Baldy 2018).

One of the most highly valued and critically important species for basketweaving is California hazelnut (*Corylus cornuta* Marsh var. *californica*; Ortiz 1993; 1998; Smith 2016), a multi-stemmed, deciduous shrub. Hazelnut stems are integral to the weaving of baby baskets (cradles), which are composed of ~300 stems and currently are sold for ~\$800. As Maggie Peters, a Yurok basketweaver, shared, "These baskets are in high demand by northwest California Indian families who want their children to begin their lives in a cultural way." Cultural burns for hazelnut are designed to manipulate the post-fire growth response of California hazelnut, stimulating it to re-sprout from underground buds (Fryer 2007; Clarke et al. 2013), and to produce straight, unbranched shoots suitable for use in basketweaving. Historically, cultural burning for hazelnut basketry stems occurred predominantly in the summer and fall months, although occasionally in the spring (Lake 2007). Hazelnut stem regrowth would then be harvested in the following spring (April and May) after one full growing season (spring burn, ten to 12 months post burn; fall burn, 18 to 21 months post burn; Thompson 1991; O'Neale 1932; Lake 2007).

From the 1920s to the 2000s, fire exclusion policies and regulations against cultural burning increased the scarcity of suitable basketry stems for basketweavers (Heffner 1984; Ortiz 1993; Smith 2016). In response, some basketweavers developed alternative techniques to stimulate the



growth of hazelnut basketry stems, such as cutting (coppicing), propane torch burning, and pile burning (Heffner 1984; Hunter 1988; Ortiz 1998; Marks-Block et al. 2019). Others were able to maintain burning for basketry materials—albeit in limited areas—throughout the fire exclusion era (Bower 1978; Heffner 1984; Hunter 1988; Ortiz 1998). With the relatively recent expansion of cultural burning in this region initiated by TREX and the Roots and Shoots initiatives, opportunities emerged to evaluate the effects of cultural burning on hazelnut basketry stem production, shrub density, and basketweaver stem harvesting across sites with distinctive fire regimes and land tenure arrangements: for example, between sites with relatively short burning intervals in recent decades (*i.e.*, every three to ten years) in Yurok territory, and at sites in Karuk territory that only recently have been burned after years of fire exclusion.

Our study was motivated by three broad questions. First, is cultural burning by indigenous peoples a form of ecosystem engineering that has positive feedback on ecological and cultural processes? If so, we expected that cultural burning may increase basketry stem productivity, hazelnut shrub density, or reduce the harvesting costs (in search, collection, and travel time) of gathering suitable stems. Basketweaver ecological knowledge and previous experimental studies (O’Neale 1932; Ortiz 1998; Anderson 1999; Lake 2007; Marks-Block et al. 2019) led us to predict that basketry stem production and quality are affected by time since fire and shrub size (*i.e.*, shrub stem densities), and that burn characteristics (*e.g.*, season, severity, and

frequency) and site characteristics (*e.g.*, canopy closure or solar access, aspect, forest stand structure, and deer browse) may be other important factors.

Second, does cultural burning alter species’ assemblages, such that in the absence of such fire perturbation, plant communities may shift to alternative stable states (Beisner et al. 2003)? We hypothesized that repeated, short-interval cultural burning acts as a beneficial, culturally desired perturbation in hazelnut groves, and that cultural burning maintains high shrub densities and other forest stand characteristics (*e.g.*, relatively low overstory basal area; Anderson 1999; 2018). Following this, if burning is inconsistent or absent, then hazelnut vigor was expected to decline with reduced densities and basketry stems post burn.

Third, how does fire and resource governance in pre-colonial and contemporary contexts affect cultural fire geography, basketry stem availability, and gathering practices? Here, we examined how centralization in governance structures (Larson and Soto 2008) as well as differences in land tenure (Huntsinger and Diekmann 2010; Norgaard 2014) affected fire-enhanced resource use in Karuk and Yurok territory. We predicted that distinctive Karuk and Yurok land tenure history and current resource access configurations likely influence hazelnut basketry stem gathering decisions. These histories and configurations affect cultural fire frequencies, hazelnut shrub densities, and site productivity that also affect gathering rates of hazelnut basketry stems and travel

distance to gathering sites. The use of these rates and metrics were informed by human behavioral ecology and foraging theory, which suggested that resource acquisition decisions were informed by micro-economic costs and tradeoffs (Stephens and Krebs 1986; Winterhalder and Smith 2000) as well as property regimes and land tenure (Smith 1988; Aswani 1998).

Methods

Study area

Our study area was the 1919 km² ancestral territory of the Yurok Tribe and the 2728 km² ancestral territory of the Karuk Tribe (Fig. 1; Waterman 1920; Baumhoff 1963) in the mid-Klamath watershed of California. Settlements historically were concentrated along the Klamath River and the Pacific coast (Waterman 1920; Kroeber 1936), and hunting and gathering grounds for critical ecocultural resources were owned and tended by either families or individuals (Waterman 1920; Bettinger 2015). Today, the Yurok and Karuk tribes include approximately 6000 to 7000 members, and make up two of the most populous federally recognized tribes in California (currently 109 tribes; United States Census Bureau 2010). In Karuk territory, the federal government did not establish a reservation or ratify treaties, but instead unilaterally created Forest Reserves in the majority of their territory that are now the Klamath and Six Rivers national forests (Rawls 1986; Davies and Frank 1992; Conners 1998; Miller 2017). Currently, the Karuk Tribe has merely 3.83 km² of their ancestral territorial lands held in trust by the federal government, with the remainder largely under the jurisdiction of the USDA Forest Service and scattered private homesteads (Fig. 1; Davies and Frank 1992; Norgaard 2014; US Census Bureau 2017). In Yurok territory, multiple overlapping jurisdictions occur, including Redwood National Park (192 km²; Underwood et al. 2003) and Six Rivers National Forest (577 km²) outside of the reservation established by the federal government. The reservation is located along a 1.6 km buffer following the Klamath River from its estuary to ~80 km upriver near the confluence of the Klamath and Trinity rivers (~225 km²; Huntsinger and Diekmann 2010). However, 106 km² (47%) of the reservation is under private timber company ownership (Yurok GIS Program 2015). While we did not formally collaborate with the neighboring Hoopa Valley Tribe, several Hoopa Tribal members collaborated on this project.

The Cultural Fire Management Council (CFMC) organizes cultural burns within Yurok territory, and all members are either basketweavers or have basketweavers within their families. When deciding and planning burn locations with limited resources, the presence of hazelnut groves increases the ranking of a potential CFMC burn site. The Hoopa Valley Fire Department also conducts burns for

hazelnut stems (Salberg 2005), and the Karuk Tribe works directly with the Forest Service, the Orleans/Somes Bar Fire Safe Council, and private landowners to burn hazelnut groves (Senos et al. 2006; Long and Lake 2018).

Hazelnut basketry stem measurements and surveys

To evaluate whether cultural burning generates positive feedback to tribal members in the form of increased hazelnut basketry stem production, stem quality, and hazelnut shrub density, we established and monitored 48 20 × 20 m plots (each plot = 400 m²) from January 2015 to March 2019. Given the unpredictability of cultural burns, plots were established when we learned of recent and potential burn locations. Limited resources and environmental variability prevented all plots and shrubs from being burned within and across burn sites each year.

Plots were placed in relatively high-density hazelnut groves (≥10 shrubs) within two prescribed burn sites and 19 cultural burn sites (Fig. 1). Plots were located >2 m from roads and fire control lines and established after identifying easily accessible hazelnut groves from burn unit perimeters or game trails. Multiple plots (two to five) were placed within burn units that contained numerous hazelnut groves to evaluate the effects of environmental heterogeneity on basketry stem productivity within those locations. After the plot was established, site aspect was measured with a compass and classed as: east (67.5° to 112.5°), southeast (112.5° to 157.5°), south (157.5° to 202.5°), southwest (202.5° to 247.5°), or west (247.5° to 292.5°). Slope and elevation were measured using a global positioning system. Canopy closure measurements were taken facing inward at the four corners of each plot using a spherical densiometer, and then averaged (Lemmon 1956; Fiala et al. 2006). Basal area of each plot was determined by measuring all trees (>10 cm diameter at breast height [dbh]) with the dominant overstory tree species designated by proportional basal area: black oak (*Quercus kelloggii* Newb.), Pacific madrone (*Arbutus menziesii* Pursh), bay laurel (*Umbellularia californica* [Hook. & Arn.] Nutt.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and ponderosa pine (*Pinus ponderosa* Douglas ex Lawson & C. Lawson), and subsequently classified as conifer or broadleaf hardwood.

Plot surveys

In each plot, we recorded individual hazelnut shrub density; due to its multi-stemmed growth habit, a shrub was considered a single individual if it was a minimum of 15 cm from other shrubs. We randomly selected and tagged ten shrubs for long-term monitoring. We counted quality basketry stems and total stems in each of the ten tagged shrubs. We defined suitable quality basketry stems as straight and unbranched stems >10 cm in length. After the plot was established, we recorded and re-sampled shrub stem data every year in the dormant season (October to April), as

dormant stem morphology does not change until bud-break and gathering season in April or May. We grouped our hazelnut shrub and stem measurements according to growing seasons post burn based on a May to September growing season each year. We developed three post-burn temporal classes: one growing season post burn (5 to 20 months; $n = 302$ shrubs); two growing seasons post burn (21 to 30 months; $n = 144$ shrubs); and ≥ 3 growing seasons post burn (>31 months, $n = 507$ shrubs). The burn season affected the post-burn growing season time span before our post-burn survey because winter- and spring-burned shrubs re-sprouted quickly after the burn, whereas summer- and fall-burned shrubs did not re-sprout until the following spring. Given basketweaver interest in the effects of seasonality of burning on hazelnut stem re-growth, we classified burn season by Julian day, defining winter as days 355 through 78, spring as days 79 through 171, summer as days 172 through 265, and fall as days 266 through 354.

Because plant growth is influenced by prior rainfall, we also compiled precipitation (cm) records for a 12-month period beginning in August of the year preceding the survey from the closest Remote Automated Weather Station (RAWS) to the plot (Yurok, Slate Creek, Somes Bar, Dutch-Indy, and Slater Butte, California; <https://raws.dri.edu/ncaF.html>). We compiled fire frequency data (burn events from 1989 to 2019) within each plot to evaluate effects on shrub density. Fire frequency was converted into a dichotomous variable: less than three burn events or at least three burn events and was ascertained through conversations with landowners and fire managers, and by examining the California Department of Forestry and Fire Protection's prescribed fire GIS database (<https://frap.fire.ca.gov/mapping/gis-data/>).

One growing season post-burn surveys

Given that basketweavers prefer to gather in areas burned after only a single growing season, typically in April or May (10 to 20 months post burn), we recorded additional data from shrubs and plots ($n = 36$) within the one growing season post-burn temporal class. Because basketweavers select basketry stems based both on their diameter and length, we recorded the length of the longest basketry stem in each shrub, and we took the average of the largest and smallest diameters of basketry stems in each shrub. We also recorded the proportion of stems browsed by deer, elk, and other ungulates for each shrub, and the post-burn char height on trees (>10 cm dbh) to the nearest 0.5 m to evaluate whether fire severity affected hazelnut stem re-growth.

Hazelnut stem gathering observations

To supplement our ecological surveys, we monitored hazelnut basketry stem gathering to evaluate whether land tenure and fire governance differences as well as fire type

(wildfire and cultural fire) effect resource acquisition decisions in Karuk, Yurok, and Hupa territories. From 2015 to 2019, we developed working collaborative relationships with basketweavers and hazelnut stem gatherers by attending 13 cultural fire planning meetings and 15 basketweaving classes, and by discussing our research interests at Karuk and Yurok Tribal government meetings. Through these collaborative exchanges, we attended hazelnut stem gathering trips, and requested and collected six gathering diaries from three basketweavers to evaluate where and why basketweavers select hazelnut stem gathering areas. Moreover, we conducted 13 in-depth semi-structured interviews (30 to 60 minutes per interview) with Karuk and Yurok resource users and seven fire managers about fire-enhanced resource use and cultural burning that included questions on hazelnut burning, hazelnut stem and nut gathering, basketweaving, and the type of property ownership at burn sites. Interviewees were identified and recommended by Karuk staff in the Department of Natural Resources and Yurok leaders on the Tribe's culture committee. The Karuk and Yurok Tribal councils and the Stanford University Institutional Review Board (IRB) approved these human subjects methods, and individuals provided consent to record gathering practices and statements surrounding hazelnut stem gathering.

During hazelnut stem gathering season (April and May of each year from 2015 to 2019), we attended 17 hazelnut stem gathering trips, during which we observed individuals gathering hazelnut stems and asked semi-structured and open-ended questions regarding basketry stem quality, basketweaver gathering site and stem preferences, and the availability and accessibility of hazelnut



Fig. 2 Three generations of Yurok Indians gathering hazelnut basketry stems at a cultural burn site near Weitchpec, California, USA (left to right): Phillis Donahue (mother), Chris Peters (son), and Nicki Peters (granddaughter). Cultural fires generate significant resources to sustain Karuk and Yurok basketweaving. Photo credit: F.K. Lake, taken circa 2010. Each of the three people in the photograph gave permission for their image to be used by the authors

basketry stems. Gathering hazelnut stems is an intergenerational activity that brings together friends and relatives, and basketweaving teachers and their students (Fig. 2). From 2015 to 2019, 90 people were observed gathering hazelnut stems. Observed hazelnut basketry stem harvesters were 75% women, and, on average, gathered in groups of three (range = 1 to 8 individuals). The majority (57%) of 30 gathering groups were intergenerational, with a mix of elders (>60 years), middle-aged gatherers (25 to 60 years), and youth (<25 years), and 66% of groups were composed of basketweaver mentors and their students (including familial mentorships). Of the 72 recorded gathering trips, those made by family-member groups were most common (63%), whereas trips made by groups of friends (21%), and trips made by individuals (17%) were less frequent.

During these trips, the sum of an individual's harvested stems and their time spent in a hazelnut grove were recorded to produce 55 independent gathering rates. Distances to hazelnut stem gathering areas recorded from these trips and from basketweaver reports were converted to a standard 80 km hr⁻¹ rate, chosen conservatively due to winding mountainous roads with a 55 miles per hour (88 km hr⁻¹) automobile speed limit. The gathering site's fire history was also recorded and then classified either as a cultural fire site, wildfire site, or a fire-excluded site. We also recorded the site's land ownership (USDA Forest Service, private, or tribal) along with ancestral territory (Karuk, Yurok, Hupa) of the gathering site, and categorized site quality as relatively good or poor based on basketweaver post-harvest evaluations. From these data, we generated simulations of hazelnut stem foraging that included searching and gathering rates within cultural fire sites, wildfire sites, and unburned sites.

Statistical methods

To evaluate the effects of growing seasons post burn on hazelnut basketry stem production (quantity of basketry stems per shrub), we employed a negative-binomial generalized linear mixed model (GLMM) using the *glmmTMB* package in R (R Core Team 2014; Magnusson et al. 2017) and used Type III Wald Chi Square tests using the *car* package (Fox and Weisberg 2018) to perform backward model selection. Growing season post burn (class), aspect (class), elevation (meters above sea level), sample year, basal area (>10 cm dbh), precipitation (cm), dominant overstory tree (>10 cm dbh), and slope (degrees) were modeled as co-variate direct effects, and each plot was set as a random effect.

Given basketweaver preferences for harvesting stems one growing season post burn, we developed another negative-binomial GLMM that applied only to 30 plots surveyed one growing season post burn. Then, we performed a backward model selection process and analyzed additional variables. The initial model set the plot as a random effect and included the following direct effects as

covariates: proportion of ungulate browse, burn char height, burn season (winter, spring, summer, and fall), pre-burn total stems, precipitation, canopy closure, basal area (>10 cm dbh), elevation, aspect (east, south, southwest, and west), dominant overstory tree (>10 cm dbh), sample year (2015 to 2019), and slope.

To assess the density of hazelnut shrubs, we applied a multi-variate gamma generalized linear model (GLM) using Type III Wald Chi Square tests to perform backward model selection using the *car* package in R (Fox and Weisberg 2018). Burn frequency (either less than three burn events or at least three burn events from 1989 to 2019), basal area (>10 cm dbh), canopy closure, dominant overstory tree (>10 cm dbh), elevation, aspect, and slope were all evaluated as potential explanatory variables. A univariate gamma GLM was also used to compare the relationship between basal area and shrub density, and a Wilcoxon rank sum test was employed in R (R Core Team 2014) to evaluate the relationship between territory (Karuk and Yurok) and shrub density.

To examine average stem diameter and length of basketry stems within shrubs surveyed after one growing season post burn, we selected gamma distributed GLMMs, as length and diameter distributions were skewed toward smaller sizes. Potential explanatory variables that were treated as direct effects in the initial stem diameter model were: basal area (>10 cm dbh), plot canopy closure, annual precipitation, aspect, slope, dominant overstory tree (>10 cm dbh), and burn season (e.g., fall, winter, spring, summer). These explanatory variables were then included in the initial stem length model with the addition of ungulate browse proportions. As with other GLMMs, the plot was set as a random effect, and Type III Wald Chi Square tests were used to perform backward model selection.

Model diagnostics were analyzed using the *DHARMA* package in R (Hartig 2019). To analyze the differences within categorical predictor variables that showed significance in the GLMMs, estimated marginal means (\bar{x}) were generated and then 95% confidence intervals were compared using the Tukey method using the *emmeans* package (Lenth 2018). Estimated marginal \bar{x} values for categorical values are averaged over the values of other significant model co-variables, which helps account for imbalances in sampling effort. The *sjPlot* package (Lüdtke 2019) was used to analyze and visualize the effects of significant continuous predictor variables in the GLMMs.

Foraging gains from basketweaver gathering trip observations were modeled as logistic functions using the *growthcurver* package in R (Sprouffske and Wagner 2016) based upon assumptions of the marginal value theorem and foraging theory that predict diminishing gathering returns resulting from the depletion of basketry stems through harvesting (Charnov 1976; Stephens and Krebs 1986).

Across observed gathering sites, we evaluated associations between gathering site fire type (wild, cultural) and territory (Karuk, Yurok, Hupa) by employing Pearson's Chi-square (χ^2) test of independence using R statistical software (R Core Team 2014). Separately, the travel distances to hazelnut gathering sites within cultural burn, wildfire, and unburned (fire excluded) locations were compared in R using a Wilcoxon rank sum test.

Results

Hazelnut basketry stem productivity

We found that fire strongly increased basketry stem productivity, but the effect declined rapidly over time (Fig. 3). Hazelnut shrubs one season post burn produced a 13-fold increase in basketry stems (estimated marginal \bar{x} = 10.776, SE = 0.87), compared to shrubs three or more growing seasons post burn (estimated marginal \bar{x} = 0.801, SE = 0.08), and six times more stems than shrubs two growing seasons post burn (estimated marginal \bar{x} = 1.807, SE = 0.25, Fig. 3). Other covariates also emerged as important predictors: stem production declined with overstory tree basal area (Fig. 4), while sample years exhibited significant

differences in basketry stems due to imbalances in yearly burning (χ^2 = 19.9, df = 4, P < 0.001).

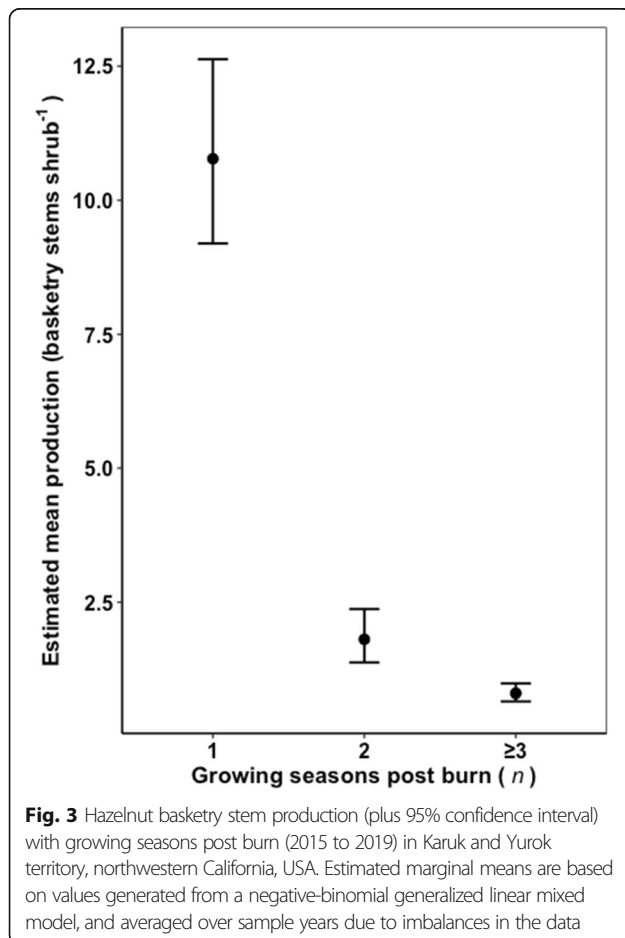
Considering only shrubs growing one season post burn, a number of covariates significantly predicted basketry stem productivity (Table 1). Shrub vigor, measured by pre-burn total stems, had a strong positive relationship on basketry stem production (Table 1), whereas ungulate browse reduced basketry stems (estimate = -0.706, SE = 0.146, Z = -4.826; Fig. 5; Table 1). Burn season and aspect class also emerged as significant covariates in the single season post-burn model of best fit (Table 1).

Hazelnut shrub density

Hazelnut shrub density within plots was affected by burn frequency, aspect, and elevation (Table 2). Plots that were burned at least three times from 1989 to 2019 had 1.86 times more individual shrubs than plots burned less than three times (Fig. 6). Plots within eastern aspects had 2.2-fold higher density of hazelnut shrubs (estimated marginal \bar{x} = 93.5, SE = 18.33) than those growing in southern (estimated marginal \bar{x} = 43.5, SE = 3.99) and southwestern aspects (estimated marginal \bar{x} = 42.5, SE = 4.86, P < 0.001; Table 2). Shrub densities also decreased with increased elevation (range = 170 to 934 m a.s.l., estimate = 0.000024, SE = 0.0000115, t = 2.13, P < 0.05; Table 2). Although territory was not a significant covariate in the multi-variate gamma GLM, shrub densities in Yurok territory were 2.19-fold greater than shrub densities within Karuk territory (Wilcoxon test statistic = 74, P < 0.001; Fig. 6). Additionally, overstory tree basal area was nonsignificant in the gamma GLM, but displayed a negative relationship with shrub density in univariate analysis (estimate = -0.00019, SE = 0.00007, t = 2.67, P < 0.05).

Basketry stem length and diameter

Basketry stem length and diameter was affected by burn season. Summer burns produced larger stem diameters (estimated marginal \bar{x} = 4.54 mm, SE = 0.32) when compared with spring (estimated marginal \bar{x} = 3.08 mm, SE = 0.25, P = 0.003) and winter burning (estimated marginal \bar{x} = 3.64 mm, SE = 0.25, P = 0.037; Fig. 7). Spring burns also produced shorter stem lengths than all other burn seasons (estimated marginal \bar{x} = 0.524 m, SE = 0.057, P < 0.05). The diameter and length of stems had an inverse relationship with overstory tree basal area (>10 cm dbh, P < 0.01; Figs. 7 and 8), and the proportion of ungulate browse was negatively correlated with stem length (estimate = -0.357, SE = 0.102, Z = -3.49, P < 0.001) in the gamma generalized linear mixed model. Furthermore, stems growing beneath canopies dominated by hardwoods were significantly longer (estimated marginal \bar{x} = 0.83 m, SE = 0.062) than stems growing beneath coniferous canopies (estimated marginal \bar{x} = 0.65 m, SE = 0.051; Fig. 8).



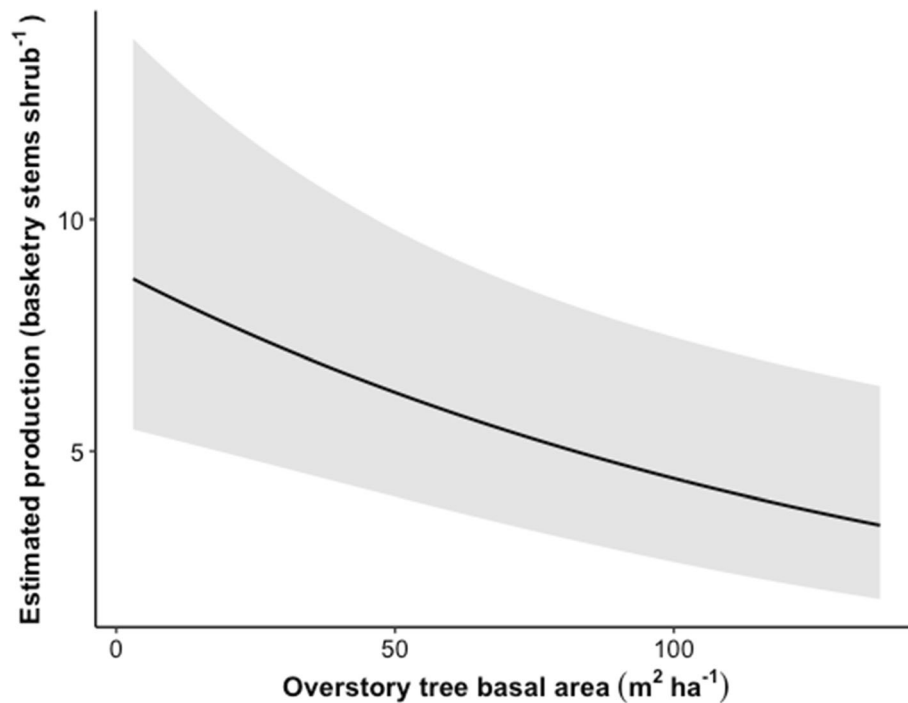


Fig. 4 Estimated hazelnut basketry stem production (plus 95% confidence interval, gray) with overstory tree (>10 cm dbh) basal area in Karuk and Yurok territory, northwestern California, USA, from 2015 to 2019. Estimates include shrubs in all temporal growing season classes (one, two, and three or more growing seasons post burn)

Hazelnut basketry stem gathering

All hazelnut basketry stems were gathered within a few weeks of bud break in the spring, between 20 March and early May, depending on the site aspect and elevation. The majority of basketweavers observed were either retired (14%) or employed by the Tribes, Forest Service, or local school districts (78%). While some employers provide flexible work hours that enable the gathering of ecocultural species like hazelnut, most hazelnut stem gathering observed here occurred on the weekends (84% of gathering trips). Basketweavers expressed that they would prefer to gather close to home, but few suitable burned hazelnut groves were located in close proximity to their residences. Three basketweavers noted that, despite the fact that they had relatively small patches (<500 m²) of hazelnut on their landholdings that they burned regularly, these sites produced insufficient quantities of basketry stems to satisfy their needs. Thus, individuals with small hazelnut patches on their properties needed to gather at other burned sites to support their weaving.

Of all stem gatherers, we consistently recorded annual harvesting from six individuals from 2016 to 2019. Only one of these individuals gathered exclusively in Karuk territory while the other five individuals consistently gathered within Yurok territory. The five who gathered within Yurok territory, on average, gathered at 1.4 burn

sites from 2016 to 2018 (range of total distinct sites = 3 to 5), and in 2019 visited 2.8 sites (six distinct sites visited). Four of these basketweavers reported that they engaged in five or more gathering trips within the hazelnut gathering season.

Gathering hazelnut stems requires a considerable commitment if burned areas are distant and the presence of quality hazelnut stems is unknown. Because some basketweavers now reside relatively far from ancestral territories and burned hazelnut groves, basketweavers were observed to travel considerable distances to gather. Based on 49 recorded trips to gathering patches, harvesters traveled a median distance of 34 km one way (range = 0 to 472 km) and an average of 60 km (± 10.9 km). Basketweavers travelled 3.8-fold greater distances to reach wildfire gathering sites (\bar{x} = 129 km, SE = 40 km) compared with cultural burn areas (\bar{x} = 38 km, SE = 6 km, Wilcoxon test statistic = 72, $P < 0.01$).

From 2015 to 2019, basketweavers and stem gatherers selected 21 independent burn areas to gather hazelnut basketry stems; 76% of these sites were culturally burned and 24% were burned by wildfires. Of these sites, 29% were on US Forest Service land, 48% were privately owned, and 23% were tribally owned fee or trust lands (Yurok and Hoopa Valley reservations). Gathering trips in Yurok territory all occurred at culturally burned sites,

Table 1 Variables affecting hazelnut basketry stem production one growing season post-burn (2015 to 2019) in Karuk and Yurok territory, northwestern California, USA. Results of a Wald Type III Chi Square test (χ^2) on the significance of ungulate shrub browse proportion, pre-burn total stems, burn season (winter, spring, summer, and fall), and aspect class (east, southeast, south, southwest, and west) on basketry stem production generated from a negative-binomial generalized linear mixed model. Aspect classes included east (67.5° to 112.5°); southeast (112.5° to 157.5°); south (157.5° to 202.5°); southwest (202.5° to 247.5°); and west (247.5° to 292.5°). Only shrubs located in southern aspects ($n = 124$, estimated marginal $\bar{x} = 13.62$, SE = 0.99) produced significantly different stems compared with those found in eastern aspects ($n = 56$, estimated marginal $\bar{x} = 8.01$, SE = 1.23). Shrubs burned in the winter ($n = 42$, estimated marginal $\bar{x} = 15.54$, SE = 1.73) produced 1.67-fold greater basketry stems than shrubs burned in the spring ($n = 55$, estimated marginal $\bar{x} = 9.32$, SE = 1.05, $P < 0.01$), and 1.43-fold greater basketry stems than shrubs burned in the fall ($n = 113$, estimated marginal $\bar{x} = 10.89$, SE = 0.92, $P < 0.05$). No other seasonal comparisons exhibited significant differences, and burn char height, dominant overstory tree, canopy closure, annual precipitation, elevation, and slope did not exhibit strong effects on basketry stem production and were removed from the model. Hazelnut shrub plots ($n = 30$; 400 m²) are set as random effects. df = degree of freedom

Fixed effects	χ^2	df	P
Ungulate browse proportion (%)	23.29	1	<0.0001
Pre-burn total stems (n)	116.09	1	<0.0001
Burn season	13.41	3	0.003
Aspect class	10.04	3	0.018

whereas the 20 trips to gathering sites in Karuk and Hupa territories were more likely to occur at wildfire sites (Table 3).

Poor gathering sites ($n = 12$) tended to be sites gathered two or more growing seasons post burn, or sites that were heavily browsed by ungulates. Within five cultural burn sites on Forest Service land in Karuk territory, harvesters deemed stems to be poor quality due to heavy browsing. This was likely caused by the isolation of sites and lack of burning in surrounding areas, creating a strong patch-choice effect that attracted large numbers of browsers to the small area of the burn. Other sites that were assessed as relatively poor quality were those that were not burned at a sufficient intensity. At low-intensity burn sites, gatherers found that basketry stems were challenging to access given the limited consumption of underbrush and surface and ladder fuels (e.g., down logs with branches, or small trees and shrubs).

Gatherers spent a mean 56 ± 16 minutes per hazelnut stem gathering site. At cultural burn sites, mean gathering rates were significantly higher than gathering rates recorded at four wildfire locations and at a fire-excluded

site (Fig. 9). While wildfires in this region burn hazelnut shrubs, basketweavers remarked that searching for hazelnut shrubs in these typically remote wildfire areas requires considerable additional time. Ms. Verna Reece, a renowned Karuk basketweaver and teacher, shared that she is one of the few gatherers who invests the necessary time and effort to drive the roads through wildfire areas in Karuk territory to scout and locate suitable hazelnut groves. Because Ms. Reece shares her knowledge of locations of hazelnut patches within wildfire areas, many of her students benefit from her initial reconnaissance and knowledge of local fire history.

Discussion

Basketry stem quality and ecology

Post-burn basketry stem qualities are important to basketweavers, who require a variety of stems of different lengths and diameters depending on what they intend to weave (Lake 2007: 243; O’Neale 1932). Longer stems provide enhanced functionality than shorter stems, as they can be cut depending upon the basketry project (V. Reece, personal communication). Therefore, measurements of stem diameter and length may assist both fire managers and basketweavers to identify and prioritize forest stand characteristics, burn season, and the frequency of cultural fires in hazelnut groves of interest across the landscape and, thus, promote socio-cultural values and ecological heterogeneity.

Overstory basal area was found to be negatively correlated to stem length, and hardwood overstories supported longer stem lengths when compared with coniferous overstories (on average 18 cm longer). These relationships may be attributed to greater understory light transmittance in forest stands with lower basal area, and broadleaf trees such as oaks (Fralish 2004; Barbier et al. 2008). Given that lower basal areas also support overall basketry stem production, canopy thinning in hazelnut groves would likely improve quality and quantity of basketry stems. Targeting relatively young coniferous trees for thinning would also support the recovery and growth of encroached hardwoods, whose populations have become compromised by Douglas-fir in the region (Hunter and Barbour 2001; Engber et al. 2011; Cocking et al. 2012; Schriver et al. 2018).

Shrubs that were burned in the spring produced significantly shorter stems compared to all other burn seasons. This result can be attributed to the truncated growing season caused by these burns, which occurred after bud break. For certain basketry projects that require longer stems (e.g., baby cradles), these stems are less functional. However, shorter stems also tend to have smaller diameters, which is a desired quality for basketweavers producing baskets that require a tight weave (e.g., basket caps; Johnson and Marks 1997). The stem

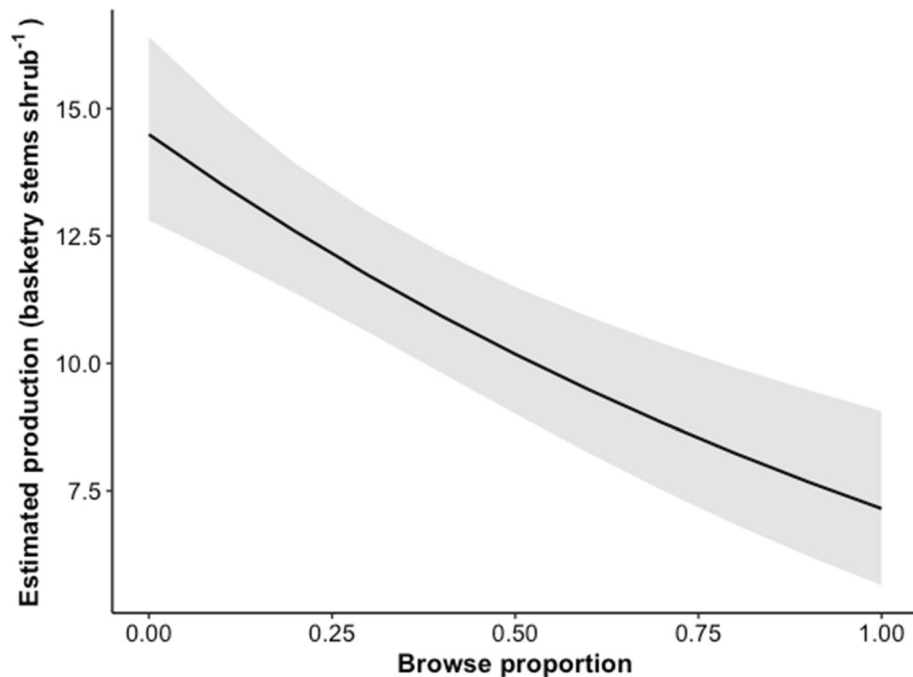


Fig. 5 Proportion of hazelnut shrub browsed with estimated basketry stem production values (plus 95% confidence interval, gray) from the one growing season post-burn temporal class in Karuk and Yurok territory, northwestern California, USA, from 2015 to 2019

wood to pith ratio is also different among spring- versus fall-burned hazelnut shoots, which affects the tensile strength and durability for use in weaving (Rentz 2003; Lake 2007). Moreover, spring burning raises concerns for some tribal members as burning during this season may negatively affect wildlife and was less common preceding colonialism (Knapp et al. 2009; Marks-Block et al. 2019). Tribal members have also taken advantage of recent winter droughts (Griffin and Anchukaitis 2014) and dry periods to increase cultural burning for hazelnut basketry stems. Stems produced from these burns also had a smaller diameter compared with those produced from summer burns, and were longer than stems burned in the spring. Hence, finding receptive burning opportunities in the winter may produce stems of desirable

qualities, without the potential negative effects of burning in the spring.

Ungulate browse also shortened stems and initiated lateral stem branching, reducing the functionality and quality of stems. When high proportions of stem browse occurred at cultural burn sites, basketweavers rated their quality as poor, and few basketweavers selected these sites for gathering. While browse occurs at all sites, if burning is conducted near residences, the nearby presence of dogs and people may discourage interspecies competition for post-burn hazelnut resprouts, and have the additional benefit of reducing wildfire hazards. Additionally, expanding the frequency and area (extent and place) of cultural burn sites, and managing wildfires to achieve resource objectives and socio-ecological benefits, may reduce interspecies competition for hazelnut resprouts by providing sufficient high-quality browse for ungulates across the landscape (Wan et al. 2014).

Table 2 Variables affecting hazelnut shrub density (2015 to 2019) in Karuk and Yurok territory, northwestern California, USA. Results of a Wald Type III Chi Square test (χ^2) on the significance of burn frequency, elevation, and aspect class on hazelnut shrub density generated from a gamma generalized linear model. Aspect classes included east (67.5° to 112.5°); southeast (112.5° to 157.5°); south (157.5° to 202.5°); southwest (202.5° to 247.5°); and, west (247.5° to 292.5°). df = degree of freedom

Fixed effects	χ^2	df	P
Burn frequency	23.6	1	<0.0001
Elevation	4.8	1	0.027
Aspect class	21.9	4	<0.001

Ecology of basketry stem production and hazelnut shrub density

Our results clearly show that cultural burning optimizes the production of hazelnut basketry stems, but that this effect is the product of short fire intervals (e.g., 3 to 5 yr). Because basketweavers can quickly exhaust a small hazelnut patch, optimizing basketry stem production requires a mosaic of recently burned patches, those regenerating from harvest, and those ready to be burned all within close proximity to residential locales. More

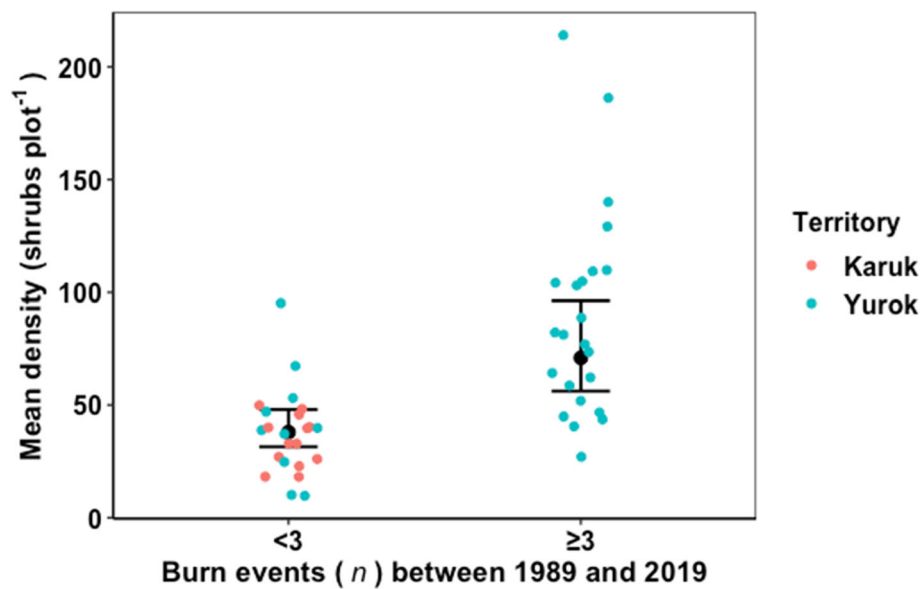


Fig. 6 Hazelnut shrub densities with number of burns in Karuk and Yurok territory, northwestern California, USA, from 1989 to 2019. Data was collected from 2015 to 2019. Scattered colored points are 400 m² plot shrub densities. Black points with 95% confidence intervals (bars) are estimated marginal means generated from a generalized linear model. Sites with less than three burn events had significantly greater hazelnut shrubs (estimated marginal \bar{x} = 71.0, SE = 9.53) than plots burned less than three times (estimated marginal \bar{x} = 38.1, SE = 4.02)

common fall burns do not produce basketry stems until ~18 months post burn; thus, different sites need to be burned annually to ensure annual harvests. This fire regime strongly concurs with California Indian basketweaver knowledge of hazelnut fire ecology and

practice of cultural burning (O'Neale 1932; Thompson 1991; Ortiz 1998; Anderson 1999), and aids in the interpretation of regional fire history studies regarding fire frequency and seasonality (Taylor and Skinner 1998, 2003; Fry and Stephens 2006; F. Lake, USDA Forest Service,

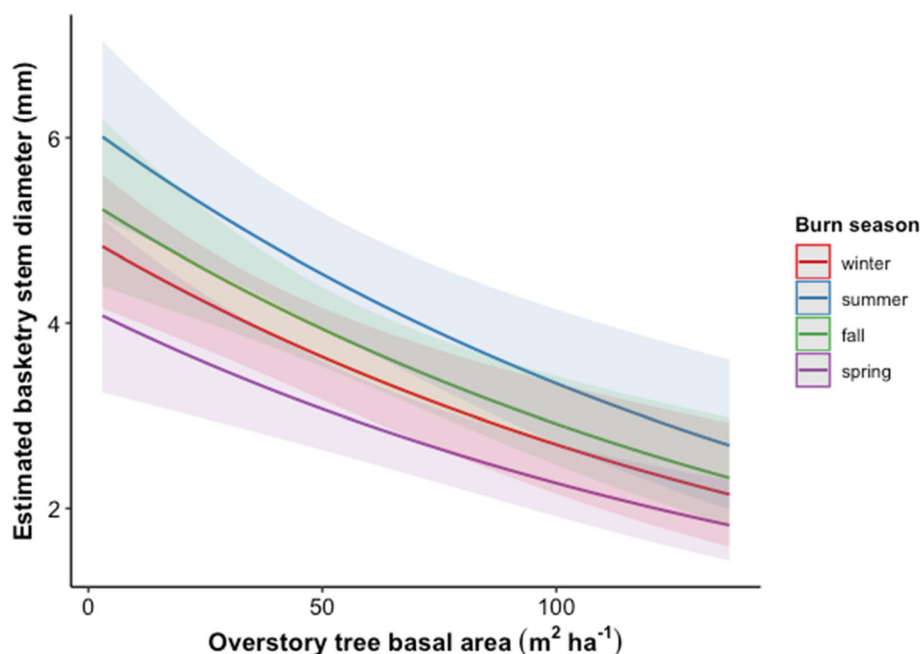
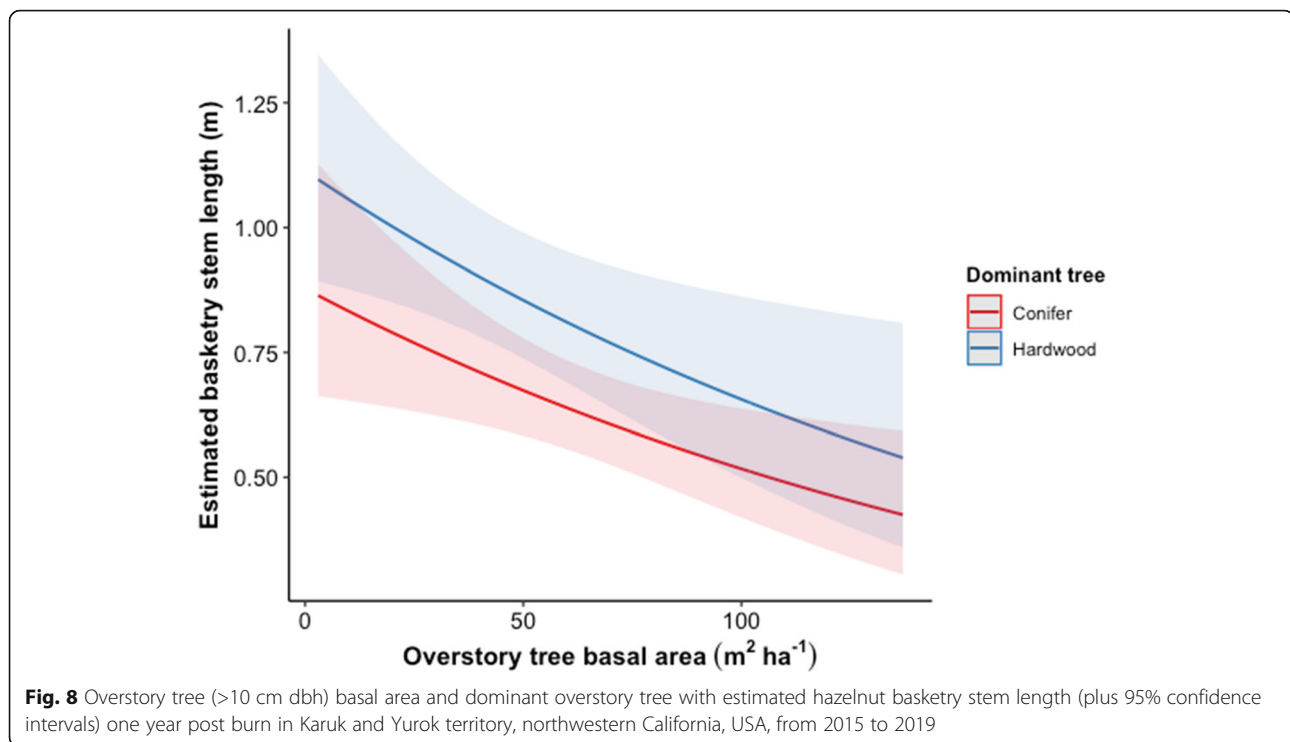


Fig. 7 Overstory tree (>10 cm dbh) basal area with estimated hazelnut basketry stem diameters (plus 95% confidence intervals) and burn season (summer, fall, winter, and spring) in Karuk and Yurok territory, northwestern California, USA, from 2015 to 2019



Arcata, and E. Knapp, USDA Forest Service, Redding, California, USA, unpublished data).

Higher hazelnut shrub densities occur in areas that have burned in ≥ 3 events within 30 years, increasing the density of basketry stems in these areas post burn compared with hazelnut groves where fire has been excluded and shrub densities are lower. Greater shrub density and basketry stem production in areas with relatively less overstory basal area also suggest that short-interval burning would benefit hazelnut shrubs, as these overstory conditions are promoted by frequent, low-intensity fire regimes (Stephens and Fulé 2005; Scholl and Taylor 2010). Given the vital importance of hazelnut stems in Karuk and Yurok culture, and for many other tribes regionally, burning for hazelnut undoubtedly affected the abundance of hazelnut across the pre-colonial landscape. Greater densities of hazelnut shrubs at lower elevations

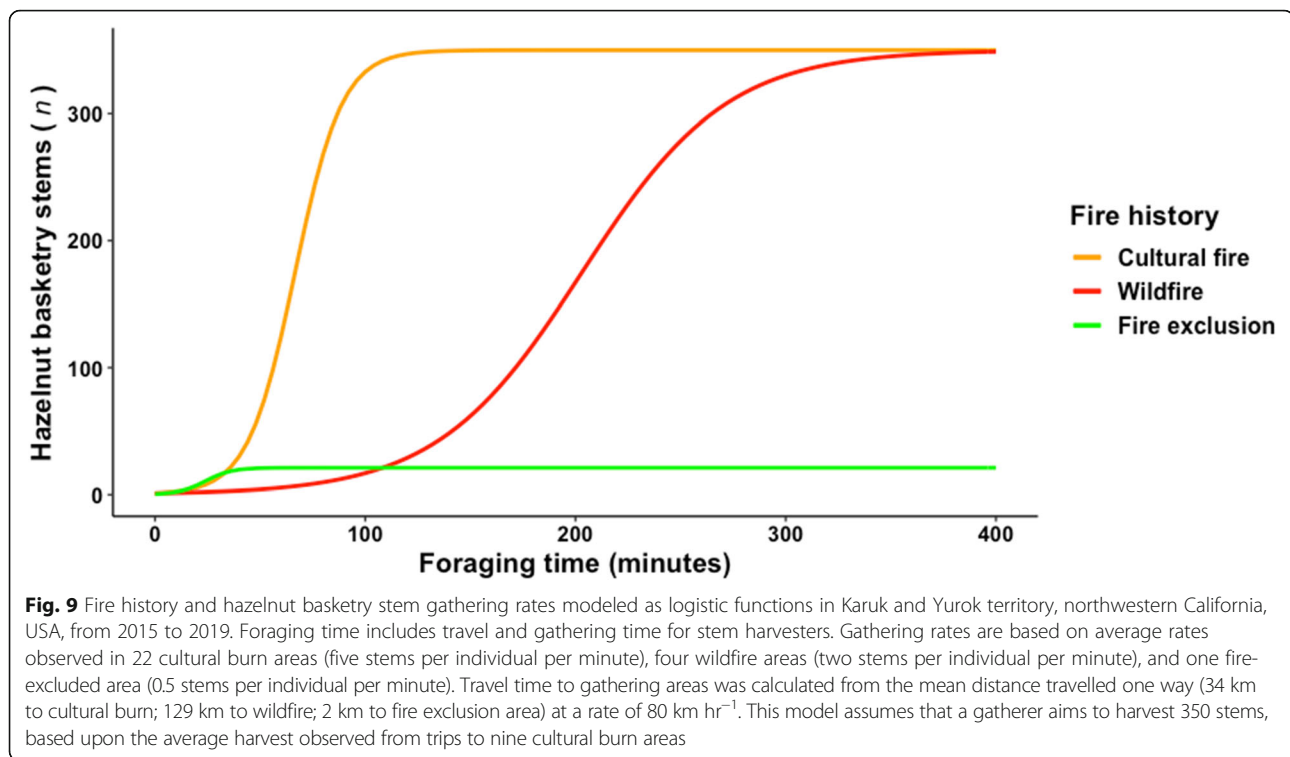
Table 3 Hazelnut stem gathering trips by tribal territory and fire type in Yurok, Karuk, and Hoopa territory, northwestern California, USA. Trips were observed or reported by basketweavers and stem gatherers from 2014 to 2019. According to Pearson's χ^2 test, trips to gathering sites in Karuk and Hupa territories were significantly more likely to occur at wildfire sites compared with trips in Yurok territory ($\chi^2 = 41.03$, $df = 2$, $P < 0.0001$)

Fire type	Gathering trips (n) per territory		
	Yurok	Karuk	Hupa
Cultural fire	69	6	3
Wildfire	0	7	3

may be an artifact of the historical settlement of Karuk and Yurok villages along the Klamath River (Waterman 1920; Kroeber 1936), and the repeated cultural burning of hazelnut groves in close proximity to villages and favored resource camps.

A staggered, low intensity, and frequent cultural fire regime, as proposed by Lightfoot and Parrish (2009), alters the species assemblage and maintains ecoculturally valuable hazelnut groves in a relatively stable ecological state (Botkin and Sobel 1975; Petraitis and Latham 1999; Beisner et al. 2003). This socio-ecological system is akin to the burned areas that Lewis and Ferguson (1988) referred to as “fire yards and corridors” that were regularly burned to maintain prairies. However, in this case, these yards are not anthropogenic prairies, but the park-like forests often described by early European settlers (Sudworth 1900; Leiberg 1902; Pyne 1982; Muir 2008). Unlike anthropogenic burning in the spinifex desert of Australia (Bliege Bird et al. 2008), or the swidden Mayan milpa that creates a shifting successional mosaic (Nigh and Diemont 2013), hazelnut groves are maintained by frequent low-intensity burning that inhibits successional processes. The focal ecocultural species in a hazelnut grove is woody and has a re-sprouting life history, which suggests that a distinctive burning regime is required to maintain hazelnut, compared to a “yard” of herbaceous perennials or annuals.

This socio-ecological model was described in 1916 by Lucy Thompson, a Yurok woman, who stated that, “The



Douglas fir timber...has always encroached on the open prairies and crowded out the other timber; therefore they have continuously burned it" (Thompson 1991: 33). This finding was further developed and articulated as a state and transition model by Huntsinger and McCaffrey (1995) that included woodlands, but did not address important understory ecocultural species like hazelnut. Similarly, other ecological studies in northern California montane forests have found that repeated burning by lightning fires maintains steady shrubland states (Odion et al. 2010; Lauvaux et al. 2016), and that, in the absence of fire, oak woodlands transition to Douglas-fir stands (Hunter and Barbour 2001; Engber et al. 2011; Schriver et al. 2018). Hence, this fire-mediated dynamic is quite prevalent in the region, and supports the finding that hazelnut is less abundant in the absence of frequent fire.

Over the long term, positive feedbacks between cultural burning and hazelnut provide a niche-construction mechanism that improves landscapes in a wide variety of ways (Jones et al. 1994, 1997; Smith 2011; Odling-Smee et al. 2013; Bliege Bird 2015). Cultural burning increases stem production for basketweavers, but also increases quality forage for ungulates (Lawrence and Biswell 1972; Kie 1984; Long et al. 2008; Williamson and Weckerly 2020), and may also improve nut production for humans and wildlife (Lake 2007; Fine et al. 2013; Armstrong et al. 2018). Cultural burns may also increase wildlife habitat, supporting biodiversity (Martin and Sapsis 1992; Hankins 2009) and endangered species such as the

California Condor (*Gymnogyps californianus* [Shaw, 1797]) and Spotted Owl (*Strix occidentalis* [Xántus de Vésey, 1860]) that feed in edge habitats and clearings (Cowles 1967; Franklin et al. 2000; Roberts et al. 2011; Nabhan and Martinez 2012; Eyes et al. 2017). The improvements in habitat and biodiversity that emerge from understory burning (Webster and Halpern 2010; Knapp et al. 2013; Wynecoop et al. 2019) have cascading effects on a wide range of other plant and animal species, which in turn sustain the cultural traditions, economic livelihoods, and social and physical well-being of the fire-dependent cultures that rely on these species and processes in their ancestral territories (Heffner 1984; Ortiz 1993; Mathewson 2007; Eriksen and Hankins 2015; Smith 2016).

Basketry stem gathering and fire governance

Cultural burning directly supports the maintenance and revitalization of northwestern California Indian basketweaving by reducing the costs associated with basketry stem gathering. Foraging efficiencies are greatly improved by burning, and subsequently influence the selection of basketry stem gathering sites. Basketry stem gathering rates are 10-fold greater in cultural burn areas compared with fire-excluded hazelnut groves, leaving little incentive to gather in unburned areas (Anderson 1999). Without accounting for the increase in travel time to wildfire areas, cultural burn areas generated gathering rates that are 3-fold greater than those in wildfire areas,

which we attribute to greater shrub densities associated with repeated cultural burning. Accordingly, stem gatherers selected burn sites of higher quality more frequently than those areas of poor quality and lower shrub densities. These results offer strong evidence that stem-gatherer decision-making adheres to basic optimal foraging theories of maximizing efficiency (Stephens and Krebs 1986).

Land dispossession and limited tribal autonomy over burn practices have caused stem gatherers to select less than ideal harvesting sites. In Karuk territory, land dispossession was comparatively greater than in Yurok territory, thus, in recent decades, Tribal members have not been able to maintain as many hazelnut groves with consistent cultural burning. Collaborative burning between the Karuk Tribe and the USDA Forest Service tends to fluctuate with staff who are supportive of burning, but who may often transfer from the region (Diver 2016; Smith 2016). The sites where these collaborative burns occurred have predominantly been in remote locations where overstory basal area is relatively high, shrub densities are relatively low, and ungulate browse has been heavy. As a result, Karuk stem gatherers tend to gather in areas burned by wildfires, where they have found higher quality basketry stems. However, compared with culturally burned sites in Yurok territory, the gathering costs are higher due to increased travel and lower shrub densities. Despite USDA Forest Service policy changes that permit gathering by indigenous peoples (Kalt 2007), several basketweavers expressed that the persistence of racism, as well as its ongoing manifestations of harassment, imprisonment, and violence toward Indigenous peoples for gathering, hunting, and burning on their lands, makes them hesitant to gather hazelnut stems on national forests (Smith 2016; Norgaard 2019).

Gatherers generally do not harvest in hazelnut groves that they perceive as belonging to other families, or in tribal territories where they do not have social ties or permission. Hence, while higher quality groves occur in Yurok territory, individuals without Yurok ancestry or familial ties will gather at lower-quality hazelnut groves out of respect for land affiliations, unless they are invited. This social dynamic reflects the historically decentralized Karuk and Yurok governance structures preceding colonialism, in which usufruct rights to resource tracts were organized at the level of families and individuals (Waterman 1920; Thompson 1991; Huntsinger and Diekmann 2010; Bettinger 2015).

The centralization of resource and fire management by the US government and the fragmentation of tribal land ownership reduced access to ecocultural resources such as hazelnut basketry stems (Huntsinger and Diekmann 2010). Nonetheless, Karuk and Yurok Tribal members initiated successful burning programs that have reduced

the relative scarcity of hazelnut stems and support cultural revitalization. To adjust to these new modes of governance, the Tribes developed their own natural resource departments and wildland fire departments, and established partnerships with the USDA Forest Service and non-governmental organizations such as fire safe councils and The Nature Conservancy, to co-manage fire and resources (Long and Lake 2018). Tribal basketweavers have also self-organized to form organizations such as the California Indian Basketweavers Association (LeBeau 1998; Kallenbach 2009) and Karuk Indigenous Basketweavers to address the need for cultural burn partnerships. In Karuk territory, these partnerships have supported the development of long-term cultural fire restoration projects that intend to initiate regular repeated burns in hazelnut groves (USDA Forest Service PSW Region 2018).

In Yurok territory, basketweavers and their families have initiated a successful cultural burning program that reduced the relative scarcity of hazelnut stems. The Cultural Fire Management Council (CFMC) began to burn hazelnut groves annually in 2013, and supported families and the Tribe to maintain regular burns. In 2019, the CFMC President, Margo Robbins (Yurok), shared that, “Ten years ago it wasn’t often that you’d see a baby in a basket. Now there are lots of babies in baskets because of TREX.” Basketweavers like Margo articulate a clear connection between burning and its role in supporting cultural revitalization.

Conclusion

Partnerships between tribes, non-governments organizations, and government agencies have supported the contemporary burning of hazelnut groves, much like collaborative burning projects in South America and Australia (Fache and Moizo 2015; Mistry et al. 2019; Neale et al. 2019), but increased tribal sovereignty and familial autonomy over burning in ancestral lands will ensure not only its maintenance, but its expansion (Baldy 2013; Robbins et al. 2016). Collaborations between fire managers and American Indian communities will support the revitalization of cultural burning and help achieve multiple socio-ecological management objectives (Lake et al. 2017; LeCompte 2018; Lewis et al. 2018; Long and Lake 2018; Wynecoop et al. 2019). Collaboration with basketweavers is vital when burning objectives include hazelnut basketry stems. Ideally, multiple hazelnut groves in a region will be burned frequently (every three to five years) in a staggered fashion, which will reduce obstacles to access (e.g., downed logs and dense stands of small trees), support high shrub densities, and offer yearly harvesting opportunities.

The revitalization of Karuk and Yurok cultural burning provides an alternative model for restoring fire and

ecological function to landscapes that experienced fire exclusion and industrial timber extraction (Nikolakis and Roberts 2020). Compared with many non-tribal restoration initiatives focused upon conservation and hazardous fuel–fire risk reduction, California Indian initiatives primarily aim to restore socio-ecological relationships with ecocultural fire-enhanced species for cultural, ceremonial, and subsistence use. Because their practices were partially responsible for the historical fire regime, burning practices of indigenous and place-based fire-dependent cultures may be more effective at restoring the desired reference landscapes that conservation organizations and public land agencies intend to re-create (Kimmerer 2011; Lake 2013; Bliege Bird and Nimmo 2018). Moreover, tribes, resource users, and local entities appear to be well equipped to maintain burning over the long term, whereas limited budgets and complex political processes have constrained prescribed burning by land management agencies (Steelman and Burke 2007; North et al. 2015; Schultz and Moseley 2019). Cultural burns observed here indicate that this fire governance model exhibits considerable potential to support fire-adaptive socio-ecological communities (Abrams et al. 2015; Roos et al. 2016).

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Authors' contributions

All authors contributed to study design and writing the manuscript. TMB implemented the study and analyzed the data. All authors read and approved the final manuscript.

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Availability of data and materials

Datasets used and analyzed during this study are available from the corresponding author upon request.

Ethics approval and consent to participate

Stanford University IRB approved this study (#33064), as did the Karuk and Yurok Tribal Councils.

Consent for publication

Consent for photographs on file.

Competing interests

All authors declare that they have no competing interests.

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