Drought, Wildfire, and Climate Connections: Research in Forests of the Western U.S.

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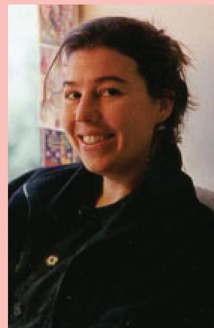
Introduction

The occurrence and severity of wildfires is influenced by climate and forest species composition. While these relationships have been well-studied in lower elevation ponderosa pine forests, research on higher elevation subalpine forests is more limited (Figure 1a). This article highlights the research of Tania Schoennagel, a researcher at the University of Colorado, who has studied the relationship between climate patterns and fire occurrence in high-elevation subalpine forests of the Rocky Mountains (see pink box). First, there is a description of the difference between low-elevation ponderosa pine forests and higher-elevation subalpine forests regarding wildfire frequency and severity and the influence of climate. Next, there is a discussion of the effects of past fire suppression in the different types of forests. Finally, the article summarizes two recent articles by Schoennagel that analyzed the relationship between global climate patterns and wildfire occurrence in subalpine forests of the Rocky Mountains.



Tania Schoennagel is a Research Fellow in the Geography Department at the University of Colorado. She got her Ph.D. in Ecology from the University of Wisconsin-Madison in 2002. Her research addresses the causes and consequences of western forest disturbances, primarily wildfire. As a landscape ecologist, she conducts research at multiple spatial and temporal scales to examine: (1) disturbance dynamics and successional patterns, (2) effects of past climate variability and future climate change, and (3) ecological implications of forest management policy and changing land use. She employs field studies, dendrochronology, GIS analyses and spatial modeling. Her research generally focuses on fundamental ecological questions with applications to forest management, land-use policy and climate change.

Wildfire Frequency and Severity in Subalpine and Ponderosa Pine Forests

Wildfire frequency and severity is influenced by climate and stand density, and is different in two types of forests at different elevations in the Rocky Mountains. High-elevation subalpine forests typically experience infrequent high-severity wildfires, while low-elevation ponderosa pine forests historically experienced more frequent low-severity fires. Fire frequency in these forest types is different by orders of magnitude. In high-elevation subalpine forests, the historical reoccurrence interval for fire is on the order of centuries whereas it is on the order of decades in most low-elevation ponderosa pine forests (Schoennagel, et al., 2004). The reason for this difference is related to climate and forest fuel abundance. Rocky Mountain ponderosa pine forests occur at lower elevations (5500 – 8500 feet in the Colorado Front Range), where the summers are warm and dry (Figure 1b). Ignitions of the dry vegetation can occur fairly easily and often. In comparison, higher elevation subalpine forests (9000-11000 feet in the Colorado Front Range) have cooler summers and more moist vegetation. Fires in subalpine forests occur less frequently at this elevation because it takes a sustained dry period for the vegetation to ignite. Drought frequency is a significant limiting factor affecting fire frequency in the subalpine zone, but not in the ponderosa pine zone (Schoennagel, et al., 2004). Subalpine forests have naturally cooler and moister conditions, and precipitation deficits that dry out the vegetation occur infrequently. In contrast, in the ponderosa pine zone, fuels are often sufficiently dry for ignitions throughout late summer and hence fires occur more frequently.

Figure 1a. Subalpine fire in Grand Teton National Park (Photo by Tania Schoenagel, Schoennagel, et al., 2005).

Climate is interrelated with stand density, and together they influence fire severity in these two types of forests. Stand

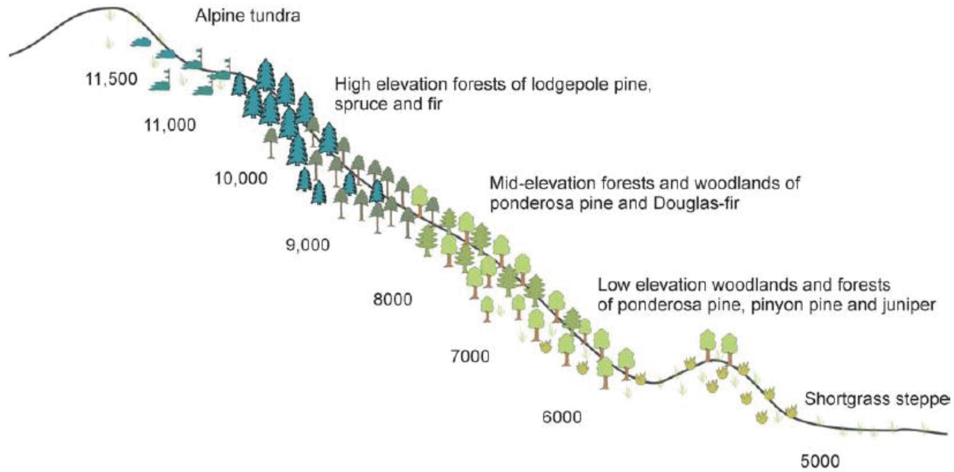


Figure 1b. Colorado forests' species composition change rapidly with changes in elevation, (Graphic created by Laurie Huckaby, Romme, et al., 2006).

density refers to how close the trees grow to one another. Because the high-elevation subalpine zone tends to be moister than the low-elevation ponderosa pine zone, trees can grow closer together (more dense). Higher tree densities in subalpine forests contribute to high fire severity because the trees become ladders for the fire to climb into the canopy and travel as a high-severity crown fire, killing many of the overstory trees. On the other hand, in dry, low-elevation ponderosa pine forests, frequent fires kill mostly the smaller trees and keep the landscape more open (less dense). Here, fires are typically low-severity; they spread along the forest floor consuming much of the ground vegetation (grasses and herbaceous plants), but leaving many of the overstory trees.

Forest Management Practices in Subalpine and Ponderosa Pine Forests

There are differences in the effects of past fire suppression and current restoration practices in the two forest types. The pattern of more frequent frequent low-severity fires low-elevation in ponderosa pine forests may have changed in some of these forests due to fire suppression in the last century[1]. The purpose of fire suppression is to extinguish all forest fires, even those caused naturally by lightening. Fire suppression during the 20th century has led to more dense forest stands that are now at greater risk for high-severity fires by preventing the natural cycle of low-severity fires in ponderosa pine forests that kill small vegetation and keep forests less dense. Supporting evidence shows that there has been an increase in tree densities and a subsequent increase in high-severity fires in some ponderosa pine forests due to fire suppression since the early to mid-1900s (Schoennagel et al. 2004). A fuels reduction program including selective logging and/or prescribed burning has been intended to restore the open forest landscape and decrease the amount of ladder fuels, which help low-severity fires spread to the canopy and become high-severity fires.

However, research is showing that high-elevation subalpine forests have not experienced the same amount of or effects from fire suppression (Schoennagel et al. 2004). Because of the differences in climate, stand density, and historical fire frequency and severity, a fuels reduction program will not restore subalpine forest to natural conditions like it will for most ponderosa pine forests. Specifically, subalpine forests are denser due to a cooler, moister climate and the characteristics of the trees that grow there, and this leads to high-severity wildfires. Furthermore, high-severity fires are hard to suppress, especially in remote high-elevation forests. Therefore, fire suppression has had little effect on fire frequency or stand density in subalpine forests, so a fuels reduction program is not necessary to restore a natural habitat (Schoennagel, et al., 2004). The fundamental differences in forest type and the effectiveness of various forest management approaches, including fuels reduction, may require different protection methods for subalpine versus ponderosa pine forests with multiple uses.

Drought, Climate Patterns, and Fire Occurrence in Subalpine Forests

Schoennagel's recent research finds that the atmospheric mechanisms affecting patterns of drought-induced fires can be hemispheric in scale. Schoennagel looked at the connections

[1]While most ponderosa pine forests experience frequent low-severity wildfires, not all ponderosa forests fit this model. Many higher-elevation or higher-latitude ponderosa pine forests may have historically experienced less-frequent high-severity or mixed-severity fires (Sherriff and Veblen 2006; Kaufmann et al. 2006). Some moister ponderosa pine forests may be characteristically dense and have not experienced an increase in fire severity due to fire suppression.

between fire and broad-scale climate patterns, including El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-decadal oscillation (AMO) in the Rocky Mountains. She found correlations between fire occurrence and climate patterns at both short and long time scales (Schoennagel, et al., 2005 and Schoennagel, et al., 2007).

Three primary broad-scale climatic patterns, the ENSO, PDO, and AMO, describe variation in sea surface temperatures in the Pacific and Atlantic Oceans, which influence the climate of the western U.S.. ENSO reflects deviations from average sea surface temperatures (SSTs) in the equatorial Pacific Ocean, oscillating between warmer than average SSTs (El Niño) and cooler than average SSTs (La Niña) at 2-6 yr cycles. The PDO index represents variability in average SSTs in the North Pacific Ocean, varying between cool and warm phases at 20-30-yr cycles. The AMO index reflects average annual SSTs in the North Atlantic Ocean, which cycle between warm and cool phases at 50-80 yr frequencies (discussion adopted from Schoennagel, et al., 2007).

Schoennagel's studies analyzed how often fires occurred during particular phases of each climate pattern compared to the expected fire frequency. Schoennagel and her colleagues compared the portion of total years in the study period occurring in each climate phase to the portion of fire years occurring during each phase. She used a chi-squared statistical test to determine if the two proportions were significantly different. If the difference was statistically significant ($P \leq 0.05$), then there was a correlation between fire occurrence and that particular climate phase (Schoennagel, et al., 2005 and Schoennagel, et al., 2007).

The first study analyzed how different phases of ENSO and PDO affect drought-induced fire occurrence in subalpine forests across the Rocky Mountains from 1700-1975 (Schoennagel, et al., 2005). The three study sites were: Jasper National Park (representing the northern Rockies), Yellowstone National Park (representing the central Rockies), and Rocky Mountain National Park (representing the southern Rockies). Not surprisingly, she found that fires tended to occur during periods of extreme drought. Drought in turn, was affected by ENSO and PDO phases. She found that during years when the PDO and ENSO were either both in their positive (warmer than average) or negative (cooler than average) phases, there was a higher incidence of fire occurrence. However, these climate patterns affected the regions differently (Figures 1c,d):

- Years of both –PDO and –ENSO phases experienced more fires in southern Rockies (P=0.006, significant).
- Years of both +PDO and +ENSO phases experienced more fires in northern and central Rockies (P=0.556, not significant).
- PDO affects fires in the northern Rockies more than ENSO.
- ENSO affects fires in the southern Rockies more than PDO.
- The correlations between ENSO and PDO are not as strong in the central Rockies as in the northern and southern Rockies.

(Note that the results are only for the areas contained in the National Parks, not the entire Rocky Mountain region.)

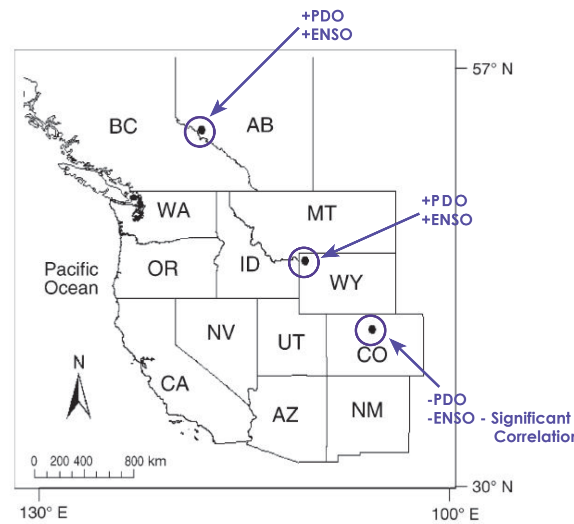


Figure 1c. Location of the three study sites used to examine patterns of climate-fire interactions with phases of the ENSO and PDO from Schoennagel, et al.,2005 (black circles). From north to south: Jasper National Park, Alberta, Canada; Yellowstone National Park, Wyoming; Rocky Mountain National Park, Colorado (Schoennagel, et al., 2005, Figure 1).

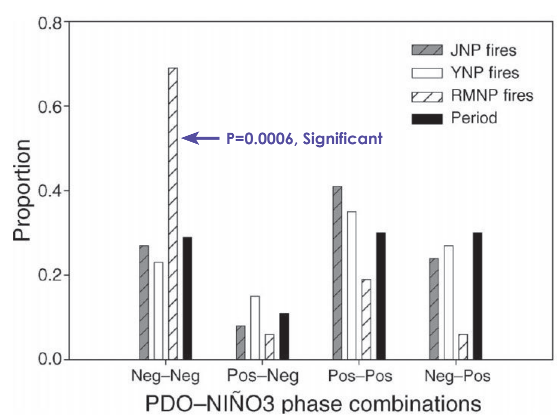


Figure 1d. The proportion of the total number of fires at each study area relative to the total proportion of years during the 1700-1975 study period (black bars) in each PDO-ENSO phase combination. Chi-square tests show that the fires occurred more often than expected in RMNP during negative PDO-La Niña conditions (P=0.006, significant). The frequency of fires in YNP and JNP did not different significantly from expectations, although fires occurred most often during the positive PDO- El Niño conditions (Schoennagel, et. al., 2005, Figure 5).

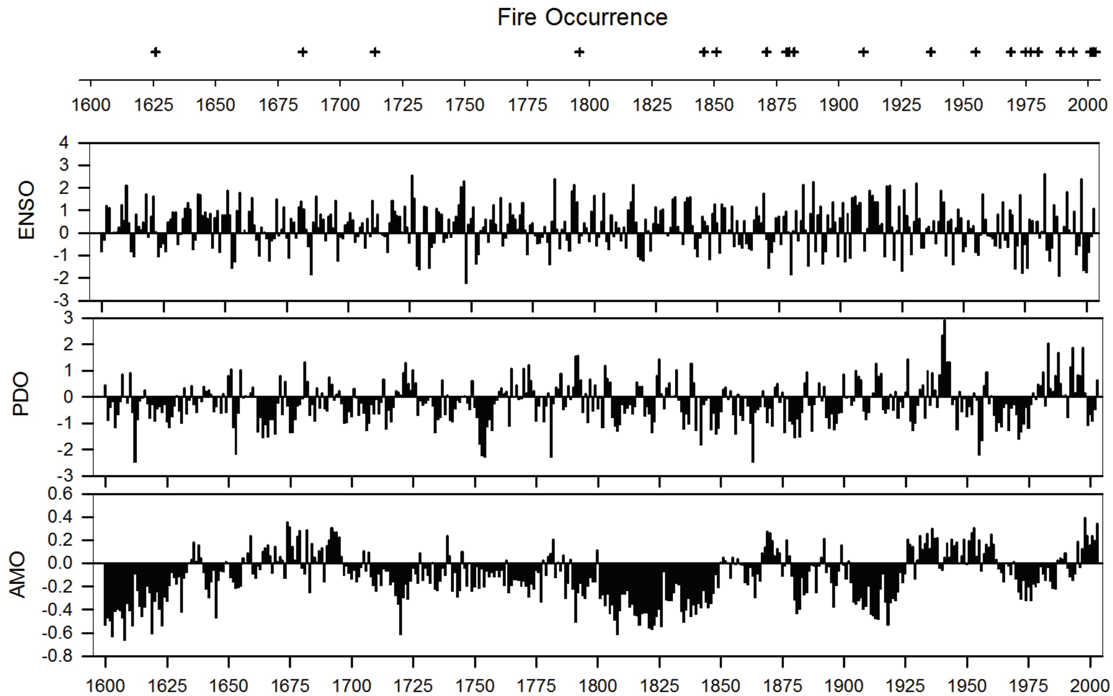


Figure 1e Time series of ENSO, PDO, AMO, and fire occurrences from 1600-2003 in the study area in western Colorado (Schoennagel, et al., 2007, Figure 2).

The second study covered a smaller study area (western Colorado), but it included analysis of the AMO in addition to ENSO and PDO during the period of 1600-2003 (Schoennagel, et al., 2007). Because the AMO is a multi-decadal climate oscillation, it changes signs (phases) at low-frequency (long) time scales of about 50 years, and may have a significant long-term influence on drought and fire regimes in the West. The positive AMO is associated with drought across much of the western US, and prevailed during the 1930s Dust bowl and the 1950s drought (Sutton and Hodson, 2005) (Figure 1e). Schoennagel found that in western Colorado, fires in the subalpine zone occurred most often during years when the +AMO, –ENSO and –PDO phases combined (P=0.041, significant) (Figure 1f). Also, fires generally were synchronous with the +AMO phase over very long time-scales (many decades). Based on this research and that by Kitzberger et al. (2007), the western U.S. could be entering a period of high fire activity due to the recent shift to a warm AMO phase in 1998 that may persist for decades.

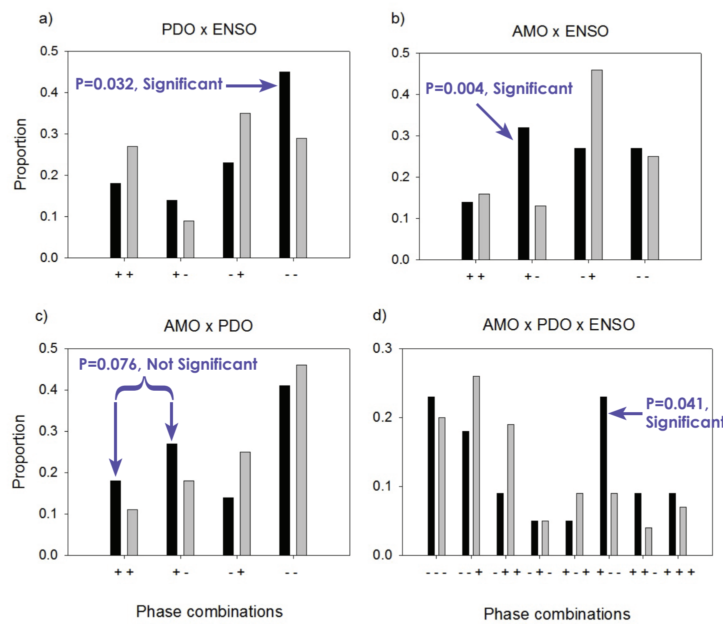


Figure 1f. Relative frequencies of fire and climate occurrences in each of the (a-c) two-way and (d) three-way combined phases of the AMO, PDO, and ENSO during the 1600-2003 study period. Phase combinations refer to different combinations of warm and cool phases on the AMO, PDO, and ENSO in a given year. Black bars represent observed fire occurrence; gray bars represent expected fire occurrence. Significant departure from the expected occurrence was evaluated by chi-square tests, and some results are shown here (Schoennagel, et. al., 2007, Figure 5).

Summary

The research highlighted here shows how high-elevation subalpine forests differ from low-elevation ponderosa pine forest in terms of wildfire frequency and severity, due to fundamental differences in climate and forest fuels. In addition, large-scale climate patterns like ENSO, PDO, and AMO influence the occur rence of drought and severe wildfires in the Rocky Mountains. There is a significant correlation between years experiencing a positive (warm) AMO, a negative (cool) PDO, and a negative (cool) ENSO and wildfire occurrence in the southern Rocky Mountains, especially in Colorado. Other research corroborates these results. For example, recent work on fires and climate by Westerling et al. (2006) also showed that in the last 15 years there was a 5-fold increase in area burned across the western U.S. due to earlier snowmelt, higher temperatures and longer fire season, and these patterns where most pronounced in the northern Rockies and in high-elevation forests. Other related sources are in the references section. Understanding wildfire-climate relationships could be useful in predicting expected wildfire activity in different regions and potential impacts on water resources (see green box).

Wildfire and Water Resources

Romme and colleagues synthesized research on the ways wildfires can affect water resources by impacting streamflows or water quality (2006). Fires can increase streamflows by decreasing the amount of forest canopy that intercepts precipitation and by decreasing the number of live trees that take up water from the soil. However, unless the annual rainfall is above 18-20 inches and at least 15-20% of the forest canopy is dead, no effect on runoff is expected because reduction in interception and transpiration are usually negated by increase in soil evaporation. The exception is when high-severity fire burns so hot that it causes the soil to become hydrophobic and not allow much infiltration. In that case, runoff will increase. A related study has found that by killing ground vegetation, wildfires increase erosion and have a much greater effect on water quality than streamflows. (Romme, et al., 2006)

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On the Web

- Tania Schoennagel’s Website: http://spot.colorado.edu/~schoenna/.
- Colorado Forest Restoration Institute: http://www.cfri.colostate.edu/.