Sierra Institute
for Community and Environment

Forest Science for the Sierra Nevada and southern Cascades: An Annotated Bibliography

Applied Management

1. Climate change and forests of the future: Managing in the face of uncertainty. Millar C.I., Stephenson N.L., Stephens S.L. 2007. *Applications* 17(8): 2145-2151.

In light of a significant divergence from historical forest ecosystem conditions, and continued uncertainty regarding the magnitude – and in some cases, direction – of future climate signals, researchers offer a variety of concrete approaches for forest managers. These are divided into adaptation and mitigation strategies, though a "toolbox approach," utilizing a variety of these methods in combination, is deemed most favorable. Adaptation approaches focus on increasing the resistance and resilience of forests, and enabling forests to respond to future change. Mitigation approaches target on the reduction of greenhouse gases, which, for long-term impact, should include the removal of biomass via mechanical thinning and prescribed fire. Managers are cautioned against simply restoring historical conditions, and encouraged to employ a broader range of tactics that take into consideration regional shifts in land-use and climate.

2. An ecosystem management strategy for Sierran mixed-conifer forests. North M., Stine P., O'Hara K., Zielinski W., Stephens S. 2009. Gen. Tech. Rep. PSW-GTR-220. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 49 p.

A conceptual, rather than prescriptive, approach to managing mixed conifer forests of the Sierra Nevada is presented in this USFS General Technical Report. Targeted management goals include fuels reduction, ecosystem restoration, and habitat protection. Appreciating the impact that site variability will have on silvicultural prescriptions, authors guide users toward the creation of key structural and fuel conditions while maintaining sufficient habitat features.

3. Science synthesis to support socioecological resilience in the Sierra Nevada and Southern Cascade Range. Long J.W., Quinn-Davidson L., Skinner C.N. 2014. Gen. Tech. Rep. PSW-GTR-247. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 712 p. 2 vol.

Focusing on the forested regions of the Sierra Nevada, southern Cascades, and Modoc Plateau, this report offers management strategies appropriate for the task of increasing socioecological resilience in the face of key stressors. Stressors are both biophysical (climate change, fire, pests and pathogens), and social (changes in economy and demography). With a focus on fire, this report examines the interplay between social and ecological concerns, including collaborative processes. Techniques for landscape-scale, adaptive management are also discussed, exploring the potential use of fire in restoring reference conditions and landscape heterogeneity. Covered topics include, but are not limited to: forest ecology, Tribal resources and fire, aquatic and

terrestrial ecosystems, air quality, and the potential for job creation and collaboration in National Forest management.

4. Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada. North M., Brough A., Long J., Collins B., Bowden P., Yasuda D., Miller J., Sugihara N. 2015. *Journal of Forestry* 113(1): 40-48.

Researchers used a mixed-methods approach to examine the amount and distribution of limitations for mechanical fuels on National Forest Service land in the Sierra Nevada. The objective of this study was to determine the suitability of mechanical treatments for increasing the pace and scale of forest restoration and fuels reduction. Constraints were categorized as biological, legal, operational, and administrative and were studied in the context of four scenarios representing varying degrees of adherence to existing regulations. Findings show that legal constraints (designated roadless and wilderness areas) most significantly reduce the acreage available for treatment. Relaxation of regulations has a greater impact on some constraints (e.g. administrative) than others (e.g. operational). Researchers suggest that mechanical treatment used with prescribed or managed fire may be better suited than mechanical treatment alone to achieving restoration and fuels reduction goals quickly and on a large scale. Recommendations include the targeted relaxation of constraints, ideally in areas with special management designations (e.g. demonstration areas) and within the framework of adaptive management.

5. California forest carbon plan: Managing our forest landscapes in a changing climate (Draft). Forest Climate Action Team. 2017.

This document is a draft implementation plan for the State of California's forest carbon goals, as well as a mechanism to address carbon emissions from forests, e.g. wildfire. Strategies put forth in this plan aim to maintain the health of California's forests such that they are a net sink, not source, of atmospheric carbon. The approach is a collaborative one at the watershed or landscape scale. The Plan includes a description of current forests, projections of future conditions, as well as goals and actions to guide forest restoration and management.

6. The California spotted owl: current state of knowledge. Gen. Tech. Rep. PSW-GTR-254. Gutiérrez R.J., Manley P.N., Stine P.A. 2017. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

This most recent assessment of the California spotted owl (CASPO) outlines current knowledge regarding ecology, habitat, population, and threats to the species. Declines in forest health, attributable to past timber harvest and fire suppression policies, threaten shrinking CASPO populations by reducing habitat quality, increasing fragmentation, and augmenting the risk of high-severity fire. Landscape-scale forest restoration and management strategies may, therefore, be well aligned with CASPO conservation. In addition to the aforementioned topics, the report also discusses the current state of Sierra Nevada forests and forest management within the context of CASPO viability.

Climate Change/Drought

7. Pervasive drought legacies in forest ecosystems and their implications for carbon cycle models. Anderegg W.R.L., Schwalm C., Biondi F., Camarero J.J., Koch G., Litvak M., Ogle K., Shaw J.D., Shevliakova E., Williams A.P., Wolf A., Ziaco E., Pacala S. 2015. *Science* 6247(349): 528-532.

Researchers examined the legacy effects of severe drought on tree growth globally, and tested the ability of global carbon cycling models to detect these effects. Widespread mortality resulting from prolonged drought may diminish the future ability of forested ecosystems to act as a carbon sink. However, mortality and other drought legacy effects are not well integrated into global carbon cycling models, potentially leading to an underestimate of the projected effects of climate change. Legacy effects (stomatal conductance, wood anatomy and density, vulnerability of the xylem to drought, drought related tree mortality, and aboveground primary production) can last between 2-4 years following severe drought. Gymnosperms, especially of the Pinaceae family, displayed significantly longer and greater legacy effects than did angiosperms. Global carbon cycling models were found to insufficiently represent the structural and physiological properties responsible for legacy effects, limiting their ability to capture variability in carbon storage in the short- and long-term.

8. Progressive forest canopy water loss during the 2012-2015 California drought. Asner G.P., Brodrick P.G., Anderson C.B., Vaughn N., Knapp D.E., Martin R.E. 2015. *PNAS* E249-E255.

Spectral reflectance and LiDAR technology were combined to quantify progressive changes in canopy water content (CWC) over the course of California's 2011-2015 drought. CWC is defined as the total amount of liquid water contained within canopy foliage, and is measured on a volume per area basis (L/m^2). Southern California and low elevation forests in the vicinity of the Central Valley displayed the lowest CWC values over the course of the drought. Statewide, significant changes were observed in CWC over the four years, progressively moving upward in elevation. Especially large declines in CWC were observed in coastal redwood, high elevation pinyon-juniper, lodgepole pine, red fir, and black oak forests. From 2011 to 2015, more than 10 million hectares and approximately 888 million large trees (≥12.7 cm dbh) underwent progressive decreases in CWC. Researchers highlight potential management applications for this technique, including tree mortality forecasting, implementation planning for fuels reduction, and watershed management.

9. Increased water deficit decreases Douglas fir growth throughout western US forests. Restaino C.M., Peterson D.L., Littell J. 2016. *PNAS* 113(34): 9557-9562.

Researchers examined relationships between climate (climatic water deficit, vapor pressure deficit, temperature, and precipitation) and Douglas fir growth in forests in the western US (AZ, CA, CO, ID, MT, NM, OR, UT, WA, WY) using historical (1916-2006) and projected future hydroclimates. High temperature and vapor pressure deficit (VPD) are both negatively correlated with growth. Though their effects may be interactive, they limit growth via separate mechanisms. Temperature decreases photosynthetic activity, while VPD leads to stomatal closure and eventually CO_2 starvation. Temperature was found only to be limiting in the southernmost sites

of the study area, while VPD is a limiting factor at all latitudes. Projected future conditions indicate that decreases in growth resulting from the stress of increasing temperatures will outweigh any potential CO_2 fertilization effect.

10. Does prescribed fire promote resistance to drought in low elevation forests of the Sierra Nevada, California, USA? van Mantgem P.J., Caprio A.C., Stephenson N.L., Das A.J. 2016. *Fire Ecology* 12(1): 13-25.

Researchers sought to test the commonly-held assumption that reductions in stand density following prescribed fire alleviate resource competition, thereby increasing resistance to drought and other stressors. Live and dead trees were sampled within burned and unburned mixed conifer forests at low elevation on the western slope of the Sierra Nevada. Burned plots had lower average stand densities and a greater quadratic mean diameter. The probability of individual tree mortality was predicted by the size of the tree, its species, and the plot's history of prescribed fire. There was found to be an interactive effect between species and fire history, with species in the genus *Pinus* displaying the greatest sensitivity to prescribed burning histories. Insufficient indicator variables and plot sizes prevented a definitive conclusion regarding the effect of competition on stress resistance. However, even in burned plots, current stand density and basal area are significantly greater than reconstructed stand conditions (1911). Researchers suggest that increasingly aggressive use of prescribed fire may hold promise as an adaptive tool for drought and wildfire stress, though many barriers to deployment exist.

11. Long-term climate and competition explain forest mortality patterns under extreme drought. Young D.J.N., Stevens J.T., Earles J.M., Moore J., Ellis A., Jirka A.L., Latimer A.M. 2017. *Ecology Letters* 20: 78-86.

This paper examines the impacts of competition (stand basal area) and climatic water deficit (CWD) on tree mortality throughout California. CWD is defined as the difference between potential and actual evapotranspiration, and represents the extent to which a system is water-limited. Research was conducted between 2012-2015, during some of the State's most extreme drought years in recent history. Over this period, mortality was found to increase most significantly in areas with higher CWD, i.e. stands already at the margins of tolerable climatic conditions. As a tree mortality variable, basal area had a greater influence in water limited stands. Researchers also developed a unified metric, the forest deficit-competition index (FDCI), to quantify stand-level water stress for a given basal area. Management implications include reducing tree density in fire-suppressed stands, especially of smaller trees, with the aim of improving survivability of larger trees under drought conditions. Researchers also suggest application of the FDCI to quickly identify the most drought-susceptible areas on the landscape.

Fire and Fuels

12. Stand- and landscape-level effects of prescribed burning on two Arizona wildfires. Finney M.A., McHugh C.W., Grenfell I.C. 2005. *Canadian Journal of Forest Research* 35(7): 1714-1722.

Researchers evaluated the effects of prior prescribed burns on wildfire severity in the context of the 2002 Rodeo and Chediski wildfires (AZ). These fires burned in ponderosa pine forests on a portion of the White Mountain Apache lands and the Apache-Sitgreaves National Forest. Since the 1940s, the White Mountain Apache Tribe has been conducting prescribed burning, and the USFS has more recently utilized this management tool on neighboring NFS lands. For these treated units, satellite imagery was used to determine fire severity, measured as the differenced normalized burn ratio. Fire severity increased with time since treatment, and decreased with the number of repeated burns, size of the treatment area, and distance from the edge of the treatment. Treated areas affected the direction of spread of wildfire, illustrating the importance of landscape-scale planning and treatment. Researchers indicate the importance of a mosaic of heterogeneous landscape conditions in interrupting fire spread, achievable through repeated prescribed fires or managed wildfires.

13. Silvicultural and reserve impacts on potential fire behavior and forest conservation: Twenty-five years of experience from Sierra Nevada mixed conifer forests. Stephens S.L., Moghaddas J.J. 2005. *Biological Conservation* 125: 369-379.

Researchers compared the ability of seven silvicultural systems, and two reserve types (referred to collectively as "treatments"), to reduce the effects and behavior of wildfire in high and extreme fire weather. Research was conducted at the Blodgett Experimental Forest, managed under a fire suppression regime for nearly a century. Under different modeled fire weather scenarios, treatments showed significant differences in shrub cover, fuel loads, basal area, live crown ratio, and percent canopy cover. Treatments also had significantly different effects with regard to torching, fireline intensity, and diameter-class specific tree mortality. Researchers point out that over 100,000 hectares of forest plantations in California have gone untreated since initial site preparation and planting, providing conditions for shrub growth. As a result, extensive mortality occurred across diameter classes and modeled weather conditions in each plantation system studied. Management recommendations include: removal of slash to reduce surface fuel loading, fuels management as an integral component of watershed health, and the development of novel silvicultural systems in harmony with historic natural disturbance regimes.

14. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade mountains, California and Nevada, USA. Miller J.D., Safford H.D., Crimmins M., Thode A.E. 2008. *Ecosystems* 12: 16-32.

Using pre- and post-burn satellite imagery, fire severity was quantitatively assessed for wildfires >40 ha occurring between 1984-2006 within the Sierra Nevada Forest Plan Amendment. For the majority of forest types studied, the proportion of area burned in high-severity fires has increased. Rates of increase were greater in low- and middle-elevation forest types compared with high elevation forests. Absolute area burned, however, increased more in fir-dominated than

pine-dominated forests. The relationship (R^2) between fire behavior and climate has become stronger over the course of the study period, and precipitation has superseded temperature as the primary explanation of variance in fire size and area burned. Researchers posit that the rising importance of precipitation is attributable to the indirect effect of increasing fuel loads.

15. Simulating fire and forest dynamics for a landscape fuel treatment project in the Sierra Nevada. Collins B.M., Stephens S.L., Roller G.B., Battles J.J. 2009. *Forest Science* 57(2): 77-88.

Researchers studied the effects of an actual landscape fuel treatment (Last Chance project on the Tahoe National Forest) on conditional burn probabilities and stand structure using modeled wildfire. Treatment included thinning from below, followed by surface fuels treatment, mastication, and underburning. Treatments were simulated within three upper tree diameter limit regimes (30.5 cm, 50.8 cm, and 76.2 cm). Structural attributes (tree density, basal area, canopy base height, canopy cover, and canopy bulk density) were modeled under these and a no treatment condition at ten-year time steps from 2007-2037. All stand structural characteristics (except canopy base height) differed between treated and untreated stands throughout the duration of the simulation. The most conservative diameter limit (30.5 cm) showed only a slight increase in canopy base height and, as such, may be less effective than desired at reducing ladder fuels. Differences between the 50.8 cm and 76.2 cm limits were minimal, suggesting that thinning need not incorporate this largest dbh class. Compared to no treatment, simulated treatments reduced conditional burn probabilities both within the treatment area and across the modeled landscape through 2027. The magnitude of reduction was indistinguishable between diameter limit treatments. Treatment longevity is estimated at 20 years for a single entry.

16. Prescribed fire as a means of reducing forest carbon emissions in the Western United States. Wiedinmyer C. and Hurteau M.D. 2010. *Environmental Science & Technology* 44(6): 1926-1932.

Researchers modeled potential reductions in carbon emissions resulting from the use of prescribed fire as a mitigation tool for catastrophic wildfire in the Western US. The study was restricted to western forests, amenable to prescribed fire treatments, with historically low to mixed severity fire effects at frequent return intervals. These systems contributed, on average, 35% of annual CO_2 emissions (2001-2008) for the region as a whole, and as much as 49% at the state level (NV). Statewide reductions ranged from 1-26% when wildfires were replaced with prescribed fire. When analyzed by forest type, emissions reductions were on the order of 50-60%. Researchers acknowledge inherent limitations in the study: first, systems with regular historical occurrence of stand-replacing fire may be less well-suited to prescribed fire as a management technique. Second, no regulatory or other feasibility measures are considered.

Structure and Composition

17. Initial changes in forest structure and understory plant communities following fuel reduction activities in a Sierra Nevada mixed conifer forest. Collins B.M., Moghaddas J.J., Stephens S.L. 2006. *Forest Ecology and Management* 239: 102-111.

Researchers studied the effects of a variety of fuel reduction techniques on forest structure, as well as understory plant richness and abundance. Treatments include: mechanical (thinning from below and mastication), prescribed fire, mechanical followed by prescribed fire, and an untreated control. Using modeling, researchers examined the impact of wildfires under 80th percentile weather conditions on post-treatment stand survivability. Survivability (80% of dominant and co-dominant trees) was best achieved by treatments involving fire, which reduced fuels continuity. These treatments also created forest structure most similar to historical (i.e. 19th century) conditions. Total understory species abundance did not differ significantly between treatments and controls. However, understory composition was significantly affected by the mechanical and fire treatment, which increased the abundance and richness of exotic species. Though the magnitude of these changes is small, and compositional changes may occur with succession, implications for exotic species spread using high-intensity treatments should be considered.

18. Comparison of thinning and prescribed fire restoration treatments to Sierran mixed-conifer historic conditions. North M., Innes J., Zald H. 2006. Canadian Journal of Forestry Research 37: 331-342.

Using modeled 1865 stand conditions at the Teakettle Experimental Forest, researchers assessed the ability of various restoration techniques to re-create said conditions. Applied treatments were combinations of two burn categories (prescribed fire and no fire), and three thinning categories (none, understory, and overstory). The combination of understory thinning and prescribed burning was the most effective in: reducing small tree density, decreasing the presence of white fir, and reducing clustered stems, all while retaining intermediate and large trees. In part, the effectiveness of this treatment is attributed to the presence of thinning slash, which increased the extent and intensity of prescribed burning. All of the treatments tested removed too many trees in the 50-75 cm size class, more of which should be retained for future old-growth conditions. None of the treatments significantly affected stand composition, which has shifted from nearly 50% shade tolerant and 50% shade intolerant to 84% and 14%, respectively. Researchers recommend the repeated use of prescribed fire both to reduce stand density in small-diameter classes and increase spatial heterogeneity. Fire should be used in conjunction with thinning prescriptions that target certain species, and which retain a greater number of intermediate trees.

19. Impacts of fire exclusion and recent managed fire on forest structure in old growth Sierra Nevada mixed-conifer forests. Collins B.M., Everett R.G., Stephens S.L. 2011. *Ecosphere* 2(4).

Researchers replicated a 1911 timber inventory within present-day Yosemite National Park, quantifying differences in forest structure, composition, canopy cover, and live tree carbon stocks. Much of the study area has been managed for wildfire, allowing for comparisons between no fire, low-, and moderate-severity fire regimes. Tree densities increased for all but the largest size classes. Moderate severity fire areas were the only ones that did not show statistically

significant differences in tree density, canopy cover, and live tree carbon between the 1911 and 2005-2007 surveys. Species composition differed significantly for pine and true fir species groups between the 1911 and recent survey. Pine comprised a greater, and true fir a lesser, component (basal area) of survey sites in 1911. Management recommendations are targeted removal of trees <61.0 cm diameter at breast height (dbh). These dbh classes represent those whose removal a) has the greatest impact on fire behavior and b) would help recreate historical conditions.

20. Long-term overstory and understory change following logging and fire exclusion in a Sierra Nevada mixed-conifer forest. Knapp E.E., Skinner C.N., North M.P., Estes B.L. 2013. *Forest Ecology and Management* 310: 903-914.

Researchers examined structural and compositional changes of both the over- and understory in three "Methods of Cutting" plots, established in 1929 on the Stanislaus-Tuolumne Experimental Forest. These plots had undergone varying intensities of selection cutting and were compared to an unlogged control. For all plots, average tree density, quadratic mean diameter, and basal area increased compared to the 1929 baseline. Though structure differed significantly between the unlogged control and the three treatments in 1929, logged treatments were not significantly different from one another. All logging treatments led to a reduction in the percentage of basal area comprised of pines. While logging does appear to have played a role in structural and compositional changes, researchers posit that other factors, such as site suitability and climate change, may have interacting effects. Understory composition differed significantly from 1929 conditions, with a reduction in shrub cover and a decrease in herbaceous species richness. The restoration of conditions suitable for natural pine regeneration would require significant decreases in stand density, exposure of bare mineral soil, and the creation of gaps, all of which would likely also impact understory structure and composition. Researchers suggest the combined use of mechanical thinning and prescribed fire for meeting these objectives, given that fire alone is likely insufficient for thinning out larger, more fire resistant trees.

21. Twentieth-century shifts in forest structure in California: Denser forests, smaller trees, and increased dominance of oaks. McIntyre P.J., Thorne J.H., Dolanc C.R., Flint A.L., Flint L.E., Kelly M., Ackerly D.D. 2015. *PNAS* 112(5): 1458-1463.

Using forest surveys from the 1920s-1930s, researchers examined changes in forest structure and composition in relation to climatic water deficit (CWD) across the state of California. Over the period in question, CWD increased across much of California, the combined result of warming temperatures, earlier snowmelt, and the limited ability of shallow soils to store water in drier summers. Observed changes in forest structure include significant declines in large trees across all regions of the state, and increased density of small trees in much of the state. Decreases in large tree density did correlate with CWD, while changes in the density of small trees did not, presumably due to the increased vulnerability of large trees to drought stress. Only a weak correlation was found between increased density of small trees and reduced density of large trees. Further investigation is recommended to better elucidate these connections. Compositional changes were evaluated as a ratio of abundance of oaks and pines. Pines have decreased in abundance in all regions, whereas oaks have increased in all but those most severely affected by

Phytophthora ramorum (sudden oak death). The ratio of oak to pine abundance is positively correlated with CWD.

22. 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. Safford H.D. and Stevens J.T. 2017. Gen. Tech. Rep. PSW-GTR-256. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 229 p.

In this GTR report, yellow pine and mixed-conifer (YPMC) forests in California are compared with their natural range of variation (NRV). The NRV is reconstructed from the 16th – mid 19th century, and accounts for both process and structure. Current reference forests are those with minimal human disturbance (i.e. relatively intact fire regimes and a lack of degradation). Current average YPMC conditions are characterized by higher tree densities mostly of small, shade-tolerant trees; longer return intervals for fire events; and fewer acres burned on a landscape scale. Fires that do escape are typically more severe and larger, due in part to greater surface fuel loading, leaf area index, coarse woody debris, snag density, and a protracted fire season.