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A Sustainable Future for Use of *Notholithocarpus densiflorus* Acorns

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ABSTRACT

Notholithocarpus densiflorus (tanoak) acorns continue to be a cultural food staple of American Indian tribes in the Klamath-Siskiyou bioregion. Tribal traditional knowledge of these trees includes changes with climate, fire regimes, and forest dynamics coupled with cultural adaptive stewardship practices. Recent prolonged drought, wildland fires, and other climatic and non-climatic threats and other stressors are affecting not only acorn production, but also the tribal cultures that depend upon tanoaks across the landscape to provide a range of cultural and ecosystem services. The objective of this research was to synthesize the available traditional and Western scientific data about *N. densiflorus* stewardship practices to promote acorn-food security. A cross-scaled research framework was developed to investigate which metrics and indicators are important for assessing changes in the condition of: *N. densiflorus* codominant forests across the landscape, tribal orchards, individual heritage trees, and in the quality of acorn food. Trial field experimental research approaches integrated tribal and Western scientific knowledge to determine the desired ecological conditions for *N. densiflorus* forests as well as the factors involved in acorn production and the tribal use of orchards, including tree-specific characteristics. This cross-scale, interdisciplinary, multiple-method research approach provides insights about climate and fire effects on acorn production. The range of methods includes aerial LiDAR to characterize forests, acorn gathering-site condition surveys, tribal acorn-foraging trials, and individual acorn-quality assessments. This information is being used to develop current tribal food-security-associated climate-adaptation strategies. Tribal knowledge and stewardship practices of the Karuk and Yurok Tribes of northwestern California are used as case-study examples.

Keywords: agroforestry, Karuk, Yurok, Klamath-Siskiyou, Western Klamath Restoration Partnership

Introduction

Notholithocarpus densiflorus (tanoak) acorns[1] continue to be a cultural food staple of American Indian tribes in the Klamath-Siskiyou bioregion of northwestern California and southwestern Oregon (Bowcutt 2013; Halpern 2016). Tribal knowledge of *N. densiflorus* includes changes with climate, fire regimes, and forest dynamics coupled with cultural, adaptive, stewardship practices. Drought, fires, and other climatic and non-climatic threats and stressors are affecting not only acorn production, but also the tribal cultures that depend upon tanoaks across the landscape to provide a range of cultural and ecosystem services (Voggesser et al. 2013). The objective of this research was to synthesize data about *N. densiflorus* stewardship practices to promote acorn-food security as a pyro-agroforestry systems approach (Rossier and Lake 2014). Tribal knowledge and stewardship practices of the Karuk and Yurok Tribes of northwestern California are used as case study examples (Rossier and Lake 2014; Halpern 2016).

Methodology and results

A cross-scaled research framework was developed to investigate which metrics are important for assessing changes in the condition of: *N. densiflorus* codominant forests across the landscape, tribal orchards, individual heritage trees, and the quality of acorns used for food. Trial field experimental research approaches integrated tribal and Western scientific knowledge to determine the desired ecological conditions for *N. densiflorus* forests as well as the factors involved in acorn production and the tribal use of orchards, including tree-specific characteristics. This cross-scale, interdisciplinary, multiple-methods research approach provides insights about climate and fire effects on acorn production and tribal-food security (Lake 2013). The range of methods includes aerial LiDAR to characterize forests, forestry plots and acorn gathering-site condition surveys, tribal acorn foraging trials, and individual acorn quality assessments.

N. densiflorus forest and fire ecology can be evaluated using ecological characteristics, sociocultural elements, and metrics across scales ranging from: region to landscape, habitat to patch/stand, individual trees to acorns. Each scale, component, and applicable metric is presented in Figure 1. At the regional scale the main ecological characteristics are variations of weather due to climate (Lenihan et al. 2008; Young et al. 2018). For example, annual precipitation and high and low temperatures influence the levels of pests and acorn production. The regional sociocultural elements are the broader tribal communities' need for high-quality acorns for ceremonial and family meals (Ortiz 2008). The regional metrics used are snow-water equivalent, Palmer drought index, disease/pathogen infection, and the tribal population that consumes acorn food products.

At the landscape scale, changing fire regimes is the main ecological characteristic (Lake 2013; Tepley et al. 2017), and the sociocultural element is acorn gathering access at locations that have had recent fuel reduction treatments and wildland fire effects. Metrics used by scientists and managers at the landscape scale include: Fire Return Interval, severity and extent of wildland fires, and tribal gatherers' opportunity to access and secure acorns in multiple locations.

At the habitat scale, the ecological characteristics within the temperate, mesic, mixed conifer-hardwood forest (that includes predominately *Pseudotsuga menziesii*

1. The acorns of both *N. densiflorus* var. *densiflorus* and *N. densiflorus* var. *echinoides* are used.

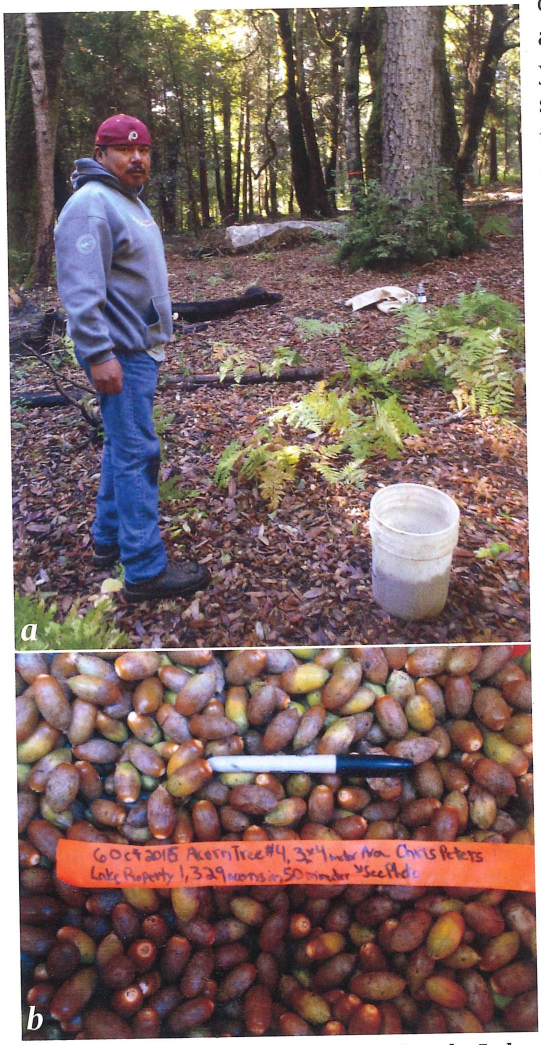
Scale	Ecological Characteristics	Socio-Cultural Elements	Metrics
Region	Climate/Weather: Precipitation, Temperature, Diseases	Tribal need for acorn- Ceremonies and Meals	Snow Water Equivalent, Palmer Drought Index, Disease/Pathogen Infection rates; Tribal population consuming acorn products.
Landscape	Disturbance (Fire) regime	Gathering access and locations	Fire-Return Interval, Severity, Extent; Tribal gatherers' opportunities
Habitat	Competition, Community Assemblage, Wildlife use	Relationship with and Land-use history, ownership, Knowledge of suitable places	Proportion to oak to other tree species, TES species-Critical habitat; Number of experienced practitioners/tribe
Patch/Stand	Elevation, aspect, % slope [site access], Basal area, trees per hectare, dominant tree age, canopy cover, fuel loading [mobility], disturbance/fire history [fire exclusion, tree densification, timber harvesting, disease, thinning, burning], understory diversity		Proportion of oaks burned with desirable fire effects, number of other harvestable cultural-use species, distance from road, fuel load
Tree	Age, height, canopy volume, condition, acorn size, number of acorns	Understory conditions, topography [access], tree phenology, density of canopy and fallen acorns, acorn quality and size, other wildlife use	Diameter, height, presence of pathogens/evidence of disease, acorn development or masting, proportion of good (white top) to bad (brown top/insect holes) acorns
Acorns	Size, presence of infection/infertile or mold, nut meat quality, moisture content, tannins and nutrient content		Amount of edible nut meat "one cup serving" grams/vol.

Figure 1/ Scale, component and applicable metric for evaluating *Notholithocarpus densiflorus* forest ecology.

and *N. densiflorus* with other conifers and hardwoods) are competition between tree species, the community assemblage of species resulting from fire regimes, pathogen/disease, forest management, and resultant wildlife use (Ortiz 2008; Bowcutt 2013). The sociocultural elements at the habitat scale are the relationships with land-use history (e.g., ancestral tribal lands, European colonization, fire suppression, forest management, and collaborative landscape forest restoration) and existing tribal community knowledge of suitable acorn gathering places (Lake 2013; Bowcutt 2013; Rossier and Lake 2014). Habitat metrics that scientists and managers are using with remote sensing (e.g., aerial LiDAR) and conservation planning include the proportion of *N. densiflorus* to other trees and to other threatened, endangered and sensitive species, e.g., *Pekania pennanti* (Pacific fisher), and *Strix occidentalis caurina* (northern spotted owl); and, in cultural terms, the number of experienced acorn practitioners among the Karuk and Yurok Tribes.

At the patch/stand scale, the ecological characteristics include: elevation, aspect, slope, basal area, trees per hectare, dominant tree-age, canopy cover/light, fuel loading (e.g., ground, surface, ladder, and canopy/crown bulk density), the site's disturbance/fire history (e.g., fire exclusion, tree densification, timber harvesting, disease, thinning, and burning), and understory vegetation diversity. Sociocultural elements at the patch/stand are: how access is affected by topography, the density of understory vegetation-fuels affecting acorn gathering (foraging), management factors that promote more open *N. densiflorus* tree growth, and site vegetation. The metrics used for the patch/stand are: the proportion of these trees burned with desirable fire effects (e.g., lower intensity/severity, minimal surface, and ladder fuels), access, and mobility related to distance from road or trail (e.g., for elders and youth-intergenerational teaching). Other factors such as the presence and quality of other habitat associates like *Vaccinium ovatum* (evergreen huckleberry) and *Trichloma matsutake* (matsutake mushrooms) are ecologically and culturally important. It should be noted that many *N. densiflorus*-dominated stands with a legacy of tribal stewardship and use are historical orchards. Within fixed-area forestry inventory plots (30 meters in diameter), all trees with a DBH greater than 7.5 cm were sampled to determine species, height, crown position (e.g., open, dominant, codominant, intermediate, suppressed), and height to live crown (the distance to the first main branches). Also sampled were two groups of saplings and seedlings: those with a DBH between 2.5 to 7.5 cm, and those with a DBH between 0 and 2.5 cm respectively); shrub cover was sampled as well. Surface fuels were sampled along four 15-meter transects in each cardinal direction. Additionally, tribal cultural practitioner evaluations of the plots or similar sites, ranked as good, moderate, or poor, were used. The combined plot of tree measurements and fuel summary statistics, LiDAR point cloud imagery, and cultural use condition rank were used to classify the site.

At the tree scale, the main ecological characteristics are: age, diameter (DBH), height, canopy volume (crown area/position), acorn size, and the masting cycle or year-to year-production of acorns. Related are the sociocultural elements for individual trees: the understory conditions, topography (biophysical setting), tree phenology around the time of acorn gathering (e.g., late summer infertile acorns, later summer/ early fall pest-infested acorns, and fall good-quality acorn drop), the density of canopy and fallen acorns, acorn size and quality, and what wildlife are consuming acorns. For example, at the Lake Property, under Tree # 4 on October 6, 2016, 1,329 acorns were gathered in 50 minutes in an area of 3 × 4 meters.



Photos 1a-b/ Collecting acorns in 2016 at the Lake property: 1,329 acorns in 50 minutes.

At the acorn scale, ecological characteristics and sociocultural elements of importance are their size, the presence of pests and the level of mold and infection by, for example, *Curculio occidentalis.* (filbert weevil) and *Cydia latiferreana* (filbert worm moth), nutmeat quality, moisture, tannins, and nutrient content. To investigate changes in acorn quality pre- and post-fuels treatment, and after wildland fire, the acorn crop was evaluated at a few sites using the tribal criteria of accessibility, abundance, and proportion of good acorns (Halpern 2016). The metric of importance is the amount of edible nutmeat and, collectively, after gathering and processing acorns for consumption, the total amount of "one-cup servings" of soup for ceremonial and family-home consumption each year.

Fall-gathered acorns (usually September to November of each year) were dried in boxes, racks, or sacks where adequate warmer air temperatures could dry out the acorns. Once acorns were dry enough (after 2 months to 1 year), they were externally and internally evaluated. Each host tree of a site was the sample unit and each collecting period (date/year) was a sampling batch, from which a subsample of acorns was examined for external presence of insect/pest damage-holes, scars, mold, or cracks. Acorns were measured with calipers (length × width in mm), then cracked and the amount of edible good nutmeat assessed. Each sample batch was dried (at room temperature > 16 ˚C, or oven dried) and the total proportion of edible good nutmeat to waste (shells, rotten nut tissue) was determined. Additionally, following the cultural practice of making acorn flour for soup, samples were leached, and then cooked to make acorn soup. Leaching generally consisted of running clean non-chlorinated water over and through the acorn flour for 3-4 days, with occasional mixing to remove tannins after which the flour was allowed to drain. Generally, six cups of coarse, ground acorn flour was leached and then cooked with one gallon of water on a stove top (as modern acorn soup is made). From each batch of cooked acorn soup, two cups were extracted, placed in a one-pint canning jar and then oven-dried at 100 ˚C for 48 hours. The pre-dry (wet) weight and post-dry weight were noted to estimate the equivalent dry weight (grams) of acorn flour (in the form of dried crust or "cracker") to liquid-water content. For example, a one-cup serving of acorn soup when dried had between 15 and 20 grams of dried edible acorn cracker.

Conclusion

A range of ecological and sociocultural factors at different scales influence both the condition of *N. densiflorus* forest and acorn use for tribal food security (Fig. 2). Climatic and environmental conditions affect tree health and acorn production. Using remote sensing with aerial LiDAR and ground-based forestry plot inventories combined with tribal practitioner surveys and acorn evaluation is an interdisciplinary multiple-method approach (Lake 2013; Halpern 2016). Preliminary research results inform scientists and managers of the tribal practitioner's perspective on what characteristics support acorn food security (Rossier and Lake 2014). This research supports the Western Klamath Restoration Partnership and Karuk Tribe-University of California Berkeley Collaborative's Agroforestry projects (Rossier and Lake 2014; Lake et al. 2018). Climate, management, treatments, and fire affect site conditions and acorn quality, which in turn influence tribal access and foraging/gathering efficiency. Traditional acorn knowledge as a fine scale evaluation approach can inform collaborative landscape restoration strategies, influence wildland fire management, and be incorporated into tribal climate-vulnerability assessments and adaptation planning efforts (Gilles 2017; Lake et al. 2018). Climatic and non-climatic stressors, including drought, fire, and pathogen/disease that affect *N. densiflorus*-dominated forests, also directly impact and influence tribal acorn cultural and consumption practices (Ortiz 2008; Bowcutt 2013; Halpern 2016). Many Karuk and Yurok families use the groves or orchards on tribal, private, and public lands that have been used for generations (Bowcutt 2013; Rossier and Lake 2014). This information is informing current tribal food security efforts associated with eco-cultural restoration strategies.

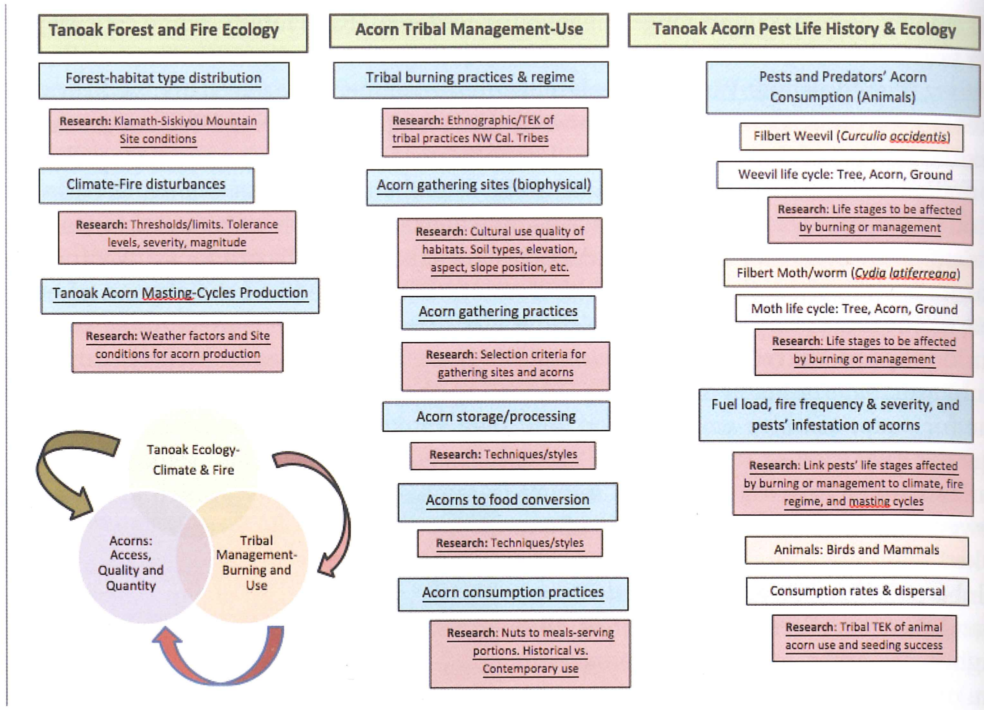


Figure 2/ Overview of research showing the range of ecological and sociocultural factors that influence the condition of *Notholithocarpus densiflorus* forest and acorn use.

Photographers. Title page: Michel Timacheff (*Notholithocarpus densiflorus* var. *densiflorus*). Photos 1a-b: Frank K. Lake.

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