Mortality and Resprouting in California Oak Woodlands Following Mixed-Severity Wildfire

David D. Ackerly,[1,2*] Melina Kozanitas,[1,3] Prahlada Papper,[1] Meagan Oldfather,[4] and Matthew Clark[5]

1. Dept. of Integrative Biology
University of California
Berkeley, CA 94720, USA
* corresponding author: *dackerly@berkeley.edu*

2. Dept. of Environmental Science, Policy, and Management
University of California
Berkeley, CA 94720, USA

3. Dept. of Biology
Sonoma State University
Rohnert Park, CA 94928, USA

4. Dept. of Ecology and Evolutionary Biology
University of Colorado
Boulder, CO 80303, USA

5. Dept .of Geography, Environment, and Planning
Sonoma State University
Rohnert Park, CA 94928, USA

ABSTRACT

We quantified fire severity in the Tubbs Fire (Sonoma Co., CA, October 2017) across different vegetation types, as well as post-fire mortality and regeneration of tree species in permanent plots at the Pepperwood Preserve. The fire burned 14,895 ha, with > 25% in both medium and high severity. Chaparral and *Pinus attenuata* stands mostly burned at high severity, while other vegetation types experienced a fairly even distribution of fire severity. The fire killed 50% of saplings (DBH < 1 cm) and 27% of trees (DBH ≥ 1 cm), with higher mortality in high-severity patches. *Quercus agrifolia*, *Q. kelloggii*, *Arbutus menziesii* and *Umbellularia californica* exhibited very high levels of topkill combined with basal resprouting. *Pseudotsuga menziesii*, which lacks resprouting ability, exhibited high mortality, especially in saplings at high severity. The results provide a baseline to examine potential vegetation change due to high-severity fire, especially in high-severity stands of *P. menziesii*.

Keywords: Pepperwood Forest Dynamics Project, basal sprouting, topkill, survival, mixed hardwood forest, fire severity, *Quercus, Pseudotsuga menziesii, Arbutus menziesii, Umbellularia californica*

Introduction

Wildfire is frequent in California's Mediterranean-type ecosystems, due to annual summer drought that enhances flammability of live and dead fuels. California ecosystems exhibit a diversity of fire regimes, from frequent, low-intensity fires in grasslands to high-intensity, stand-replacing fires in chaparral and closed-cone pine forests. In oak woodlands and mixed hardwood forests of the Sierra Nevada foothills and Coast Ranges, most fires burn through the understory, consuming litter and burning seedlings and saplings, with minimal damage to overstory trees (Davis and Borchert 2006). However, extreme fire conditions can lead to mixed-severity fires with pockets of high mortality and extensive resprouting of burned trees. In the San Francisco Bay Area, extreme fire conditions are usually linked to Diablo Winds, easterly downslope wind events that bring high winds and very low humidity.[1] Diablo Winds are linked to the largest Bay Area fires of the past century, including the 1923 Novato and Berkeley Hills fires, the 1965 Hanley Fire, and the destructive 1991 Tunnel Fire in Oakland.

During an extreme Diablo Wind event in Napa and Sonoma counties on October 8, 2017, multiple ignitions coalesced into four major fires: Tubbs, Atlas, Nuns, and Pocket (Fig. 1a). Collectively, these fires burned 65,700 ha and at the time were the most destructive fires in California history, with 31 deaths and >7,500 structures burned. The Tubbs Fire was the most destructive of the four, igniting near Calistoga and spreading more than 15 km overnight under high wind conditions. After the extreme conditions on the first night, the fire continued to spread north and then east, as winds shifted, burning at lower intensity and eventually covering 14,895 ha (Fig. 1b).

Pepperwood Preserve, a research facility northeast of Santa Rosa, was heavily burned, with fire covering about 85% of the 1,263 ha site (Fig. 1b). Starting in 2013, we established the Pepperwood Forest Dynamics Project, a network of forest plots designed to study effects of topography on forest dynamics, and to provide a baseline for responses to extreme events (Oldfather et al. 2016). Taking advantage of this resource as a baseline, we conducted rapid surveys of fire severity in the months after the Tubbs Fire, and a full resurvey of individual survival and regeneration in the summer of 2018, to address the following questions:

1. What were the patterns of fire severity in relation to vegetation type in the Tubbs Fire?
2. How do the dominant tree species differ in mortality, topkill, and resprouting responses to low- vs. high-severity fire, and how do responses differ between saplings and trees?

Methods

Fire severity

We estimated burn severity using Landsat 8 satellite images recorded before and after the Tubbs Fire. Images were from the U.S. Landsat Analysis Ready Data (ARD) that provide automated atmospheric correction and surface reflectance retrieval.[2] Landsat 8 ARD tiles LC08_CU_001008 and LC08_CU_002008 were used (pre-fire: 09/25/2017, 10/04/2017; post-fire: 10/27/2017, 11/05/2017). Fire severity was calculated using the

1. For details on Diablo Winds, see http://www.fireweather.org/diablo-winds/.
2. Available at https://www.usgs.gov/land-resources/nli/landsat/us-landsat-analysis-ready-data.

relativized burn ratio (RBR) described in Parks et al. (2014). This ratio uses the normalized burn ratio (NBR), which is sensitive to plant chlorophyll, moisture and burned materials. Pre- and post-fire difference in NBR was calculated (dNBR) to provide a measure of burn severity. The RBR is the dNBR adjusted with a pre-fire NBR factor that prevents the index from failing in some situations. Following Parks et al. (2014) the delta normalized burn ratio (dNBR), we classified the dNBR raster product into four burn severity classes: <35 (unchanged), 35-130 (low), 130-298 (medium), and >298 (high).

The fire severity layer was intersected with the Sonoma County vegetation map[3] to determine the relative frequency of vegetation types burned in the fire, and the distribution of fire severity within each type. Agricultural and developed areas were excluded from analysis, and rare vegetation types were combined, resulting in 14 types for analysis.

Tree mortality and regeneration

The Tubbs Fire burned at very high severity under high wind conditions on the first night (Oct. 8-9), and then at lower severity for the following several days. The location of the first night fire perimeter at Pepperwood was determined based on Google Earth imagery, weather stations, and wildlife cameras (Fig. 1c). Only 3 of our original plots were located within this high-severity zone, all dominated by *Pseudotsuga menziesii*. To expand sampling of hardwood species, we added 4 more plots, following the same protocol as the original 2013 sampling, for a total of 54 plots (Fig. 1c).

In 2013, all individuals > 50 cm tall were tagged, mapped and measured, and recorded as saplings (height > 50 cm, diameter at breast height (DBH) < 1 cm) or trees (DBH ≥ 1 cm). A total of 3,900 individuals from 25 species were recorded, with 7 species comprising 98% of basal area: *Quercus agrifolia* (29% of total basal area), *P. menziesii* (24.1%), *Q.*

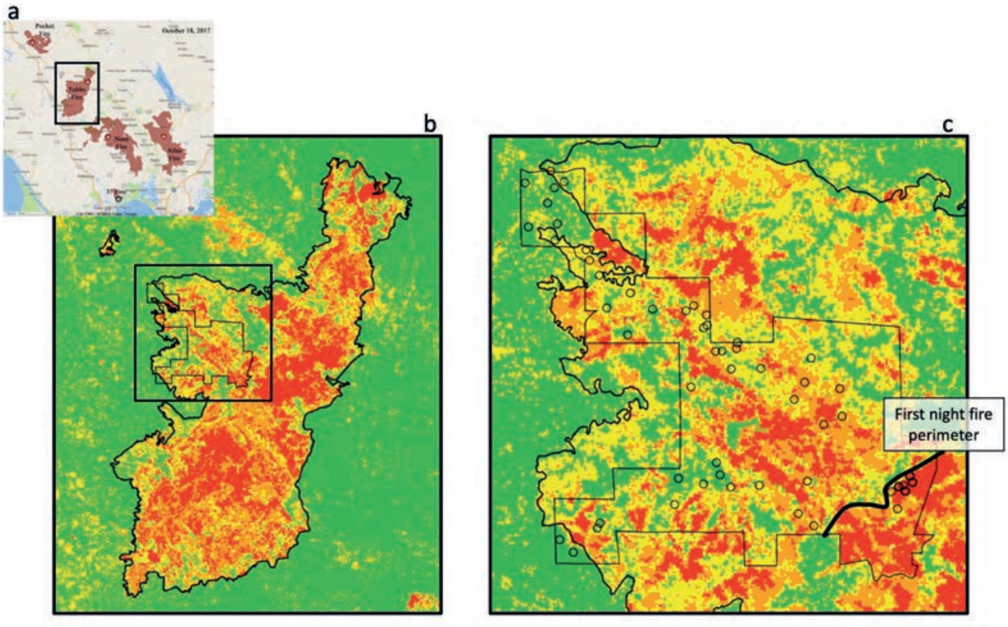

Figure 1/ (a) San Francisco North Bay region, showing location of four fires in 2017; (b) Fire severity map for the Tubbs Fire: green = unchanged; yellow = low severity; orange = medium severity; red = high severity; (c) detail for Pepperwood Preserve: open circles show locations of 54 forest dynamics plots; dark line shows upper edge of high severity fire zone on the first night of the Tubbs Fire.

3. Available at http://sonomavegmap.org.

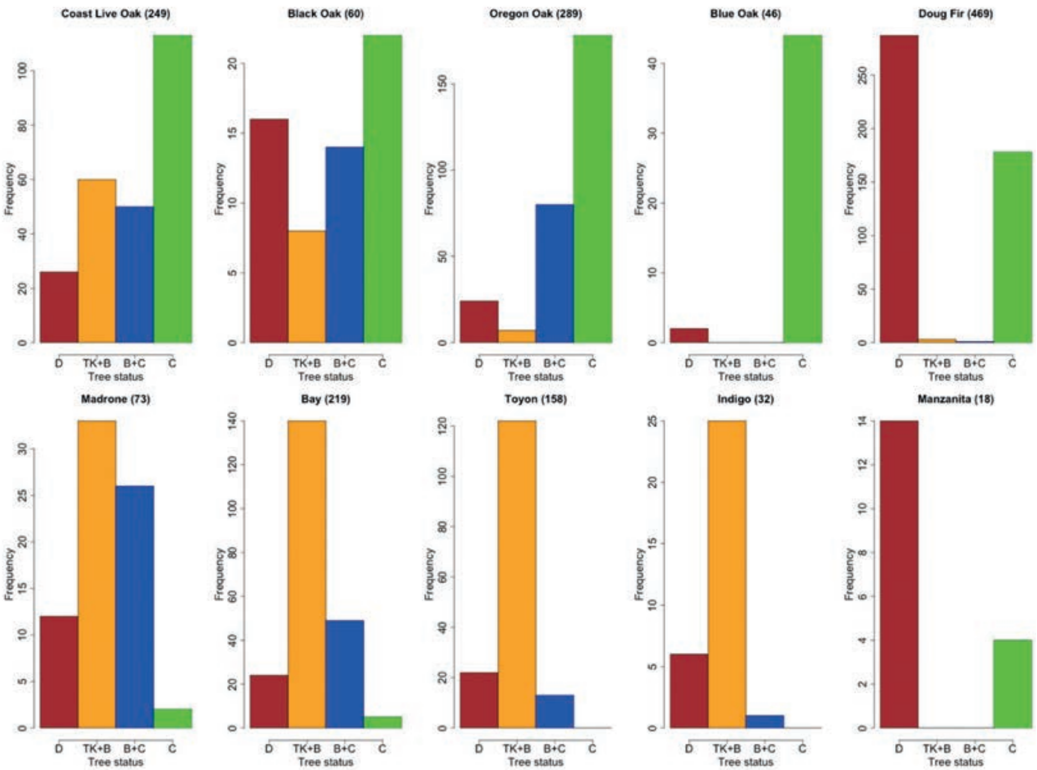

Figure 2/ Post-fire status of trees (DBH ≥ 1 cm) in forest dynamics plots at Pepperwood. D = dead; TK+B = topkill + basal resprouting; B+C = basal resprouting + green foliage in crown; C = green foliage in crown with no basal resprouting. Sample sizes shown after each species name.

garryana (23.6%), *Q. douglasii* (7.7%), *Q. kelloggii* (6.6%), *Arbutus menziesii* (4.4%), and *Umbellularia californica* (2.7%). We analyzed these species and three additional shrubs: *Arctostaphylos manzanita*, *Heteromeles arbutifolia*, and *Amorpha californica* var. *napensis*.

In summer 2018, plots were resurveyed to determine post-fire status of all tagged individuals. For each individual we recorded the following: presence/absence of basal resprouts; presence/absence of epicormic sprouting on major branches; presence/absence of green foliage on apical branches of the crown; percentage of the canopy with green foliage (estimated visually by two observers). We were not able to determine whether green foliage in the crown were leaves that survived the fire, regrowth on undamaged tips, or post-fire resprouts from apical branches. Based on these observations, the status of each individual was classified into one of four classes (Figs. 2-4):

- D: Dead (no basal resprouting and no green foliage in the crown)
- TK+B: Topkill and resprouting (basal resprouting present, no foliage in the crown)
- B+C: Resprouting and living crown (basal resprouting present, green foliage in the crown)
- C: Living crown only (basal resprouting absent, green foliage in the crown)

Results were analyzed separately for saplings and trees, and results are shown for the seven plots that burned at high severity on the first night, as well as for all burned plots together.

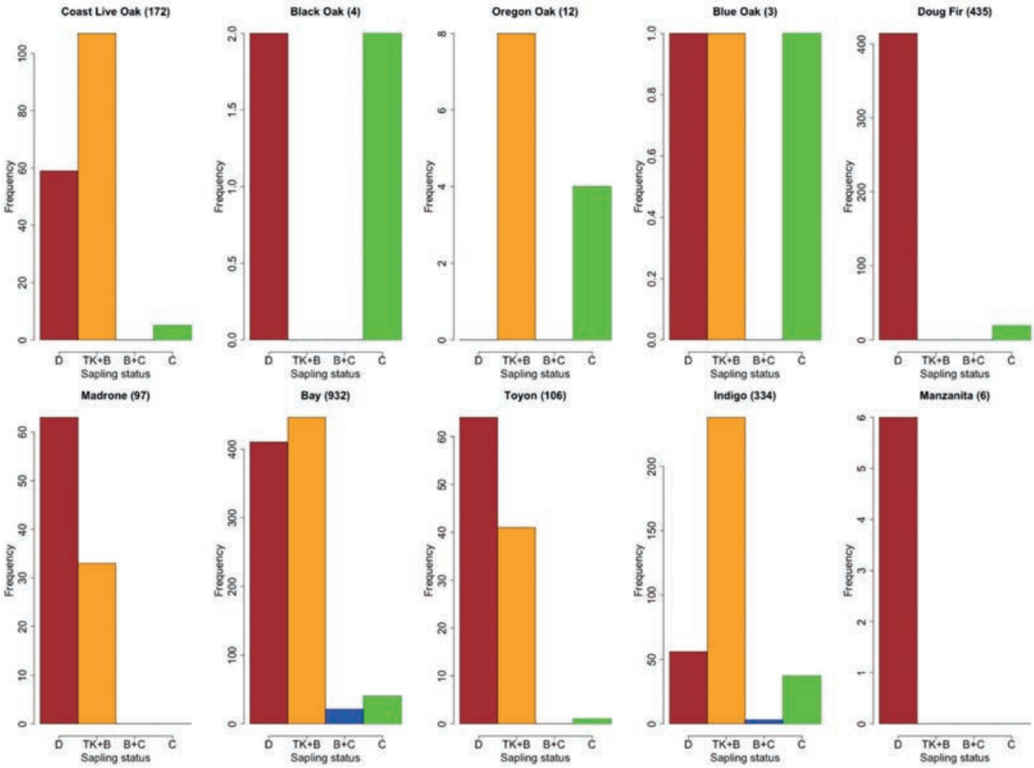

Figure 3/ Post-fire status of saplings (height > 50 cm, DBH < 1 cm) in forest dynamics plots at Pepperwood. D = dead; TK+B = topkill + basal resprouting; B+C = basal resprouting + green foliage in crown; C = green foliage in crown with no basal resprouting. Sample sizes shown after each species name.

Results

The Tubbs Fire burned a total of 14,895 ha, with 13,351 ha within Sonoma County (where we had a complete vegetation map available for analysis). Within the county, the distribution of fire severity was: unchanged 13.2%, low severity 22.1%, medium severity 35.8%, high severity 28.9% (Fig. 1b).

The three most common vegetation types within the fire zone were grassland, *P. menziesii* woodland, *Q. agrifolia* woodland, *Q. garryana* woodland, and then a grouping of other oak woodland alliances (lumped here as "oak woodland") (Fig. 5). More than 75% of chaparral and *Pinus attenuata* burned at high severity. *Quercus douglasii*, *Q. garryana*, and riparian vegetation experienced low levels of high severity (< 15%). *Quercus douglasii* and *Q. garryana* both occur primarily as oak savannas with a grass understory and absence of ladder fuels, reducing fire severity.

At Pepperwood, 43 of our original 50 plots burned and 4 additional plots were installed within the high-severity zone. We surveyed the post-fire status of 3,983 individuals. The fire killed 1,175 of 2,325 saplings (50%) and 445 of 1,658 trees (27%). We observed a spectrum of species strategies of post-fire survival or regeneration for trees (Figs. 2-4). In the four oaks, the most common status was crown survival with no basal resprouting (C). In *Q. kelloggii*, *Q. agrifolia*, and *Q. garryana*, basal resprouting was also common,

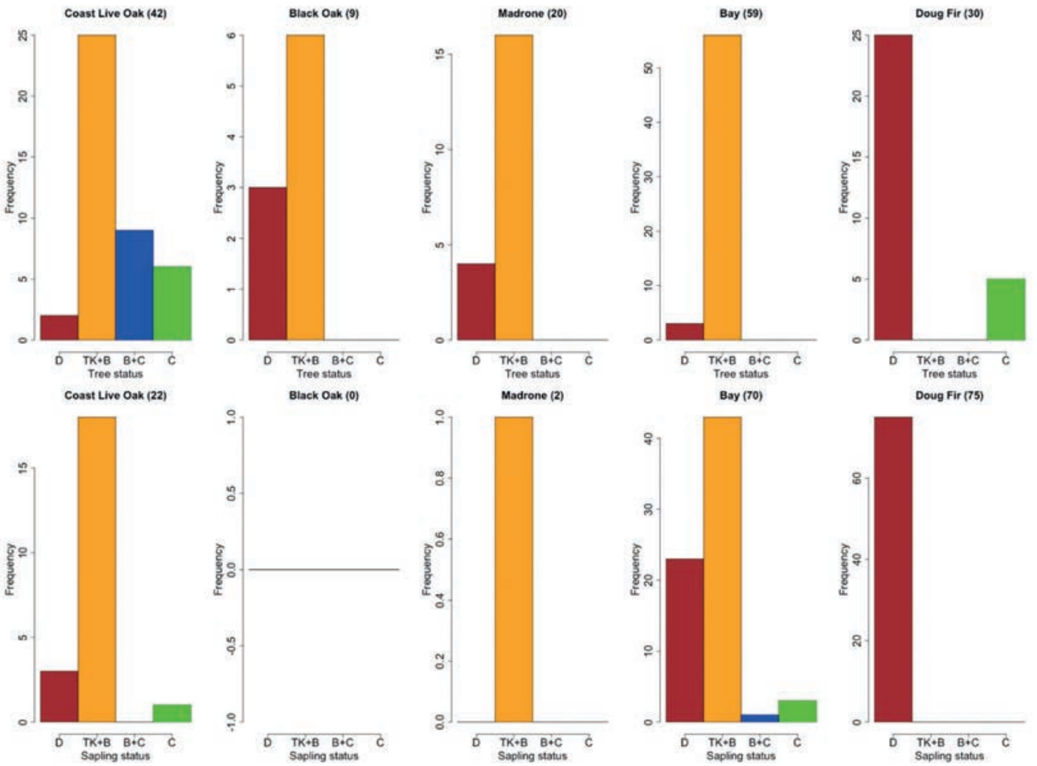

Figure 4/ Post-fire status of trees and saplings for five species in high severity plots that burned on the first night of the fire. D = dead; TK+B = topkill + basal resprouting; B+C = basal resprouting + green foliage in crown; C = green foliage in crown with no basal resprouting. Sample sizes shown after each species name.

but not in *Q. douglasii*. *Quercus kelloggii* exhibited fairly high levels of mortality, while *Q. agrifolia* had many individuals that were topkilled and resprouted at the base. *Arbutus menziesii* and *U. californica* both exhibited very high levels of basal resprouting, together with either topkill or green crowns, and low levels of mortality. Two of the understory shrubs, *Heteromeles arbutifolia* and *Amorpha californica* var. *napensis*, also had very high levels of topkill combined with basal resprouting. *Pseudotsuga menziesii* and *Arctostaphylos manzanita* are non-sprouting species, and individuals of these species were either killed or survived with a living canopy. For saplings, which are exposed to higher fire intensity in the understory, all species exhibited high levels of mortality or topkill combined with basal resprouting (Fig. 3; note very small sample sizes for some species).

The seven plots within the high-severity zone of the first night of the Fire were dominated by *Q. agrifolia*, *Q. kelloggii*, *A. menziesii*, *U. californica*, and *P. menziesii* (Fig. 2). Almost all of the hardwoods were topkilled, with high levels of resprouting, and little mortality. *Pseudotsuga menziesii* incurred very high mortality of trees and 100% mortality of saplings.

Discussion

The Tubbs Fire was a mixed-severity fire that burned through grasslands, chaparral, oak and mixed hardwood woodlands, and coniferous forest. A full range of fire severity

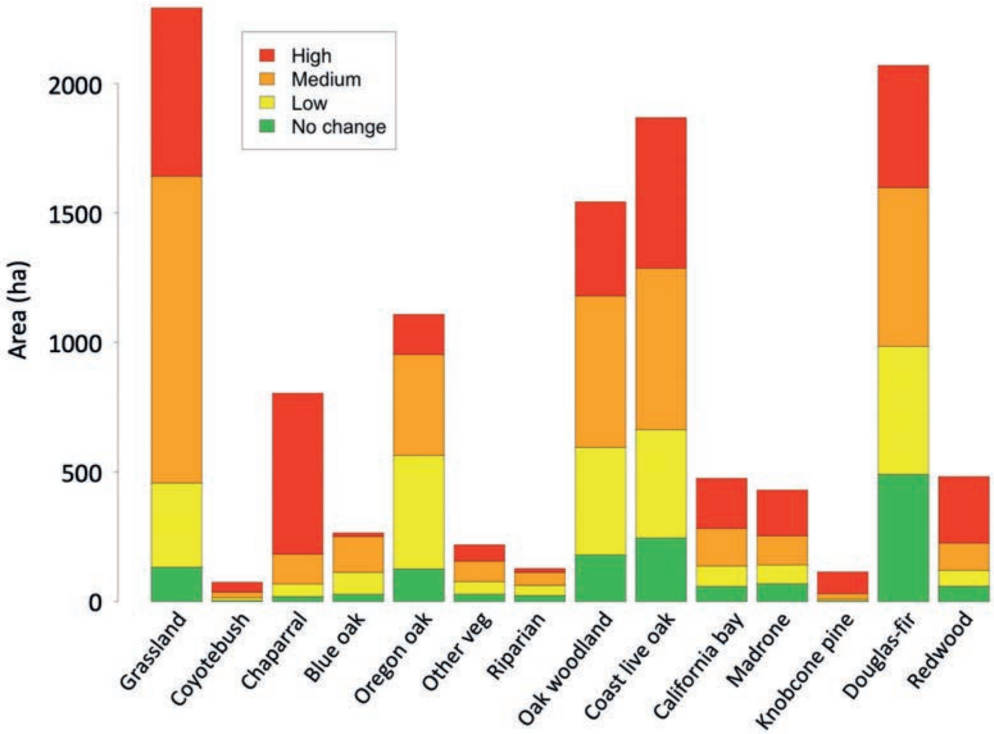

Figure 5/ Distribution of fire severity in different vegetation types for the portion of the Tubbs Fire in Sonoma County, CA in 2017.

was observed across vegetation types, with two typical crown-fire systems, chaparral and *P. attenuata*, exhibiting a higher proportion of high-severity fire.

Hardwoods (*Quercus* spp., *A. menziesii*, and *U. californica*) exhibit very high resprouting capacity, either from the base or from epicormic sprouts in the canopy (especially *Q. agrifolia*). *Pseudotsuga menziesii* and *A. manzanita*, which lack the capacity to resprout, experienced higher levels of overall mortality, especially in high-severity patches.

The role of fire in vegetation dynamics and potential vegetation type conversion is of great interest, especially in the face of a changing climate. Based on the extensive resprouting (as well as post-fire seed germination), stands of hardwoods are likely to recover with limited change in species composition. The most interesting changes may occur in fire-killed stands of *P. menziesii*. Some stands had a scattered understory of *Quercus*, *Notholithocarpus*, and *U. californica*, which are regenerating quickly from basal resprouts. *Pseudotsuga menziesii* is wind dispersed, and regeneration of seedlings dispersing from nearby seed trees is underway. Over the next decade or so, the boles of the dead trees will fall and create a tangled ground layer of fallen logs (with the possibility of novel fire regimes; Stephens et al. 2018). This mortality is a product of acute drought compounded by the long-established removal of a key ecosystem process: frequent, low- to moderate-intensity fire. The recent tree mortality has many implications for the future of these forests and the ecological goods and services they provide to society. Future wildfire hazard following this mortality can be generally characterized by decreased crown-fire potential and increased surface-fire intensity in the short to intermediate term. The scale of present tree mortality is so large that greater potential for "mass fire" exists in the coming decades, driven by the amount and continuity of dry, combustible, large woody material that could produce large, severe fires. For long-term adaptation to climate change, we highlight the importance of moving beyond triage of dead and dying trees to making "green" (live). Large high-severity patches are more likely to exhibit delayed recovery, due to dispersal limitation (Shive et al. 2013).

The expansion of *P. menziesii* is a widespread management concern in coastal California. Seedlings and, at times, large trees, are manually removed in open space preserves to prevent overtopping of oak woodland (Barnhart et al. 1996). *P. menziesii* would have been more limited in a frequent-fire environment, due to the fire-sensitivity of the saplings. However, large trees have thick bark and are tolerant of all but the highest severity fire events, and persistent seed trees will continue to disperse seed across broad landscapes following fire events (Uchytil 1991). The mortality of numerous saplings and small trees in the Tubbs Fire may provide a window for local land managers to follow up with sustained removal of newly establishing saplings and maintain selected patches in hardwood or shrubland vegetation.

Photographers. Title page: Béatrice Chassé (*Quercus kelloggii*).

Works cited

Barnhart, S.J., J.R. McBride, and P. Warner. 1996. Invasion of Northern Oak Woodlands by Pseudotsuga menziesii (Mirb.) Franco in the Sonoma Mountains of California. *Madroño* 43(1): 28-45.

Davis, F.W., and M.I. Borchert. 2006. Central Coast Bioregion. In *Fire in California's Ecosystems*, edited by N.G. Sugihara, J.W. van Wagtendonk, K.E. Shaffer KE, J. Fites-Kaufman, and A.E. Thode, pp. 321-349. Berkeley: University of California Press.

Oldfather, M.F., M.N. Britton, P.D. Papper, M.J. Koonts, M.M. Halbur, C. Dodge, A.L. Flint, L.E. Flint, and D.D Ackerly. 2016. Effects of topoclimatic complexity on the composition of woody plant communities. *AoB Plants* 8: plw049.

Parks, S.A., G.K. Dillon, and C. Miller. 2014. A New Metric for Quantifying Burn Severity: The Relativized Burn Ratio. *Remote Sensing* 6(3): 1827-1844.

Shive, K.L., C.H. Sieg, and P.Z. Fulé. 2013. Pre-wildfire management treatments interact with fire severity to have lasting effects on post-wildfire vegetation response. *Forest Ecology and Management* 297: 75-83.

Stephens, S.L., B.M. Collins, C.J. Fettig, M.A. Finney, C.M. Hoffman, E.E. Knapp, M.P. North, H. Safford, and R.B. Wayman. 2018. Drought, Tree Mortality, and Wildfire in Forests Adapted to Frequent Fire. *BioScience* 68(2): 77-88.

Uchytil, R. 1991. *Pseudotsuga menziesii* var. *menziesii*. In *Fire Effects Information System*. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.fed.us/database/feis/plants/tree/psemenm/all.html