Conifer Encroachment in California Oak Woodlands[1]

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Abstract

California deciduous oak woodlands provide many ecological, cultural, and economic benefits, and often represent unique plant communities that harbor native rare and declining species. Oak woodlands have suffered substantial losses in area and ecological integrity in the post-settlement era due to land conversion and widespread fire exclusion. Remnant oak woodlands in many areas are undergoing further conversion to conifer forest as shade-tolerant, and often less fire-tolerant species invade and increase in abundance. This process, known as conifer encroachment, has been identified across the Pacific West; efforts to restore these ecosystems have increased in California over the past several decades. The process of conifer encroachment is known to occur in many ecosystems in California, but principally affects oak woodlands dominated or co-dominated by Oregon white oak (*Quercus garryana*) and California black oak (*Quercus kelloggii*). Encroachment proceeds through four phases including establishment, piercing, overtopping, and decadent; oak crown recession occurs by the third stage, after which oak mortality becomes abundant. The concomitant increased shading and needlecast from the conifers diminishes plant and animal biodiversity and ecosystem services, and alters fire regimes. We discuss encroached oak woodland structure and dynamics in northern California, identifying conifer species that have the capability and propensity under a fire-suppression management regime to invade and degrade remnant oak woodlands.

Key words: California black oak, ecosystem restoration, forest composition, forest structure, Garry oak, Oregon white oak, prescribed fire

Introduction

A century of fire suppression and management regimes has diminished the resilience of many of California's ecosystems by disrupting natural disturbance processes. Deciduous oak woodlands, primarily those dominated by Oregon white oak (*Quercus garryana*) and California black oak (*Quercus kelloggii*), provide an example where removal of fire can result in the conversion from oaks to less fire-tolerant tree species, primarily native conifers. This process has been described variably as conifer invasion, forest densification, mesophication, succession, and conifer encroachment. The process of conifer encroachment has been observed and studied from California to British Columbia. Conifer species that typically encroach oak woodlands include Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), incense-cedar (*Calocedrus decurrens*), and western juniper (*Juniperus occidentalis*). Frequent fire acts as a strong control on these coniferous species by killing regeneration, thereby

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limiting recruitment to sapling and mature stages (Engber and Varner 2012a). When fire is excluded, proliferation and growth of conifers outpaces oaks resulting in eventual overtopping by conifers, and oak mortality (Barnhart and others 1996, Cocking and others 2012, Devine and Harrington 2006, Devine and Harrington 2013, Engber and others 2011, Sugihara and Reed 1987). In this paper, we present information on the process of conifer encroachment from observations and lab and field studies at various sites across northern California. We focus on the suite of conifer species predisposed to increase within oak woodlands, the effect this process can have on natural resources, and restoration methods currently being utilized to reverse encroachment in parts of northern California.

Effects of conifer encroachment on oak woodlands

Effects on stand structure and composition

Conifers pre-disposed to expand into oak woodlands are generally shade-tolerant, fast growing, and susceptible to fire as juveniles. Encroaching species and rate of encroachment vary by region depending on climate, substrate, and the local vegetation. In coastal sites, encroachment is often exclusively Douglas-fir (Barnhart and others 1996, Engber and others 2011, Sugihara and Reed 1987). In higher elevations and areas in the interior of northern California, Douglas-fir is joined or eclipsed by white fir and incense-cedar (Skinner and Taylor 2006, Skinner and others 2006). Encroachment by western juniper occurs in more arid environments (table 1). While a suite of other conifer species also regenerate in oak woodlands during fire-free intervals or following single fires (for example, ponderosa pine, gray pine, knobcone pine), these species have sparse crowns and tend to co-exist with deciduous oaks.

Table 1—The expected time to development of different stages of conifer encroachment after conifer establishment (values are based on data from published research and personal observations by the authors)

Region	Encroaching species[a]	Understory cessation (years)	Oak crown recession[b] begins (years)	Oak mortality begins[c] (years)	Oaks replaced[d] (years)
North Coast Ranges	PSME	5-10	20-30	30-40	60-100
Western Klamath	PSME	5-10	20-30	40-50	80-100
Central Klamath /Trinity	PSME, CADE, ABCO	10-20	30-40	60-80	100-150
Southern Cascades /northern Sierra	ABCO, PSME	10-20	30-40	60-80	100-150
Eastern Klamath /Shasta Basin[e]	JUOC	20-30	not observed[f]	≥20	not observed[f]
Northern CA serpentine[g]	CADE, PIJE, PSME	10-20	30-50	60-80	≥100

[a] listed by commonality/importance. PSME = *Pseudotsuga menziesii*, CADE = *Calocedrus decurrens*, ABCO = *Abies concolor*, JUOC = *Juniperus occidentalis*, PIJE = *Pinus jeffreyi.*
[b] Refers to the dieback of oak crowns during the piercing stage.
[c] Oak mortality begins during the overtopping stage and peaks as stands reach the decadent stage.
[d] Refers to timeline estimates for 90 percent or greater mortality of pre-encroachment oaks within a stand.
[e] Earlier oak mortality in the Eastern Klamath and Shasta Basin is based on empirical observations at several Oregon white oak sites and might be accounted for by more severe competition for water in this arid region.
[f] Complete replacement of oaks and dieback of oak crowns was not observed with western juniper encroachment; development of these stages may be limited by lower height potential and density of western juniper.

Conifer encroachment often occurs as an initial wave (establishment stage), preceding additional successional development. Tanoak (*Notholithocarpus densiflorus*), evergreen huckleberry (*Vaccinium ovatum*) and other common Douglas-fir understory species succeed Douglas-fir encroachment in coastal oak woodlands (Sugihara and Reed 1987). Encroaching conifers can reach high densities (Cocking and others 2012) especially in wetter climates (for example, Douglas-fir, Coast Ranges) as opposed to dry regions (for example, western juniper, eastern Klamath/Shasta Basin). During establishment, encroaching trees are subject to competition pressure with understory herbaceous and shrub species, especially in herbaceous-dominated Oregon white oak woodlands. As conifers ascend to the oak canopy (piercing stage), competition for sunlight between oaks and conifers becomes substantial, with Douglas-fir having the ability to grow through oak crowns without canopy gaps (Hunter and Barbour 2001). This stage is characterized by many conifers that have pierced pre-existing oak crowns, resulting in an abundance of interlocked crowns and competition for space within the same canopy stratum

(Cocking and others 2012). As conifers emerge above the woodland canopy, increased shade causes dieback of shade-intolerant oaks (overtopped stage). This often results in structural failure of oaks and eventual oak mortality in late stages of encroachment (decadent stage, fig. 1).

Figure 11—Stages of conifer ecnroachment in deciduous oak woodland ecosystems.

Understory response and altered flammability

Un-encroached oak woodlands naturally produce fuelbeds conducive to fire spread with two primary components that are grown and replaced annually: cured herbaceous fuels and oak leaf litter. Understory grasses and forbs generate a porous, low bulk density fuelbed (Engber and others 2011) and senesced leaves of Oregon white and California black oak are highly flammable, rivalling litter from the most fire-adapted pines of the western United States (Engber and Varner 2012b, table 2).

Table 2—Comparison of flammability of deciduous oaks and three encroaching conifers

species	functional group	flame ht (cm)
Quercus kelloggii	deciduous oak	83.0[a]
Quercus garryana	deciduous oak	76.0[a]
Calocedrus decurrens	encroacher	47.1[c]
Pseudotsuga menziesii	encroacher	26.2[b]
Abies concolor	encroacher	21.8[c]

Sources of data: [a] Engber and Varner 2012; [b] Fonda and others 1998; [c] Varner and Banwell, unpublished data.

Flammable fuelbeds promote a frequent fire regime, allowing managers to utilize prescribed fire on about 5 year intervals (Underwood and others 2003); frequent fires serve as a bottleneck for conifer seedling establishment. Non-sprouting, seed reliant conifers are reduced in density, while oaks persist, via either survival as adults or re-sprouting if top-killed by fire. As the oak woodland fuelbed is shaded and replaced by conifer needles and timber litter, the fire feedback is reversed, understory flammability declines, and the bottleneck on conifer establishment is removed (Engber and others 2011). While encroachment results in reduced understory flammability under moderate fire weather (for example, prescribed fire windows), it may increase canopy (crown) fire risk during extreme fire weather events.

Impacts to natural resources and ecosystem resilience

California oak woodlands are important natural resources providing species diversity, water and nutrient cycling, rangeland production, and ecosystem resilience. As mast producers, oaks are essential for survival of many mammal and bird species (Standiford 2002). A critical consideration for the future of mast production at a landscape scale in northern California is the apparently bleak future for tanoak (*Notholithocarpus densiflorus*) due to mortality caused by sudden oak death (Rizzo and others 2002) and the resistance of Oregon white oak to the introduced pathogen responsible for this widespread mortality, *Phytophthora ramorum*. Oregon white oak and California black oak may be key to sustaining acorn-dependent wildlife in parts of northern California as tanoak declines. Oak woodlands are also essential to rangeland health; oaks provide shade for grazing animals during hot summer months and support better late season forage by sustaining higher soil moisture content and nutrients beneath their canopies than adjacent open grassland (Dahlgren and others 1997, Joffre and Rambal 1993) and stands encroached by Douglas-fir (Devine and Harrington 2007). Drought resilient native perennial grasses (Volaire and Norton 2006) and nearly all other understory herbaceous species decline early in the encroachment process, quickly reducing forage quality and quantity and disrupting natural carbon, nutrient, and water cycling processes. The effects of conifer encroachment on water yield may be the most important natural resource consideration relating to this specific issue in California and the Pacific Northwest. When viewed in the sole context of vegetation structure, conifer encroachment in northern California oak savannas, woodlands, and neighboring grasslands is akin to afforestation (Engber and others 2011, Sugihara and Reed 1987), which substantially and more permanently impacts water yield (Farley and others 2005). Furthermore, rainfall interception (a major factor affecting evapotranspiration and water balance; see Zhang and others 2001) is often substantially lower for deciduous as opposed to coniferous forests (Rutter and others1967, 1975; Zinke 1967). Thus, increased groundwater infiltration and reduced evapotranspiration are a major benefit to the California's water supply in un-encroached oak woodlands.

Restoration effectiveness and feasibility

Treatments of encroaching conifers

Restoration treatment intensity and methods vary depending on stage of encroachment. During establishment, conifer seedlings and saplings can be killed by prescribed fire in oak litter/grass fuels (fig. 2-top; Engber and Varner 2012a). Beyond

establishment (about 10 years on productive sites), some conifers become resilient to prescribed fire, and fuelbed changes reduce the likelihood that fire alone will achieve restoration objectives, necessitating mechanical or hand treatments (Cocking and others 2012, Engber and Varner 2012a, Sugihara and Reed 1987). As encroachment proceeds into the piercing and overtopping stages, mechanical treatments (for example, hand-felling or feller-buncher operations) become necessary to remove large, fire-resistant conifers prior to re-introduction of prescribed fire. Smaller cut material may be piled and burned or chipped for biomass utilization while larger material can be sold as saw logs to offset restoration costs while simultaneously achieving objectives. Research on growth release of Oregon white oaks following piercing and overtopping stages shows substantial growth response of oaks even for trees with severely reduced crowns and apparently low vigor (Devine and Harrington 2013). Once an oak stand reaches decadent stage, where oak mortality is widespread, restoration may not be feasible without planting a new cohort of oaks.

At Whiskeytown National Recreation Area, managers have utilized mechanical equipment (feller-bunchers) to remove commercial conifers up to 45.7 cm (18 inches) in diameter (fig. 2 – bottom left). Treatments have focused on full-release (crown thinning) around oaks and a substantial reduction in the proportion of Douglas-fir within stands. Where mature conifers have pierced oak crowns, branch and bole injuries may be sustained to the oaks during conifer removal. Conifer girdling (severing the vascular cambium in a strip around the tree bole) is an alternative treatment on individual trees that can mitigate damage concerns to oaks and provide snag habitat within post-treatment stands (fig. 2 – bottom right). Girdled trees decompose slowly and pose little threat to the structural integrity of oak crowns. Where ground-based equipment is employed for conifer removal, rehabilitation of bare ground should be prioritized to mitigate post-treatment erosion or invasion of non-native species (Devine and others 2007). At Whiskeytown NRA, up to 70 percent of the bare ground was mulched with pre-commercial stems and/or chips following treatments, and berms were pulled by hand. Seeding or transplanting native grass species can also help mitigate erosion and will hasten restoration of understory herbaceous cover. Follow-up treatments to reduce surface fuels may be necessary after erosion threats have abated.

Figure 12—Top - Fire-scorched Douglas-fir seedlings, 2013 Rx Burn, Redwood National Park. Bottom left - Mature California black oak/ponderosa pine stand following removal of encroaching Douglas-fir and tanoak at Whiskeytown National Recreation Area, 2014. Saplings were crushed by feller-buncher operations and used to mitigate post-treatment erosion. Bottom right – A girdled Douglas-fir tree that had grown through an Oregon white oak crown at a restoration site on private land in Humboldt County, NRCS, 2014.

Post-fire response of encroached oak stands

In the Bald Hills of Redwood National Park, oak mortality has been very low within units that have been prescribed burned five or more times at 3 to 5 year intervals, limited mostly to small oaks <15.2 cm (6 inches) DBH (Engber, personal observation). In wildfires, oak mortality is also rare due to re-sprouting (Cocking and others 2012). In high-severity fires oaks are able to reclaim sites by re-sprouting and new stems attain large size quickly where conifers are limited to re-establishment by seed from surviving trees. By contrast, low intensity fire has little effect on the later stages of encroachment (beyond piercing) since both conifers and oaks often survive, perpetuating conversion to conifer dominance (Cocking and others 2014). Data from the Klamath Mountains shows evidence that pierced and overtopped oaks undergoing crown recession may be more susceptible to fire in encroached stand conditions due to lower vigor as a result of competition (Cocking and others 2012).

Thresholds to potentially irreversible conversion

The stand dynamics of oak woodlands across an un-encroached to encroached gradient raises key questions about restoration feasibility, cost, and maintenance. As the amount of encroaching tree biomass increases within oak woodlands, the cost of treatment rises substantially, with few or limited available markets as outlets for restoration byproduct material. This increasing cost is not alleviated by prescribed fire (often a cheaper option) which is generally rendered ineffective in conifer encroached understories typical of pierced and overtopped stand conditions (Engber and others 2011). The relative cost of treatment can be thought of as required energy input to restore an oak dominant state (fig. 3).
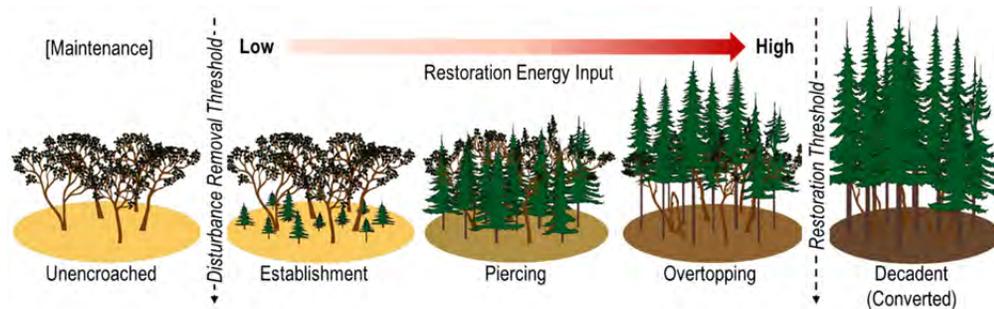

Figure 13—A conceptual model with artwork adapted from Cocking and others (2012) showing the change in energy required to revert to oak dominance across encroached stages. Dashed arrows mark thresholds where stands pass out of maintenance or into conversion and are beyond the limits of restoration. Restoration energy input is the energy required to move stages back toward unencroached woodland. Stages further right in the diagram are more difficult to revert to previous states.

The relationship between encroachment stage and restoration cost is analogous to wildfire effects on encroached oak stands - increasing intensity of fire (in other words, higher energy input) is required to kill larger conifers and adjust overstory dominance back to re-sprouting oaks (Cocking and others 2014). This relationship is likely not linear, but asymptotal where the shifts to later stages of encroachment

represent crossing of thresholds, and reverting to a previous state requires large amounts of energy (or may not be possible).

Conclusion

Given the increasing costs of restoration at later stages of conifer encroachment, and subsequent losses of biodiversity and ecosystem services, the need to increase restoration efforts in California oak woodlands is urgent. The resource impacts associated with a decline of an unquantified total area of encroached oak woodlands are an additional consideration given the economic, ecological, and cultural importance of oak ecosystems in California. For restoration efforts to be successful managers will need access to information similar to that presented in this paper which provides an overview of the encroachment process, and, importantly, a framework to develop restoration or maintenance plans and identify limiting factors - depending on encroachment stage – for California oak woodlands.

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