Climate Change and Wildfire Impacts in Southwest Forests and Woodlands

Climate Change and Variability in the Southwest Ecosystem Series

Summary of Issue

Wildfire requires three things to burn: heat, fuel and oxygen. If one of the three requirements is removed, the fire activity will be limited. Similarly, once a fire has started to burn, its behavior is determined by three factors: fuel (type and quantity), topography (slope and aspect) and weather (wind, humidity, and temperature). The specific weather conditions during a fire event greatly influence how the fire burns. It follows that long-term climate variability can influence fire behavior by affecting site-specific fuel conditions (fuel moisture, type and arrangement).

Each year of vegetation growth results in an accumulation of more burnable fuel materials on the ground. This is especially so in the arid southwest, which has low decomposition rates of organic materials because of the low moisture availability in the soil. Thus, the fires we see today in some forest landscapes are of a much higher intensity than those at the turn of the 20th century due to decades of fire suppression, an increase in biomass due to the post-1976 increase in Southwestern precipitation (Swetnam and Betancourt 1998) and warming temperatures coupled with recent drought conditions.

In many cases, high-intensity fires result in complete stand replacement in areas burned (Figure 2). "Stand replacement" refers to the high percentage of tree mortality in areas impacted by high-intensity fire. For Southwest ponderosa pine communities, large crown fires are more prevalent now than in the past based on historical records and long-term tree-ring records (Swetnam 1990, Swetnam and Betancourt 1998, Westerling et al. 2006).

Figure 1. Fire triangle

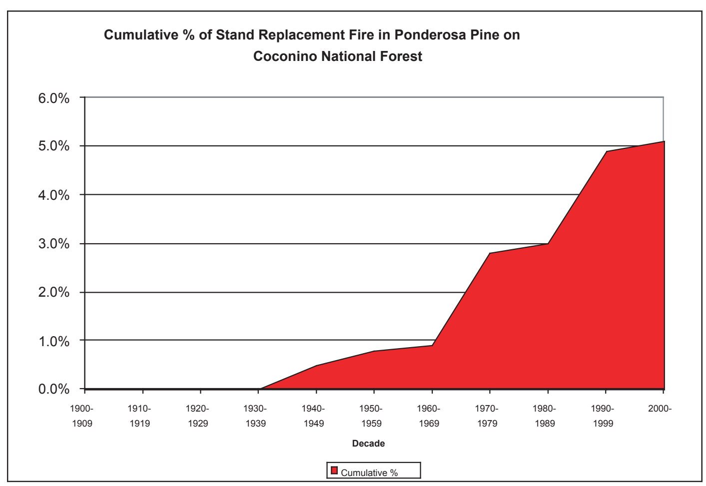

Figure 2. Cumulative percentage of stand replacement fires in ponderosa pine on the Coconino National Forest, compiled from US Forest Service data by Ecological Restoration Institute.

Figure 3. Open old growth pine forest near Flagstaff, AZ, circa 1900 (top). Example of present day forest conditions in northern Arizona (bottom).

Changes in Arizona's Forests

Ponderosa pine forests across Arizona looked differently prior to 1850 than they do today (Figure 3). Typical characteristics of these pine stands were:

1) An open, park-like structure
2) Clumped, large diameter pine trees of various ages
3) A productive and diverse understory of grasses and forbs
4) A low abundance of underbrush and small diameter trees
5) An infrequent establishment of new trees

Land managers struggle to determine to which condition a landscape should be restored — especially within the context of climate variability. Land management decisions are based on 10-year plans developed years before implementation, yet in that time frame the environmental conditions may have changed enough that the proposed management actions may no longer be appropriate. Extreme climate change may force managers to consider new management practices with changing environmental conditions (for example consideration of thinning to reduce wildfire risk vs. rehabilitation following high-intensity wildfire events).

Forest and Climate Change Science for Land Management

Southwestern forests are complex systems that have been studied for decades. Synthesis of this existing research allows us to identify and address complex forest ecosystem interactions. Climate variability plays a prominent role in

Research on Forest Restoration Alternatives

Photo series depicting a range of stand densities (low to high) and the resulting fire behavior (ground fire to active crown fire) on research plots in northern Arizona in October 1999. (Courtesy of ERI)

Researchers in Ponderosa pine forests across Arizona are investigating what restoration alternatives are appropriate and achievable under present forest ecosystem conditions. Plots have been established at the Grand Canyon by the Ecological Restoration Institute to look at a variety of ponderosa pine stand densities and their various responses to fire (see photo series). Researchers have found that reductions in basal area, overall tree density, and density of small-diameter trees reduces the likelihood of crown torching. Fulé et al. (2001) found that thinning smaller trees followed by a prescribed fire resulted in fire behavior characterized by less canopy consumption, shorter flame lengths, and a slower rate of spread than in untreated areas.

modulating Southwestern forest ecosystem processes as identified in several recent scientific studies. Swetnam and Betancourt (1990, 1998) have shown that long-term cycles in precipitation across Arizona and New Mexico associated with the El Nino-Southern Oscillation (ENSO) modulate wildfire events. El Nino events typically bring above-average winter precipitation to the Southwest, while La Nina events bring below normal winter precipitation. The cycle (typically 3-7 years) of El Nino (wet winters) and La Nina (dry winters) events condition the landscape for wildfire by providing moisture to grow biomass and then producing dry conditions conducive for wildfires. The role of antecedent climate conditions in modulating wildfire variability is a unique and often overlooked feature of Southwestern forests. The weather conditions at the time of a wildfire event are important in controlling fire behavior, but fuel structure and heavy fuel moisture levels have been conditioned by climatic conditions experienced months to years before the event. Anomalously wet or dry periods can influence the level of wildfire activity from many seasons to years into the future (Crimmins and Comrie 2005).

Drought conditions on much longer timescales (decades) can interact with forest ecosystems in complex ways. Long-term droughts can stress trees leaving them susceptible to insects and disease, or can directly cause mortality because of lack of soil moisture. Even though fine fuels are often limited during droughts due to the lack of precipitation, a large-scale die-off in trees can produce the ideal conditions for high intensity fires. Breshears et al. (2005) suggested that the recent die-off of piñon pine across Arizona and New Mexico was the result of a combination of drought conditions and higher temperatures. The study warns that the above-average temperatures of the recent drought caused additional stress to vegetation and that this type of tree die-off might be more severe and extensive as temperatures warm into the future.

Temperature changes also have a marked effect on forest vegetation because of their direct impact on moisture availability, either because of an increased rate of evaporation or a more rapid snowmelt. Long-term climate pattern shifts toward higher spring and summer temperatures that include an earlier spring (and thus earlier snowmelt) in southwestern forests have been suggested as contributors to larger wildfires and longer wildfire seasons in the region (Westerling et al. 2006)

Extreme fire weather events (such as high temperatures, low relative humidity, high winds) that control wildfire behavior during wildfire events are also expected to change with increasing temperatures and changing global circulation patterns. A study by Brown et al. (2004) shows that the number of low relative humidity (<30%) days may increase by up to two weeks across the southwest United States with increasing temperatures through the 21st century. The increasing frequency of extreme fire weather conditions and drought-stressed vegetation could combine to promote enhanced wildfire activity under a changing southwestern U.S. climate.

Future directions in climate change science and forest management research

Integrating climate change science into forest management is a difficult task because of the complex interaction between forest ecosystem processes and both short-term and long-term climate variability. A sample of forest-climate research was highlighted above, but there is much applied research that still needs to be conducted to assist forest managers and policy makers in managing wildfire under changing climatic conditions. Some future directions in climate change-forest management research include:

1. Research into regional-scale precipitation-temperature-biomass relationships. How much biomass can be sustained on a landscape given certain climatic conditions?
2. Implementation of long-term monitoring and comparative studies to determine the effects of current management decisions and actions in the wake of climate variability.
3. Research studies focused on the direct impacts of increasing temperatures on specific vegetation in the Southwest.
4. Research on climate patterns that may provide predictive outlooks for planning fire and fuels management activities, seasons to years in advance.
5. Development of educational and outreach efforts to allow current climate change research to reach the public in a broader and more marketable manner.

Additional research will help refine specific management actions and policy decisions. As discussed above, a substantial body of knowledge on connections between forest management, wildfire, and climate change with applications to assist decision making already exists. Granted that climate change projections are not perfect, there is a strong confidence that projections of increasing temperatures are accurate. It is unclear what the overall magnitude of temperature increases expected to occur over the next century will be, due to complexities related to local scale effects and feedbacks (e.g. land cover changes), changes in greenhouse gas concentrations (e.g. increases or decreases due to policy actions), and model specific biases. At a minimum, the knowledge that temperatures are increasing and will likely be increasing over the next 100 years should be incorporated into long-term planning and decisionmaking. An understanding of the past, present, and potential future connections between wildfire and climate variability can help land managers make better informed strategic plans at many timescales from seasons to decades into the future.

Additional Sources of Information

Additional information may be obtained on forest management, fire climatology, and climate change science via the following sources:

- Allen, C.D. and D. D. Breshears, 1998: Drought-induced shift of a forest–woodland ecotone: Rapid landscape response to climate variation. *Procedings of the National Academy of Sciences*, **95**, 14839-14842.
- Keane, R., K.C. Ryan, T.T. Veblen, C.D. Allen, J. Logan, and B. Hawkes, 2002: Cascading effects of fire exclusion in the Rocky Mountain ecosystems: a literature review. USDA Forest Service General Technical Report. RMRS-GTR-91, 24 pp.
- Shafer, S., P. J. Bartlein, and R. S. Thompson, 2001: Potential changes in the distributions of western North America tree and shurb taxa under future climate scenarios. *Ecosystems*, **4**, 200-215..
- Westerling, A. L, T. J. Brown, A. Gershunov, D. R. Cayan, and M. D. Dettinger, 2003: Climate and Wildfire in the Western United States. *Bulletin of the American Meteorological Society*, **84**, 595-604.
- Websites
    - o The Wildland Fire Lessons Learned Center (www.wildfirelessons.net)
    - o Ecological Restoration Institute (www.eri.nau.edu)
    - o USDA Forest Service Rocky Mountain Research Station (www.fs.fed.us/rm/)
    - o CLIMAS Overview of Fire Research (http://www.ispe.arizona.edu/climas/learn/fire/index.html)

References Cited

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer, 2005: Regional vegetation die-off in response to global-change type drought. *Proceedings of the National Academy of Sciences*, 102, 15144-15148.

Brown, T.J., B.L. Hall, and A.L. Westerling, 2004: The impact of twenty-first century climate change on wildland fire danger in the western United States: an applications perspective. *Climatic Change*, 62 , 365-388.

Crimmins, M.A. and A.C. Comrie, 2004: Wildfire-Climate Interactions Across Southeast Arizona. *International Journal of Wildland Fire*, 13, 455-466.

Fulé, P.Z., C. McHugh, T.A. Heinlein, and W.W. Covington. 2001. Potential fire behavior is reduced following forest restoration treatments. Pp. 22-28 in *Ponderosa pine ecosystems restoration and conservation: Steps toward stewardship*, ed. R.K. Vance et al. Proceedings RMRS-22. Ogden, Utah. USDA Forest Service.

Fulé, P.Z., W.W. Covington, H.B. Smith, J.D. Springer, T.A. Heinlein, K.D. Huisinga, and M.M. Moore. 2002: Testing ecological restoration alternatives Grand Canyon, Arizona. *Forest Ecology and Management*. 170:19-41.

Swetnam, T.W. and J.L. Betancourt, 1990: Fire-Southern Oscillation relations in the southwestern United States. Science, 249, 1017-1020.

Swetnam, T.W. and J.L. Betancourt, 1998: Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate*, 11, 3128-3147.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and Earlier Spring Increases Western U.S. Forest Wildfire Activity. *Science*, 313, 940-943.

ARIZONA COOPERATIVE EXTENSION
THE UNIVERSITY OF ARIZONA • COLLEGE OF AGRICULTURE AND LIFE SCIENCES

The University of Arizona
College of Agriculture and Life Sciences
Tucson, Arizona 85721

Alix Rogstad
Fire Education Specialist and Area Extension Agent for the U.S. Cooperative Extension Service, University of Arizona

Michael Crimmins
Climate Science Extension Specialist, Department of Soil, Water and Environmental Science, University of Arizona

Gregg Garfin
Program Manager, Climate Assessment for the Southwest (CLIMAS)

This information has been reviewed by university faculty.
cals.arizona.edu/pubs/natresources/az1425.pdf