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California black oak responses to fire severity and native conifer encroachment in the Klamath Mountains

Matthew I. Cocking [a,*], J. Morgan Varner [a], Rosemary L. Sherriff [b]

[a] Department of Forestry and Wildland Resources, Humboldt State University, Arcata, CA, USA
[b] Department of Geography, Humboldt State University, Arcata, CA, USA

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ABSTRACT

Fire exclusion in forests across the western United States has resulted in widespread vegetation change, often with notable increases in density and cover of fire-sensitive species. In California oak woodlands, encroachment by the more shade-tolerant native Douglas-fir (*Pseudotsuga menziesii*) is particularly common, and results in the piercing and eventual overtopping of crowns of shade-intolerant trees. We investigated canopy competition, paired tree ages, and post-fire effects in a recently burned, encroached California black oak (*Quercus kelloggii*) woodland. Pre-fire woodland overstory was heavily dominated by Douglas-fir, which commonly pierced and overtopped California black oak crowns. Trees that pierced overstory oak crowns were younger (mean difference = 43.6 years, $p < 0.001$) than their paired oaks. Fire effects were variable, leaving some areas unchanged and others with complete above-ground stem mortality. Although above-ground stem-kill was often high for California black oak, the majority (82%) resprouted from the root collar. Logistic modeling revealed a significant relationship between California black oak mortality and neighboring Douglas-fir height and plot heat load index. The probability of California black oak mortality increased as neighboring Douglas-fir height increased and decreased with increasing heat load index. Probability of mortality for Douglas-fir decreased with increasing tree size, while the probability of California black oak top-kill was much higher than that for 20–30 cm dbh Douglas-fir across a continuous measure of char height. Results indicate that competitive pressure from encroaching trees may compromise California black oak's ability to survive fire while resilience of encroaching Douglas-fir improves with greater size. Caution should be taken when planning and implementing restoration activities in California black oak woodlands to minimize loss of compromised, remnant oaks while still achieving adequate removal of encroaching conifers.

1. Introduction

In western North America, fire is believed to have played a crucial role in the formation and maintenance of many ecosystems (Agee, 1993). The effects of periodic fire are especially important in the development and maintenance of oak savannas and woodlands (Abrams, 1992; Scholes and Archer, 1997; Tveten and Fonda, 1999; Peterson et al., 2007; Engber et al., 2011). In California, historically frequent natural and cultural ignitions enabled persistence of these disturbance-prone ecosystems, harboring species with strong resilience to and dependence on recurrent fire (Holmes et al., 2008). In the past century, fire exclusion has led to or enabled alteration of oak woodland composition by allowing increased establishment of fire-susceptible native conifers that compete for resources with pre-existing oaks.

California black oak (*Quercus kelloggii* Newb.) is one of the most widespread of the western oaks, inhabiting mid- to high elevations from southern Oregon to Baja California, Mexico (McDonald, 1990). California black oak often associates with other fire-prone species, notably ponderosa pine (*Pinus ponderosa* Laws.) (McDonald, 1969) and other fire-tolerant hardwoods in northern California (Sugihara et al., 1987; Fry, 2008). California black oak endures in fire-prone environments by avoiding stem mortality in low-intensity fire (Skinner et al., 2006; Fry, 2008; Taylor, 2010) and sprouting vigorously from the root collar, bole, or crown when more severe fire occurs (McDonald, 1969; Plumb, 1980; McDonald and Tappeiner, 1996; Skinner et al., 2006). Among western USA oaks, leaf litter from California black oak ranks as the most flammable (Engber and Varner, 2009). Skinner et al. (2006) suggest that the more rapid decomposition of California black oak litter, historically greater presence of herbaceous understory plants, and insufficient crown

* Corresponding author. Address: Department of Forestry and Wildland Resources, Humboldt State University, 1 Harpst Street, Arcata, CA 95521, USA. Tel.: +1 707 601 6730.
E-mail addresses: micocking@gmail.com, mic5@humboldt.edu (M.I. Cocking).

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mass to support canopy fires indicate historically frequent low-intensity fire as the agent for maintaining large, overstory black oaks with much lower densities of conifers than currently seen in much of the Klamath region. Thus, understory fuel conducive to frequent low-intensity fire, re-sprouting capacity, and association with fire-prone species suggest the integral role fire historically played in California black oak-dominated woodlands prior to fire exclusion. During the recent regime of fire suppression (post – 1910), increases in native conifer establishment in California black oak ecosystems were noted by the mid-20th century in the southern Cascades (Barr, 1946) and later in the Sierra Nevada (Vankat and Major, 1978). Recent research by Stewman (2001) and observations from others (McDonald and Tappeiner, 1996; Garrison et al., 2002; Skinner et al., 2006) suggest that California black oak ecosystems are highly susceptible to encroachment by conifers, particularly Douglas-fir, white fir (*Abies concolor* (Gordon & Glend) Hildebr.), and incense-cedar (*Calocedrus decurrens* (Torr.) Florin).

Encroachment by native conifers in California oak woodlands is of increasing conservation concern. Among coniferous invaders, native Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the predominant encroaching species in formerly open, fire-adapted oak woodlands of Northwestern California. Douglas-fir encroachment has been documented in several native oak ecosystems including Oregon white oak (*Quercus garryana* Hook.) (Reed and Sugihara, 1987; Engber et al., 2011), coast live oak (*Quercus agrifolia* Née) (Barnhart et al., 1996; Hunter and Barbour, 2001), as well as California black oak (Stewman, 2001; Skinner et al., 2006). At the seedling and sapling stage, Douglas-fir is highly susceptible to fire (Ryan and Reinhardt, 1988; Engber, 2010), but becomes increasingly resistant with the development of thicker bark as trees age, a so-called negative bark allometry (Jackson et al., 1999). Once established, Douglas-fir recruitment to the overstory is achievable by canopy through-growth (Hunter and Barbour, 2001) or via existing canopy gaps. This presents the possibility for two divergent temporal pathways: one in which frequent fire promotes persistence of oak woodland structure by limiting conifer establishment, and another in which long fire-free intervals facilitate conifer establishment and subsequent oak decline (Fig. 1).

Low vigor and elevated tree stress have been linked to greater susceptibility to fire for many species in different regions (Waring, 1987; Van Mantgem et al., 2003; Varner et al., 2009; O'Brien et al., 2010) and can be brought on by increasing competition from neighboring vegetation (Asbjørnsen and Brudvig, 2007; Marcos et al., 2007; Oheimb et al., 2010). Increased resource competition from encroaching conifers on individual California black oaks may reduce overall oak health and impair their resilience to subsequent stress and injury caused by fire. Post-fire effects studies in California have reported highly variable mortality for California black oak and indicate a consistent re-sprouting response (often referred to as "top-kill") that appears to vary with fire intensity. In low-intensity prescribed fires in the Sierra Nevada, Kobziar et al. (2006) observed mortality of California black oak ranging from 10% to 60% (excluding top-kill). At a similar Sierra Nevada site Stephens and Finney (2002) reported 100% stem mortality of California black oak but noted that 90% of top-killed oaks re-sprouted from the root collar following low to moderate intensity prescribed burns. In contrast, Fry (2008) observed only one dead California black oak 4 years after a low-intensity prescribed burn in central California and did not note any re-sprouting. In a wildfire, Regelbrugge and Conard (1993) reported similar results (74% aboveground kill, 89% re-sprouting) to those found for California black oak in prescribed fire by Stephens and Finney (2002).

Attempts to model the probability of California black oak mortality from fire have been problematic (Stephens and Finney, 2002) or lacked adequate data to model complete mortality as opposed to top-kill (Regelbrugge and Conard, 1993). Kobziar et al. (2006) found that California black oak deviated from a consistent pattern

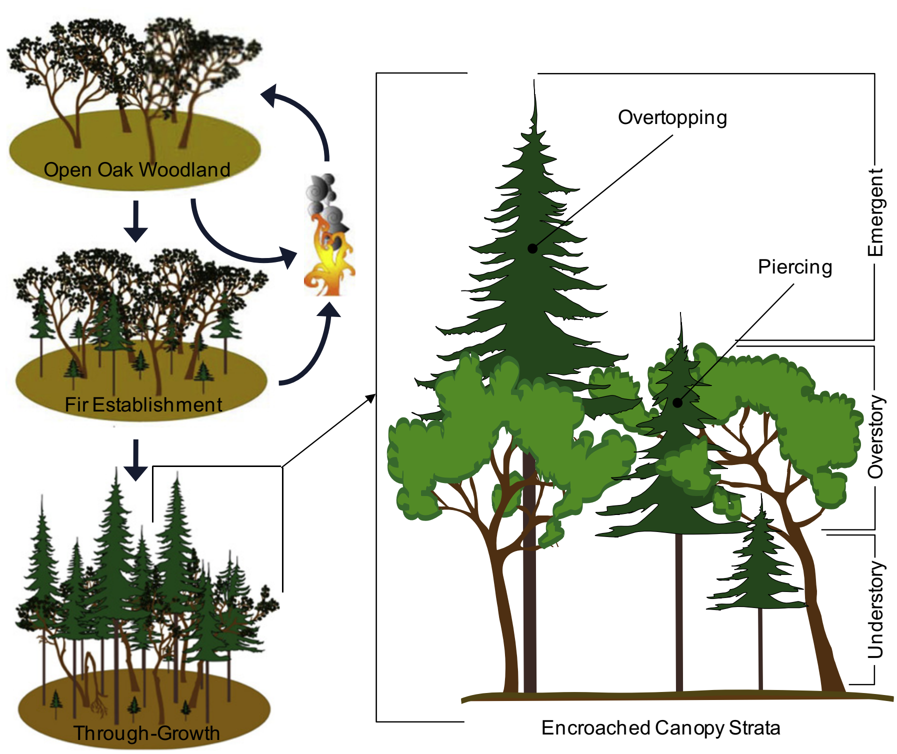

Fig. 1. Conceptual pathway illustrating the pattern of Douglas-fir encroachment in oak woodlands. Frequent fire limits establishment by killing young conifers and maintaining open oak woodland. Without fire, conifers establish and subsequent through-growth results in increased competition with distinct canopy stratification. Canopy strata depictions adapted from Oliver and Larson (1996) and Hunter and Barbour (2001).