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Climate Change and Fire in the Southwest

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Intermountain West Frequent-Fire Forest Restoration

Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability….Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science and Policy Working Group 2004).

Most frequent-fire forests throughout the Intermountain West have been degraded during the last 150 years. Many of these forests are now dominated by unnaturally dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-severity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of frequent-fire forests of the Intermountain West. By allowing natural processes, such as low-severity fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The Southwest Fire Science Consortium (SWFSC) is a way for managers, scientists, and policy makers to interact and share science. SWFSC's goal is to see the best available science used to make management decisions and scientists working on the questions managers need answered. The SWFSC tries to bring together localized efforts to develop scientific information and to disseminate that to practitioners on the ground through an inclusive and open process.

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Cover Photo: Ground fuels burn with low intensity during a scheduled prescribed burn at Gus Pearson Natural Area in the Ft. Valley Experimental Forest, U.S. Forest Service. Change in southwestern ecosystems is inevitable, but there is sound evidence that treating forests with thinning and prescribed burning for ecological restoration and fuel hazard reduction can reduce fire severity and can potentially increase a forest's resilience to climate change. *Photo by Jake Bacon, courtesy of the Ecological Restoration Institute, Ft. Valley Experimental Forest, and Rocky Mountain Research Station (U.S. Forest Service).*

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Introduction

Global climate change will lead to shifts in climate patterns and fire regimes in the Southwest over the coming decades. The intent of this working paper is to summarize the current state of scientific knowledge about climate change predictions in the Southwest as well as the pathways by which fire might be affected. While the paper is focused on the Southwest, in particular Arizona and New Mexico, some of the material cited covers a broader area.

Climate Change Predictions for the Southwest

In the Southwest, temperature is predicted to rise by more than 3 degrees Fahrenheit (up to 9 degrees F) by the year 2100, with temperature rise higher in the summer and fall than winter and spring (Cayan et al. 2013). Across the Southwest, an average of 17 more freeze-free days are projected by 2100 (Cayan et al. 2013). There is no disagreement among various general circulation models that temperature will increase; the only question is how much, and that depends partly on emissions in coming decades. In terms of extreme events, heat waves are projected to increase in frequency, intensity, duration, and spatial extent, and higher relative humidity during heatwaves will keep nighttime temperatures particularly elevated (Gershunov et al. 2013).

Predicting precipitation in the Southwest is difficult, in part because variability in precipitation in the Southwest over time, from days to decades, is greater than for other parts of the United States (Cayan et al. 2013). In addition, the models are not able to perfectly capture current precipitation patterns in the Southwest, so precipitation predictions for the future may be imperfectly modeled as well (McAfee et al. 2011). Depending on emissions scenarios, models used, and approaches taken, groups of researchers have arrived at different predictions for precipitation in the Southwest. For example, in the Colorado River Basin, Wi et al. (2012) projected slightly higher annual precipitation through the year 2079. However, they also projected a decrease in winter snowfall for most of the Basin. On the other hand, many studies have predicted that the Southwest will be drier over the coming century (Seager et al. 2007, Seager and Vecchi 2010), with drying and warming already evident in the Southwest (Overpeck and Udall 2010). Spatial variability for regional projections is high; many models predict precipitation surpluses in the north and deficits in the south. The emissions scenario used also affects precipitation projections, with higher-emissions scenarios resulting in less precipitation on average (Cayan et al. 2013) (Figure 1). Finally, models predict different outcomes depending on the season; modeling of atmospheric circulation patterns predicts that storm tracks will move north, resulting in decreased winter precipitation in the Southwest, but on the other hand some models forecast increased winter precipitation. It is agreed, however, that winter snowpack is likely to

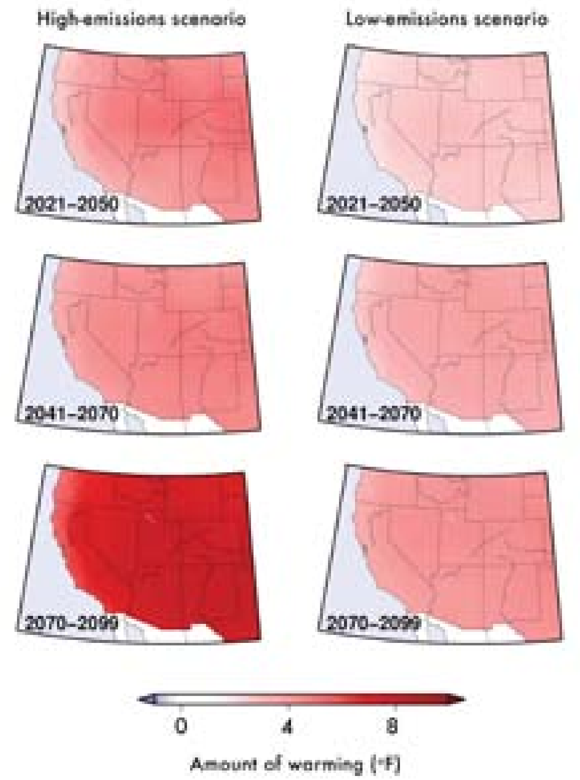


Figure 1. From Cayan et al. (2013). Projected temperature changes for high and low emission scenarios. Annual temperature change (degrees F) from historical (1971–2000) for early- (2021–2050; top), mid- (2041–2070; middle) and late- (2070–2099; bottom) 21st century periods. Results are the average of 16 statistically downscaled climate models. *Source: Nakicenovic and Swart (2000), Mearns et al. (2009).*

decrease because of increasing temperatures, which will reduce spring runoff and result in decreased soil moisture by early summer (Cayan et al. 2013). Summer precipitation predictions vary widely, in part because the monsoon is poorly understood and modeled at this time (Cayan et al. 2013).

In terms of extreme events, both enhanced precipitation events and droughts are projected to intensify in the coming century (Gershunov et al. 2013). Droughts, including droughts during severe La Niña events, are predicted to be worse than any drought since at least the Medieval Climate Anomaly (1100–1300 CE) (Seager et al. 2007, Dominguez et al. 2010, Cook et al. 2015). The changes are projected to be driven by a decrease in winter precipitation (Seager and Vecchi 2010), and droughts are projected to last longer than historical droughts; up to 12 years or more (Cayan et al. 2010).

Impacts of Climate Change on Fire in the Southwest

Hessl (2011) proposed that there are three pathways through which fire activity might be influenced by climate change: changes in fuel condition (fuel moisture), changes in fuel loading, and changes in

Box 1: Predicting Climate Change and Impacts

Climate change predictions are based on scenarios of global human activity, and include greenhouse gas emissions as the primary driver of climate change in the future (IPCC 2013). The emissions scenarios are then used in models to project climate over the next century. Dozens of models have been built that incorporate aspects of the global climate system (e.g., atmosphere, oceans, land and sea ice, and greenhouse gases) to understand how the global climate operates and how climate variables like temperature, precipitation, cloud cover, and storm tracks might change (Flato et al. 2013). Finally, impacts of climate change (on fire, air quality, human health, etc.) are predicted. Levels of uncertainty increase as researchers predict 1) emissions, 2) atmospheric concentrations of greenhouse gases, 3) radiative forcing (energy that warms the Earth), 4) climate change, and finally, 5) impacts of climate change (Myhre et al. 2013). However, it is possible to have a high degree of confidence in climate change predictions if there is both strong evidence and agreement among models (Stocker et al. 2013).

ignitions. Ecosystems in which fires are typically limited by fuel moisture (higher-elevation or higher-latitude, wetter ecosystems) are likely to be most affected by either increased or decreased fuel moisture. Ecosystems in which fires are typically limited by fuel (drier, less productive ecosystems) are likely to be most affected by increases or decreases in fuel loading (Westerling and Bryant 2008, Flannigan et al. 2009, Littell et al. 2009). Changes in ignitions may happen anywhere, although Krawchuck et al. (2009) note that there are few areas of the globe where ignitions are a limiting factor for fire. Most studies have focused on climate change impacts on area burned, with some also forecasting fire occurrence or other fire regime attributes; however, predicting fire severity is much more difficult (Flannigan et al. 2009).

An important point to keep in mind is that short-term and long-term climate change impacts on fire regimes may be different (Rocca et al. 2014). For example, in the short term, fire risk may be increased due to climate change (e.g., higher temperatures, longer fire seasons, lower fuel moisture), but in the long term, fire risk may decrease if fuels change with a changing climate (e.g., a forested ecosystem does not return after a fire) (Rocca et al. 2014). Additionally, land use changes over the past century (fire exclusion, logging, grazing) have resulted in altered forest structure and increased fuel loadings in many forests in the Southwest. These changes may magnify impacts from climate change, for example when both high fuel loads and climate conditions allow for the occurrence of a severe crown fire.

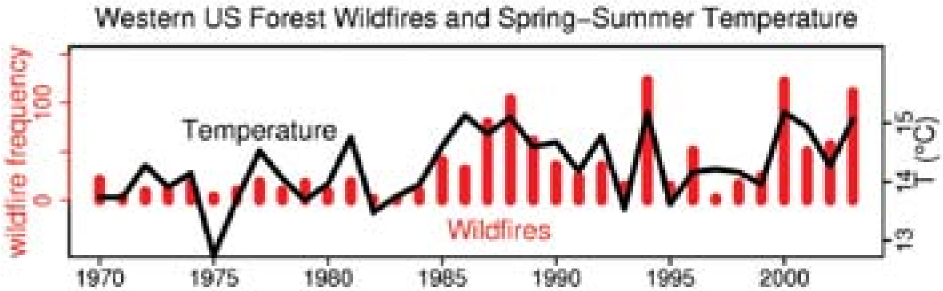
Alteration of Fuel Condition

Fuel condition (fuel moisture) could be altered by changing fire seasons, increased droughts or wet periods, or changing fire weather (Hessl 2011). In terms of changing fire seasons, we have already started to see a longer fire season across the western US, which has been linked to more large fires and fires of longer duration (Westerling et al. 2006) (Figure 2). Fire seasons are projected to increase around the globe in places where the fire season isn't already all year (Flannigan et al. 2013), and the fire season for very large wildfires (>50,000 acres) is also projected to lengthen (Stavros et al. 2014).

Changes in climate patterns and fire weather may also alter fuel condition. Decreases in relative humidity through the year 2089 are forecasted to increase days of high fire danger in the Southwest and other parts of the American West, as measured by the energy release component (Brown et al. 2004). Temperature will also play a role; Spracklen et al. (2009) found that increasing temperature will lead to 54% more area burned across the American West in the period 2046–2055, compared to the period 1996–2005. A study in the Southern Rockies Ecoregion, which included parts of Wyoming, Colorado, and New Mexico, agreed: the authors found that area burned and number of fires have been increasing over the past few decades, and area burned is likely to increase through the year 2070 by two to five times due to both temperature and precipitation changes (Litschert et al. 2012). The increase in area burned will depend on which climate scenario turns out to be most accurate; all climate scenarios project increased temperature, but precipitation may increase or decrease (Litschert et al. 2012). The National Research Council (2011) also predicted large increases in area burned across the West due to a 1.8 degrees F increase in temperature, with projections for different regions ranging from a 74% increase in Southwest deserts to a 656% increase in parts of the Rocky Mountains.

Hessl (2011) points out that fire-climate relationships that have been described for the recent past may not hold true for the future. This is because relationships between climate and fire are specific to particular ecosystems and fuel types, but vegetation shifts and changes in fuel characteristics may occur with climate change. For example, climate change may result in conditions more conducive to the establishment of invasive grasses, and also increase the chances of fire ignition and spread, promoting the fire-invasive cycle (Abatzoglou and Kolden 2011). Additionally, humans

Figure 2. From Westerling et al. (2006). Annual frequency of large (23,000 acres) western U.S. forest wildfires (bars) and mean March through August temperature for the western United States (line).



may change ignition or suppression patterns compared to the recent past (Hessl et al. 2011).

Changes in Fuel Loading

Fuel loading may change with climate change for many reasons, including changes in dominant species, insect outbreaks, mortality events, severe drought, severe fire, reduced fire, or changes in regeneration. Tree mortality events are already increasing in the western United States (van Mantgem et al. 2009) and worldwide (Allen et al. 2010) due to recent warming and droughts, and are likely to continue impacting forested ecosystems as climate changes further. In the Southwest, vegetation cover is projected to decline, mostly due to increasing temperatures, and most species are predicted to shift north by an average of 58 miles (Notaro et al. 2012). Yucca and oak are projected to expand their range, and pine and juniper ranges are projected to shrink (Notaro et al. 2012). Allen and Breshears (1998) provide an excellent example of how an extreme event (the 1950s drought) led to a shifting of the ecotone between ponderosa pine and piñon-juniper woodland by over 1.2 miles in less than five years, showing that range expansions and contractions, along with changes in species dominance, can happen very quickly.

Disturbances themselves may impact fuel type and amount. Williams et al. (2010) estimated that 7.6–11.3% of southwestern forests and woodlands were heavily impacted by bark beetle-induced mortality from 1997 to 2008, and 2.7–3.0% of forests and woodlands were burned in moderate to high-severity fire from 1984 to 2006. These disturbances are likely related to drought and high temperatures during these decades, and are likely to continue affecting southwestern forests and woodlands. Regeneration after severe fire in ponderosa pine forests in the Southwest can result in dense stands of young trees, or tree regeneration may not happen, and a previously forested ecosystem can switch to a non-forested shrub or grass community (Savage and Mast 2005, Strom and Fulé 2007). Even without severe fire, changes in regeneration patterns could result in forests converting to non-forested ecosystems over the next century if the most severe emissions scenario occurs (Azpeleta et al. 2014).

Changes in fuel loading may result in increased or decreased fire activity, depending on whether fuel loading is enhanced or diminished. Even if fire activity increases, there is likely to be a self-limiting aspect of fire over time, with severe fires only able to burn when enough vegetation has grown back to carry another fire (Williams et al. 2010).

Changes in Ignitions

Only one study, published in 1994, has attempted to predict changes in lightning with climate change. Price and Rind (1994) predicted that in the Southwest, due to an increase in thunderstorms and a decrease in precipitation, the number of lightning fires will increase by 61%, while the area burned in lightning fires will increase 141% in a scenario where CO_2 doubles. This is equal to a 7.6 degrees F increase in temperature. Human ignitions are not tied to climate change, but may increase with increasing population density as well. Ignitions are the least understood pathway through which climate change might influence fire activity in the future.

Summary and Conclusion

Climate change will increasingly alter climate averages, extreme climate events, and ecological processes in the coming years and decades. Temperature is universally forecasted to rise in the Southwest. Models disagree about precipitation; some predict increased precipitation and some predict decreased precipitation, and there also may be variability by area and by season. It is generally agreed, however, that snowpack and spring/early summer runoff will be less in a warmer climate. In addition, droughts will likely be more intense and last longer.

Climate change may impact fire through three pathways: alteration of fuel moisture, alteration of fuel loading, and alteration of ignitions. Alteration of fuel moisture in the Southwest may happen through longer fire seasons, increased temperatures, decreased relative humidity, or changes in precipitation. Alteration of fuel loading has been predicted due to tree mortality and loss of vegetation cover, range shifts, changes in regeneration patterns, and disturbances themselves, such as insect outbreaks and severe fire. Lightning ignitions may increase, but ignitions are the least understood aspect of how climate change may influence fire.

Different ecosystems will respond to climate change differently. Ecosystems in which fires are generally

Box 2: Historical Climate-Fire Relationships

Regional and global climate patterns affect fire occurrence across the Southwest, and we know a great deal about these fire-climate relationships by studying patterns of fire and climate captured in tree rings. Climate reconstructions from tree rings are built by collecting tree cores, crossdating and measuring the rings, calculating statistical relationships between the tree-ring measurements and the modern, instrumentally-measured climate variable of interest, and then using these relationships to reconstruct that climate variable in the period before instrumental measurements were taken, as far back in time as the tree rings go. Historical low-severity fire dates are determined by collecting cross-sections of fire-scarred trees, crossdating the rings, and determining the dates of fire scars present in the wood to the precise year of occurrence. Then, fire dates and climate patterns can be compared over long time periods to understand relationships between them.

Some of the fire-climate relationships that have been evaluated in the Southwest include:

Drought: High synchrony in fires across Arizona and New Mexico were linked to severe drought (Swetnam and Betancourt 1998).

Temperature: Synchronous fire years were tied to decadal- and century-scale variations in temperature in sequoia groves in California (Swetnam 1993).

El Niño Southern Oscillation (ENSO): Large areas burned in Arizona and New Mexico were historically correlated with cool phases of ENSO (La Niña conditions) (Swetnam and Betancourt 1990).

Pacific Decadal Oscillation (PDO): Area burned in the Southwest was linked to cool phases of the PDO; PDO enhances or suppresses ENSO phases (Westerling and Swetnam 2003)

Atlantic Multidecadal Oscillation (AMO): Positive phases of AMO were linked to high fire synchrony across western North America (Kitzberger et al. 2007).

Although none of these fire-climate relationships can be used to predict fire in any given area, and although some of the relationships have become weaker in the modern period with an increase in human-caused fires, understanding the relationships between fire and these climate variables is still valuable for fire management and regional planning.

limited by fuel moisture (wetter, more productive ecosystems which typically need a drought year to burn) will be most affected by changes to fuel moisture. Ecosystems in which fires tend to be limited by fuel availability (drier, less productive ecosystems in which fire may be limited by fuel continuity) will be most affected by changes to fuel loading. Any changes in ignitions will likely affect all ecosystem types. The impacts of climate change on fire regimes may change over time; fire risk may be high initially but decrease in the long term with changes in vegetation and fuels.

Change in southwestern ecosystems is inevitable. Managers must include climate change predictions in management strategies, despite the uncertainties that remain in predicting fire activity into the future. Adding to the challenge is that climate not the only thing changing; land use, population density in the wildland urban interface, invasive species, and fire management are also changing. However, there are steps that managers can take. For example, we know that treating forests with thinning and prescribed burning for ecological restoration and fuel hazard reduction does reduce fire severity. "Buying time" for a forest and potentially increasing resilience to climate change by reducing the chance of high-severity fire may be a sound strategy. Management goals in the face of climate change could also include managing for ecosystem services such as clean air and water, soil health, and native species.

More guidance is available from: USDA Forest Service Climate Change Adaptation Plan 2014: *http://www.usda.gov/oce/climate_change/adaptation/Forest%20Service.pdf*

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For more information about forest restoration, contact the ERI at (928) 523-7182 or **nau.edu/eri**.

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