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Publication Date

2016

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Prescribed fire and tanoak (*Notholithocarpus densiflorus*) associated cultural plant resources of the Karuk and Yurok Peoples of California

by

Arielle Anita Halpern

A dissertation in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy

in

Integrative Biology

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:
Professor Wayne P. Sousa, Co-Chair
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Spring 2016

Abstract
Prescribed fire and tanoak (*Notholithocarpus densiflorus*) associated cultural plant
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by
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Doctor of Philosophy in Integrative Biology
University of California, Berkeley
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The targeted application of prescribed fire has long been used by Native Californian
peoples to manage plant resources of cultural value. Their ability to employ this
management tool has been increasingly restricted by local, state and federal agencies
in response to recent drought conditions and the highly flammable state of most western
U.S. forests, where, for decades, fires of any magnitude have been suppressed as a
matter of policy. This diminished access to cultural prescribed fire has impacted tribal
access to many of the plant resources and cultural activities upon which Karuk and
Yurok cultures are based. The research presented in this dissertation: 1) uses historical
and modern references to describe fire management practices of tribes throughout
California, specifically targeting acorns as food resource, 2) investigates the effect of
non-traditional spring burns on rates of tanoak (*Notholithocarpus densiflorus*, Fagaceae)
acorn infestation by frugivorous Filbertworms (*Cydia latiferreana*, Tortricidae) and Filbert
weevil larvae (*Curculio occidentalis,* Curculionidae), 3) evaluates the effectiveness of
indigenous acorn collection criteria in correctly assessing the consumption quality of
acorns, and 4) examines the responses of culturally significant plant species found in
tanoak gathering areas to prescribed fire applied non-traditionally in spring. Assessed
metrics were species diversity, species richness, and vegetative cover.

Traditionally, fires used to maintain productive heritage tanoak stands were set in late
summer and fall. However, prescribed burns at this time of year have become very
difficult to implement, so this study focused on the responses of the assemblages to a
more easily executed, spring burn. During the two year study of acorn infestation rates
in response to fire, I found that spring prescribed fire reduced acorn infestation in both
the year of the fire and one year post-fire. Indigenous acorn collection criteria were very
effective in distinguishing edible acorns from both inedible and insect-infested acorns.
However, the traditional method of acorn evaluation did misclassify a sizeable
proportion of the acorns as inedible, when they were actually of good food quality.
Intended or not, this conservative misidentification provides added insurance that
insect-infected acorns are not added to those stored within a household for future use.
Over the three years that the responses of culturally valuable understory taxa to fire
were monitored, all three metrics (species diversity, species richness, and vegetative
cover) were sharply reduced by fire. Species diversity and richness showed substantial
recovery by the second post-fire year, but neither had fully recovered. Understory plant
cover showed very little, in any, recovery two years after the experimental fires. In
particular, the percent cover of tanoak seedlings and lignotuber sprouts were greatly
reduced, which may increase visibility of abscised acorns to tribal gatherers. As a single
cultural fire targets multiple resource goals, these results indicate that some, but not all,
resource goals traditionally achieved with fall fire were met with spring prescribed fire.

Acknowledgements

Introduction

Native American tribes in California rely on prescribed fire to maintain populations of food, fiber and medicinal plant species, browse for game, and protect important domestic and spiritual areas from destructive fires in prone ecosystems (Timbrook et al. 1982, Lewis 1993, Anderson 2005, Anderson 2006, Lake 2007). The effects of fire exclusion have had drastic effects on forested, culturally valuable ecosystems including increased fuel accumulation and subsequent risks of catastrophic wildfires, shifts in species ranges and assemblage composition, and the decline or disappearance of rare habitats (Stephens and Ruth 2005, Anderson 2005). Fire exclusion policies have hindered access to culturally relevant fire prescriptions, many of which are specific to season, time of day, and the presence of environmental or climatic indicators (F. Lake, personal communication, B. Tripp, personal communication, Blackburn and Anderson 1993, McCreary 2004, Anderson 2007, Lake 2007). Understanding the effects of indigenous fire prescriptions and more effectively incorporating the Native Californian perspective into fire management decisions can help reduce the threat of fire to human health and ecosystem degradation, protect multi-stakeholder ecosystem services, actively promoting indigenous culture, and foster bio-cultural diversity (Senos et al. 2006, Kimmerer 2011, Higgs et al. 2012).

Indigenous fire management practices combine biological, spiritual, social, and cultural factors to guide decisions on where, when, what, and how to burn (Lewis 1993, Connors 2000, Salmon 2000, Anderson 2005). As we seek to understand the mechanisms and underlying motivations for burning among indigenous peoples in California, we must consider the traditional ecological hypotheses that describe the methods and outcomes of traditional fire management and effects that these prescriptions have on targeted cultural resources. In forested ecosystems generated in post-suppression era, it is especially important to understand the effects of altered fire regimes on the abundance and quality of cultural resources. These lines of inquiry extend quickly into the effect that these altered regimes and assemblages will have on access to the material support of indigenous Californian cultures, tribal health and wellness, and cultural strength and resilience (Senos et al. 2006, Norgaard 2014).

In my dissertation, I sought to determine how late spring prescribed fire affected cultural resources associated with tribally managed tanoak (*Notholithocarpus densiflorus*, Fagaceae) stands. Tanoak acorns are one of the most valued terrestrial plant resource systems to the Karuk and Yurok Tribes of California and one that was traditionally managed using fall or winter prescribed fire (Jack 1916). In addition to acorns, a number of understory plant species of cultural value are found in tanoak stands including *Berberis nervosa*, *Chimaphila umbellata*, and *Galtheria shallon* for medicine*, Vaccinium ovatum, V. parvifolium*, *Ribes sanguineum,* and *Rubus parviflorus* for food*,* and *Xerophyllum tenax* for basketry (Schenck and Gifford 1952, Davis and Handryx 1991, Peters and Ortiz 2010). It is important to consider that multiple cultural resources are managed using a single prescribed fire event. The specificity of indigenous fire management parameters is hypothesized to target these multiple resource management goals. In the chapters that follow, I present results from several different

studies examining the effects of non-traditional spring burns and cultural collection activities on Karuk and Yurok cultural plant resources found in tanoak habitat.

In the first chapter, I review published and unpublished literature to determine the use and seasonality of historical indigenous fire prescriptions designed to target acorn resources throughout the state of California. Information contained in journal articles, books, bulletins, reports, ethnographies, and university theses is compiled and analyzed. Using published GIS layers, I correlate the ranges for acorn producing oak species in California with historical tribal ancestral territories to determine the species of acorn producing trees with which different indigenous ethnolinguistic groups may have interacted. Throughout the state, indigenous Californian people applied fire to manage for acorn resources in the late summer-fall and came into contact with a variety of oak species. Whether acorns from all available oak species were culturally used is dependent upon tribal preference.

In the second chapter, I examine the effect of late spring prescribed fire on tanoak acorn edibility and larval infestation. Acorns are consumed by frugivorous Filbertworm (*Cydia latiferreana*, Tortricidae) and Filbert weevil (*Curculio occidentalis*, Curculionidae) larvae (Tappeiner et al. 1990, Vander Wall 2001). Larval infested acorns are considered inedible by the Karuk and Yurok People. The application of fall prescribed fire is thought to reduce acorn infestation by targeting vulnerable periods in the life cycles of insect consumers and reducing the number of reproducing adults. The reduction in reproduction rates would decrease the number of larvae during the following year and reduce consumption pressure on the subsequent year's tanoak acorn crops. As humans are one of multiple different species of acorn consumers, the effect of selective mammalian balanophagy was examined in the presence and absence of fire. My results show that there was a difference in both ambient rates of acorn infestation at burned and unburned sample sites and that spring prescribed fires significantly reduced acorn infestation. Rates of infested acorns were higher in areas open to mammalian acorn consumers compared with those in excluded areas. This suggests that mammals are selectively consuming non-infested acorns.

In the third chapter, I investigate the capacity for learned indigenous acorn collection criteria to effectively diagnose the state of cotyledon tissue as edible or inedible/insect infested. During traditional acorn gathering, the practitioner examines the acorn pericarp for indications of internal infestation and judges whether an acorn it is edible. Indigenous collection criteria were extremely effective at distinguishing both generally inedible (incomplete nut maturation, mold, and insect infestation) and specifically insect infested acorns from edible acorns. Criteria were most effective at distinguishing good acorns from insect infested acorns; however, some edible acorns were misclassified as inedible. Intended or not, this conservative misidentification provides added insurance that insect-infested acorns are not added to those stored within a household for future use.

In the fourth chapter, I assess the effect of late spring prescribed fire and acorn removal (as a proxy for gathering) on cultural plant species diversity, richness, and percent

cover. Cultural plant species were identified using existing ethnobotanical publications and unpublished ethnobotanical surveys (Schenck and Gifford 1952, Davis and Handryx 1991, Peters and Ortiz 2010, Lake). Fire reduced diversity, richness, and percent cover in the year of the fire. All metrics displayed trends towards recovery in the post-fire year but did not return to pre-burn levels. Percent cover recovered the least of all the metrics possibly due to the combined effect of a growing season burn and extreme drought conditions on vegetative regrowth following the fire.

Taken together, the results from these studies show that late spring prescribed fire effectively meets some, but not all, of the examined cultural management targets traditionally achieved using fall prescribed fire. Acorn resources are enhanced with spring prescribed fire. The response of habitat associated plant resources is unclear. Altered forested ecosystems and changing social and political dynamics in the Klamath Bioregion necessitate novel approaches and collaborations to maintain Karuk and Yurok cultural resource needs and tribal community health and wellness.

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CHAPTER 1

Balanophagy and Acorn Management in Indigenous California

Introduction

Balanophagy, or the consumption of acorns, was a near ubiquitous practice among the indigenous peoples of California in the pre-European contact era (Driver 1952, Mayer 1976, Ortiz 1991, Anderson 2005, Anderson 2007, Bowcutt 2013).   Precise management practices, including pruning and burning, were employed among Native Californian groups to promote the longevity and reliability of the oak resource systems upon which they depended (Blackburn and Anderson 1993, Anderson 2005, Ortiz 2006, Pei et al. 2009, Turner et al. 2009, Anderson and Lake 2013). Fire was the primary tool used to enhance the production of edible acorns by trees in the genera *Quercus* and *Notholithocarpus* with specific regimes of applied fire used to reduce incidences of infestation by granivorous larvae (Blackburn and Anderson 1993, Swiecki and Bernhardt 2006, Anderson 2007). The regular application of low intensity fire in the understory of oak dominated forests, many of which were tribal acorn orchards, provided a number of other benefits including the regeneration of habitat associated plant species of cultural value, increased ease of acorn collection, and the fostering of forest characteristics that discouraged the spread of stand replacing fires, that would otherwise reduce acorn production (Anderson 2005, Ortiz 2006).   In Alta California, Governor Jose Joaquin de Arrillaga passed the first fire suppression law in 1793 that forbade California Indians, as subjects of the Missions, to burn (Timbrook 1993). Since the onset of state and federally mandated fire suppression in California at the turn of the 20th century, the capacity to engage in these highly specific tribal management activities has become increasingly difficult due to changes in forest structure and composition (Taylor and Skinner 2003, Stephens and Ruth 2005, Wiens et al. 2010). Given ethnographically documented relationship between fire and acorn quality, the availability of good quality acorns has decreased in the absence of prescribed fires targeted specifically to tend acorn resource systems (Jack 1916, Anderson 2005). The longevity and continuity of cultures is, in part, dependent upon the material resources that support cultural activities. It is of paramount importance to incorporate fire management goals and outcomes (e.g. desired fire effects) that address cultural resource targets as a means of ensuring cultural wellbeing and continuity. Here I review extant ethnographic literature describing the processes by which Native Californian peoples managed individual species of acorn producing trees in order to offer a concise and synthesized account of the species-specific management activities surrounding a valued indigenous Californian food resource.

Quercus and Notholithocarpus
Quercus spp. are members of the Fagaceae (Beech) Family of monoecious evergreen and deciduous shrubs and trees (Baldwin and Goldman 2012). Species of the genus *Quercus* are thought to have initially diversified and evolved with the widespread cooling and drying period occurring in the middle Eocene epoch approximately 40-60 mya (Raven and Axelrod 1978). Further speciation events occurred in response to continued

topographic and climatic shifts in the Cenozoic and Quaternary periods (Raven and Axelrod 1978). The genus contains 600 species most of which live in the northern hemisphere (Baldwin and Goldman 2012). Eighty-nine varieties of oaks have been recorded within the California Floristic Provence including hybrids, subspecies, and variants (Baldwin and Goldman 2012).

Within the genus *Quercus*, five sections have been defined, three of which grow in California: Lobatae/ subgenus Erythrobalanus (Black/Red Oaks), Protobalanus Intermediate (Golden Oaks) and Quercus/ subgenus Leucobalanus (White Oak) (Nixon et al. 2002, Johnson et al. 2009). The red and white oak sections consist of a combination of evergreen and deciduous species while the Golden Oak section is entirely evergreen (Johnson et al. 2009). Extensive hybridization occurs within each section; however, no incidences of hybridization have been reported between sections (Nixon et al. 2002). Acorns mature in either one or two years. Members of the Quercus (white oak) section of the genus require one year for acorns to mature. Acorns produced by members of Section Lobatae (black/red oak) mature in two years, and acorns from section Protobalanus require one or two years to mature (Nixon et al. 2002).

Notholithocarpus densiflorus (Fagaceae) is a paleoendemic taxon in western North America (Manos et al. 2008). Recent reclassification of the castenoid component of the family Fagaceae has shifted the taxon status from the genus *Lithocarpus* to its new genus *Notholithocarpus* based on pollen and floral morphology (Manos et al. 2008). At present, the genus is now more closely related to the genus *Quercus* (Manos et al. 2008).

Acorns in Native California
Oak (*Quercus* and *Notholithocarpus*) species are a common and charismatic component of many of the vegetation zones of the California Floristic Province (Griffin and Critchfield 1972, Plumb and McDonald 1981, Johnson et al. 2009). Of the 89 taxa of oaks found in California, 15 species are endemic (Griffin and Critchfield 1972, Plumb and McDonald 1981, Baldwin and Goldman 2012). Within those endemic species, 8 taxa, including Tanoak, grow to tree sized and 7 grow as shrubs (Plumb and McDonald 1981). Oak species are important components of the northern, southern, and foothill woodlands, as well as the mixed conifer, mixed evergreen, and chaparral vegetation zones (Plumb and McDonald 1981).

Acorns were one of the most exploited terrestrial resource systems in pre-contact aboriginal California and are still used and consumed as a cultural and ceremonial food among surviving indigenous populations (Ortiz 2006, Anderson 2007). It is estimated that acorns comprised up to half the diet of many of the indigenous peoples of California (Heizer and Elsasser 1980). Acorns possess a number of features that made them attractive as a food source:

1. Acorns are abundant in California given the number of oak species present and the variety of habitats in which they occur. Wolf estimates that *Q. douglasii* alone

would produce 250,000 tons of acorns in California compared to the average state barley yield for 1926-1930 which was 740,000 tons (Wolf 1945). Bainbridge estimates that a population of well-established oaks could produce 5280 kg/ha per year (Bainbridge 1986, Bainbridge 2006). Production values vary by species and have been shown to vary by year (Koenig and Knops 2013). While different tribal groups preferred certain species of acorns over others, the variety of acorn producing species in most California ecosystems allowed for a measure of resource security in the event that acorn production for particular species was low in a given year (Schenck and Gifford 1952, Anderson et al. 1997, Anderson 2007).

2. <u>Acorns have high nutritional value</u>: Depending on the species, acorns are comprised of 2-9% protein, 5-20% fat, and 52-70% carbohydrates (Wolf 1945, Bainbridge 1987). Many of the more widely used acorn species such as *Q. kelloggii*, *Q. lobata*, *Q. douglasii*, and *N. densiflorus* have particularly high carbohydrate and moderate fat content. The low levels of protein were supplemented by the game, insect, mollusk, and salmonid components of most native Californian diets (Wagnon 1946, Heizer and Sturtevant 1978, Heizer and Elsasser 1980). Acorns are also a good source of Vitamin C and A (King and Titus 1943, Bainbridge 1985). The hydrolizable tannins present in acorns display anti-carcinogenic and anti-mutagenic properties making acorns a valuable medicinal food (Horikawa et al. 1994, Meyers et al. 2006, Takahashi et al. 2010)

3. <u>Acorns are easy to store and harvest</u>: The Sierra Miwok could collect all of the acorns needed for the year in the span of a single month (Mayer 1976, Dixon 1907). Wolf (1945) reports that a single square foot under a *Q. agrifolia* tree in Riverside County yielded 175 good acorns weighing more than one pound and that a one-hour collection trial yielded 150 lbs. of good Q. lobata acorns (Wolf 1945). Storage occurred either in the home in baskets around the fire source or in granaries suspended above the ground to guard against moisture and pests (Dixon 1905, Dixon 1907, Gifford 1932, Kroeber 1932, Merriam 1955).

Fire in Native California

Fire is an integral agent of disturbance in California's ecosystems. Abundant data described the evolution of life history characteristics in response to fire and the reliance of certain plant populations and assemblages on the regular burning of above ground biomass (Sugihara 2006, He et al. 2011, Halofsky et al. 2011). Martin and Sapsis (1992) estimate that between 5.6 and 13 million acres of California burned annually though lightning or anthropogenic initiated ignitions (Martin and Sapsis 1992). In the Klamath Bioregion, fire studies have shown that prior to the establishment of European settlements, the majority of fires, both natural and anthropogenic, occurred during the late growth season and dormant season (late summer to winter) (Fry and Stephens 2006, Taylor and Skinner 1998, Taylor and Skinner 2003). Fire return intervals and the spatial extent of individual fires were significantly reduced based on the results of dendrochronology and fire history studies on California's forested ecosystems for the record during the pre-European settlement and European settlement pre-suppression period (Kilgore and Taylor 1979, Taylor 1993, Stephens and Fry 2005, Fry and Stephens 2006). This could be due to a factors including the direct application of fire by

indigenous groups to smaller areas of land and the heterogenous habitat patches influenced by biophysical topographical divers (e.g. aspect, slope position) that were created by allowing of lightning caused ignitions to run their course with no suppression attempts to hinder their spread.

Many of the terrestrial habitat types and plant species utilized by indigenous Californian groups were dependent upon the regular application of fire (Timbrook et al. 1982, Timbrook 1990, Blackburn and Anderson 1993, Anderson and Moratto 1996, Lake 2007, Anderson and Rosenthal 2015). Fire maintained open oak woodlands and grasslands that would be otherwise encroached upon by less culturally valuable plant assemblages (Anderson 2007, Anderson and Rosenthal 2015). Cuthrell et al (2013) demonstrated that the historical vegetation patterns surrounding a pre-contact Costanoan village site were typical of regularly burned grasslands and woodlands and contrasted sharply with the fire-excluded north coast sage scrub and Douglas fir woodland present today (Cuthrell 2013). Regular application of fire was used to encourage resprouting responses in plant species that would attract groups of ungulates that indigenous Californians would hunt for food and materials (Jack 1916). Basketry fibers derived from native plant species required fire both to maintain suitable habitat as well as encourage usable growth forms and discourage insect species that would consume growing shoots (Anderson 1996, Anderson et al. 1997, Anderson 1999, Lake 2007). The health of oak trees was thought to be maintained by fire. Traditional ecological knowledge posits that diseases were kept at bay through the application of fire either by direct destruction of pathogens in the duff and litter layers or through the smoke from fires set at the onset of the moist Mediterranean winter (Schenck and Gifford 1952, Anderson 2007).

Fire suppression has had a host of deleterious effects on California's ecosystems (McCreary 2004). Within the mixed conifer-hardwood forests of the Klamath River Bioregion fire suppression has created of large, dense, single aged stands of small diameter hardwoods and conifers amounting to less than suitable habitat for young oaks to grow to a dimension sufficient to become culturally relevant acorn producing trees and shift the assemblage composition of the understory away from culturally valuable species that thrived under a different burning regime (Thysell and Carey 2001, Carey 2002). The result is that as many of the older heritage acorn trees, the legacy of tribal acorn management, become decadent and die, there are few younger generation trees that have been sufficiently tended in an appropriately structured habitat to replace them.

Fire and Oaks

Species of acorn producing trees are highly dependent on the regular application of fire to keep habitat open, reduce competition from encroaching tree and shrub species, encourage appropriate dimensions and canopy architecture, and reduce incidences of larval infestation in acorns (Blackburn and Anderson 1993, Lewis 1993, Anderson 2005, Anderson 2007). Given the regular frequency of fires, many of the tended areas in which acorn producing trees grew would not be subjected to the high intensity fires that would top-kill most species of oaks (Jack 1916, Plumb and McDonald 1981, Anderson et al. 1997). The regular consumption of surface and ladder fuels would act as a barrier

to the spread of any extensive, high-severity fire when combined with open, culturally valued habitats structure such as well-spaced stands of large diameter trees with moderate canopy overlap (Lake, pers. com). Fire application in oak gathering areas was applied to coincide with vulnerable stages in the life cycles of granivorous larvae, most notably *Curculio occidentalis* (Curculionidae) and *Cydia latiferreana* (Tortricidae) (Swiecki and Bernhardt 2006, Anderson 2007). Fires were set in the fall when the infested or incompletely developed acorns were mostly abscised from the tree. Larvae within these acorns would emerge and enter sound acorns to consume cotyledon tissue, overwinter in the litter/duff layer, and pupate during the winter months. Burning during the fall and winter when larvae were still vulnerable would reduce the number of acorns lost to larval consumption as well as reduce populations of reproducing adults the following year. Anderson (2007) presents a concise description of the life histories of *Q. kelloggii* and *C. latiferreana* overlaid with seasonal activities in the native Californian oak management calendar (Anderson 2007).

In a 1916 letter to the California Fish and Game Commission, Klamath River Jack concisely describes the benefits of fire to culturally significant species of animals and plants on the Klamath River in northwestern California:

> "*Fire burn up old acorns that fall on ground. Old acorns on ground have lots of worms; no burn old acorn, no burn old bark, old leaves, bugs, and worms come more every year. Fire make new sprout for deer and elk to eat and kill lots of brush so always have plenty open grass land for grass. No fire brush grow quick and after while choke out all grass and make too much shade, then grass get sour, no good for eat. No fire then too much leaf stay on ground. No grass can grow up. Too much dead leaf, ground get sour. Indian burn every year just same, so keep all ground clean, no bark, no dead leaf, no old wood on ground, no old wood on brush, so no bug can stay to eat leaf and no worm can stay to eat berry and acorn. Not much on ground to make not fire so never hurt big trees, where fire burn. Now White Man never burn; he pass law to stop all fire in forest and wild pasture*…" (Jack 1916).

Methods
Data were collected via an extensive review of published and unpublished journal articles, books, bulletins, reports, ethnographies, and university theses to characterize information on the use and timing of fire application specifically for the management of acorn resources. GIS layers from the USGS Geoscience and Environmental Change Science Center on the distribution of oak species were projected onto a map of the ancestral territories of Californian indigenous ethnolinguistic groups using ArcGIS (Little 1971, Little 1976, USGS 1999, Redlands Institute, University of Redlands 2002). This information was used to describe which ethnolinguistic groups may have come into contact with individual species of *Quercus* and of *Notholithocarpus* regardless of whether there is extant ethnographic information to document specific use. I focus on individual taxa and examine the distribution of each taxa, the nutritional content of acorns for each taxa where available, the indigenous groups that might have encountered specific taxa given the geography of ancestral territories, and the methods

and timing employed by indigenous groups to manage each species of acorn producing tree. In this review I will address only the species mentioned in ethnographic literature as being of cultural value and those for which data on indigenous fire application is present.

Species Distribution and Native Californian Use
Black Oak Section
Q. agrifolia (Coast Live Oak) Fig. 1a
Q. agrifolia is the species of California oak most suited to coastal climates and is found along the Pacific coast and inland in the Transverse, Peninsular, and inner Coast ranges (Pavlik et al. 1991). Habitats containing coast live oak components cover 15.2% of the state (Griffin and Critchfield 1972, Plumb and McDonald 1981). Coast Live Oak ranges from the northern portion of Baja to Mendocino County in the north (Little 1971, Pavlik et al. 1991). Its acorns mature in 6-8 months after pollination in contrast to sister taxa in the Erythrobalanus subgenus which take 18 months (Pavlik et al. 1991). Nutritional analysis of *Q. agrifolia* acorns indicates that the cotyledon tissue contains 4.40% protein, 20.42% fat, 11.68% fiber and 52.74% carbohydrates (Wolf 1945). Though smaller in size than acorns from *Q. kelloggii*, *Q. douglasii*, or *Q. lobata*, their comparatively high lipid content makes then a valuable source of plant based fats in the Native Californian diet (Wolf 1945). Coast Live Oak acorns were reported to be used by the Chumash, Ohlone, and Pomo people (Bocek 1984, Gifford 1967, Timbrook 1990) though the species range overlaps with the ancestral territories of the Wappo, Coast and Eastern Miwok, Esselen, Salinan, Tataviam, Gabrielino, Luiseno, Ipai, Tipai, and Cahuilla peoples (USGS 1999, Redlands Institute, University of Redlands 2002). In addition to using Coast Live Oak acorns, the Pomo people are reported to burn for acorns during the fall though no specific reference to burning for Coast Live Oak acorns is given (Kniffen 1939).

Q. kelloggii (Black Oak) Fig. 1b
Black oaks are winter deciduous trees that grow predominantly in mountainous areas between 2,000 and 6,000 ft. (Pavlik et al. 1991). Its species range covers 18.4% of California making it the most widely distributed *Quercus* taxon member in the state (Griffin and Critchfield 1972, Plumb and McDonald 1981, McCarthy 1993). Black oaks are distributed from northern California to southern San Diego County. Their range is most concentrated and contiguous in northern California in the Coast, Klamath, Siskiyou, and Sierra Nevada Ranges with isolated populations predominating in the southern reaches of their distribution in the central and southern portions of the state (Little 1971). Wolf's (1945) analysis of the nutritional composition of dried Q. kelloggii cotyledon tissue describes contents of 4.56% protein, 17.97% fats, 11.40% fiber, and 55.48% carbohydrates (Wolf 1945).

Records of black oak acorn use are present for the Miwok, Cahuilla, Pomo, Karuk, Mono, Chukchansi/Choynomni, Nisenan, Northeastern Maidu, Wintu, Hupa, Shasta, Yuki, Hill Patwin, Northern Maidu, Southern Maidu, and Yokut people (Chesnut 1902, Goddard 1903, Dixon 1905, Dixon 1907, Sparkman 1908, DuBois and Kroeber 1908,

Kroeber 1932, Beals 1933, Barrett and Gifford 1933, DuBois 1935, Kniffen 1939, Gayton 1948, Schenck and Gifford 1952, Gifford 1967, Haney 1992, Anderson 2005, Duncan 2012) In addition to the peoples mentioned above, the species range of black oak intersects with the ancestral territories of the, Wappo, Cahto, Wailaki, Sinkiyone, Lassik, Nomlaki, Nongatl, Mattole, Whilkut, Chimariko, Chilula, Modoc, Achumawi, Atsugewi, Yana, and Konkow (Little 1971, USGS 1999, Redlands Institute, University of Redlands 2002). Black oaks exist in isolated populations within the ancestral territories of the Monache, Tubatulabal, Kawaiisu, Kitanemuk, Tataviam, Gabrielino, Chumash, Salinan, Esselen, Constanoan, Luiseno, Cupeno, Ipai and Tipai (Little 1971, USGS 1999, Redlands Institute, University of Redlands 2002). References are made to fall burning for black oak acorns by the Maidu, North Fork and Western Mono, the Chukchansi, and the Choynumni (Anderson 2005, Duncan 2012). A single report for the burning of Black Oak/White Oak woodlands comes from the Karuk People (B. Tripp, personal communication) though this burning was not done to necessarily manage for acorns as black oak acorns are not the preferred species for the Karuk People (B. Tripp, personal communication).

Q. wislizenii (Interior Live Oak) Fig. 1c
Q. wislizenii is distributed widely in the foothill, upland slopes, river floodplains, and valley bottoms of the Sierra Nevada, Coast, Klamath, and Cascade Ranges that encircle California's central valley and south into the Transverse and Peninsular Ranges (Little 1976, Pavlik et al. 1991). Its distribution covers 16% of the state and is the third most widely distributed *Quercus* species in California (Griffin and Critchfield 1972, Plumb and McDonald 1981). The Sierra Miwok, Nisenan, Northwest Maidu, Northeast Maidu, Wintu, River and Hill Patwin, Southern Maidu, and Miwok were reported to harvest and use Interior Live oak acorns (Dixon 1905, Kroeber 1932, Beals 1933, Barrett and Gifford 1933, DuBois 1935, Mayer 1976, Levy 1978, Duncan 2012). Q. wislizenii is also distributed extensively in the territories of the Chumash, Esselen, Salinan, Costanoan, Wappo, Pomo, Yuki, Cahto, Wailaki, Nomlaki, Wintu, Yana, Konkow, Nisenan, Kitanemuk, and Tataviam. It is present less extensively and in isolated populations in the ancestral territories of the Northern, Southern, and Foothill Yokuts, Monache, Tubatulabal, Kawaiisu, Serrano, Gabrielino, Luiseno, Cahuilla, Cupeno, Ipai and Tipai. There are no direct references to burning *Q. wislizenii*, but the Tubatulabal, Kawaiisu, Yokut, Miwok and Salinan people burned for acorns in the fall (Anderson 2005, Anderson et al. 2012).

White Oak Section
Q. sadleriana (Deer Oak, Sadler Oak)
Q. sadleriana is a unique shrubby member of the genus and section *Quercus* both for its conical shape, limited range, and for the retention of leaves beyond two years (Pavlik et al. 1991, Nixon et al. 2002). It is a relict endemic species to the Klamath Ranges in Trinity, Del Norte, Shasta, and Humboldt Counties in northern California (Jerome 1979, Pavlik et al. 1991) and is an associate in regional montaine forests between 3,000 and 7,000 ft. (Jerome 1979). Schenck and Gifford (1952) report the use of *Q. sadleriana* acorns by the Karuk people (Schenck and Gifford 1952). Karuk cultural practitioner and Forest Service Research Scientist Frank Lake has noted that these acorns do not

require as much leaching time during processing as they are tribally referred to locally in Orleans, CA as "sweet acorn" (F. Lake, personal communication)

Q. lobata (Roble Oak, Valley Oak) Fig. 1d
Q. lobata is a lower elevation species of *Quercus* that grows predominantly in California's Great Central Valley and the foothills of the interior Coast and Transverse Ranges (Little 1971, Pavlik et al. 1991). Populations are also found in the Santa Cruz and Santa Catalina Islands (Little 1971, Pavlik et al. 1991). Q. lobata is distributed across 5.8% of the state of California (Griffin and Critchfield 1972, Plumb and McDonald 1981). A representative Valley oak with a diameter of 4 ft. yielded 500 lbs. of acorns during a single collection (Wolf 1945). Dried Q. lobata acorns are composed of 4.90% proteins, 5.54% fat, 9.46% fiber, and 69.02% carbohydrates (Wolf 1945). The Plains Miwok, Nisenan, Northwestern Maidu, Chumash, Sierra Miwok, Wintu, Yuki, River and Hill Patwin, Pomo, Southern Maidu, and Yokuts all used acorns from *Q. lobata* (Chesnut 1902, Kroeber 1932, Beals 1933, DuBois 1935, Kniffen 1939, Gayton 1948, Mayer 1976, Levy 1978, Timbrook 1990, Duncan 2012). In addition*, Q. lobata* is distributed in the ancestral territories of the Pomo, Wappo, Nomlaki, Yana, Konkow, Esselen, Salinan, and Monache (USGS 1999, Redlands Institute, University of Redlands 2002). It is found in the western portions of the ancestral territories of the Tubatulabal, Kawaiisu, Kitanemuk, Tataviam, Gabrielino (USGS 1999, Redlands Institute, University of Redlands 2002). No direct references were made to the specific burning of *Q. lobata* but the Miwok were reported to burn for acorns between August and October (Levy 1978, Anderson 2005).

Q. douglasii (Blue Oak) Fig. 1e
Q. douglasii is found primarily on the interior foothills of California encircling the Great Central Valley (Little 1971, Pavlik et al. 1991, Griffin and Critchfield 1972). Its distribution is similar to that of *Q. wislizeni* and *Q. lobata* with whom it is often found in association (Griffin and Critchfield 1972). Habitats with *Q. douglasii* components cover 17.5% of the state making these oaks the second most widely distributed species in California (Plumb and McDonald 1981). They are one of the few members of the genus that displays drought deciduous leaves (Pavlik et al. 1991). Wolf (1945) reports that a single Blue Oak with a diameter of 20 in. produced 160 lbs of acorns in a single collection (Wolf 1945). Blue Oak acorns were used by the Sierra Miwok, Nisenan, Ohlone, Wintu, Yuki, River and Hill Patwin, Southern Maidu, and Miwok People (Chesnut 1902, Kroeber 1932, Barrett and Gifford 1933, Beals 1933, DuBois 1935, Levy 1978, Mayer 1976, Duncan 2012, Bocek 1984). *Q. douglasii* is present in the ancestral territories of the Nomlaki, Konkow, Yana, Yokut, Monache, Salinan, Kawaiisu, Kitanemuk, and Esselen peoples (USGS 1999, Redlands Institute, University of Redlands 2002). Isolated populations appear in portions of the ancestral territories of the Tataviam and Chumash peoples in the southern part of California as well as the Yuki, Achumawi, and Atsugewi people in the northeast (USGS 1999, Redlands Institute, University of Redlands 2002). No particular references to burning Q. douglasii for acorns were located but the Salinan were recorded to burn for acorns in the fall when the grass is dry (Anderson et al. 2012). The eastern Miwok burned their acorns in

August (Levy 1978) and other Miwok groups were documented burning for acorns in October when the first chill came (Anderson 2005).

Q. garryana (Oregon White Oak) Fig. 1f
Q. garryana is the only species of California Oak with a range that extends well beyond the northerly boundaries of the state into Oregon, Washington, and British Columbia (Little 1971, Griffin and Critchfield 1972, Pavlik et al. 1991). *Q. garryana* is most widely distributed in the northwest portion of the state in Humboldt, Shasta, Trinity, Mendocino, and Sonoma counties at elevations between 1,000 and 4,000 ft. (Little 1971, Pavlik et al. 1991, USGS 1999, Redlands Institute, University of Redlands 2002). Isolated populations are present in Santa Clara County near Gilroy and in the western Sierra Nevada Ranges (Little 1971, Pavlik et al. 1991, USGS 1999, Redlands Institute, University of Redlands 2002). *Q. garryana* is distributed across 5.5% of the state making it the seventh most populous oak in California (Plumb and McDonald 1981). Wolf reports of individual trees east of Little Shasta Valley producing 50 lbs. of acorns each (Wolf 1945). Nutritional content for *Q. garryana* acorns was described as 3.94% protein, 4.47% fats, 11.95% fiber, 68.87% carbohydrates (Wolf 1945). The Pomo, Hupa, Shasta, Yuki, and Karuk people were all reported to use Oregon White Oak acorns (Chesnut 1902, Goddard 1903, Dixon 1907, Kniffen 1939, Schenck and Gifford 1952). The taxa is present in the ancestral territories of the Tolowa, Chimariko, Wintu, Whikut, Nongatl, Lassik, Sinkiyone, Wailaki, Cahto, Nomlaki, Achumawi, Atsugewi, and Wappo peoples (Little 1971, USGS 1999, Redlands Institute, University of Redlands 2002). Small, isolated populations are present in the ancestral territories of the Nisenan, Miwok, Costanoan, Yokuts, Monache peoples (Little 1971, USGS 1999, Redlands Institute, University of Redlands 2002). The Shasta people burned *Q. garryana* acorns in the fall when leaves begin to abscise (Lewis 1973).

Q. dumosa (Coastal Scrub Oak)
Defining the distribution for *Q. dumosa* and the location of isolated populations has been a challenge given the extent to which it hybridizes with other members of the White Oak section including, *Q. turbinella* and *Q. durata* (Tucker 1952a) and Q. englemanni (Griffin and Critchfield 1972). What were previously thought to be populations of *Q. dumosa* are actually *Q. berberidifolia* in interior chaparral assemblages and *Q. cornelius-mulleri* in desert edge assemblages (Pavlik et al. 1991). Nixon (2002) suggests that what had previously been described as the Q. dumosa complex should be separated into five species with distinct distributions: *Q. dumosa*, *Q. berberidifolia*, *Q. john-tuckeri*, *Q. cornelius-mulleri*, and *Q. pacifica* (Nixon et al. 2002). *Q. dumosa* is distributed only in southern California and northern Baja on hillsides proximate to the ocean (Pavlik et al. 1991). The Chumash, Wintu, and Yuki peoples were all reported to use acorns from the Coastal Scrub Oak (Chesnut 1902, DuBois 1935, Timbrook 1990); however, given the geographic location of the ancestral territories of the aforementioned tribes it is more than likely that they were utilizing acorns from mis-classified *Q. berberidifolia*. Given that the Wintu and Yuki peoples lived north of the corrected species distribution, this is likely that these people used a different species of scrub oak acorn.

Q. berberidifolia (Scrub Oak)
Q. berberidifolia is an important and widespread component of chaparral and woodland habitats below 5,000 ft (Pavlik et al. 1991). *Q. berberidifolia* is distributed in more mesic habitats than sister scrub oak taxa throughout the Coast, Transverse, and Peninsular Ranges (Pavlik et al. 1991, Nixon et al. 2002). The Wintu people used acorns from *Q. berberidifolia* (DuBois 1935). No records exist for burning areas of *Q. berberidifolia* for acorns but as *Q. berberidifolia* and the previous *Q. dumosa* are scrub oaks, recently re-classified, and commonly found in chaparral assemblages, fire return interval, severity and intensity in these communities may differ than for those tree species of oak in savannah, woodland, and forest assemblages (Tucker 1952a, Nixon et al. 2002).

Q. turbinella (Desert Scrub Oak, Shrub Live Oak) Fig. 1g
Q. turbinella is another taxa in the southern scrub oak complex of the White Oak section. Historically, it was classified as *Q. dumosa* along with many other members of the scrub oak complex (Tucker 1952b, Tucker 1953, Nixon et al. 2002). Given the ambiguity in identification, a clear description of the species distribution is challenging. Little (1976) describes the distribution of *Q. turbinella* along xeric portions of the interior Coast, Transverse, and Peninsular Ranges with an isolated population located in the New York Mountains (Little 1976, Tucker 1953). Tucker (1953) classifies the distribution of *Q. turbinella* as being restricted in California to the New York Mountains in eastern San Bernardino County while *Q. turbinella* subsp. *californica* is distributed along the eastern slopes of California's southern ranges (Tucker 1953). The Mohave people were reported to use acorns from *Q. turbinella* (Anderson 2007) though there is no record of management or burning. The eastern population of *Q. turbinella* resides within the ancestral territories of the Southern Paiute people whose territory neighbors that of the Mojave people to the north (Little 1976, USGS 1999, Redlands Institute, University of Redlands 2002).

Intermediate Oak Section
Q. chrysolepis (Canyon Oak) Fig. 1h
Q. chrysolepis is the most widely distributed species of tree oak in the state with a range that extends beyond California north into southern Oregon, east into Nevada and Arizona, and south into Baja California (Little 1971, Pavlik et al. 1991). *Q. chrysolepis* grows in a wide variety of forest, woodland, and chaparral habitats from sea level up to 9,000 ft in elevation (Pavlik et al. 1991). Habitats *containing Q. chrysolepis* cover 12.7% of California making it the 5th most widely distributed *Quercus* taxon in the state (Griffin and Critchfield 1972, Plumb and McDonald 1981). Wolf (1945) estimates that a single 4 ft. diameter tree produced 400 lbs of fresh acorns during a single collection event (Wolf 1945). The nutritional composition of Canyon Oak is 4.13% proteins, 8.65% fats, 12.73% fiber, and 63.52% carbohydrates (Wolf 1945). The Cahuilla, Sierra Miwok, Hupa, Shasta, Yuki, Pomo, Northern Maidu, Karuk, and Kumeyaay people all used acorns from the Canyon Oak (Chesnut 1902, Goddard 1903, Dixon 1905, Dixon 1907, Sparkman 1908, Kniffen 1939, Schenck and Gifford 1952, Haney 1992, Wilken 2012). Q. chrysolepis is present within the ancestral territories of the Wappo, Cahto, Wailaki, Sinkiyone, Lassik, Nomlaki, Nongatl, Whilkut, Wintu, Chimariko, Chilula, Yurok, Tolowa,

Achumawi, Atsugewi, Yana, Konkow, Nisenan, Washo, Owens Valley Paiute, Monache, Yokut, Tubatulabal, and Kawaiisu peoples (Little 1971, USGS 1999, Redlands Institute, University of Redlands 2002). Isolated populations are found within the ancestral territories of the Southern Paiute, Serrano, Cupeno, Tipai, Ipai, Luiseno, Gabrielino, Tataviam, Kitanemuk, Chumash, Salinan, Esselen, and Costanoan peoples (USGS 1999, Redlands Institute, University of Redlands 2002). No specific information on the management or burning of *Q. chrysolepis* is present but Anderson reports that an elder of Tubatulabal, Kawaiisu, Yokut, and Miwok decent would burn for acorns in the fall (Anderson 2005). The Pomo were reported to burn for acorns in the fall (Kniffen 1939), the eastern Miwok would burn in August (Levy 1978), and the Salinan would burn for acorns in the fall when the grass is dry (Anderson et al. 2012).

Q. vaccinifolia (Huckleberry Oak)
Q. vaccinifolia is a shrub species which grows at the highest elevations of any *Quercus* taxa in California (Pavlik et al. 1991). It replaces sister taxon *Q. chrysolepis* at elevations between 3,000 and 10,000 in the Klamath and Sierra Nevada Ranges (Griffin and Critchfield 1972, Pavlik et al. 1991). It is also present in assemblages in the North Coast Ranges above Mendocino County (Pavlik et al. 1991). Acorns from *Q. vaccinifolia* are used by the Maidu people of the Sierra Nevada (Duncan 2012).

Notholithocarpus
N. densiflorus (Tanoak, Tanbark Oak) Fig. 1i
N. densiflorus is the only species in the genus *Notholithocarpus,* it is most closely related to the genus *Quercus* (Manos et al. 2008). Tanoaks are distributed from the Umpqua River in southern Oregon to Mariposa County (Jepson 1909, Griffin and Critchfield 1972, Baldwin and Goldman 2012). *N. densiflorus* grows in mesic habitats and, as such, is more widely distributed in northern California and Oregon than in central California (Griffin and Critchfield 1972). Tanoaks are present in isolated pockets along the western edge of the Sierra Nevada Range while contiguous distribution occurs in the northern Coast Range from Sonoma County to the California-Oregon border (Little 1971). Geographically isolated populations are common in the species' distribution with four genetically distinct groups of tanoaks emerging in the southern and northern Coast Ranges and Klamath and Sierra Nevada Ranges (Little 1971, Nettel et al. 2009, Dodd et al. 2013). Habitats containing Tanoak cover 7.8% of the state of California (Plumb and McDonald 1981, Griffin and Critchfield 1972). Nutritional analysis for dried tanoak acorns describes cotyledon tissue containing 2.93% proteins, 12.08% fats, 20.14% fiber, and 54.43% carbohydrates (Wolf 1945). Tanoak acorns are the preferred species of acorn for the Karuk, Hupa, and Yurok, Pomo, Chilula, Tolowa, and Ohlone people; the Shasta and Yuki people were also reported to use the acorns (Chesnut 1902, Goddard 1903, Dixon 1907, Kniffen 1939, Schenck and Gifford 1952, Warburton and Endert 1966, Gould 1975, Lake Jr and Lake-Thom 1982, Ortiz 2006). The species is distributed in the ancestral territories of the Tolowa, Chilula, Wiyot, Whilkut, Nongatl, Mattole, Sinkiyone, Lassik, Wailaki, Cahto, and Wappo (USGS 1999, Redlands Institute, University of Redlands 2002). Isolated populations are present in the territories of the Coast, Eastern, and Lake Miwok, Esselen, Salinan, Konkow, Yana, Nisenan, and Chumash (Little 1971, Redlands Institute, University of Redlands 2002).

Both the Karuk and the Yurok people burn under tanoak orchards in the late summer or fall to reduce larval infestation of acorns, to facilitate acorn collection, to encourage the growth of habitat associated plants of cultural value, and browse for game (Jack 1916, Schenck and Gifford 1952, Warburton and Endert 1966, Lewis 1993).

N. densiflorus var. echinoides
A shrub varietal of tanoak, *N. densiflorus* var. *echinoides* is found at higher elevations in the northern regions of the tanoak distribution in Shasta, Trinity, and Siskiyou counties and in the Cascade, Klamath, Siskiyou, and Sierra Nevada Ranges between 2,000 and 7,000 feet in elevation (Griffin and Critchfield 1972, Manos et al. 2008, Baldwin and Goldman 2012). The Karuk people are reported to use acorns of this tanoak varietal (Schenck and Gifford 1952).

Of the species of oaks (including *N. densiflorus*) present in California, 14 are mentioned as being used by specific Native Californian groups. Of those 14 species, three species are members of the section Lobatae (*Q. agrifolia, Q. kelloggii, Q. wislizenii*), seven species belong to the section *Quercus* (*Q. sadleriana, Q. douglasii, Q. lobate, Q. garryana Q. dumosa, Q. berberidifolia, Q. turbinella*)*,* two belong to the section Protobalanus Intermediate (*Q. chrysolepis, Q. vaccinifolia*) and two species are in the genus *Notholithocarpus (N. densiflorus, N. densiflorus* var. *echinoides*).

The species used most extensively by native Californian groups are *Q. kelloggii* used by 17 groups (Miwok, Cahuilla, Pomo, Karuk, Mono, Chukchansi/Choynomni, Nisenan, Northeastern Maidu, Wintu, Hupa, Shasta, Yuki, Hill Patwin, Northern Maidu, Southern Maidu, Yokuts), *Q. lobata* used by 12 groups (Plains Miwok, Nisenan, Northwestern Maidu, Chumach, Sierra Miwok, Wintu, Yuki, River and Hill Patwin, Pomo, Southern Maidu, Yokuts), *Q douglasii* used by 9 groups (Sierra Miwok , Nisenan, Ohlone, Wintu, Yuki, River and Hill Patwin, Southern Maidu, Miwok), Q. *wislizenii* used by 9 groups (Sierra Miwok, Nisenan, Northwest Maidu, Northeast Maidu, Wintu, River and Hill Patwin, Southern Maidu, Miwok), and *Q. chrysolepis* used by 9 groups (Cahuilla, Sierra Miwok, Hupa, Shasta, Yuki, Pomo, Northern Maidu, Karuk, Kumeyaay).

Species specific references to seasonality of fire focused on *Q. kelloggii* and *N. densiflorus*. References are made to five tribes utilizing late summer/fall fire for the maintenance of *Q. kelloggii* for acorn production (Maidu, North fork Mono, Chukchansi, Choynumni, Western Mono). Two tribes reference using fall fire to maintain *N. densiflorus* for acorn production (Karuk, Yurok). One tribe is recorded to have used fall fire to maintain *Q. garryana* for acorn production (Shasta). Five references are made to the use of fall fire for unspecified oak species as well as general maintenance (Salinan, Eastern Miwok, Pomo, Tolowa, and an elder of Tubatulabal/Kawaiisu/Yokut/Miwok decent). A single reference was made to the use of spring fire for the maintenance of *Q. kelloggii* though not necessarily for acorns used for human consumption but more associated with hazel basketry management (Karuk).

Discussion

Available ethnographic record show that *Q. kelloggii* was by far the most utilized and the most widely distributed species of acorn by indigenous Californians (Chesnut 1902, Goddard 1903, Dixon 1905, Dixon 1907, Sparkman 1908, DuBois and Kroeber 1908, Kroeber 1932, Beals 1933, Barrett and Gifford 1933, DuBois 1935, Kniffen 1939, Gayton 1948, Schenck and Gifford 1952, Gifford 1967, Plumb and McDonald 1981, Haney 1992, Anderson 2005, Duncan 2012). This was followed by *Q. lobata* as the second most utilized but only 6th most widely dispersed taxon (Chesnut 1902, Kroeber 1932, Beals 1933, DuBois 1935, Kniffen 1939, Gayton 1948, Mayer 1976, Levy 1978, Plumb and McDonald 1981, Timbrook 1990, Duncan 2012). Other species such as Tanoak are noted as being a preferred species of acorn within the literature available from specific tribal groups but their use may be restricted by their comparatively small distribution compared to other more cosmopolitan species of oaks (Jack 1916, Schenck and Gifford 1952, Davis and Handryx 1991, Ortiz 2006).

Despite a large number of records for use of individual species of acorn producing tree in indigenous California, comparatively few records on the season and method of burning exist. Those that do primarily reference Black Oak (*Quercus kelloggii*) and Tanoak (*Notholithocarpus densiflorus*). All references point to the late summer and fall as the time when burning occurred for all species of acorn across tribal groups (Table 5). Associated references could be used to infer the timing of burning as in Timbrook et al. (1982, 1990) where extensive treatment is given to the Chumash people burning grasslands for seeds (Timbrook et al. 1982, Timbrook 1990). As many of the species of oaks within Chumash ancestral territory grow in open savannahs and woodlands interspersed with culturally valuable seed producing plants, inferences could be made that when burning for seeds occurred in the fall, acorn trees were also burned by association (Timbrook et al. 1982, Timbrook 1990).

The single reference to spring burning occurs in the black oak/white oak woodlands of the Klamath Bioregion. Among the Karuk people, black oak acorns are not the preferred species of acorn (B. Tripp, personal communication). Black oak woodlands were burned in the spring to encourage browse for game and other plant species of cultural value. While spring burning was employed in the cannon of management practices to encourage upslope plant species of cultural value and increase forage quality for deer and elk, it was not employed to manage specifically for acorns (B. Tripp, personal communication)

It is important to note that there are large gaps in the information available in ethnographic literature on indigenous California. Ethnographers sometimes showed bias in their focus on certain charismatic areas of indigenous life to the exclusion of others. This is exemplified in the extensive treatments available on the collection, processing, and preparing of acorns while comparatively little information is recorded on the method or timing of indigenous management for acorns (Driver 1952, Mayer 1976, Gifford 1989, Ortiz 1991, McCarthy 1993). Additionally, early ethnographers sought to understand indigenous Californian culture from within conflicting anthropological

systems of classification with varying degrees of success and acceptance (Woods 1934, Kroeber 1956, Buckley 1988). As such, large portions of information on indigenous life remains either outside the scope of recorded literature or viewed through the perspectives of ethnographers (Buckley 1988).

Further caveats present themselves as modern phylogenetic methods have restructured the classification of many taxa since the time that early ethnographies were written. The scrub oak complex has undergone extensive reclassification since the writing of the early 20th century ethnographies and the oak species named as being used by specific tribes, even via specific epithet, may now be referred to as a different species (Tucker 1952a, Nixon et al. 2002).

Conclusion

To engage in cultural activities is to make statements of identity and pride. When the resources upon which these acts of cultural identity depend dwindle or diminish, the capacity to continue to sustain cultural identity and pride diminishes. The ability to manage and utilize traditional material and food resources is a source of identity and pride to Native Californians. Current policy and the present state of California's forested ecosystems have created challenges to engaging the full canon of indigenous management practices including the fall cultural burns that were used to tend acorn gathering areas. Hopefully, these challenges will bring about new opportunities for collaboration to work towards healthier communities and resilient landscapes.

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Tables 1. Species of acorn producing tree in Native California for Section Lobatae and their recorded use among indigenous Californian groups.

Species of Use, Section Lobatae (Red/Black Oak)	Native Californian Use
Q. agrifolia	Chumash, Ohlone, Pomo (Bocek 1984, Gifford 1967, Timbrook 1990)
Q. kelloggii	Miwok, Cahuilla, Pomo, Karuk, Mono, Chukchansi/Choynomni, Nisenan, Northeastern Maidu, Wintu, Hupa, Shasta, Yuki, Hill Patwin, Northern Maidu, Southern Maidu, Yokuts (Haney 1992, Barrett and Gifford 1933, Sparkman 1908, Kniffen 1939, Gifford 1967, Schenck and Gifford 1952, Anderson 2005, Beals 1933, Duncan 2012, DuBois 1935, DuBois and Kroeber 1908, Goddard 1903, Dixon 1907, Chesnut 1902, Kroeber 1932, Dixon 1905, Gayton 1948)
Q. wislizeni	Sierra Miwok, Nisenan, Northwest Maidu, Northeast Maidu, Wintu, River and Hill Patwin, Southern Maidu, Miwok (Mayer 1976, Levy 1978, Duncan 2012, Dixon 1905, DuBois 1935, Kroeber 1932, Beals 1933, Barrett and Gifford 1933)

Tables 2. Species of acorn producing tree in Native California for Section Quercus and their recorded use among indigenous Californian groups.

Species of Use, Section Quercus (White Oaks)	Native Californian Use
Q. sadleriana	Karuk (Schenck and Gifford 1952)
Q. lobata	Plains Miwok, Nisenan, Northwestern Maidu, Chumach, Sierra Miwok, Wintu, Yuki, River and Hill Patwin, Pomo, Southern Maidu, Yokuts (Levy 1978, Duncan 2012, Mayer 1976, DuBois 1935, Chesnut 1902, Kroeber 1932, Kniffen 1939, Beals 1933, Gayton 1948, Timbrook 1990)
Q. douglasii	Sierra Miwok , Nisenan, Ohlone, Wintu, Yuki, River and Hill Patwin, Southern Maidu, Miwok (Levy 1978, Mayer 1976, Duncan 2012, Bocek 1984, DuBois 1935, Chesnut 1902, Kroeber 1932, Beals 1933, Barrett and Gifford 1933)
Q. garyanna	Pomo, Hupa, Shasta, Yuki, Karuk (Schenck and Gifford 1952, Kniffen 1939, Goddard 1903, Dixon 1907, Chesnut 1902)
Q. dumosa	Chumash, Wintu, Yuki (DuBois 1935, Chesnut 1902, Timbrook 1990)
Q. berberidifolia	Wintu (DuBois 1935)
Q. turbinella	Mojave (Anderson 2007)

Tables 3. Species of acorn producing tree in Native California for Section Protobalanus and their recorded use among indigenous Californian groups.

Species of Use, Section Protobalanus Intermediate (Golden Oaks)	Native Californian Use
Q. chrysolepis	Cahuilla, Sierra Miwok, Hupa, Shasta, Yuki, Pomo, Northern Maidu, Karuk, Kumeyaay (Sparkman 1908, Haney 1992, Goddard 1903, Dixon 1907, Chesnut 1902, Kniffen 1939, Dixon 1905, Schenck and Gifford 1952, Wilken 2012)
Q. vaccinifolia	Northeastern Maidu (Duncan 2012)

Tables 4. Species of acorn producing tree in Native California for other species of acorn producing tree and their use among indigenous Californian groups.

Other species of acorns used	Native Californian Use
N. densiflorus	Karuk, Hupa, Yurok, Shasta, Yuki, Pomo, Tolowa. Chilula (Chesnut 1902, Goddard 1903, Dixon 1907, Kniffen 1939, Schenck and Gifford 1952, Warburton and Endert 1966, Gould 1975, Lake Jr and Lake-Thom 1982)
N. densiflorus var. *echinoides*	Karuk (Schenck and Gifford 1952)

Table 5. Seasonality of fire prescription for acorn species according to Native Californian groups

Tribe	Acorn Species	Season of Burn
Yurok	Tanoak	Fall every year, Late Summer (Warburton and Endert 1966, Lewis 1973, Fryer 1995)
Maidu	Black Oak?	Fall/Winter (Duncan 2012)
Pomo		Fall (Kniffen 1939)
Tubatulabal/Kawaiisu/Yokut/ Miwok		October, first chill (Anderson 2005)
North Fork Mono	Black Oak	Fall, Sept./Oct. (Anderson 2005)
Chukchansi/Choynumni	Black Oak	Late August (Anderson 2005)
Western Mono	Black Oak	Oct., Nov., Dec. (Anderson 2005)
Karuk	Tanoak, Black Oak	Fall for Tanoak (Schenk and Gifford 1952), Spring for Black Oak* (Tripp, pers. comm)
Shasta	White Oak	Fall (when leaves begin to fall) (Lewis 1973).
Salinan	Oaks	Fall, when grass is dry (Anderson et al. 2012)
Eastern Miwok	Oaks	August (Levy 1978)
Tolowa	Oaks	Fall, after acorn harvest (Gould 1975)

Native Californian Ancestral Territories and Acorn Producing Species Distribution, Fig. 1a-1i (USGS, 1999, Redlands Institute 2002)

Fig 1a) Native Californian ancestral territories with species distribution for *Q. agrifolia*

Fig. 1b) Native Californian ancestral territories with species distribution for *Q. kelloggii*

Fig. 1c) Native Californian ancestral territories with species distribution for *Q. wislizeni*

Fig. 1d) Native Californian ancestral territories and the species distribution for *Q. lobata*

Fig. 1e) Native Californian ancestral territories and the species distribution for *Q. douglasii*

Fig. 1f) Native Californian ancestral territories and species distribution for *Q. garryana*

Fig 1g) Native Californian ancestral territories and species distribution of *Q. turbinella* and *Q. turbinella* subsp. *californica*.

Fig. 1h) Native Californian ancestral territories and species distribution of *Q. chrysolepis*

Fig 1i) Native Californian ancestral territories and species distribution of *N. densiflorus*

CHAPTER 2

Prescribed Fire and Tanoak Acorn Quality

Introduction

Fire is an important agent of spatial and temporal disturbance in California's terrestrial ecosystems which Native American communities have harnessed to maintain resources essential to livelihood and cultural continuity (Lewis 1973, Martin and Sapsis 1992). The use of fire in the management of pre-colonial forests by Native Peoples provided sustenance to human and animal populations, shaped local and regional patterns of diversity, and created spatially and temporally heterogeneous terrestrial communities (Lewis 1973, Martin and Sapsis 1992, Stephens et al. 2007). Acorns produced by trees of the genera *Quercus* and *Notholithocarpus* are used ubiquitously as a food source by Native Californian peoples (Davis and Handryx 1991, Gifford 1989, Anderson 2005, Anderson 2007). Acorns are a reliable resource that affords abundant proteins, carbohydrates, and fats (Wolf 1945, Gould 1975, Basgall 1987, Bettinger et al. 1997). Within the agro-forestry systems developed in indigenous California, the application of prescribed fire was the most important tool for maintaining quantities of edible acorns sufficient to support the nutrition of human and animal populations as well as important ceremonial activities (Driver 1952, Lewis 1973, Norgaard 2014). Indigenous burning practices are very precise; their applications vary by season, elevation, habitat type, and desired resource outcome (B. Tripp, F Lake, personal communication). Throughout California, understory vegetation is burned in the late summer to fall to facilitate resource collection and reduce populations of frugivorous insects that infest acorns (Lewis 1973, Anderson 2005, Anderson 2007). Dendochronology and fire scar studies conducted in the Klamath Bioregion confirm that the majority of pre-colonial burns (before 1750) occurred in the fall or winter (Fry and Stephens 2006, Taylor and Skinner 1998, Taylor and Skinner 2003). These data also document a large increase in fire return interval between pre-colonial and suppression periods (Skinner et al. 2009). In modern day forested ecosystems within California, native acorn crop management activities have become increasingly difficult to implement due to the high risk condition of under-managed forests and limited resources available to assist and supervise the application of indigenous prescribed fire (McCreary 2004, Anderson 2007). In this paper, we investigate the effects of spring fire prescriptions, a more attainable management strategy in the context of current political and environmental conditions, on cultural resource quality and abundance. We show that even a non-traditional pattern of late-spring prescribed burning can reduce infestation of Tanoak *(Notholithocarpus densiflorus,* Fagaceae) acorns by larval predators.

Acorns

Tanoaks are found at low and mid-elevations in the coastal and slightly inland portions of the Klamath Mountains between the Yurok coastal village of Requa at the mouth of the Klamath River to Seiad Valley in Siskiyou County (Niemiec et al. 1995, Sawyer 2007, Bowcutt 2013). Tanoak acorns are considered 'two year' acorns as their maturation occurs during the year following flowering and pollination. Tanoak acorns are an important nutrient source in the cultural diet of the Karuk and Yurok people; they are used in the preparation of acorn soup, bread, and as a ceremonial foodstuff (Wolf 1945,

Davis and Handryx 1991, Anderson 2005). The procurement and processing of Tanoak acorns engages cultural ecological knowledge on many levels including timing of resource procurement, management of familial gathering areas, the weaving of baskets associated with acorns, and ceremonial activities utilizing tanoak products (Gould 1975, Anderson 2005, Anderson 2007). Tanoaks will abscise infested or improperly developing acorns earlier in the fall while retaining viable acorns in the canopy until kernel filling is completed resulting in a bimodal acorn abscission pattern (Niemiec et al. 1995, Rohlfs 1999, Vander Wall 2001).

Acorns and Insects

Tanoak acorns are heavily attacked by the filbert weevil (*Curculio occidentalis*. Curculionidae) and the filbertworm (*Cydia latiferreana*, Tortricidae) (Tappenier 1990, Vander Wall, 2001). Tanoak and insect life histories are illustrated in Figs 1 and 2, respectively. From late spring thru early fall, adult weevils deposit eggs into the developing cotyledon through an oviposition hole; adult filbertworms lay eggs on the exterior seed coat close to the acorn cupule or on the bark of adjacent twigs of the tree (Rohlfs 1999, Swiecki and Bernhardt 2006). After the eggs hatch, filbertworm larvae will burrow into the acorn through the micropile (Rohlfs 1999). Consumption of acorn tissue by larvae of both insects begins during the summer months once the eggs have hatched (Michelbacher and Ortega 1958, Rohlfs 1999) Infestation can occur in the canopy or on the ground once the developing larvae exit the recently dropped acorn in search of additional food sources (Michelbacher and Ortega 1958, Rohlfs 1999, Vander Wall 2001). During the late fall and winter months larvae will overwinter in the litter/duff layer or in fallen acorns and re-emerge as adults the following spring (Rohlfs 1999, Swiecki and Bernhardt 2006). While not as conspicuous as members of the sister taxa *Quercus*, tanoaks can generate synchronous production of abundant seeds at regular intervals; this fruiting patterns can swamp seed predators (Silvertown 1980, Kelly 1994, Koenig et al. 2002, Kelly and Sork 2002a, Bowcutt 2013). Nut bearing trees exhibit traits to reduce the impact of predation including the abortion and early dropping of infected nuts and masting (Janzen 1971, Silvertown 1980, Sork et al. 1993, Kelly 1994, Vander Wall 2001, Espelta et al. 2008). In addition, acorn insect predators exhibit the capacity to undergo prolonged diapause which may counteract the defensive effect of variable resource production in masting tree species (Janzen 1971, Hanski 1988, Maeto and Ozaki 2003, Bel-Venner et al. 2009)

Fire, Acorns, Insects, and other Consumers

The application of resource-specific prescribed fire was the primary method used by the Karuk and Yurok Tribes to reduce the incidence of larval infestation in acorn resource systems (Lewis 1993, Anderson 2005, Anderson 2007). Fall prescribed fires targeted vulnerable phases in the life-cycle of insect predators when recently emerged larvae are beginning to consume cotyledon material and night-time ignitions increased the chances of reducing nocturnal adult filbert worm populations (F. Lake, B. Tripp, personal communication). Low severity surface and ground fires set in tanoak orchards likely caused large reductions in larval populations living in the litter/duff later and in

recently abscised acorns (Anderson 2005). Field observations suggest that even minimal scorching of the acorn pericarp was sufficient to kill enclosed larvae (F. Lake, A. Halpern, personal observation).

Traditional ecological knowledge shared by Karuk and Yurok tribal community members states that prescribed fire will have an effect on larval predation in acorns in both the year of the fire and the subsequent year; however, the effect will be larger in the subsequent year (F. Lake, B. Tripp, personal communication). The reduction in predation intensity during the year of the fire is hypothesized to occur due to heat-caused mortality of predator populations in abscised acorns and the duff layer in the immediate vicinity of Tanoak trees. The enhanced post-fire year effect is thought to result from the previous year's treatment fires reducing the number of living larvae that reach reproductive maturity; this reduces the number of eggs and larvae present in the post-fire year to consume the acorn crop.

Large mammals, including deer and black bear, visit recently burned orchards to forage on acorns (F. Lake, personal communication). Cultural practitioners report evidence of large mammals preferentially consuming sound acorns and leaving infested or otherwise inedible acorns (F. Lake, personal communication).

Questions and hypotheses

The following hypotheses were tested about the relationship between acorn production, prescribed fire in spring, and acorn infestation and the quantity and quality of the acorn food resource system.

A) Baseline (unburned) acorn infestation rates will be similar across research sites and between years.
B) Prescribed fire will reduce incidence of insect infested acorns. Rates of insect infestation will be reduced in burned cages the year of the fire but the effect of treatment will be more pronounced in the subsequent post-fire year.
C) Infestation rates will be higher in burned, uncaged plots likely due to selective balanophagy on high quality acorns by non-human mammalian consumers following fire.

Methods

Study Site Selection
The study was conducted in 2013 and 2014 within the ancestral territories of the Karuk and Yurok Tribes of California in the mid-Klamath River watershed between Somes Bar and Morek, CA (41°22′34″N 123°28′34″W and 41.3439° N, 123.8539° W). Research sites within tribal ancestral territories were selected based on the following criteria:

1) Presence of acorn-producing tanoak stand
2) Presence of historical management according to tribal practitioners (K. McCovey personal communication)
3) Contained within private property or reservation land

4) Property steward supportive to the application of prescribed fire and prescribed fire already planned and funded.

A site is defined as the area intended for burning within the boundary of private or reservation property. Five research sites were identified and developed (Tables 1 and 2). Three of the five elected sites (Cooper Upper, Cooper Lower, FKL) were exposed to two treatments, fire (spring burn) and no fire (control). FKL had an insufficient number of unburned control cages and was omitted from the test of hypothesis B. Two sites were unable to be burned due to available burn days and existing state fire restrictions (BG40, Butler). Data from these two sites were used in the tests of hypotheses A and C.

Sample Trees and Exclosures

Once a site had been identified, a set of suitable sample trees was selected within the site; these were distinguished by the presence of acorn remains from the previous year's crop within the dripline of the canopy, and a minimum dbh of 30 cm. The number of sample trees selected within a site (range of 13-30) depended on the size of the site itself and the number of tanoaks present. A single plot measuring 2m x 1m was established under the densest part of the canopy of each sample tree, as judged visually. Our initial study designed focused exclusively on insect impacts, so mammals were excluded from all plots by installing mesh cages over each of the study plots. These exclusion cages, which measured 2m x 1m x 30 cm were constructed of reinforcing bar, ¼" hardware cloth and 2" hex mesh. The design allowed acorns to fall into the excluded plot where they were inaccessible to large herbivores and the mesh size was large enough to allow fire and small insects to pass through unimpeded. The exclusion cage was subdivided into two contiguous 1x1 meter subplots. Acorns used for this analysis were collected from one of the subplots (all acorns in the subplot were removed) while those in the adjacent subplot were left undisturbed as a treatment for an associated experiment on the combined effects of fire treatment and seed removal on cultural plant species diversity (Chapter 4). All plots were constructed between 2011 and 2013. Additional non-contiguous, 1x1 meter uncaged plots were installed adjacent (1-3 meters away) to each caged plot in 2014 to quantify annual rates of acorn consumption by mammalian seed predators and to assess whether selective balanophagy affects the quantity of food grade acorns available for human gatherers following prescribed fire. Uncaged plots received the same burned or unburned treatment as their caged counterparts. Extant acorns and understory vegetation were left undisturbed after the establishment of the plots.

Treatment Fires

Fire line construction included the removal of duff and litter layers down to bare mineral soils at a width of roughly 1 meter in a perimeter that completely encircled the site. Any live or dead biomass that crossed the fire line from the burn unit into the neighboring area was relocated into the burn unit. All treatment fires were executed during the last two weeks of June in 2013. Once ignitions commenced within burn units, broadcast burns were allowed to move unimpeded. As a result, some plots within treatment areas burned while others did not creating a haphazard spatial distribution of treated and untreated cages within treated research sites. Fire line intensity was calculated to assess homogeneity of fire treatments among fire treated research sites (FKL, Cooper

Upper, Cooper Lower). Presence/absence of scorch and scorch height were assessed where visible for each tree within the treatment perimeter to estimate fire line intensity using the following equation (S. Stephens, personal communication).

Fire line intensity (kW/m)=250 x flame length (m) [2]

Stand Assessment for Site Similarity

Sites were assessed for similarity using a variety of stand level metrics including a comparison of slope, aspect, and elevation from the middle of the treatment area. Sample tree diameter was measured at breast height for each tree under which a plot had been placed, canopy closure directly over each plot was estimated using a concave densitometer, and canopy area was determined by taking canopy radius measurements at the cardinal directions and calculating the elliptical area of the tree canopy. See Tables 1 and 2 for descriptive site characteristics.

Acorn Collection

Laboratory dissections were performed on acorns collected from the experimental plots in 2013 and 2014. For both years, collection of acorns from all cages was conducted at three time points: early (late September-early October), mid (mid-late October) and late acorn production season (early-mid November). In 2014, in addition to the three collections from the exclosure cages, acorns were collected from each uncaged plot to measure the impact of acorn consumption by mammalian seed predators on acorn infestation rates and to assess the impact of herbivory on the quantity of edible acorns at each site.

Paper sacks containing acorns from each plot were stored in canvas bags by sampled site and time point. No plastic was used to contain stored acorns so as to reduce mildew, enhance airflow, and speed drying. Acorns were allowed to dry for 3-4 months at room temperature in order to mimic indigenous acorn storage protocols. Acorns were cracked using a hammer and picked apart by hand. The cotyledon was examined for frass, the presence of larvae, or cotyledon discoloration resulting from insect consumption. Insect attacked acorns are defined based on either the presence of a larva within the acorn, a partially or completely consumed cotyledon, or the presence of frass within the pericarp. Edible acorns were considered those with undamaged cotyledons that had completed maturation.

Statistical Tests

All analyses were performed in JMP Pro (SAS Institute Inc., Cary, NC 1989-2007) and R (R Core Team 2013). Data derived from the three acorn collections made at each caged or uncaged plot were pooled prior to analysis. The average proportion of acorns attacked by insects was compared among sites and burn treatments. The proportion of acorns attacked by insects was calculated by dividing the number of insect-infested acorns per plot by the cumulative acorn production per plot. Proportion data was transformed using an arcsine transformation to meet the ANOVA assumptions of

homogenous variance. Particular subsets of the five research sites were included in different analyses. Significance was assessed at α=0.05 for all analyses.

The following analyses were performed

a) A two-way ANOVA was conducted to compare the baseline (untreated) rate of insect infestation in acorns collected from exclusion cages in unburned areas of four research sites during the 2013 and 2014 sampling years. The site FKL was excluded from this analysis due to lack of sufficient unburned cages. A Levene's test was conducted to assess the assumption of homogeneity of variances among site and year test groups. An arcsine transformation was successful at achieving homogeneity of variance ($f_{(7,94)}$=0.57, p=0.45). A post-hoc Tukey HSD test was used to determine which site and year combinations significantly differed from each other if a significant difference was detected.

b) A mixed model ANOVA was used to assess rates of insect attack between burned and unburned treatment categories at the two research sites (Cooper Lower and Cooper Upper). Levene's test was used to test the assumption of homogenous variances among treatment, year, and site test groups. An arcsine transformation was successful at achieving homogeneity of variance ($f_{(7,74)}$=1.93, p=0.07). In the model, Treatment (burned vs. unburned) and Year (fire year vs. post-fire year) were treated as fixed factors and Site was treated as a random factor. A post-hoc Tukey HSD was used to assess which treatment, site, and year combinations significantly differed from each other.

c) Using 2014 data, a two-way ANOVA was conducted examining the effect of herbivory exclusion (caged and uncaged) and treatment (burned and unburned) on rates of acorn infestation. A Levene's test was used to test the assumption of homogenous variances among treatment and exclusion groups. Arcsine transformation was successful at achieving homogeneity of variance ($f_{(3,161)}$=2.26, p=0.08). A student's t-test was used to assess which treatment and cage combinations significantly differed from each other. A paired t-test using was performed to compare mean acorn density in caged and uncaged plots.

Results

Comparison of site characteristics

Site characteristics were similar with the exception of canopy area and aspect (Table 1). Sites spanned elevations from 368 to 742 meters and slopes were modest (10-16 degrees). There was some variation in aspect (south to northeast) (Table 1), in average tree canopy area (83-131 m^2), average dbh (70-100 cm) (Table 2), and average fire line intensity (207-399 kW/m). Variation in these site characteristics was not correlated with levels of insect infestation. Average acorn density was 20.35 acorns/m^2 in 2013 and 7.00 acorns/m^2 in 2014.

Background variation in infestation rates among unburned sites and between years

Patterns of infestation varied among research site ($f_{(3,94)}$=4.03, p=0.0096, Fig. 3) and between years ($f_{(1,94)}$=14.2536, p=0.0003, Fig. 3); however, site differences were consistent between years (i.e. no significant interaction between site and year): ($f_{(3,94)}$=1.93, p=0.13, Fig. 3). Tukey HSD tests indicated that there was no significant difference among the sites in either 2013 or 2014 (Fig. 3).

Effect of burning on infestation rates

Fire treatment significantly reduced insect infestation in collected acorns ($f_{(1,1)}$= 1107.17, p=0.019) but the effects of fire did not vary by year ($f_{(1,1)}$= 1.29, p=0.459, Fig. 4). Acorns collected in 2013 had a marginally higher average rate of infestation than those collected in 2014 ($f_{(1,1)}$= 97.90, p=0.064, Fig. 4). Tukey HSD tests indicated that rate of acorn infestation was significantly different at the Cooper Lower unburned sites in 2013 and at the Cooper Lower burned sites in 2014 (Fig. 4).

Effect of mammalian acorn consumption

Mammalian herbivory significantly affected the proportion of infested acorns in caged and uncaged plots ($f_{(1,132)}$=5.39, p=0.022, Fig. 5). The effects did not vary by burn treatment ($f_{(1,132)}$=3.61, p=0.06, Fig. 5). Selective consumption of sound acorn by mammalian consumers did not differ between burned and unburned treatments ($f_{(1,132)}$=0.3, p=0.59, Fig. 5). The mean rate of acorn infestation in uncaged plots was higher than in caged plots (mean caged = 20.41, mean uncaged = 28.94). Average acorn density in caged plots (9 acorns/m^2) was higher than in and uncaged plots (7.5 acorns/m^2) during the 2014 sampling year (paired-$t_{(67)}$=1.63, p=0.05).

Discussion

Background rates of infestation varied among unburned sites and years. Spring prescribed fire reduced insect infestation rates by an average of 13.55% in the year of the fire and 16.25% in the year following fire; the magnitude of this effect did not differ significantly between years. Mammalian herbivory reduced the number in edible acorns; this effect was not affected by fire treatment.

Baseline infestation rates varied between sampled research sites; a variety of factors could be responsible for the difference. Infestation rates at the Butler research site were notably lower in 2014 than other sites. The decrease in infestation rates at the Butler site could have been influenced by a nearby wildland fire. The Butler Fire component of the Forks Complex wildfire (37,246 acres) burned immediately adjacent to the treatment sites from July to December in 2013; the heat and smoke of the fire could have reduced insect populations in 2014 (the year following fire).

Other studies have shown that elevation could affect rates of infestation; however, there was no discernable pattern of variation in baseline infestation rates over the range of elevations examined in this study. In studies examining patterns of *C. latiffereana* and *C. occidentalis* infestation in blue and valley oak acorns, elevation was found to have

the most significant effect; insect attack of acorns was higher at higher elevations (4,200-4,690 ft.) and lower elevations (1,250-2040 ft.) than at intermediate elevations (2,640-3,910) (Phillips 1992). Research sites for this study varied in elevation between 368 and 742 meters (1207 and 2434 ft.) and fall into the low elevation category described by Phillips.

Baseline infestation rates in unburned sites did differ between sampling years, being higher in 2013 than in 2014. Since overall seed production was also higher in 2013 than in 2014, the difference in infestation rates are not explained by the predator satiation hypothesis, which posits that during years of increased seed production, rates of seed predation will be reduced compared to years of low seed production years (Janzen 1971, Silvertown 1980, Koenig et al. 1994, Kelly and Sork 2002b). Simple predator satiation dynamics might not take into account the possibility of prolonged diapause in curculionid weevils and other insect predators, which could generate different correlation patterns (negative, positive, or inconclusive) between insect damage and acorn production in alternate years (Janzen 1971, Hanski 1988, Maeto and Ozaki 2003, Bel-Venner et al. 2009). Results from studies both supporting and contradicting the predator satiation hypothesis as it relates specifically to acorns and insect predators have been summarized in (Rohlfs 1999). In addition to the consumption of tanoak acorns, *Curculio occidentalis* and *Cydia latiferreana* are generalist consumers of nuts from the genus *Corylus* (including *Corylus maxima*, the agriculturally produced filbert) and other species of *Quercus* that grow in proximity to *N. densiflorus* in the Klamath Bioregion including *Q. kelloggii* and *Q. sadleriana* (Rohlfs 1999, Bruck and Walton 2007, Walton et al. 2007). As different species of *Quercus* exhibit different masting intervals, generalist insect populations living in areas containing other species of *Quercus* adjacent to the research sites could have migrated into the sites during the fire year (2013) and increased baseline infestation rates (Sork et al. 1993).

Treatment fires conducted in late spring significantly reduced insect infestation in acorns. Traditional ecological knowledge hypothesizes that the effect of fires will be more pronounced in the year following fire as treatments will reduce populations of reproducing adult insects (Fig. 1 and 2); however, there was no significant evidence that infestation rates were different between treatment-years. Treatment fires were similarly effective at reducing rates of acorn infestation in both the year of the fire and one year post-fire (Fig. 4). There was a sizable and significant effect of herbivory on rates of acorn infestation in uncaged compared to caged plots indicating that mammalian seed predators do feed selectively and focus on sound acorns while leaving the inedible or insect infested acorns untouched.

While late spring/early summer fire treatment was effective in reducing the numbers of infested acorns, it did not match the traditional timing of fire application. Historically and culturally, tanoak orchards were typically burned in the fall months to target adult insect predators at vulnerable larval stages in their life history and to reduce, but not completely exterminate, populations of reproducing adults which would lay the eggs that would infest the following year's acorn crop (Jack 1916, Anderson 2005, Ortiz 2006, Swiecki and Bernhardt 2006, Anderson 2007). Generally, cultural taboos are placed on

using fire as a management tool when cultural celestial indicators are absent from the sky at certain times of the year (B. Tripp, personal communication). When these celestial bodies cannot be seen, fire can only be used for heating and cooking (B. Tripp, personal communication.). Our treatment fires did not occur during the assumed optimal season for tanoak management (fall months) but did occur at a time when appropriate celestial indicators were present in the sky. Given that, while burning was done during a non-traditional time of the year, our treatment fires occurred at a time when fire management activities beyond cooking and heating are not culturally taboo. Therefore, fire management activities at this time, while not optimal, are culturally acceptable. As an extension of the current study, traditional practitioners hypothesize that treatment fires conducted during culturally optimal tanoak management season would reduce rates of insect infestation even more significantly than those conducted during other culturally acceptable fire management windows (B. Tripp, personal communication). This hypothesis remains to be tested.

The study results are consistent with published accounts of the application of prescribed fires by indigenous peoples to reduce predation pressure by insects on *Quercus* acorns in other regions of North America. Wright (1986) provided evidence to support the mitigating effect of prescribed fire on weevil infestation of acorns in red oak (*Quercus rubra*) populations in southeastern Ohio (Wright 1986). (Riccardi et al. 2004) demonstrated the combined effects of prescribed fire and thinning in reducing predation from *Curculio* and *Conotrachelus* weevils in *Q. vetulina* (black oak) and *Q. prinus* (chestnut oak). Populations of curculionid weevils were reduced following spring fire in *Q. rubra*, *Q. alb(a*, and *Q. prinus* dominated forests of West Virginia (McCann et al. 2006). In contrast, other studies have shown little to no effect of prescribed fire treatments on insect, specifically weevil populations in eastern US oak dominated forests (Lombardo and McCarthy 2008).

Mammalian seed predators were shown to preferentially consume sound acorns regardless of burn treatment thus increasing the proportion of infested acorn in open plots (Fig. 5). As one of many species that consume acorns, tribal gathering practices have been designed to ensure the availability of the resource for all species for which acorns are a dietary staple (F. Lake, personal communication, Chapter 3).

The absence of opportunities to procure, process, and consume traditional foods has been shown to have adverse effects on the health of indigenous Californian communities in the Klamath River Basin (Norgaard 2014). The act of tending wild resources such as acorns not only increases access to nutritious, culturally relevant foods but also strengthens individual and community relationship with place and ancestral lands, an essential part of indigenous identity and community well-being (Anderson 2005). Despite the likelihood that traditional patterns of fire application to tanoak groves may prove difficult to maintain in the future, our study shows that when fire is applied earlier in the year, it can still be a useful management tool for promoting a viable acorn resource.

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Table 1: Site characteristics and treatment specifics for all research sites. Control= Unburned, Treatment=Burned. One plot was constructed per tree. * 2014 only.

Site	Elevation (meters)	Slope	Aspect	Site Area (hectare)	Total Number of Trees/Plot	Treatment	Treatment Date	Burned Plots	Control Plots
Cooper Lower	368	13°	S	1.12	26	Burned	6/11/2013	21	5
Cooper Upper	423	16°	SE	0.45	18	Burned	6/23/2013	14	4
FKL	514	10°	NE	0.36	13	Burned	6/17/2013	10	3*
Butler Flat	315	11°	NE	1.45	19	Unburned	N/A	N/A	19
Beargrass 40	742		SE	3.26	30	Unburned	N/A	N/A	30

Table 2. Mean values for descriptive site characteristics data from each site. Standard error mean in parentheses.

Site	Avg. DBH (cm)	Avg. Canopy Cover (%)	Average Canopy Area (m^2)	Avg. Fireline Intensity (kW/m)
BG40	103.53 (2.37)	78.60 (0.84)	135.74 (5.11)	N/A
Butler	62.13 (1.2)	80.99 (1.23)	77.11 (2.23)	N/A
Cooper Lower	70.81 (1.53)	88.79 (0.84)	81.27 (2.93)	398.58
Cooper Upper	77.14 (2.6)	86.00 (0.56)	91.62 (4.04)	312.5
FKL	85.31 (4.33)	92.02 (0.71)	110.51 (5.61)	207.36

Fig 1**.** Multi-year description of tanoak and insect life cycles using insect life history information from (Tappeiner et al. 1990, Swiecki and Bernhardt 2006).
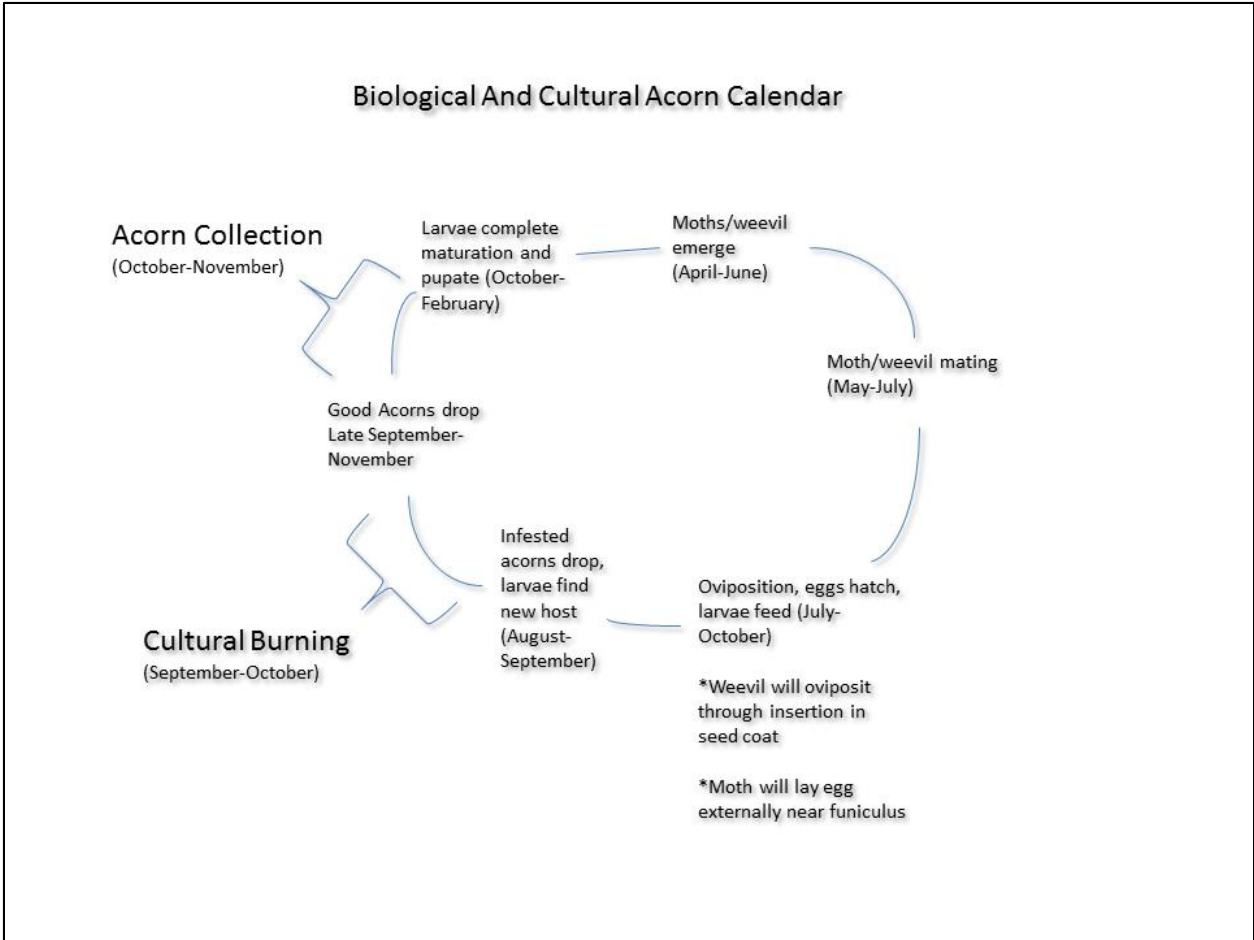
Fig 2. Seasonal description of tanoak life cycle and associated cultural management activities with modified information from (Swiecki and Bernhardt 2006, Anderson 2007, Tappeiner et al. 1990)
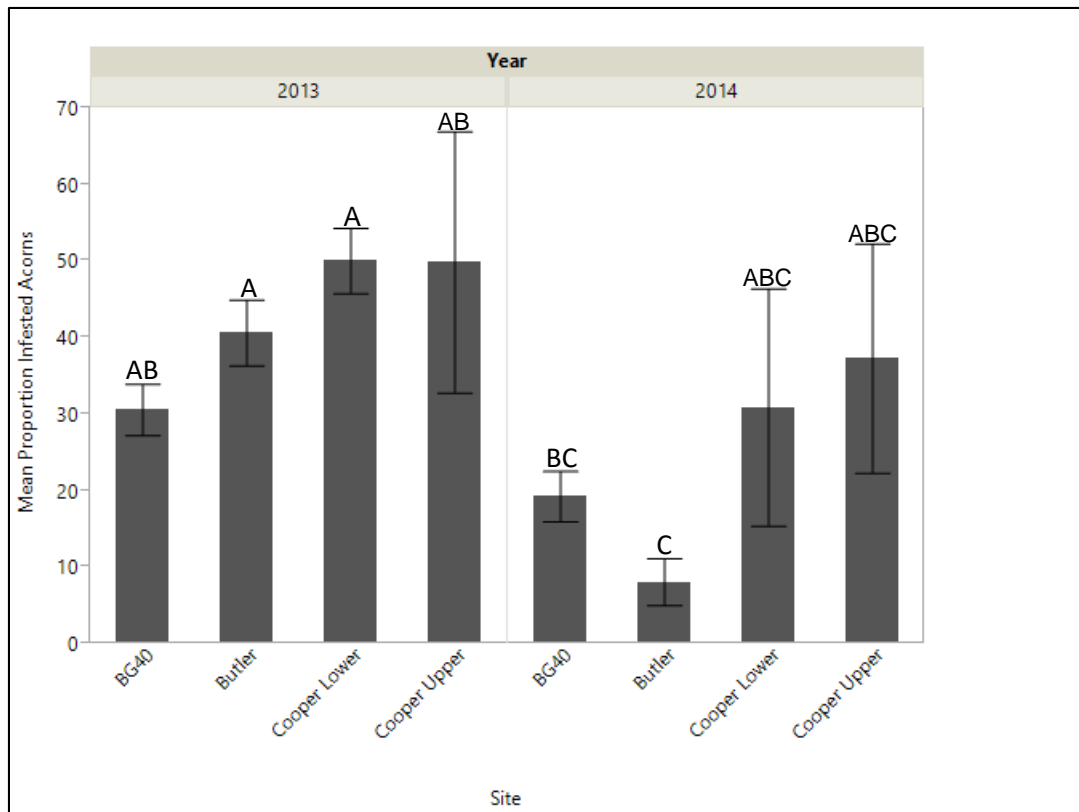
Fig. 3. Proportion of insect infested acorns at unburned sites for 2013 and 2014. Error bars represent one standard error from the mean and values represent site means. Site similarity/dissimilarity assessed by Tukey HSD tests are represented by letters above the error bars.
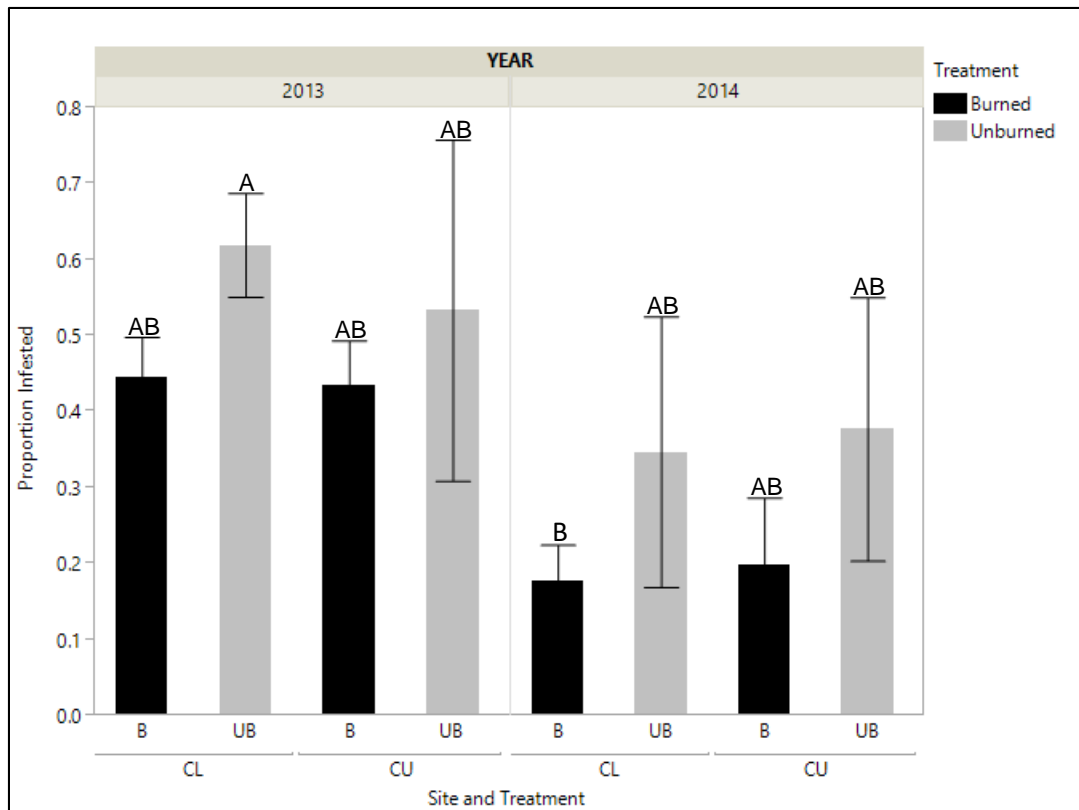
Fig. 4. Mean site and treatment acorn infestation for sample years 2013 and 2014. CL=Cooper Lower, CU=Cooper Upper. B=Burned, UB=Unburned. Black represents average values pooled over burned cages within a site, grey represents average values pooled over unburned cages. Standard error bars describe one standard error from the mean. Site similarity/dissimilarity assessed by a Tukey HSD test are represented by letters above the error bars.
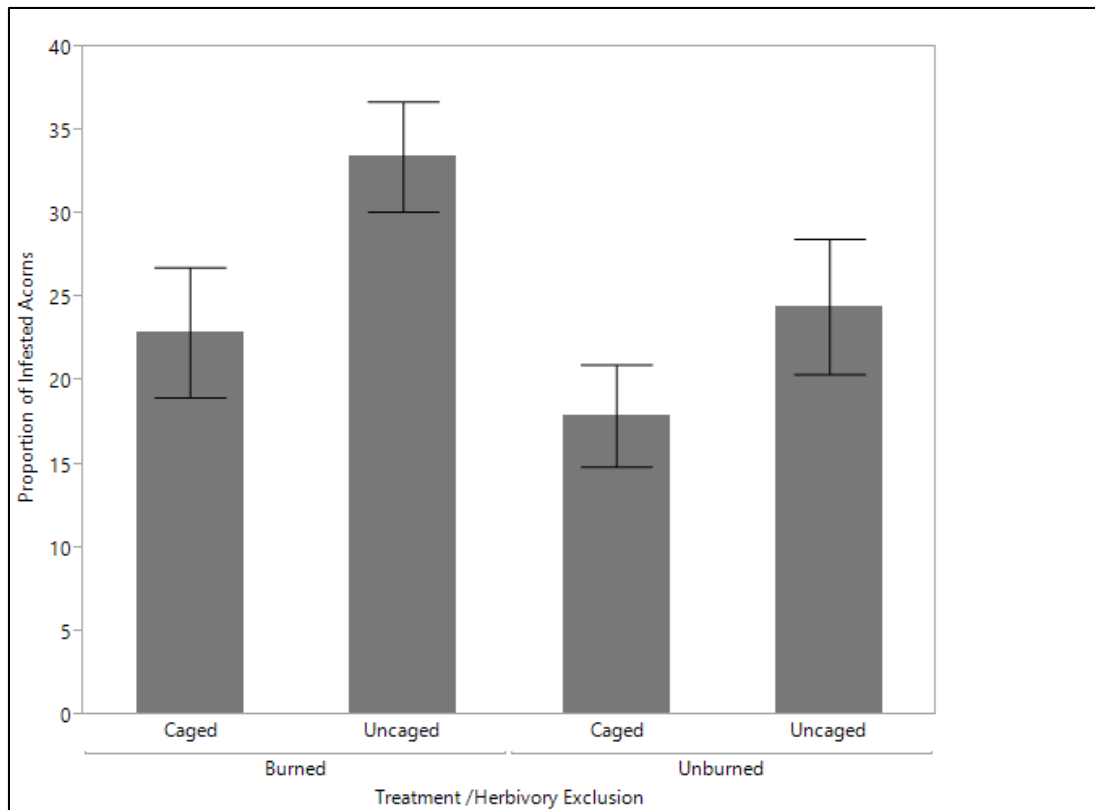
Fig. 5. Proportion of infested acorns in excluded and un-excluded plots during sampling year 2014. Data are derived from all five research sites. Standard error bars represent one standard error from the mean.

CHAPTER 3

Indigenous Acorn Assessment and Acorn Consumption Quality

Introduction

Engagement in cultural gathering practices and the consumption of traditional foods maintains and enhances cultural identity on an individual and community scale and supports the continuity of indigenous cultures around the world (Salmon 2000, Anderson 2007). Harvesting strategies and food item selection criteria are place-based, traditional cultural knowledge and skills passed down through generations in a resource-specific context. Strategies and criteria are considered an important part of the canon of traditional ecological practices that embed humans within a network of species and biological ecosystems (Salmon 2000, Long et al. 2003, Kimmerer 2011). Selection practices are intended to mirror indigenous concepts of reciprocal relationships between humans and nature such that only necessary quantities of any given resources are harvested, that enough is left to regenerate the harvested populations, and that sufficient quantities are left for other organisms that consume the same resource (Connors 2000, Salmon 2000, Anderson 2005, Kimmerer 2011).

Acorns from members of the genera *Quercus* and *Notholithocarpus* play a central role in the diet of many indigenous peoples of northwestern California (Driver 1952, Schenck and Gifford 1952, Merriam and Heizer 1967, Mayer 1976, Bocek 1984, Davis and Handryx 1991, Haney 1992). For the Karuk and Yurok peoples of California, *Notholithocarpus densiflorus* acorns are the preferred species (B. Tripp, personal communication). The emergence of established acorn economies for consumption, trade, and ceremony in California occurred at different times throughout history (Baumhoff 1963, Basgall 1987). In contemporary times, acorns maintain a prominent place in the traditional diets of most indigenous Californian peoples and continue to be used in a ceremonial context (Gould 1975, Ortiz 1991, Anderson 2007). Consistent access to a higher quality and quantity of desired acorns requires effective pest management. The Karuk, Yurok, and other tribes in California utilized several management strategies to improve acorn quality by reducing non-desired acorn pests at the landscape, stand (orchard), and individual tree level. These include burning at the landscape and orchard scale, pruning or thinning branches and competing vegetation, and ceremonies to increase tree health.

Tanoak acorns can be heavily attacked by larvae of the filbert weevil (*Curculio occidentalis.* Curculionidae) and the filbertworm (*Cydia latiferreana*, Tortricidae) (Tappenier 1990, Vander Wall, 2001). Tanoak and insect life histories are illustrated in Figs 1 and 2, respectively. Adult weevils deposit eggs into the developing cotyledon through an oviposition hole, while adult moths lay eggs on the exterior seed coat close to the acorn cupule during the late spring thru early fall (Swiecki and Bernhardt 2006). Larval consumption of acorn tissue begins during the summer months once the eggs have hatched (Michelbacher and Ortega 1958, Rohlfs 1999). Infestation by both the filbert worm and the filbert weevil can occur in the canopy or on the ground once the developing larvae exit the recently dropped acorn in search of additional food sources (Michelbacher and Ortega 1958, Rohlfs 1999, Vander Wall 2001). During the late fall

and winter months larvae will overwinter in the duff layer or in fallen acorns and re-emerge as adults the following spring (Swiecki and Bernhardt 2006). Insect damage to cotyledons, mold, and incomplete cotyledon maturation will render an acorn unusable as a desired tribal food item.

For the Karuk and Yurok peoples, tanoak acorn collection generally occurs in the fall months from late September to mid-November (C. Hostler Sr., F. Lake, B. Tripp, personal communication). The gathering of acorns is a seasonal group activity historically performed by families and groups of families (Gould 1975). Families maintained gathering rights at specific acorn orchards based on the location where a family lived along the Klamath River and time spent tending particular locations (Waterman 1920). Heritage tanoak acorn orchards are defined as traditional acorn and plant resource gathering areas, as identified by present day cultural practitioners; these sites were tended by particular families and exhibit physical characteristics of past harvesting and stewardship activities (K. McCovey, personal communication). Some acorn orchards were near villages while others were located at longer distances, some over 10 miles, from villages (Warburton and Endert 1966, Bettinger et al. 1997). Selection criteria for acorns involves the discernment of inedible and insect infested acorns from sound and potentially edible acorns (Jack 1916, Anderson 2005, Anderson 2007). I seek to assess the accuracy of cultural acorn-gathering criteria and to ascertain whether the external assessment of acorns by the non-Native researcher based on learned indigenous criteria accurately predicts the internal state of consumable cotyledon tissue.

Questions and hypotheses

This study was conducted in 2013 and 2014 at five sites along the Klamath River Watershed within the ancestral territories of the Karuk and the Yurok Tribes of California. I tested the following hypotheses surrounding the relationship between external acorn appearance and internal acorn quality which affects the edibility of an important Native food resource system:

The assessment of acorn quality based on indigenous external criteria will:

1) Accurately distinguish between acorns containing edible cotyledon tissue and acorns that are generally inedible for human consumption.

 2) Accurately distinguish between acorns containing edible cotyledon tissue and acorns that have specifically been attacked by insect larvae resulting in reduced nut meat quality.

The Karuk and Yurok People of California employ a number of visual and tactile assessment techniques to determine whether an acorn is of edible quality. An acorn is considered edible if its cotyledon is fully matured and has not sustained damage from insect predators or fungi (C. Hostler Sr., F. Lake, personal communication). Acorns with no insertions in the pericarp, a white coloring to the abscission point between the seed and the cupule, and of normal heavy weight by subjective estimation are hypothesized

to contain fully mature cotyledons that have not been affected by insect predators or fungi and are thus edible (C. Hostler Sr., F. Lake, B. Tripp, personal communication).

Methods

Acorns were collected as part of a larger study on the effects of indigenous Karuk and Yurok burning practices on acorn resource quality. Research sites at which this experiment was conducted were subjected to late spring burns to assess the impact of prescribed fire on rates of insect infestation in Tanoak acorns and on cultural plant diversity (Chapters 2 and 4). A total of 5 research sites were established between Somes Bar, CA and Morek, CA (see Tables 1 and 2 in the Chapter 3 Appendix for descriptive characteristics for each site as well as presence or absence of treatment fires, calculated fireline intensity, and other descriptive metrics used to assess site similarity). Sample trees within each site were identified based on size (minimum 30 cm diameter breast height) and/or the presence of acorn remains from past crops. A single plot measuring 2m x 1m was established under the densest part of the canopy of each sample tree. Exclusion cages, which measured 2m x 1m x 30 cm were constructed of reinforcing bar, 1/4" hardware cloth and 5 cm hex mesh for a related experiment on the effects of prescribed fire on acorn infestation (Chapter 2). The design allowed acorns to fall into the excluded cage, where they were inaccessible to large herbivores yet the mesh size was large enough to allow insects, surface, and ground fires to pass through unimpeded. Cages were divided into two 1x1 meter sub-cages for a related experiment on the effects of acorn collection and prescribed fire on cultural plant diversity (Chapter 4). The lead researcher (A. Halpern, non-Native) was trained by cultural practitioners to distinguish edible acorns from insect infested acorns according to indigenous collection criteria based on the appearance of the acorn pericarp and the weight of the seed, as described above (Karuk Tribe, Yurok Tribe personal communication). Collections occurred between September and late November in 2013 and 2014 (See Chapter 2). Acorns were collected from all cages, burned and unburned, as this treatment did not affect collection methods. At all research sites, acorns (total n=3499) were removed from one half of the caged plot and were assessed as either culturally acceptable (edible) or culturally rejected (inedible) based on learned criteria. The funiculus area was assessed for color, a cursory evaluation of the pericarp for insect insertion holes was made, and a subjective assessment of the weight of the acorn was made in-hand with heavier acorns considered to contain potentially more edible cotyledon tissue. The number of acorns assigned to the culturally acceptable and culturally rejected categories were tallied for each exclusion cage, and then the acorns were placed in appropriately labelled paper sacks for subsequent analysis in the laboratory. These collections were stored in canvas bags prior to dissection (See Chapter 2 for details). Canvas bags, rather than plastic containers were used for this purpose, so as to facilitate airflow, enhance drying, and minimize mildew and mold. Acorns were allowed to dry for 3-4 months at room temperature prior to laboratory dissection.

To investigate the relationship between external collection criteria and internal cotyledon condition, laboratory dissections were performed on the acorns collected in 2013 and 2014. Acorns previously assessed by learned cultural gathering criteria in the field were cracked open with a hammer and picked apart by hand. Cotyledon tissue was examined

in the lab; internal predation by insects was determined based on either the presence of a larvae within the acorn, a partially or completely consumed cotyledon, or the presence of frass within the pericarp. In order to assess the accuracy of indigenous collection criteria in ascertaining overall acorn edibility, additional information on the presence of mold on the cotyledon and the state of nut maturation was collected. These factors contribute to overall acorn inedibility but do not pose the immediate threat to stored acorns that insect attack creates. Once analyzed, each acorn was categorized as Laboratory Insect Attacked, Insect Attacked+Mold, Insect Attacked+Unfilled, Moldy, Moldy+Unfilled, Unfilled, Unfilled+Insect Attacked+Moldy, or Edible. Edible acorns were those with undamaged cotyledons that had completed maturation. Acorns cotyledons which had, inside the shell, turned coffee brown and lustrous with no evidence of mold or infestation were placed in the Edible acorn category on the advice of cultural advisors (R. McConnell, Yurok Tribe, personal communication). These acorns are considered a delicacy and were either set aside for individual consumption or combined with other edible acorns in the making of acorn foods (R. McConnell, Yurok Tribe, personal communication). Inedible acorns were the categories of acorns which had suffered insect attack, mold, and/or incomplete nut maturation. The acorns within these categories were grouped into a single category, Total Inedible, to allow for tests on the accuracy of indigenous collection criteria in determining the overall edibility of acorns. Additionally, those acorns which were specifically attacked by insects or any combination of insect attack and mold or incomplete maturation were pooled into the category, Insect Attacked, to analyze the accuracy of indigenous collection criteria in specifically determining insect infestation. Insect attacked acorns were those in the Insect Attacked, Insect Attacked + Mold, Insect Attacked + Unfilled, and Insect Attacked + Unfilled +Moldy categories.

Statistical Tests

Subjective analysis of individual culturally accepted/culturally rejected acorns based on learned indigenous criteria was compared with subsequent laboratory analysis for internal cotyledon state to assess the frequency of misclassification. All analyses were performed in JMP Pro and R using the DescTools package (SAS Institute Inc., Cary, NC 1989-2007, R Core Team 2013).

Contingency analyses (2x2) were conducted to compare the likelihood of correctly assessing the internal state of the acorn (Edible vs. Inedible and Edible vs. Insect Infested) based on external characteristics (Culturally Accepted/Culturally Rejected) for the pooled data. These frequencies were analyzed as four categories 1) Correctly identifying edible acorns, 2) Incorrectly identifying edible acorns, 3) Correctly identifying inedible and infested acorns, and 4) Incorrectly identifying inedible and infested acorns. G-tests of independence were performed to determine whether the hypothesis that learned indigenous criteria for acorn quality were consistent with laboratory-based determination of overall acorn edibility and acorn infestation by insects. Additionally, G-tests were conducted on acorn data for each research site to determine whether acorn assessment was consistent among sampling locations both for overall edibility and for insect infestation.

Results

The five research sites were relatively similar in slope (10-16 degrees) but varied in their aspects (south to northeast) (Table 1, Appendix). Mean tree DBH (70-100 cm) mean tree canopy area (83-131 m^2) varied across sites (Table 2, Appendix). Inter-site variation was not expected to affect the assessment of acorn quality.

Our initial test was of the ability of cultural collection criteria for acorn quality to accurately distinguish edible from inedible acorns. G-tests for pooled results across sites and years indicated that there was significant departure from the null hypothesis that methods of indigenous acorn evaluation are unable to correctly assess the edibility of the cotyledon tissue (G(1)=775.76, p<2.2x10^{-16}, n=3499). However, indigenous criteria were not 100% accurate in identifying edible vs. inedible acorns. The contingency analysis indicated that an average of 19% of the acorns characterized by indigenous collection criteria as culturally rejected were edible and an average of 28.6% of the acorns classified as culturally accepted were inedible. G-tests for all five individual research sites showed significant departure from expected values under the null hypothesis regarding overall acorn inedibility (Tables 3, 5, Appendix). While consistently significant, there was some variation in assessment accuracy between sites (Fig. 3). These patterns were observed for each site with some variation in the absolute accuracy of the assessment. More inedible acorns were classified as edible at Cooper Lower, Cooper Upper, and BG40 than at FKL or Butler.

The second analysis assessed how well cultural criteria could distinguish edible from insect infested acorns. G-test for results for pooled sites and year data showed a significant departure from the null hypothesis that evaluation by indigenous collection methods is incapable of correctly assessing the infestation state of the cotyledon tissue (G(1)=234.25, p<2.2x10^{-16}, n=3499). As for the edibility assessment (above), some acorns were misjudged. The contingency analysis indicated that 66.2% of the acorns categorized by external collection criteria as culturally inedible were not infested while 8.5% of acorns originally categorized as culturally edible were insect infested. G-tests for all five individual research sites showed significance departure from expected values under the null hypothesis regarding insect infestation (Tables 4, 6, Appendix). While consistently significant, again, there was some variation in assessment accuracy between sites (Figure 4). In a similar pattern to our first assessment, more insect attacked acorns were classified as edible at Cooper Lower, Cooper Upper, and BG40 than at FKL or Butler.

Incorrect assignment of edible acorns was predominantly due to the presence of mold in the cotyledon discovered during laboratory assessments rather than insect infestation or incomplete nut maturation (Fig. 5). Mold was the primary cause of inedibility at all sites followed by insect attack and incomplete cotyledon maturation (Tables 7, 8, Appendix).

Discussion

Cultural identifiers were very effective at determining overall acorn edibility. Those acorns that were incorrectly identified as edible were primarily due to the presence of internal mold. Cultural identifiers were also effective in identifying edible acorns and external characteristics were effective in distinguishing between non-infested and infested acorns. In addition, a large portion of the acorns identified by external criteria as insect attacked were, once examined internally, either edible or had suffered mold infestation or lack of cotyledon maturation. Despite the fact that cultural identifiers are unable to directly examine the cause of inedibility within the acorn pericarp, they were, on average, more accurate in identifying acorns which had specifically been attacked by insects than those which were generally inedible.

While very effective at diagnosing both overall inedibility and the presence of insects, an average of 19% of the acorns originally identified by external criteria as inedible contained edible cotyledon tissue once dissected. While this might seem a wasteful error in judgement, there is important cultural value to being overly conservative in the assessment of acorn infestation by insect larvae. As acorns are stored for extended periods of time in granaries or within individual dwellings, it is of paramount importance to ensure that no larvae or insects are inadvertently brought into an acorn storage area. While incomplete cotyledon maturation and mold are undesired characteristics, neither pose as much of a threat to an acorn storage area as insect larvae. Much like acorns in the orchards themselves, an insect within a storage area will bore into and consume the cotyledon tissue of neighboring edible acorns, pupate, and eventually become an adult seed predator. Members of the genus *Quercus* and *Notholithocarpus* are predominantly masting taxa and the availability of large volumes of acorns is periodic in most areas of California (McDonald and Tappeiner 1987, Koenig et al. 1994). In years when acorns are plentiful, the gathering of acorns is prioritized so as to ensure sufficient availability from storage in years when acorn crops are less abundant. Acorns are typically dried for at least two years before being cracked, ground, and prepared though it has been reported that acorns stored for longer periods of time, some up to 10 years, require less leaching time than younger acorns (C. Hostler Sr., F. Lake, personal communication). The gathering and storing of acorns is important in ensuring a constant availability of the resource within indigenous communities. Frugivorous insects accidentally introduced to a dwelling or a storage area can compromise years of gathering efforts and reduce food stores available for coming years (Anderson 2005). Whether indigenous collection criteria were specifically designed to conservatively mitigate such circumstances is not known; however, the effectiveness of cultural criteria at determining which acorns are insect-free (91.5%) is a testament to the competency of indigenous gathering practices.

Phillips (1992) noted a pronounced increase in rates of insect attack in acorns that were collected from the ground versus those that were collected directly from the tree (Phillips 1992). The knocking of tree-retained acorns to the ground either by climbing into the tree and shaking acorn retaining branches or the use of a long pole to jostle branches is a described harvesting practice utilized by native Californian peoples throughout the state (Gould 1975, Fryer 1995, Anderson 2005, Anderson 2007). While the researcher's observations of current acorn collection practices by Karuk and Yurok

cultural practitioners indicates that the predominant method of collection is the selective gathering from the ground and examination of individual acorns that have already fallen from the tree, historical records of knocking acorns loose from branches do exist for the Yurok people (Thompson 1916, Fryer 1995).

The leaving of some amount of viable resource, consciously or unconsciously, may be an example of culturally restricted harvesting practices aimed at the fulfilling of obligations towards spiritual-cultural reciprocal relationships within the network of resources and organisms with which the Karuk and Yurok people interact. Not harvesting some number of edible acorns supports Karuk and Yurok practices which mandate that, when gathering resources of any variety, some amount of the resource is left undisturbed either to ensure that other species of animals that consume the same resource are fed, to keep valued populations from being overharvested, and to ensure the continued abundance and health of the resource population in the future (Connors 2000). Restrictions on cultural harvesting can be temporal, i.e. a resource would not be harvested before or after a certain time of the year, or by restriction of take-volume, i.e. some amount of the resource would be consciously or semi-consciously left unharvested. Frequently both types of restrictions are present and performed by tribal acorn harvestres. Restricted harvesting is performed for a wide variety of resources including, among others, the gathering of "Indian potatoes" (*Triteleia* sp., *Dichelostemma* sp., and *Brodiaea* sp., Family: Themidaceae) and salmon fishing (Roberts 1932, Warburton and Endert 1966, Anderson 2005).

The harvesting of Indian potatoes serves as a comparable example. The consumed portion of Indian potatoes are the large, mature subterranean corms. Members of the deer potato genera *Triteleia* sp., *Dichelostemma* sp., and *Brodiaea* sp. flower in May to July and asexually reproduce via cormlets attached to larger central corms. During these months, traditional gatherers will use digging sticks to harvest the larger corms. During the harvesting process, the cormlets are separated from the "mother" and returned to the soil for the subsequent flowering/gathering season (Anderson 2005). Anderson (1999) cites five major management activities utilized in the maintenance of geophyte populations 1) replanting of cormlets, 2) sparing whole plants, 3) harvesting after plants have gone to seed, 4) burning areas to keep the open conditions favored by geophyte genera, 5) irrigation (Anderson and Rowney 1999). A number of traditional gatherers from tribes across California are reported to adhere to this practice of restricted harvesting of deer potatoes to ensure abundance in subsequent years (Blackburn and Anderson 1993, Anderson 2005). Other vertebrates consume the corms of deer potatoes including bear and gophers. The aeration of the soil, a by-product of the vertebrate consumer digging process and one that was mimicked by human gatherers, assists the young cormlets in their maturation process by loosening the soil, facilitating the growth of both roots and shoots, and spacing cormlets to reduce intra-specific competition (Anderson and Rowney 1999).

Similarly, salmon fishing along the Klamath River is a highly restricted and culturally ritualized process both historically and in modern day (Roberts 1932, Warburton and Endert 1966, Swezey and Heizer 1977). The Klamath River hosts species of culturally important anadromous fish, the King (Chinook) salmon (*Oncorhynchus* tshawytscha)

and the Coho salmon (*Oncorhynchus* kisutch). Rainbow or steelhead trout (*Oncorhynchus* mykiss) are also harvested. Historically, both Chinook and Coho enter the river in the fall, Chinook also entered the river during the spring months creating a biannual cultural fishing season (Swezey and Heizer 1977). The First Salmon ceremony was held by both the Yurok and the Karuk people in spring (April) to honor this most valued animal and to open the yearly fishing season (Harrington 1932, Spott and Kroeber 1942, Swezey and Heizer 1977). Heavy restrictions were placed on the catching and consumption of salmon prior to the completion of this ceremony (Harrington 1932, Swezey and Heizer 1977). During the summer, fish weirs or dams were constructed at particular locations along the Klamath and Trinity Rivers to facilitate the harvesting of late spring, but primarily fall run salmon. These weirs were constructed to allow some number of salmon to pass through and return to their spawning grounds upriver while facilitating resource procurement by cultural fishermen (Roberts 1932, Swezey and Heizer 1977).

Regarding acorns, both temporal and volume related restrictions are placed on gathering. Temporally, ground-based gathering of fallen acorns is not to occur until after a major rain or wind event dislodges tree retained acorns in fall (C. Hostler Sr., F. Lake, personal communication). Gathering is also not supposed to occur after late November, providing food for other species of vertebrates that consume acorns (C. Hostler Sr., F. Lake, personal communication). This practice stems from Yurok-Karuk beliefs that the winter is the reserved season for "spirits" in the forest. While gathering for purposes unrelated to research, the non-Native principal investigator (A. Halpern) was instructed to leave smaller acorn and restrict gathering to more acorn-dense areas so as to maximize foraging efficiency. Regarding the fulfillment of spiritual-cultural obligations while gathering acorns, it is unclear whether the obligations are fulfilled by the un/semi-conscious omission of externally questionable acorns that are internally edible or the conscious leaving of externally obvious edible acorns. Most likely it is a combination of both.

It is important to consider cultural imperatives when assessing indigenous management practices for cultural resources. Scientific findings regarding the efficacy of indigenous harvesting practices should be interpreted through the lens of the culture in question.

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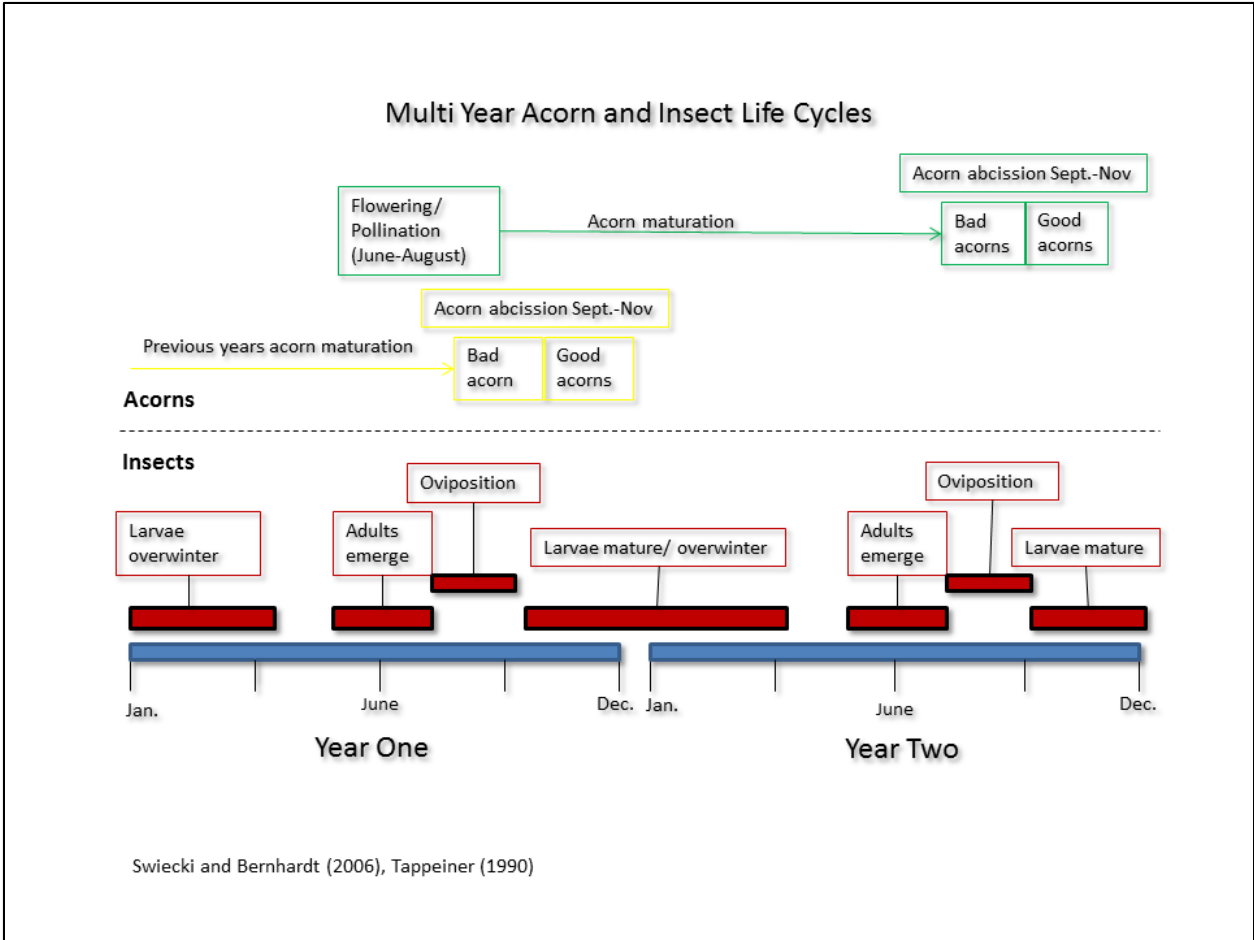
Fig. 1. Multi-year description of tanoak and insect predator life cycles (Tappeiner et al. 1990, Swiecki and Bernhardt 2006).

Biological And Cultural Acorn Calendar

Acorn Collection
(October-November)

Larvae complete maturation and pupate (October-February)

Moths/weevil emerge (April-June)

Moth/weevil mating (May-July)

Good Acorns drop Late September-November

Infested acorns drop, larvae find new host (August-September)

Oviposition, eggs hatch, larvae feed (July-October)

*Weevil will oviposit through insertion in seed coat

*Moth will lay egg externally near funiculus

Cultural Burning
(September-October)

After Anderson (2007), Swiecki and Bernhardt (2006), Karuk Tribe, pers. com

Fig 2. Seasonal description of tanoak life cycle and associated cultural management activities (Swiecki and Bernhardt 2006, Anderson 2007, Tappeiner et al. 1990)
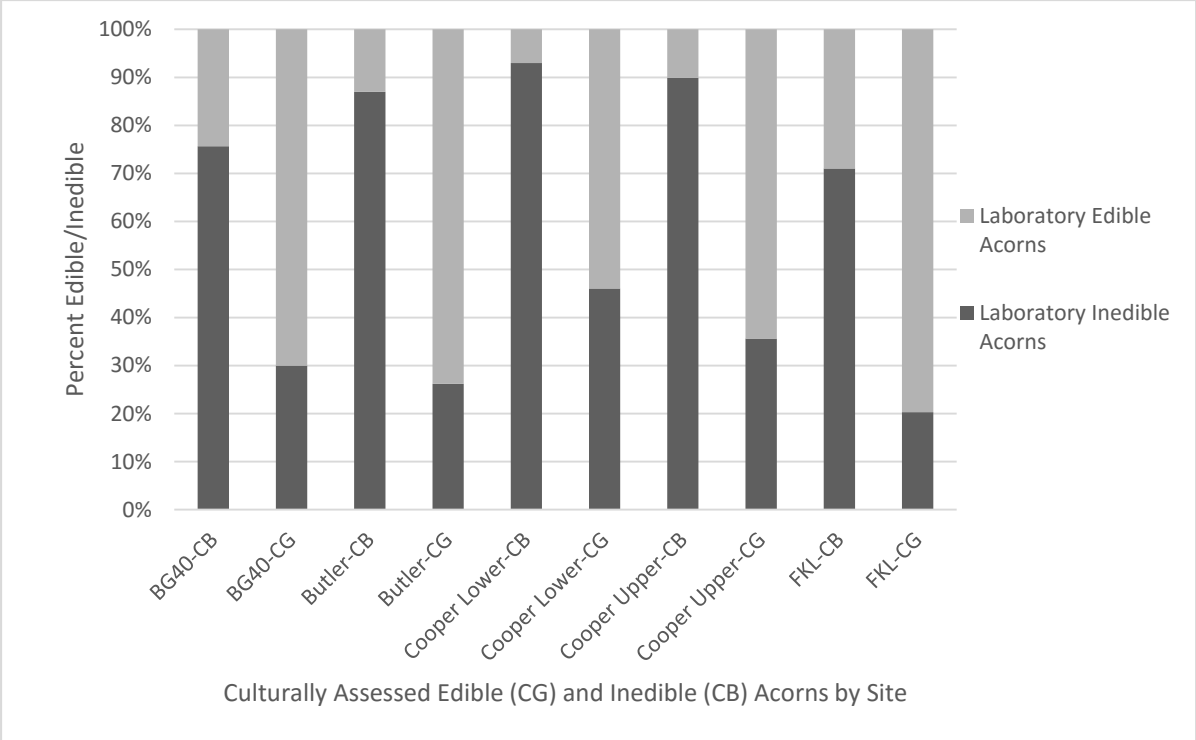
Figure 3. Stacked bar plot describing the percentage of the incidences where external cultural collection criteria accurately diagnosed the internal state of acorn cotyledon tissue edible and inedible acorns during both collection years (2013 and 2014).
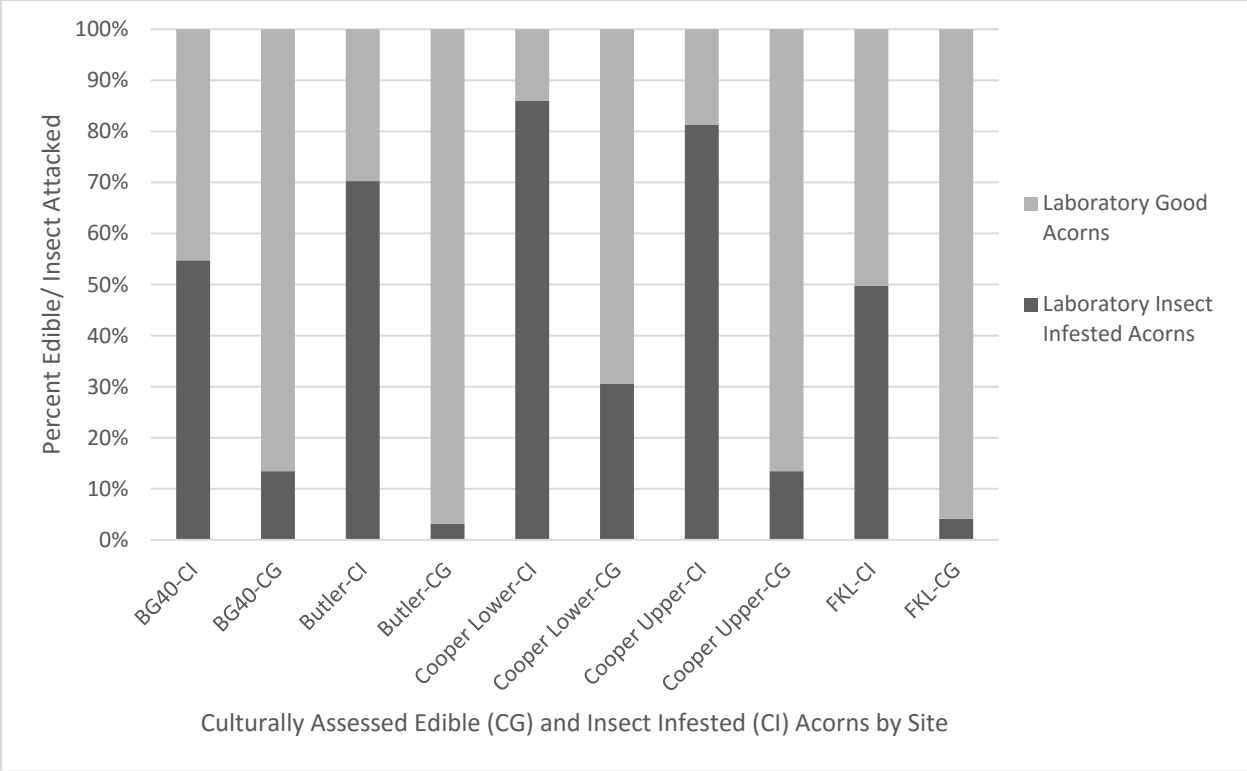
Figure 4. Stacked bar plot describing the percentage of the incidences where external cultural collection criteria accurately diagnosed the internal state of insect infested and sound acorn cotyledon tissue for both collection years (2013 and 2014).

Fig. 5. Percentage of total acorn inedibility due to 1) incomplete filling, 2) mold, and 3) insect infestation by cultural assessment and site.

Chapter 4

The Effects of Prescribed Fire and Acorn Gathering on Cultural Plant Diversity in Tanoak Acorn Gathering Sites

Introduction

Fire plays an important role in maintaining local and regional patterns of plant species diversity throughout California (Martin and Sapsis 1992, Taylor and Skinner 1998, Agee and Sk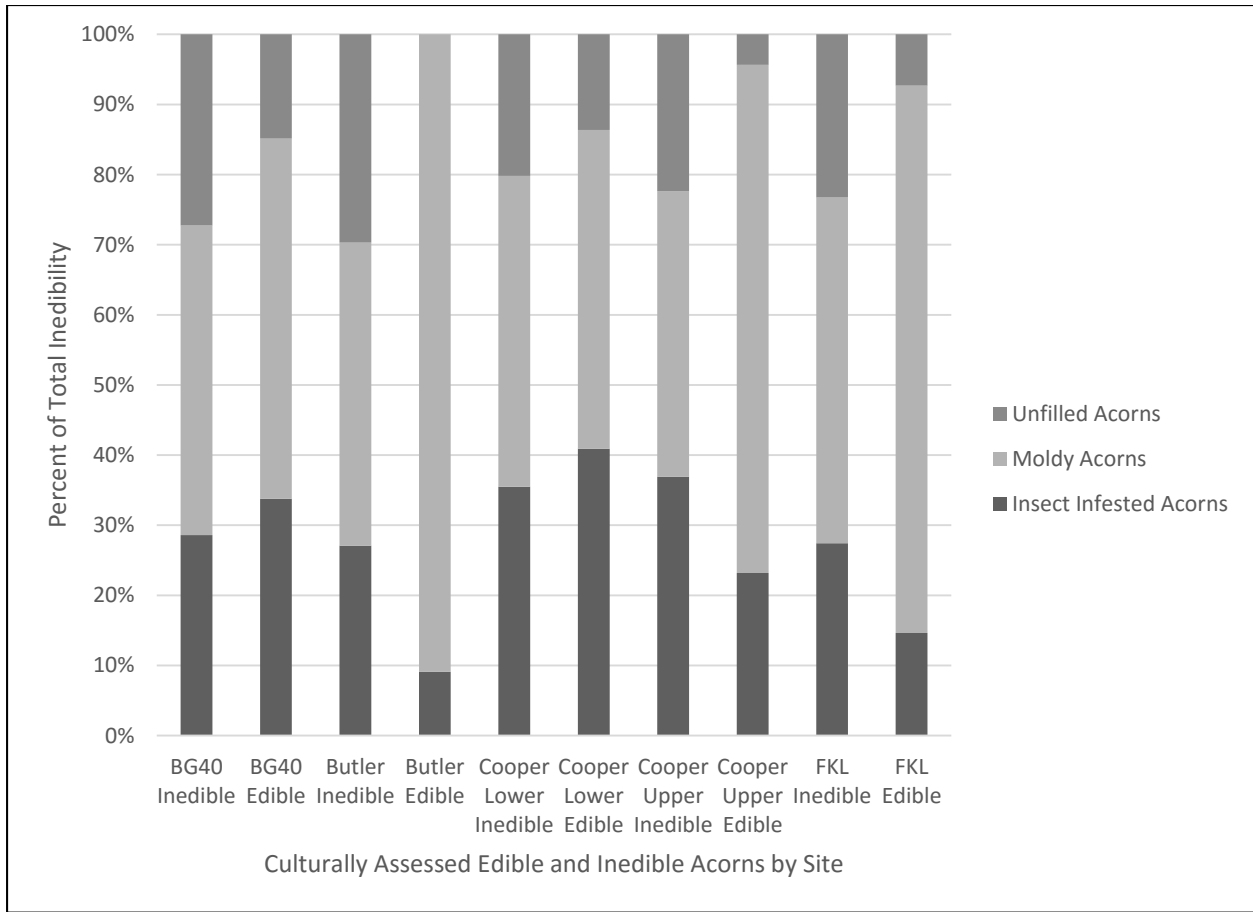inner 2005, Donato et al. 2009). Within the Klamath Bioregion in California and Oregon, heterogeneous topography, soils, and vegetation types combine with a strong west-east moisture gradient to create spatially and temporally pyrodiverse landscapes of mixed severity fire regimes (Skinner et al. 2006, Sawyer 2007, Collins et al. 2009, Halofsky et al. 2011, Perry et al. 2011). The flora of the region is unique among forests of the western United States with assemblages composed of species from the neighboring Cascade, Sierra Nevada, and Coast Range ecoregions with a large number of endemic and relict taxa (Whittaker 1960, Stebbins and Major 1965, Sawyer 2007). Martin and Sapsis (1992) define pyrodiversity as variation in time intervals between fires, seasonality, dimensions, and fire characteristics, which produces and maintains biological diversity at multiple scales (Hessburg et al. 2016). Native Californian peoples enhanced the natural pyrodiversity of the region by systematically applying prescribed fire to maintain important assemblages and induce desired morphologies in culturally relevant plant species (Martin and Sapsis 1992, Keeley 2002, Anderson 2005, Fry and Stephens 2006).

Of the terrestrial plant resource systems and habitats used by the peoples of the mid and lower-Klamath River, mixed evergreen-hardwood habitats containing tanoak (*Notholithocarpus densiflorus*, Fagaceae) are one of the most important (Anderson 2005, Anderson 2007, Bowcutt 2013). As well as providing acorns, a staple food of the Karuk and Yurok People, culturally managed tanoak stands host a variety of herbaceous and shrub associates that were used for basketry, cordage, medicine, and food (F. Lake, B. Tripp personal communication, Schenk and Gifford 1953, Davis and Hendryx 1991). According to cultural practitioners, the application of fall prescribed fire was the primary indigenous management technique used to maintain heritage tanoak orchards (F. Lake, B. Tripp, personal communication, Jack 1916). These fire treatments targeted vulnerable points in the life cycle of insect frugivores which consumed acorns and rendered them inedible to humans (Jack 1916, Anderson 2007). Not only was seasonal fire thought to increase the availability of edible acorns by reducing rates of insect infestation and facilitating collection by making acorns more visible to gatherers, it was also used as a management tool to maintain populations of a variety habitat associated understory plant species of cultural value (F. Lake, B. Tripp, personal communication). These included the promotion of particular morphological characters, such as the burning of hazel shoots in the spring and fall, or the clearing of above ground biomass (i.e. surface and ladder fuels) in gathering areas to encourage a useful species or a suite of such species that experienced reduced competition in recently burned, open areas (Timbrook et al. 1982, Lewis 1993, Anderson 1999, Anderson 2005, Lake 2007). In addition to pest reduction and the modification of specific morphological characters, frequent cultural burning helped maintained the open, widely spaced stands

characteristics of heritage acorn orchards and fostered the partially shaded environment favored by many plant species of cultural value (Tappeiner II et al. 1986, Shebitz 2005, Ramage et al. 2010, F. Lake, B. Tripp, personal communication).

The composition of a plant assemblage is affected by a number of factors including competition, herbivory, disturbance, and stress (Grime 1974, Harper 1977, Grime 1988, Grubb 1985, Crawley 1997). When disturbance or predation/herbivory is suppressed, competition often leads to a loss of local diversity as a few vigorously growing species exclude others (Paine 1966, Connell 1978). For example, it is thought that in the absence of traditional fall fire disturbance and acorn harvesting, plant assemblages in the understory of tanoak orchards will decline in diversity as tanoak seedlings outcompete assemblage associates (F. Lake, B. Tripp, personal communication). With diminished access to cultural use species like those found in tanoak orchards, tribal practitioners are unable to accumulate the volumes of plant resources needed for cultural activities to sustain traditional practices and knowledge systems. Over time, this lack of access can result in cultural degradation and loss of traditional practices and knowledge which can harm tribal community health and well-being (Lake 2007, Norgaard 2014).

In this paper, we examine the effects of acorn gathering and late spring prescribed fire on the diversity, richness, and percent cover of species of cultural value to the Karuk and Yurok tribal communities. While such prescribed fires were traditionally set in fall or winter, it has become increasingly difficult to maintain this traditional practice due to current political and environmental conditions i.e. the state and management of post-suppression era forests in the state of California (Stephens and Ruth 2005).

Methods

Our study was conducted between 2012 and 2014 within the ancestral territories of the Karuk and Yurok Tribes of California in the mid and lower-Klamath River watershed between Somes Bar and Morek, CA (41°22′34″N 123°28′34″W and 41.3439° N, 123.8539° W). Five research sites were identified and developed according to methods described in Chapter 2 (Tables 1 and 2). Three of the developed research sites were experimentally burned during the last two weeks of June of 2013 (Chapter 2). Of the three burned sites, only Cooper Upper and Cooper Lower afforded a relatively balanced mix of burned and unburned plots and therefore the analysis reported here focuses on these two sites.

Multiple experimental plots were established under tanoak canopies at each of the research sites, one plot per tree (Table 1). Each plot measured 2m x 1m, and was constructed under the densest part of the canopy (visual estimation) of each sample tree. Plot orientation was haphazard and depended on the dimensions and shape of the tree crown base. Exclusion cages were constructed around each plot to protect plants from large herbivores without blocking significant amounts of light or inhibiting the spread of treatment fires (Chapter 2). Each plot was divided into two 1x1 meter sub plots. Prescribed burns and vegetation monitoring were conducted in the same caged plots used for the fire-insect interaction study (Chapter 2).

Seed Removal

During the fall of 2013 and 2014, acorns were collected from either the left sub-plot or sub-plot closest to the tree (researcher facing the tree) depending on plot orientation. Acorns were collected at three time points the last of which was targeted to occur after the acorn season had ended ensuring that all acorns were removed from the sub-plot. Acorns were left undisturbed in the right sub-plot or the sub-plot farthest from the tree to provided data on species diversity in the absence of manual acorn removal. This created a harvest treatment factor within each of the burned treatments. Acorns collected from caged sub-plots were used in analyses assessing the effect of late spring prescribed fire on acorn infestation (Chapter 2) and the effectiveness of indigenous acorn collection criteria in determining edible acorns (Chapter 3).

Vegetation Surveys

Sampling was conducted from 2012 to 2014 in the summer months (late July-early Sept): Pre-burn assessments occurred in 2012. Post fire surveys occurred 3 months following fire in 2013, and one year post-fire surveys occurred in 2014. Surveys documented the presence or absence of plant species as well as percent cover in all plots. In 2012 and 2013, ocular estimation was used to assess percent cover; in 2014 a modified pin frame was used to assess percent cover. The pin frame consisted of a 110 cm x 110 cm square constructed of PVC pipe and string delineating 10 cm squares. The frame was suspended over the plot and plants lying under the intersection points (determined through the use of a pointer) were counted as one percent cover. A total of 100 intersection points was sampled per plot, so percent cover was estimated by the number of "hits" on a particular species. Rare species, present in the plots, but missed by the pin frame counts were assessed at 0.5% cover. An independent evaluation of the efficacy of the two cover estimations techniques found that over the range of cover values exhibited by sampled populations, the ocular technique gave modestly higher values than the pin frame technique. The average absolute difference in cover was 1.1% (+/- 0.3% SE).

Statistical Tests

Inverse Simpson's diversity, richness and vegetation percent cover of cultural use species (Table 4) were calculated for each collected and uncollected sub plot at the two research sites used in the analysis (Simpson 1949, Magurran 2004). Split-plot ANOVAs were conducted for diversity, richness, and percent cover using a within-plot fixed factor for harvest treatment and three between-plot fixed factors: burn, site, and year. Plot was considered a random factor. Significance was judged at α=0.05. All statistical analyses were performed in SYSTAT v.13 (Software 2009).

Results

<u>Species Assemblages</u>

Vegetation surveys at all sites, whether or not they were experimentally burned, generated a species list of 37 taxa all of which were perennial (Table 4). Two taxa were identified to the genus level (*Iris* spp., *Ribes*, spp.,) as floral or fruit structures were not

present at the time of surveying. Members of the genus *Rubus* were divided into two categories *Rubus* spp. and *Rubus discolor* to distinguish native and invasive species, respectively. Cultural use species were distinguished from species with no recorded cultural value based on available literature (Table 4).

<u>Experimental Responses</u>

Diversity

Burning caused an immediate reduction in species diversity ($f_{(1,122)}$=8.93, p=0.003, Fig. 2) that varied by year ($f_{(2,122)}$=10.68, p=0.00005); the greatest decline was observed in the first year after fire followed by a recovery of about 29% by the year following the experimental burn. This pattern generated a marginally significant interaction between the factors burn and year ($f_{(2,122)}$=2.28, p=0.11, Fig. 2). There was no evidence that fire enhanced local diversity on the time scale of the study. Neither the harvest factor, nor it's interactions with the other factors was statistically significant.

Richness

Burning and year interacted significantly with a sharp decline in richness immediately following the fire and a recovery of about 33% in the post-fire year ($f_{(2,122)}$=3.62, p=0.03, Fig. 3). Richness did recover pre-treatment levels by experimental fire over the time scale of the study. Harvesting treatments had no statistically detectable effect on the richness of cultural use species in the treatment sites, and there was no interaction between harvest treatments and other factors.

Percent Cover

The average absolute difference between ocular and pin frame estimates of percent cover at low cover values was 1.1% (+/- 0.5%). Burning and year interacted significantly with a reduction in percent cover immediately following experimental fires and a recovery of only about 14% in the post-fire year ($f_{(2,122)}$=12.85, p=0.00001, Fig. 4). Similar to species diversity and richness, percent cover did not recover to pre-fire levels on the time scale of the study, and the degree to which cover returned was considerably less than recovery for diversity and species richness. Tanoak percent cover, being the most abundant understory species, exhibited the same response to fire as total understory cover. There was a significant interaction between fire and treatment year ($f_{(2,122)}$=412.77, p=0.004, Fig. 5); tanoak cover was sharply reduced by fire (2013), and there was no evidence or recovery on year post-fire (2014).

Discussion

Fire treatments had a depressive effect on species diversity and richness in the year of the fire (2013), however both showed modest recovery in the 2014 post-burn sampling (Fig. 2). Percent cover, on the other hand, remained low in the post-fire year. Harvesting treatments had little to no effect on the diversity or richness of cultural use species in the treatment sites.

While species diversity and richness showed strong trends towards recovery in the post fire year, vegetation percent cover did not show as strong a recovery response. The depressed recovery in burned cages may be the combined results of a significant reduction in annual precipitation in 2013 and 2014 and the variable effects of fire seasonality on vegetation regeneration (Table 3, Brockway et al. 2002, Knapp et al. 2006). Normal precipitation levels in 2012 and lack of disturbance may have continued a normal pattern of growth in unburned cages during the fire and post fire year. The highly stressful combination of a growing season burn occurring during the first of two extreme drought years may have been responsible for the depressed recovery response in burned cages during the fire and post-fire years.

The decreased percent cover of understory tanoak during the fire and post-fire years may have cultural value: While tanoak is simultaneously a species of deep cultural significance in its adult form, it can be competitive weed as a seedling or lignotuber resprout (Wilkinson et al. 1997). Tanoak seedlings and small diameter resprouts produce no acorns and may inhibit acorn gathering by reducing acorn visibility and collection efficiency if they co-occur with acorn producing trees. Additionally, if dense enough, they could suppress other species of cultural value. Large diameter, well-spaced tanoaks in open areas, subject to regular low intensity ground fires, not only produce acorns but fire treatment makes acorns more visible for gatherers given the contrast of tan colored acorns on blackened, post-fire ground (F. Lake, personal communication).

It is likely that the timescale over which this experiment was conducted was not sufficient to observe complete post-fire regeneration of cultural species after late spring burns. Knapp et al (2006) study of the effects of fall and spring prescribed fire on understory vegetation at Sequoia National Park, in the southern Sierra Nevada, monitored post-fire regeneration over a three year period. However, given that tanoak orchards are traditionally burned every 1-7 years for acorns it is likely that our observation period corresponded to the typical management schedule (Jack 1916, F. Lake, personal communication, Chapters 2 and 3). It may be that repeated burning on a 1-7 year cycle is what maintains the desired assemblage of culturally important species.

The intermediate disturbance hypothesis of Connell (1978), inspired by Levin and Paine (1974), Horn et al. (1975), and Yodzis (1978) and tested by Sousa (1979) states that disturbance of both intermediate levels of intensity and frequency in a space-limited environment will maintain higher local diversity than either relatively high frequency or low frequency levels of disturbance. While widely known within the discipline of community ecology, this theory has clear ties to traditional ecological hypotheses surrounding management practices for cultural resources, most of which involve periodic, mild disturbance. Models describing the effects of disturbance on patch size, assemblage age and composition by (Levin and Paine 1974, Paine and Levin 1981) are equally applicable to the investigation of anthropogenic, culturally oriented manipulation of terrestrial landscapes. Traditional ecological management practices can be defined as agro-ecological manipulations aimed at maximizing the variety, quantity, and quality of species of cultural value on a local scale (Anderson 2005). As traditional

management relates to plant resources, different types of periodic disturbances are employed based on cultural climatic and environmental indicators: The separation of geophyte corms, coppicing and subsequent harvesting of tree and shrub sprouts for basket production, tools, and structural materials (Anderson 2005, Lake 2007). Individual plants and whole habitats were burned to reduce insect infestation, create fresh browse for animal species, and encourage populations of culturally valuable species that grow more vigorously in both periodically disturbed environments and the semi-open stand structures fostered by regular, sustained management (Lewis 1993, Anderson 2005, Lake 2007, Anderson et al. 2012). Aspects of the intermediate disturbance hypothesis closely parallel areas of traditional ecological knowledge especially as they relate to disturbance and management through fire. The mechanism described by traditional management practices and the intermediate disturbance hypothesis share a fundamental similarity: A level of disturbance at a frequency that is intermediate relative to the habitat in question will create circumstances favorable to both biodiversity and cultural species abundance and quality. While parameters of the disturbance regime such as seasonality, frequency, severity, and intensity are commonly considered in studies of disturbance in natural ecological communities, they play an equally significant role as factors that can increase or decrease the availability of cultural resources and thus affect the continuity and strength of indigenous cultures.

When examining the use of fire as a cultural management tool, it is important to consider the multiple resource targets that a single fire application is intended to affect (B. Tripp, personal communication). For this study, we examined the effects of late-spring fire on acorn infestation and edibility as well as abundance and diversity of habitat-associated cultural plant resources. While these non-traditional fires had a positive effect in reducing acorn infestation (Chapter 2), their effectiveness at increasing diversity and abundance of cultural habitat associates is unclear. It may be that sequential 1-7 year spring burning cycles would generate the desired increase in diversity of culturally important species. However, oak habitats were traditionally burned during the fall months in many areas of California (Chapter 1) to, perhaps, more effectively meet both acorn harvest and cultural plant species management goals. In order to accurately assess traditional ecological fire management hypotheses, it is important to conduct further investigation on traditional fall treatment burns over longer time scales and examine the effects of variation in fire frequency and fuel load to achieve desired understory characteristics and cultural resource outcomes.

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Table 1: Site characteristics and treatment specifics for all research sites. Control= Unburned, Treatment=Burned. * 2014 only.

Site	Elevation (meters)	Slope	Aspect	Site Area (hectare)	Total Number of Trees/Site	Treatment	Treatment Date	Burned Plots	Control Plots
Cooper Lower	368	13°	S	1.12	26	Burned	6/11/2013	21	5
Cooper Upper	423	16°	SE	0.45	18	Burned	6/23/2013	14	4
FKL	514	10°	NE	0.36	13	Burned	6/17/2013	10	3*
Butler Flat	315	11°	NE	1.45	19	Unburned	N/A	N/A	19
Beargrass 40	742		SE	3.26	30	Unburned	N/A	N/A	30

Table 2. Mean values for descriptive site characteristics data from each site. Standard error mean in parentheses.

Site	Avg. DBH (cm)	Avg. Canopy Cover (%)	Average Canopy Area (m^2)	Avg. Fireline Intensity (kW/m)
BG40	103.53 (2.37)	78.60 (0.84)	135.74 (5.11)	N/A
Butler	62.13 (1.2)	80.99 (1.23)	77.11 (2.23)	N/A
Cooper Lower	70.81 (1.53)	88.79 (0.84)	81.27 (2.93)	398.58
Cooper Upper	77.14 (2.6)	86.00 (0.56)	91.62 (4.04)	312.5
FKL	85.31 (4.33)	92.02 (0.71)	110.51 (5.61)	207.36

Table 3. Average annual precipitation data for Orleans, CA 2007-2014 (NOAA/National Climate Data Center). Average precipitation for the Orleans, CA is 53.44 in for years 1931-2015.

Year	Annual Precipitation (in)
2014	39.62
2013	19.34
2012	50.85
2011	42.93
2010	67.20
2009	33.44
2008	48.07
2007	48.03

Table 4. List of plant species found at all sites. *indicates species of cultural value. [1]Creasy M., Lake, F.K., Karuk Ethnobotanical Rank Values, [2] (Davis and Handryx 1991), [3] (Peters and Ortiz 2010). [4]USDA Natural Resource Conservation Plants Database

Species	Common Name	Cultural Use[1,2,3]	Growth Form[4]	Sites Present
Notholithocarpus densiflorus	Tanoak*	Food	Tree	FKL, BG40, Butler, CL, CU
Toxicodendron diversilobium	Western Poison Oak*	Medicine	Shrub/Vine	FKL, Butler, CL, CU
Whipplea modesta	Yerba de Selva		Forb	Butler, CL, CU, FKL
Pteridium aquilinium	Western Bracken Fern*	Material	Forb	FKL, BG40, Butler, CU, CL
Viola pedunculata	Johnny Jump Up*	Medicine	Forb	BG40, Butler, CL
Rosa gymnocarpa	Wood Rose*	Medicine	Subshrub	FKL,Butler, CL, CU
Arbutus menziesii	Madrone*	Material, Medicine, Food	Tree	FKL,BG40,Butler, CL, CU
Symphoricarpos mollis	Snowberry		Shrub/Subshrub	FKL, BG40, Butler, CL
Chimaphila menzesii	Little Prince's Pine*	(similar to Prince's Pine)	Subshrub	Butler,
Chimaphila umbellata	Prince's Pine*	Medicine	Subshrub	Butler, CL, CU
Trientalis borealis	Starflower*		Forb	Butler, CU
Goodyera oblongifolia	Rattlesnake Plantain*	Medicine	Forb	BG40, Butler, CL
Smilacina racemosa	False Solomon's Seal*	Medicine	Forb	Butler, CU
Vancouveria hexandra	Inside Out Flower*		Forb	BG40, Butler, CL, CU
Oxalis oregona	Redwood Sorel*	Food	Forb	Butler, CU
Rubus discolor	Himalayan Blackberry	Food (invasive)	Subshrub	FKL, Butler
Iris spp.	Iris*	Material	Forb	Butler, CL
Vaccinium ovatum	California Huckleberry*	Food	Shrub/Subshrub	FKL, CL, CU
Pyrola spp. (picta)	Wintermint*	Medicine	Subshrub	FKL, CL, CU
Pseudotsuga menziesii	Douglas Fir*	Material, Medicine	Tree	BG40, FKL, CL, CU
Boschniakia strobilacea	California Ground Cone*		Forb	CL, CU
Gaultheria shallon	Salal*	Food, Material, Medicine	Shrub/Subshrub	BG40, CU
Umbellularia californica	Pepperwood*	Food, Material, Medicine	Tree	CU
Achlys triphylla	Vanilla Leaf*	Repellant	Forb	CU
Berberis aquifolium, nervosa	Oregon Grape*	Material, Medicine	Shrub/Subshrub	BG40, FKL, CU

Corylus cornuta	Hazel*	Material, Food	Tree	Butler, CL
Alnus rhombifolia	Alder*	Material	Tree	Butler
Xerophyllum tenax	Beargrass*	Material, Other	Forb	BG40
Lotus oblongifolius/humistratus	Meadow Lotus*		Forb	BG40
Ribes spp.	Gooseberry*	Food	Shrub	BG40
Lilium columbiana	Tiger Lily*	Food	Forb	BG40
Rubus spp.	California Blackberry*	Food	Shrub	BG40, CL, CU
Arctostaphylos spp.	Manzanita*	Material, Food, Medicine	Shrub	BG40
Lonicera hispidula	Honeysuckle*	Material	Vine	Butler, CL
Cornus nuttalii	Dogwood*	Medicine, other	Tree	Butler, CL
Polystichum munitum	Western Swordfern		Forb	Butler
Apocynum androsaemifolium	Spreading Dogbane*	Material	Forb	CU
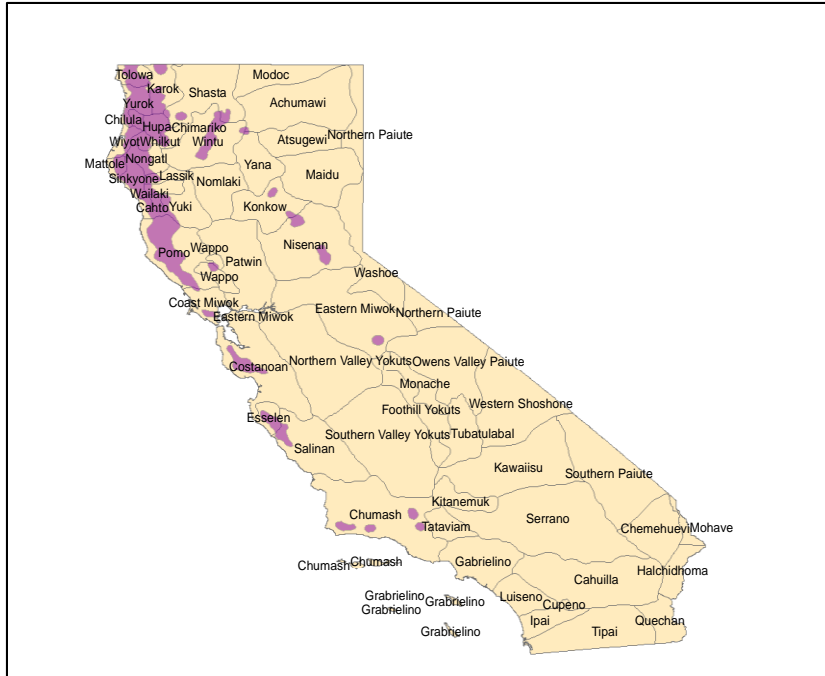
Fig. 1. Map of California with the ancestral territories of the indigenous peoples of the state. Purple area describes the species range for *Notholithocarpus densiflorus* (Fagaceae) (Griffin and Critchfield 1972, Redlands Institute, University of Redlands 2002).

 Fig. 2. Average inverse Simpson's diversity values for fire treatment categories at analyzed research sites (Cooper Upper and Lower) during the pre-burn (2012) year, the fire year (2013) and the post-fire year (2014). Harvest categories were not included as they showed no significant effect on diversity. Error bars represent standard error.
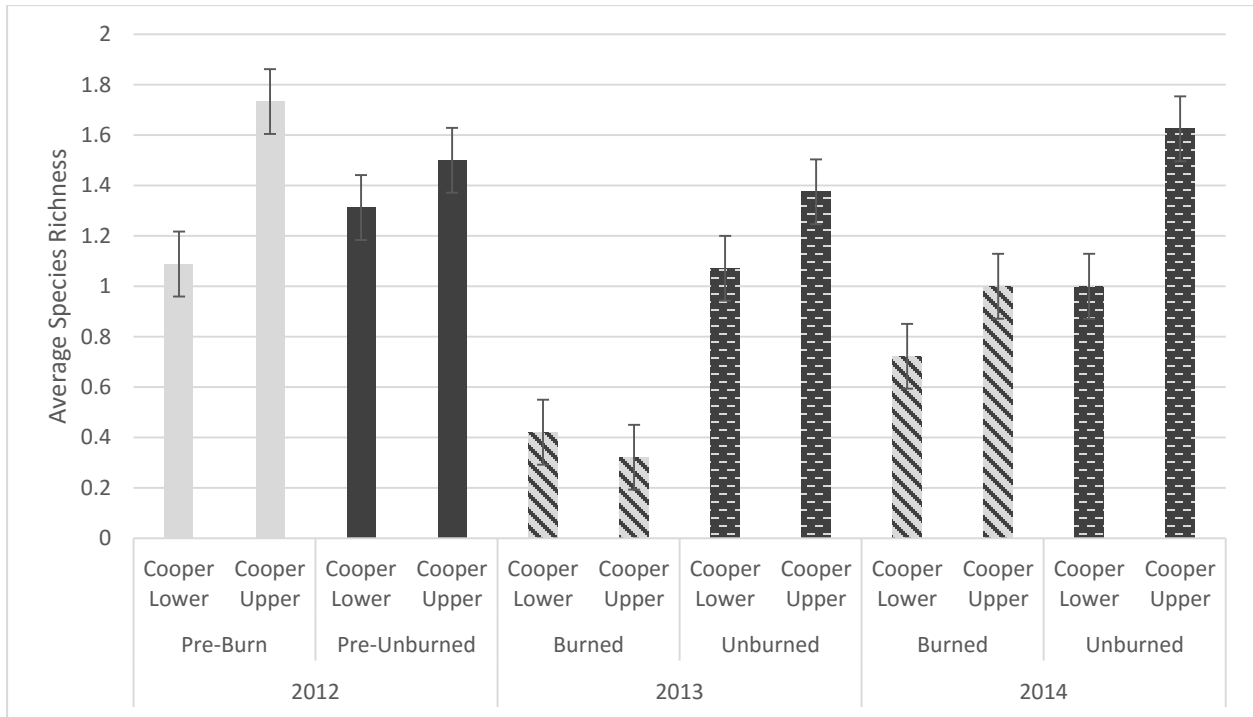
Fig. 3. Average species richness values for fire treatment categories at analyzed research sites (Cooper Upper and Lower) during the pre-burn (2012) year, the fire year (2013) and the post-fire year (2014). Harvest categories were not included as they showed no significant effect on richness. Error bars represent standard error.
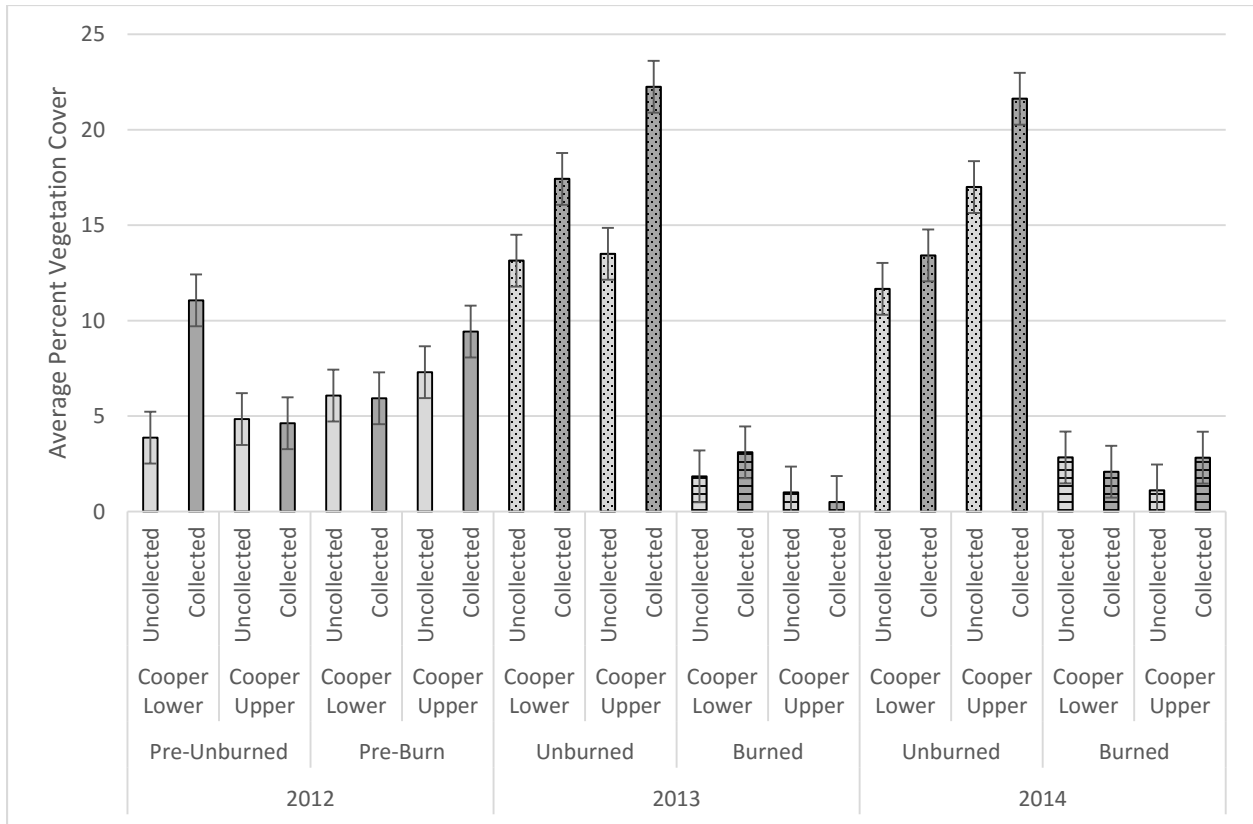
Fig. 4. Average percent cover values for fire and harvest treatment categories at analyzed research sites (Cooper Upper and Lower) during the pre-burn (2012) year, the fire year (2013) and the post-fire year (2014). Error bars represent standard error.
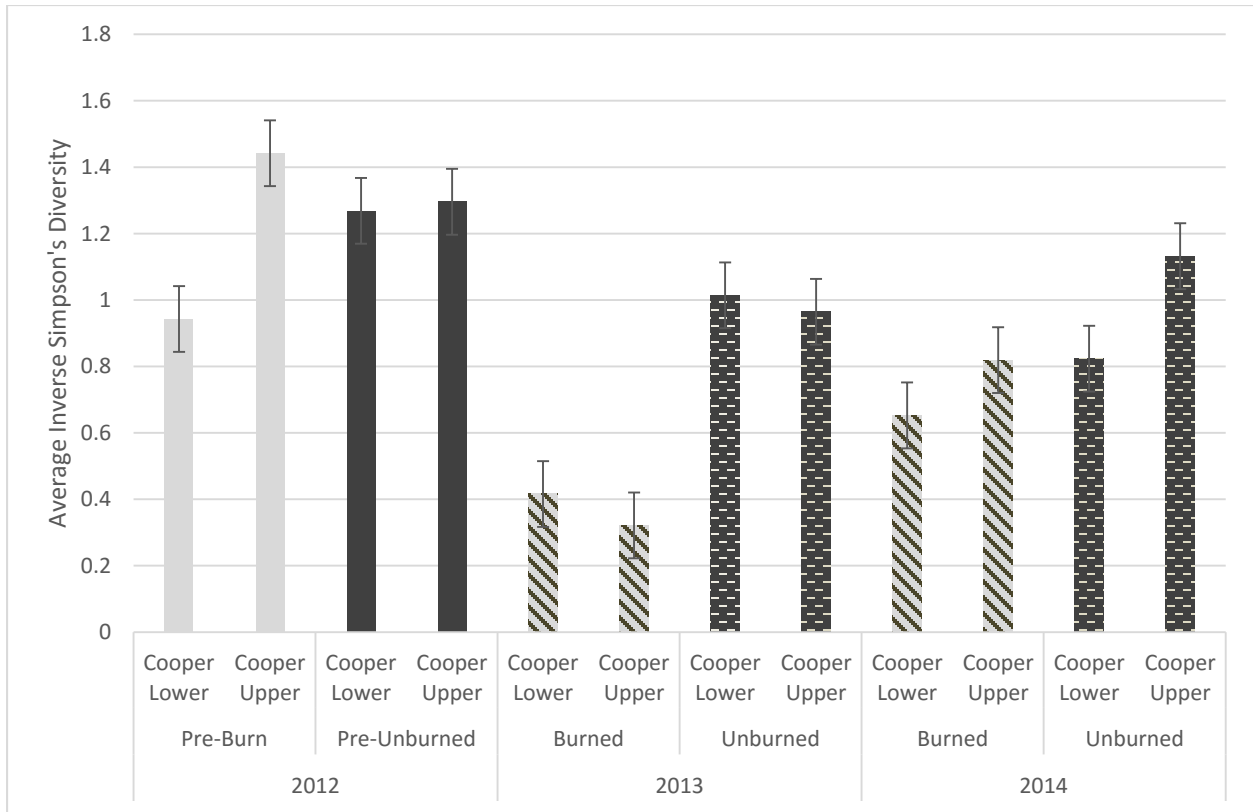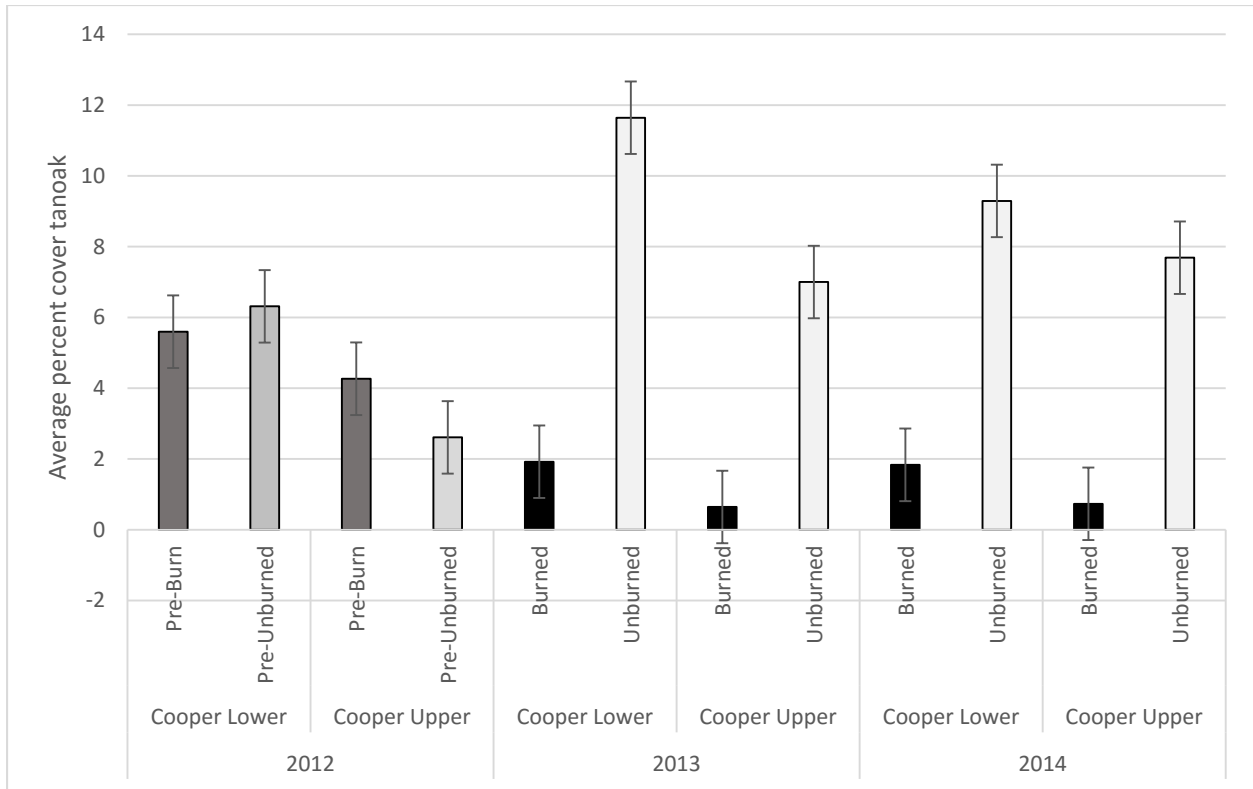
Fig. 5. Average percent cover values for tanoak in fire treatment categories at analyzed research sites (Cooper Upper and Lower) during the pre-burn (2012) year, the fire year (2013) and the post-fire year (2014). Error bars represent standard error.

Appendix: Chapter 2

Figure 1. Young acorn with filbertworm larvae and frass. Photo: Frank K. Lake (USFS) and Karuk Tribe.

Fig. 2. Acorn with Filbert Weevil preparing to oviposite. Photo: Frank K. Lake (USFS) and Karuk Tribe.

Fig. 3. Acorn with Filbert Weevil larvae and frass. Photo: Frank K. Lake (USFS) and Karuk Tribe.

Appendix: Chapter 3

Table 1: Site characteristics and treatment specifics for all research sites. Control= Unburned, Treatment=Burned. One plot was constructed per tree.

Site	Slope	Aspect	Area (acres)	Total Number of Trees/Plot	Treatment	Treatment Date	Burned Plots	Control Plots
Cooper Lower	13°	S	2.76	26	Burned	6/11/2013	21	5
Cooper Upper	16°	SE	1.10	18	Burned	6/23/2013	14	4
FKL	10°	NE	0.90	13	Burned	6/17/2013	10	3
Butler Flat	11°	NE	3.59	19	Unburned	N/A	N/A	19
BG40		SE	8.06	30	Unburned	N/A	N/A	30

Table 2. Mean values for descriptive site characteristics data from each site.

Site	Avg. DBH (cm)	Avg. Canopy Cover (%)	Average Canopy Area (m^2)	Avg. Fireline Intensity (kW/m)
BG40	100.95	78.20	131.06	N/A
Butler	70.12	86.77	83.87	N/A
Cooper Lower	73.49	87.51	85.91	5.07
Cooper Upper	77.14	86.00	94.48	6.21
FKL	83.96	91.59	110.46	7.76

Table 3. G-tests of independence between external collection criteria (Culturally Accepted/Rejected) and internal laboratory results for total inedible acorns (includes insect infested, unfilled, and moldy acorns) by site, n=3499.

Site	Number of acorns	G statistic	X^2 degrees of freedom	p-value (α=0.05)
BG40	1083	145.2	1	2.2×10^{-16}
Butler	381	66.97	1	2.2×10^{-16}
Cooper Lower	532	91.44	1	2.2×10^{-16}
Cooper Upper	534	167.01	1	2.2×10^{-16}
FKL	969	241.26	1	2.2×10^{-16}

Table 4. G-tests of independence between external collection criteria (Culturally Accepted/Rejected) and internal laboratory results for insect infested acorns (Insect Attacked/Sound) by site, n=3499.

Site	Number of acorns	G statistic	X^2 degrees of freedom	p-value (α=0.05)
BG40	1083	33.66	1	6.57×10^{-9}
Butler	381	21.18	1	4.18×10^{-6}
Cooper Lower	532	11.53	1	0.0007
Cooper Upper	534	66.57	1	3.33×10^{-16}
FKL	969	110.87	1	2.2×10^{-16}

Table 5. Percentage and number of edible and total inedible acorns identified using cultural criteria and laboratory assessments. CA=Culturally Accepted, CR=Culturally Rejected. Data on culturally rejected acorns are shaded grey.

Cultural Assessment by Site	Number of Laboratory Total Inedible Acorns	Number of Laboratory Edible Acorns	Total Acorns	Percent Laboratory Total Inedible	Percent Laboratory Edible
BG40-CR	653	210	863	75.67	24.33
BG40-CA	69	161	230	30	70
Butler-CR	294	44	338	86.98	13.02
Butler-CA	11	31	42	26.19	73.81
Cooper Lower-CR	423	32	455	92.97	7.033
Cooper Lower-CA	35	41	76	46.053	53.95
Cooper Upper-CR	338	38	376	89.89	10.11
Cooper Upper-CA	57	103	160	35.63	64.38
FKL-CR	439	179	618	71.04	28.96
FKL-CA	71	279	350	20.29	79.71

Table 6. Percentage and number of edible and insect attacked acorns identified using cultural criteria and laboratory assessments. CA=Culturally Accepted, CR=Culturally Rejected. Culturally rejected acorn data are shaded grey.

Cultural Assessment by Site	Number of Laboratory Insect Attacked Acorns	Number of Laboratory Edible Acorns	Total Acorn	Percent Laboratory Edible	Percent Laboratory Insect Attacked
BG40-CR	254	210	464	45.26	54.74
BG40-CA	25	161	186	86.56	13.45
Butler-CR	104	44	148	29.73	70.27
Butler-CA	1	31	32	96.88	3.13
Cooper Lower-CR	197	32	229	13.97	86.03
Cooper Upper-CA	18	41	59	69.49	30.51
Cooper Upper-CR	165	38	203	18.72	81.28
Cooper Upper-CA	16	103	119	86.55	13.45
FKL-CR	177	179	356	50.28	49.72
FKL-CA	12	279	291	95.88	4.12

Table 7. Percentage and number of total inedible acorns due to 1) insect infestation, 2) mold, 3) incomplete nut maturation by site and cultural assessment (Culturally Accepted=CA, Culturally Rejected=CR). Culturally rejected acorn data are shaded grey, n=3499.

Site-Edibility	Insect Infested Acorns	Moldy Acorns	Unfilled Acorns	Total Inedible Acorns	Percent Insect Infested	Percent Moldy	Percent Unfilled
BG40-CR	254	392	242	653	38.90	60.03	37.06
BG40-CA	25	38	11	69	36.23	55.07	15.94
Butler-CR	104	166	114	294	35.37	56.46	38.78
Butler-CA	1	10	0	11	9.09	90.91	0
Cooper Lower-CR	197	246	112	423	46.57	58.16	26.48
Cooper Lower-CA	18	20	6	35	51.43	57.14	17.14
Cooper Upper-CR	165	182	100	338	48.82	53.85	29.59
Cooper Upper-CA	16	50	3	57	28.07	87.72	5.26
FKL-CR	177	318	150	439	40.32	72.44	34.17
FKL-CA	12	64	6	71	16.90	90.14	8.45

Table 8. Percentage of inedibility due to mold, incomplete cotyledon maturation and insect attack for each research site. Weighted averages were caluculated using the total inedible acorns for each site, n=3499.

Site	Total Inedible Acorns	Percent Mold	Percent Unfilled	Percent Insect Attacked
BG40	722	59.56	35.04	38.64
Butler	305	57.71	37.38	34.43
Cooper Lower	458	58.08	25.76	46.94
Cooper Upper	395	58.73	26.08	45.82
FKL	510	74.90	30.59	37.06
Weighted Average		62.18	31.13	40.54