Stand Structure and Drought Alter Tree Mortality Risk in Nevada's Pinyon-Juniper Woodlands

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Severe droughts in the southwestern USA in 2002-2003 revealed that pinyon pine and juniper trees are susceptible to widespread mortality caused by severe water deficits and drought-facilitated insect outbreaks (Breshears et al., 2005; Clifford et al., 2008). Despite increased interest in forest susceptibility to drought, the influence of stand structure on the drought resilience of pinyon-juniper woodlands remains uncertain (Meddens et al., 2015). Stand structure is of particular interest because it is readily manipulated by silvicultural practices such as thinning. Page (2008) suggests, for example, thinning pinyon-juniper woodlands to between 5 and 25 percent of maximum stand density index (SDI) in order to reduce fuel loads and increase understory vegetation. If trees are more susceptible to drought in denser stands, thinning may also be a viable strategy to increase resilience to drought.

We measured 98 plots in central Nevada pinyon-juniper woodlands before and after a severe multi-year drought in order to assess the effect of stand density on drought-related tree mortality and canopy dieback (Flake, 2016). The stands are dominated by singleleaf pinyon pine (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) with a small component of curl-leaf mountain mahogany (*Cercocarpus ledifolius*). Each plot measured 0.1 ha in area, and the plot network spanned a wide range of elevations (1820 m.a.s.l to 2360 m.a.s.l), mean annual precipitation (230 mm to 414 mm), and soil properties (soil depth 7.4 to 43 cm). Plots were inventoried in 2005 (Greenwood and Weisberg, 2008, 2009) and resampled in 2015. For each tree, we estimated the amount of its canopy that was dead (dead branches, brown needles, or defoliated) in both 2005 and 2015, allowing us to calculate canopy loss over the study period.

We modeled tree canopy loss and the probability of stem mortality using generalized linear mixed-effects models. We first estimated the effects of environmental variables such as temperature, precipitation, vapor pressure deficit, climatic water deficit (Stephenson, 1998), Forest Drought Stress Index (Williams et al., 2013), soil depth, and soil available water capacity. We then added variables reflecting stand structure and tree attributes, including tree diameter and height; the basal area of neighboring trees within 4-m of the focal tree (*4-m BA*), the distance which was most strongly correlated with canopy dieback; the distance to the nearest neighboring tree (*ENN Dist*); and the ratio of the basal area of the nearest neighbor to that of the focal tree (*Neighbor Ratio*). We fit separate models for pinyon canopy dieback, juniper canopy dieback, and pinyon stem mortality.

On average, pinyons lost 23.7 ± 0.58 percent of their canopy and junipers only 10.8 ± 0.46 percent. In our study area, 10.9 percent of the pinyon pines but only 0.6 percent of junipers had died over the past decade. This mortality was driven largely by

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soil characteristics, with greater mortality on deeper soils, and by site aridity, with the greatest mortality at sites with the greatest climatic water deficit and vapor pressure deficits, but was mediated by stand structure. We found that the basal area of neighboring trees had a large effect on tree dieback and mortality after accounting for climate and soil effects. In pinyon pine, the effect of stand structure depended upon the annual water deficit of the site. At the wettest sites (10th percentile of climatic water deficit (CWD)), an increase in neighborhood basal area was associated with decreased canopy loss, while the opposite pattern was seen at the driest sites (90th percentile of CWD), where trees were predicted to lose about 10 percent of their canopy as neighborhood basal area increased from its minimum (0 m^2) to maximum (1.4 m^2). Increased neighborhood basal area was also associated with greater pinyon mortality, with an increase of mortality risk of 3.8 times from minimum to maximum basal area. For juniper, the effect was weaker and not statistically significant. Pinyon canopy health was negatively associated with proximity to adjacent trees. For each 1-m reduction in distance between a tree with its nearest neighbor, canopy health was predicted to decline by 1.6 percent. Proximity to neighboring trees was not important for juniper dieback or for pinyon stem mortality, which were driven more by abiotic factors such as soil and climate.

These results indicate that on drier sites, competition among trees reduces the resilience of pinyon-juniper woodlands during drought. This finding implies that risk of drought-induced mortality may change during stand development. Drought may precipitate self-thinning in denser, intermediate-aged stands, while sparse young stands or old-growth may be less susceptible to drought. Severe drought is not uncommon in the Great Basin (fig. 1), and it may play an important role in the long-term dynamics of pinyon-juniper woodlands by introducing structural and habitat heterogeneity.

Silvicultural treatments in pinyon-juniper woodlands may be a useful strategy in the management of denser stands. Moreover, because the effect of competition depends upon site conditions, with more arid sites more prone to competition-induced drought sensitivity, thinning may be more useful in sites with higher stocking relative to the maximum stand density index. We encourage the collection of baseline data before and after thinning treatments, as well as in comparable

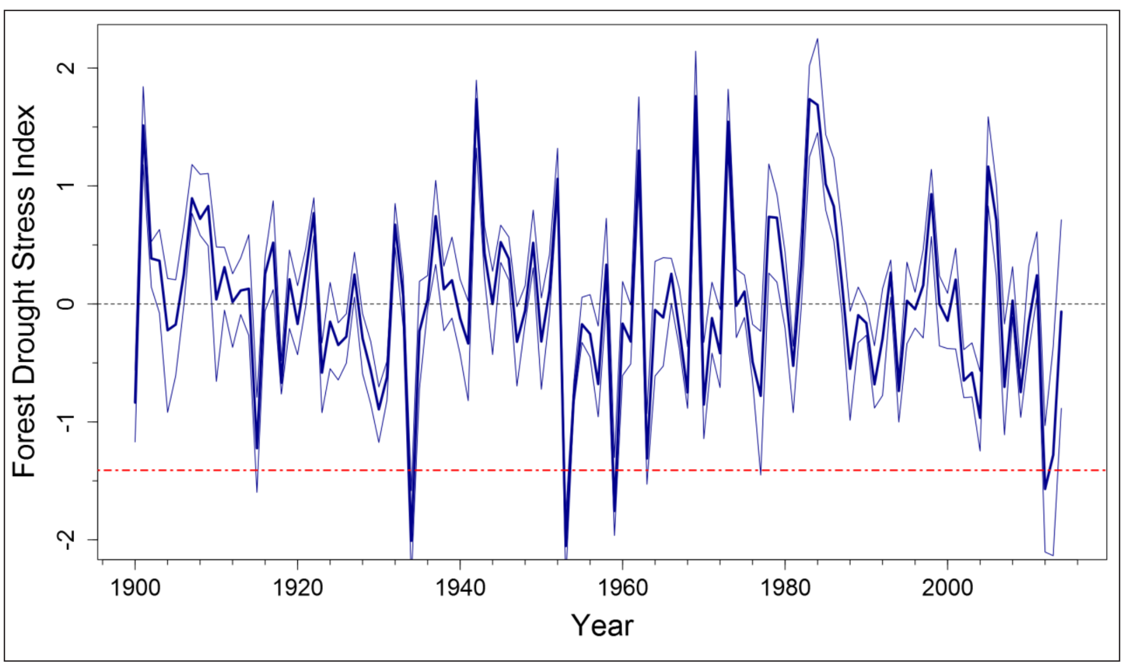

Figure 1—Forest drought stress index (FDSI; Williams et al., 2013) over the entire PRISM climate time series (PRISM Climate Group) for our central Nevada plot network. Lower values indicate greater drought stress, and values of FDSI below the horizontal line at FDSI = -1.41 are linked historically with decreased tree vigor.

control sites, in order to create datasets required to more precisely quantify stand density influences on drought resilience. Further study of stand-level processes in pinyon-juniper woodlands (e.g. self-thinning) is also needed to develop basic silivicultural guidelines (e.g. density management) appropriate for highly heterogeneous, topographically and edaphically complex woodland systems. It is probable that the thinning of dense patches of trees, particularly on dry sites likely to have low maximum pinyon-juniper stocking, will enhance drought resilience. However, additional controlled experiments manipulating densities and stand structure are needed to provide a critical test of the role of stand density in pinyon-juniper resilience to drought, and for development of silvicultural prescriptions aimed at maintaining healthy woodlands given drought conditions and climate change processes.

REFERENCES

Breshears, D.D.; Cobb, N.S.; Rich, P.M.; [et al.]. 2005. Regional vegetation die-off in response to global-change-type drought. PNAS. 102: 15144–15148.

Clifford, M.J.; Rocca, M.E.; Delph, R.; [eta al.]. 2008. Drought induced tree mortality and ensuing bark beetle outbreaks in southwestern pinyon-juniper woodlands. In: Gottfried, Gerald J.; Shaw, John D.; Ford, Paulette L., compilers. 2008. Ecology, management, and restoration of pinon-juniper and ponderosa pine ecosystems: combined proceedings of the 2005 St. George, Utah and 2006 Albuquerque, New Mexico workshops. Proceedings RMRS-P-51. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 39-51

Flake, S.W. (2016). Stand dynamics during drought: Responses of adult trees, tree regeneration, and understory vegetation to multiyear drought in pinyon-juniper woodlands. Reno, NV: University of Nevada. Thesis. 109 p.

Greenwood, D.L.; Weisberg, P.J. 2008. Density-dependent tree mortality in pinyon-juniper woodlands. Forest Ecology and Management. 255: 2129–2137.

Greenwood, D.L.; Weisberg, P.J. 2009. GIS-based modeling of pinyon-juniper woodland structure in the Great Basin. Forest Science. 55, 1–12.

Meddens, A.J.H.; Hicke, J.A.; Macalady, A.K.; [et al.]. 2015. Patterns and causes of observed piñon pine mortality in the southwestern United States. New Phytology. 206, 91–97.

Page, D.H. 2008. Preliminary thinning guidelines using stand density index for the maintenance of uneven-aged pinyon-juniper ecosystems. In: Gottfried, Gerald J.; Shaw, John D.; Ford, Paulette L., compilers. 2008. Ecology, management, and restoration of pinon-juniper and ponderosa pine ecosystems: combined proceedings of the 2005 St. George, Utah and 2006 Albuquerque, New Mexico workshops. Proceedings RMRS-P-51. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 104-112

Stephenson, N.L. 1998. Actual evapotranspiration and deficit: Biologically meaningful correlates of vegetation distribution across spatial scales. Journal of Biogeography. 25: 855–870.

Williams, A.P.; Allen, C.D.; Macalady, A.K.; [et al.]. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change. 3: 292–297.