Southern California Montane Forests Threat Assessment

Southern montane forests

Prior to Euro-American settlement, the composition of yellow pine mixed conifer (YPMC) forests was dominated by Ponderosa (*Pinus ponderosa*) and Jeffrey pines (*Pinus jeffreyi*). In southern California, Jeffrey pine is the dominant yellow pine species above 1600m (5,000 ft) and on the drier north and east sides of major mountain ranges[1,2]. Canyon live oak (*Quercus chrysolepis*) and black oak (*Quercus kelloggii*) are hardwood associates at most elevations. Dense shrub cover can occur in disturbed areas and sites with low tree density[2]. Pre-settlement conditions consisted primarily of large trees (dbh > 67 cm^3) at low densities, but selective logging and fire exclusion over the last century or more have greatly increased forest densities statewide[4]. The pre-settlement YPMC fire regime predominantly consisted of low intensity[5,6] fires at short fire return intervals (generally <15 years).

Threats to montane forests in southern California

Fire Exclusion

- In a recent assessment of USFS lands in Southern California, half of sampled YPMC stands experienced no fire in the past 100 years and current mean fire return interval is more than four times longer than pre-settlement levels[7].
- Accumulated fuels have also contributed to increased mean and maximum high severity patch size, as well as an increase in the mean proportion of high severity area per fire[7].
- Increasing fire risk has translated to increasing fire sizes in southern California conifer forest since 1910[7]. Throughout the 2000s, severe wildfires have burned large areas of montane forest[7].
- High severity fire effects over large land areas can delay or prevent YPMC forest recovery postfire because YPMC conifer species are not adapted to regenerate after high severity fire. In some burned areas, conifer forests have converted to hardwood and shrub-dominated landscapes[8,9,10,11].

Climate - Temperature

- Under current emissions scenarios, projections show that, by midcentury, maximum temperatures are projected to increase by an average of 3.2° C in currently forested montane areas above 1200 m.
- By the end of the century, maximum temperatures at montane elevations could increase on average by 5.0° C[12,13].
- Warming temperatures increase fuel aridity, length of the fire season, and the number of high fire danger days[14].
- Warming can also lead to plant mortality, especially during establishment of young shrubs and trees with shallow roots.

Climate - Precipitation

- Projections are uncertain about whether precipitation will increase or decrease across southern California.
- Precipitation is likely to be more variable than current conditions, with a higher percentage of annual rainfall occurring during extreme atmospheric river storm events[15,16].

- By the second half of the century, increasingly frequent drought during winter months is expected[17].

Climate - Snowpack

- Mean winter snowfall is projected to be 70% of current levels by midcentury (2060), and fall to 50% of current levels by end of century (2081-2100).
- By 2060, earlier spring snowmelt is projected to shift the first snowpack-free date 1-3 weeks earlier, especially at lower and middle montane elevations[18].

Climate - Drought

- Higher evaporative demand from higher temperatures will increase drought levels by creating more frequent and persistent dry conditions[19,20].
- Widespread, severe droughts are projected to occur over many land areas in the next 30-90 years and may exceed historical drought conditions[21].
- For forests in the southwestern U.S., average drought stress is projected to be higher by 2050 than in the previous 1000 years[22].
- Drought is a major driver of forest mortality[23]. During the California drought of 2012-2016 mortality was associated with the combination of dry conditions and dense forest stands[24]. In sampled stands across the Sierra Nevada Mountains, 90% of ponderosa pines were lost[26].

Ozone and other atmospheric pollution

- In conifer forests, nitrogen deposition stimulates new foliar growth, premature needle loss, and higher leaf turnover. Increased ozone and nitrogen deposition from air pollution can increase the amount of leaf and branch litter and retard litter decomposition rates by 50-125% over less polluted sites[27], contributing to an increase in fire hazards.
- Ozone pollution both increases water loss through the canopy and impedes root water uptake, increasing drought stress levels[27].

Insect and fungal agents

- The mechanisms of bark beetle and fungal attacks are highly co-evolved with tree defenses, but tree defenses are weakened under drought conditions[28,29]. A major conifer mortality event in southern California was triggered by drought between 1999 and 2003, followed by one of the most severe outbreaks of western pine beetle and associated fungi up to that time[2,26,30,31].
- Tree mortality from bark beetles is much higher under severe drought compared to moderate drought[31,32].
- Increases in temperature are predicted to result in more beetle outbreaks[33] and upward elevational and latitudinal shifts beyond current distribution limits[34].
- Outbreaks of bark beetles have been associated with years with warmer overall year-round temperatures and lacking very low winter temperatures[32].

Invasive species (Gold spotted oak borer)

- Ongoing invasion by the Gold spotted oak borer beetle (*Agrilus auroguttatus*, GSOB) is killing large numbers of oaks in southern California. GSOB causes 80-90% mortality in regional red oak species (coast live oak, California black oak). Approximately 60% mortality occurs in canyon live oak (*Q. chrysolepis*), and has not been observed in white oaks (*Q. engelmannii*)[35].
- Larger trees (greater than 12.5 cm dbh) are more susceptible to GSOB, with widespread mortality possible among old growth oaks[36].
- Contact insecticides have some limited efficacy for protecting uninfested, high-value trees, but are not likely to control larvae in infested trees[37].

Citations

[1]Keeley, J.E., Agee, J.K., Sugihara, N.G., Van Wagtendonk, J.W., Shaffer, K.E., Fites-Kaufman, J. *et al.* (2006). South Coast Bioregion. In: *Fire in California's Ecosystems*. University of California Press, pp. 350-390.

[2]Minnich, R.A. (2007). Southern California coniferous forest. In: *Terrestrial vegetation of California, 3rd edition.* (eds. Barbour, M.G. Keeler-Wolf, T., & Schoenherr, A.S.). University of California Press Berkeley and Los Angeles, CA, pp. 502-538.

[3]Minnich, R., Barbour, M., Burk, J. & Fernau, R. (1995). 60 years of change in Californian conifer forests of the San Bernardino Mountains. *Conservation Biology*, 9, 902-914.

[4]Safford, H.D. & Stevens, J.T. (2017). Natural range of variation for yellow pine and mixed-conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA. *Gen. Tech. Rep. PSW-GTR-256. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. 229 p*.

[5]North, M.P., Collins, B.M., Safford, H.D. & Stephenson, N.L. (2016). Montane forests. In: *Ecosystems of California* (eds. Mooney, H.A. & Zavaleta, E.). University of California Press Berkeley, CA, pp. 553-577.

[6]Safford, H.D., Butz, R.J., Bohlman, G.N., Coppoletta, M., Estes, B.L., Gross, S.E. *et al.* (2021). Fire ecology of the North American Mediterranean climate zone. In: *Fire ecology and management: Past, present, and future of U.S. Forested Ecosystems* (eds. Greenberg, C.H. & Collins, B.). Springer.

[7] Nigro, K. & Molinari, N. (2019). Status and trends of fire activity in southern California yellow pine and mixed conifer forests. *Forest Ecology and Management*, 441, 20-31.

[8]Franklin, J., Spears-Lebrun, L., Deutschman, D. & Marsden, K. (2006). Impact of a high-intensity fire on mixed evergreen and mixed conifer forests in the Peninsular Ranges of southern California, USA. *Forest Ecology and Management*, 235, 18-29.

[9]Franklin, J. & Bergman, E. (2011). Patterns of pine regeneration following a large, severe wildfire in the mountains of southern California. *Canadian Journal of Forest Research*, 41, 810-821.

[10]Goforth, B.R. & Minnich, R.A. (2008). Densification, stand-replacement wildfire, and extirpation of mixed conifer forest in Cuyamaca Rancho State Park, southern California. *Forest Ecology and Management*, 256, 36-45.

[11]Safford, H.D. & Vallejo, V.R. (2019). Ecosystem management and ecological restoration in the Anthropocene: integrating global change, soils, and disturbance in boreal and Mediterranean forests. In: *Global change and forest soils: conservation of a finite natural resource* (eds. Busse, M, Dumroese, D, Giardina, C & Morris, D). Elsevier Cambridge, MA, pp. 259-308.

[12]Cal-Adapt. (2018). Cal-Adapt website developed by University of California at Berkeley's Geospatial Innovation Facility under contract with the California Energy Commission. Retrieved from https://cal-adapt.org/tools/extreme-heat/.

[13]Pierce, D.W., Kalansky, J.F. & Cayan, D.R. (2018). Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. In: *California's Fourth Climate Change Assessment.* California Governor's Office of Planning and Research, Scripps Institute of Oceanography, California Energy Commission, California Public Utilities Commission.

[14]Abatzoglou, J. & Williams, A. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences of the United States of America*, 113, 11770-11775.

[15]Pierce, D., Cayan, D., Das, T., Maurer, E., Miller, N., Bao, Y. *et al.* (2013). The Key Role of Heavy Precipitation Events in Climate Model Disagreements of Future Annual Precipitation Changes in California. *Journal of Climate*, 26, 5879-5896.

[16]Polade, S., Gershunov, A., Cayan, D., Dettinger, M. & Pierce, D. (2017). Precipitation in a warming world: Assessing projected hydro-climate changes in California and other Mediterranean climate regions. *Scientific Reports*, 7.

[17]Berg, N. & Hall, A. (2015). Increased Interannual Precipitation Extremes over California under Climate Change. *Journal of Climate*, 28, 6324-6334.

[18]Sun, F., Hall, A., Schwartz, M., Walton, D.B. & Berg, N. (2016). Twenty-First-Century Snowfall and Snowpack Changes over the Southern California Mountains. *Journal of Climate* 29, 91-110.

[19]Naumann, G., Alfieri, L., Wyser, K., Mentaschi, L., Betts, R., Carrao, H. *et al.* (2018). Global Changes in Drought Conditions Under Different Levels of Warming. *Geophysical Research Letters*, 45, 3285-3296.

[20]Prudhomme, C. (2014). Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. *Proceedings of the National Academy of Sciences of the United States of America*, 111, 3262-3267.

[21]Dai, A. (2013). Increasing drought under global warming in observations and models. *Nature Climate Change*, 3, 52-58.

[22]Williams, A., Allen, C., Macalady, A., Griffin, D., Woodhouse, C., Meko, D. *et al.* (2013). Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change*, 3, 292-297.

[23]Dale, V., Joyce, L., McNulty, S., Neilson, R., Ayres, M., Flannigan, M. *et al.* (2001). Climate change and forest disturbances. *Bioscience*, 51, 723-734.

[24]Young, D., Stevens, J., Earles, J., Moore, J., Ellis, A., Jirka, A. *et al.* (2017). Long-term climate and competition explain forest mortality patterns under extreme drought. *Ecology Letters*, 20, 78-86.
[25]Asner, G., Brodrick, P., Anderson, C., Vaughn, N., Knapp, D. & Martin, R. (2016). Progressive forest canopy water loss during the 2012-2015 California drought. *Proceedings of the National Academy of Sciences of the United States of America*, 113, E249-E255.
[26]Fettig, C.J., Mortenson, L.A., Bulaon, B.M. & Foulk, P.B. (2019). Tree mortality following drought in the central and southern Sierra Nevada, California, U.S. *Forest Ecology and Management*, 432, 164-178.
[27]Grulke, N.E., Minnich, R.A., Paine, T.D., Seybold, S.J., Chavez, D.J., Fenn, M.E. *et al.* (2009). Air pollution increases forest susceptibility to wildfires: a case study in the San Bernardino Mountains in southern California. *Developments in Environmental Science*, 8, 365-403.
[28]Raffa, K.F., Aukema, B.H., Erbilgin, N., Klepzig, K.D. & Wallin, K.F. (2005). Interactions among conifer terpenoids and bark beetles across multiple levels of scale: an attempt to understand links between population patterns and physiological processes. *Recent Advances in Phytochemistry 39: 79-118*.
[29] Raffa, K.F., Aukema, B.H., Bentz, B.J., Carroll, A.L., Hicke, J.A., Turner, M.G. *et al.* (2008). Cross-scale Drivers of Natural Disturbances Prone to Anthropogenic Amplification: The Dynamics of Bark Beetle Eruptions. *BioScience*, 58, 501-517.
[30]Minnich, R.A., Goforth, B.R. & Paine, T.D. (2016). Follow the Water: Extreme Drought and the Conifer Forest Pandemic of 2002–2003 Along the California Borderland. In: *Insects and Diseases of Mediterranean Forest Systems* (eds. Paine, T.D. & Lieutier, F.). Springer International Publishing Cham, pp. 859-890
[31]Kolb, T.E., Fettig, C.J., Ayres, M.P., Bentz, B.J., Hicke, J.A., Mathiasen, R. *et al.* (2016). Observed and anticipated impacts of drought on forest insects and diseases in the United States. *Forest Ecology and Management*, 380, 321-334.
[32]Creeden, E.P., Hicke, J.A. & Buotte, P.C. (2014). Climate, weather, and recent mountain pine beetle outbreaks in the western United States. *Forest Ecology and Management*, 312, 239-251.
[33]Bentz, B.J., Régnière, J., Fettig, C.J., Hansen, E.M., Hayes, J.L., Hicke, J.A. *et al.* (2010). Climate Change and Bark Beetles of the Western United States and Canada: Direct and Indirect Effects. *BioScience*, 60, 602-613.
[34]Bentz, B.J., Duncan, J.P. & Powell, J.A. (2016). Elevational shifts in thermal suitability for mountain pine beetle population growth in a changing climate. *Forestry: An International Journal of Forest Research*, 89, 271-283.
[35]Coleman, T.W., Graves, A., Hoddle, M., Heath, Z., Chen, Y., Flint, M. *et al.* (2012). Forest stand composition and impacts associated with *Agrilus auroguttatus* Schaeffer (Coleoptera: Buprestidae) and *Agrilus coxalis* Waterhouse in oak woodlands. *Forest Ecology and Management*, 276, 104-117.
[36]Coleman, T.W. & Seybold, S.J. (2016). Goldspotted oak borer in California: Invasion history, biology, impact, management, and implications for Mediterranean forests worldwide. In: *Insects and diseases of Mediterranean forest systems*. Springer, pp. 663-697.
[37]Hishinuma, S., Coleman, T.W., Flint, M.L., & Seybold, S.J. (2011). Goldspotted oak borer: field identification guide. University of California Agriculture and Natural Resources, Statewide Integrated Pest Management Program, 6 pp.