CALIFORNIA FIRE SCIENCE CONSORTIUM

Special Topic: Synthesis for Resource Managers

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40 Years of Wildfires Alter a Sierra Nevada Watershed

Historically, wildfires used to burn Sierra Nevada forests fairly frequently during California's dry summers. Beginning around 1900, fire suppression efforts dramatically reduced the amount of wildfire burning in California. Although it was initially effective at achieving the short-terms goal of preventing losses from forest fires, fire suppression has left a legacy of dense, homogeneous forests. Such landscapes have high water demands and fuel loads, and when burned can result in catastrophically large fires. These characteristics are undesirable in the face of projected warming and drying in the western US. Alternative forest and fire treatments based on wildland fire use—a strategy in which fires are allowed to burn naturally and only suppressed under defined management conditions—offer a potential strategy to restore forests affected by fire suppression. Understanding the long-term effects of this strategy on vegetation, water, and forest resilience is increasingly important as wildland fire use becomes a more widely accepted practice.

The Illilouette Creek Basin (ICB) in Yosemite National Park has experienced 40 years of wildland fire use, following nearly 100 years of fire suppression (Figure 1). It is the only watershed in the western United States to have experienced a near-natural wildfire regime for such a long period, and also have multi-decadal records of nearby weather and streamflow (Figure 1a). Therefore, it provides a unique opportunity to study natural fire regimes compared to fire suppression and how they impact mountain hydrology differently.

Management Implications

- Vegetation change due to wildfires can cause long-term increases in peak snowpack and annual streamflow.
- Repeated wildfires lead to a more diverse landscape in terms of vegetation type and water availability.
- In dry years, fires led to less change in streamflow (compared to wet years), but more reduction in drought stress.
- The impacts of fire on water vary depending on location.

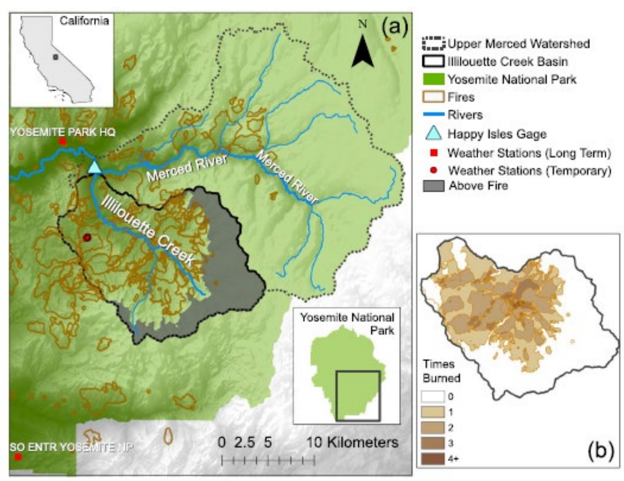

Figure 1. (a) Location of Illilouette Creek Basin, weather and gaging stations used for analyses, and all fire perimeters from 1972 to 2012. (b) Map of the number of times each area of the watershed has burned between 1972 and 2012. [1] See references for figure source.

This review summarizes the findings from four different research articles which explore different aspects of how the ICB's fire history has affected its water resources.

Aerial photos spanning 1969 to 2012 reveal clear changes to the watershed's land cover (Figure 2). Repeated wildfires in ICB between 1972 and 2012 reduced forest cover by 24% and increased shrubland area by 35%, while the amount of open meadow tripled (Figure 3). The spatial patterns of these changes have created a much more diverse landscape, with different types of vegetation more evenly distributed across the landscape compared to the nearly uniform forest that dominated when the watershed was fire-suppressed. Although aerial photos only reveal changes in broad categories of canopy cover, field visits have shown that different land covers are generally associated with different types of understory plants, demonstrating the importance of these changes to increasing biodiversity.

The study of water and fire in the ICB was initially motivated by observations that wetland plants were growing in high severity burn areas that had previously been forested. This suggested an increase in water availability. After taking thousands of surface soil moisture measurements, researchers were able to use a statistical model to show that many burned areas that are now meadows likely have higher soil moisture than they would have if they were still forested (e.g., Figure 4). Areas with elevated soil moisture are important for maintaining biodiversity and drought resilience in this type of watershed.

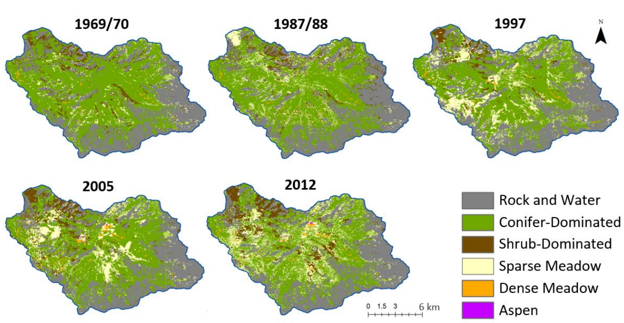

Figure 2. Vegetation maps created from aerial photography. The 1969/1970 map shows the vegetation after a long period of fire suppression. All other maps show the progression of vegetation change due to multiple wildfires beginning in the 1970s. [3]

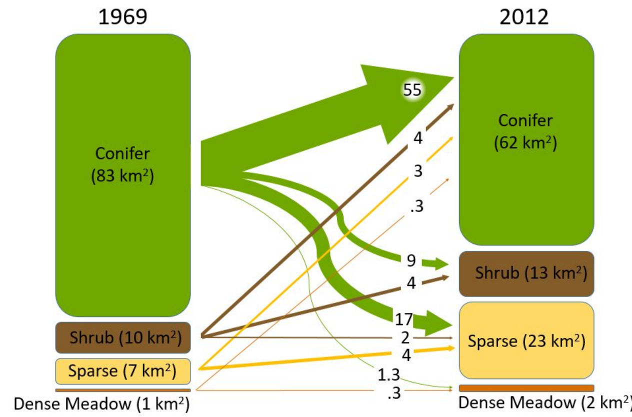

Figure 3. Vegetation type transitions from 1969 to 2012 show that nearly half of the conifer forest cover transitioned to sparse meadows, shrublands, or dense meadows following high severity fire. [3]


Figure 4. Wet meadow vegetation growing amid burned snags of the forest that formerly dominated this area.

Comparing streamflow records from before and after fires were returned to the ICB suggests that streamflow is a few percent higher than it would be under fire suppression. It can be difficult to attribute changes in streamflow to a specific cause, since streamflow naturally varies greatly from year to year. However, using a hydrologic model, researchers could separate the impacts of fire-induced land cover change from the impacts of weather variability. This modeling confirmed that the changing land cover likely increased streamflow by a small degree. As fire removes vegetation, an increase in water availability is likely related to less plant water use and the fact that less precipitation is intercepted in tree canopies and lost to evaporation (Figure 5).

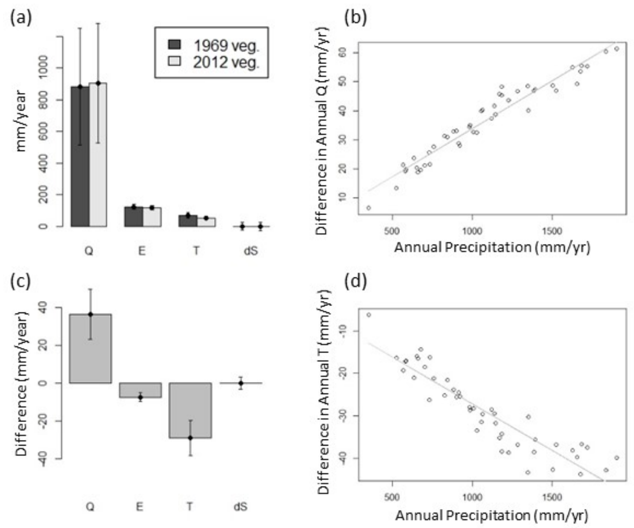

Figure 5. (a,c) According to a hydrologic model, fires led to small, but significant, increases in streamflow (Q), driven by decreases in evaporation (E) and transpiration (T). (b,d) The level of change due to fire was higher in years with more rain and snow. [1]

While streamflow increases are largest in wet years (Figure 5), the post-fire forest itself appears to benefit during dry years. Both observational data and model simulations suggest that this watershed is more drought resistant than it would be if fire suppression had continued. During the drought years of 2014 and 2015, fewer conifers died of drought-related causes in ICB compared to similar, nearby watersheds that had not burned. This is likely because, after fires thinned the forests, the remaining trees faced less competition for water. An eco-hydrologic model estimated that the changes from wildfire led to less water shortage during dry years, including 2014-2015.

Snowpack is an important component of water storage for California. Wildfires can cause blackened surfaces and reduced snowpack shading, both of which may increase snowmelt. However, dense unburned forests can also raise temperatures and increase melting via longwave radiation, as well as intercept snow in their branches and prevent it from reaching the ground (the same reasons tree wells are formed). The net impact of fires on snowpack can therefore be hard to predict. The model showed that peak snow water equivalent (SWE) in ICB was always higher in the burned scenario, which agrees with field measurements. The model showed that the timing of final snowmelt was either earlier or later depending on specific location as well as weather; higher elevation areas kept snow longer in the burned scenario (Figure 6), as did warmer winters.

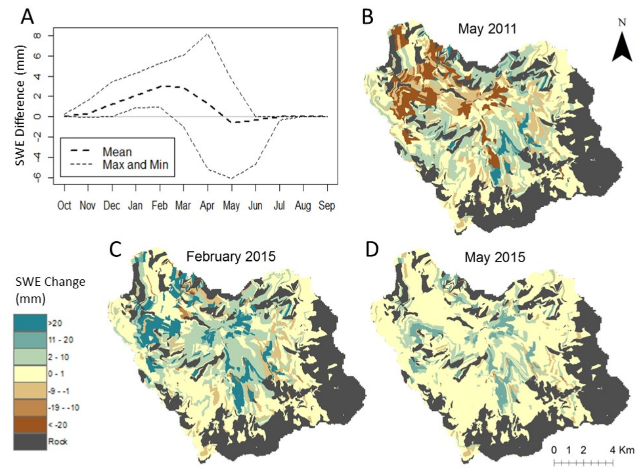

Figure 6. The impact of fires on snow water equivalent (SWE) varied in space and time. (a) Mean difference in monthly SWE in Illilouette Creek Basin between fire-suppressed (1969) and burned (2012) vegetation covers (a positive value means deeper snowpack using 2012 vegetation compared to 1969 vegetation). Dashed lines show the range between the maximum and minimum changes across all years of weather data (1972–2017). (b–d) Maps of change in SWE for February 2015 and May of 2011 and 2015 when historical fires are included in the model compared to the unburned model scenario. Exposed rock areas which were unaffected by fire are grayed out. [1]

In summary, the reintroduction of a near-natural wildfire regime to the ICB has reduced transpiration, increased peak snowpack, increased subsurface water storage in the basin, and is likely to have increased streamflow. The changes are suggestive of an overall shift toward a wetter, less drought-sensitive forest. This shift is sustained by fire; were fire to be removed from the basin again, it is probable that woody cover and water use would again increase. The hydrological impact of the changed fire regime is thus broadly positive. Model results show probable (although uncertain and highly variable with climate) increases in snowpack and streamflow: up to 1% higher, or 5×10^5 m^3 of additional SWE per year, and up to 7×10^6 m^3 of increased streamflow per year (approximately 1/60 of the capacity of the nearby Hetch-Hetchy reservoir and 1/10 of mean flow from the fire-affected portion of the watershed), with no indication of significant increases in flood risk. All of these results (as well as other work on the fire history of the ICB; see *suggestions for further readings*) suggest a possible "win-win-win" scenario in which the restored wildfire regime of ICB yields benefits for water management, forest health, and reductions in fire hazard.

Journal Articles Synthesized

Figure superscripts denote which paper is referenced.

[1]*Boisramé, Gabrielle, Sally Thompson, Christina (Naomi) Tague, and Scott Stephens. 2019. Restoring a Natural Fire Regime Alters the Water Balance of a Sierra Nevada Catchment. Water Resources Research.*
doi:10.1029/2018WR024098

[2]*Boisramé, Gabrielle, Sally Thompson, and Scott Stephens. 2018. Hydrologic responses to restored wildfire regimes revealed by soil moisture-vegetation relationships. Advances in Water Resources 112: 1242-146.*
doi:10.1016/j.advwatres.2017.12.009

[3]*Boisramé, Gabrielle, Sally Thompson, Maggi Kelly, Julia Cavalli, Kate Wilkin, and Scott Stephens. 2017. Vegetation Change During 40 Years of Repeated Managed Wildfires in the Sierra Nevada, California. Forest Ecology and Management 402:241-252.*
doi:10.1016/j.foreco.2017.07.034

[4]*Boisramé, Gabrielle, Sally Thompson, Brandon Collins, and Scott Stephens. 2017. Managed wildfire effects on forest resilience and water in the Sierra Nevada. Ecosystems 20:717-732.*
doi:10.1007/s10021-016-0048-1

Suggestion for Further Reading

Collins, B. M., Lydersen, J. M., Fry, D. L.,Wilkin, K., Moody, T., & Stephens, S. L. 2016. Variability in vegetation and surface fuels across mixed-conifer-dominated landscapes with over 40 years of natural fire. Forest Ecology and Management, 381, 74–83.
https://doi.org/10.1016/j.foreco.2016.09.010

Collins, B. M., Miller, J. D., Thode, A. E., Kelly, M., van Wagtendonk, J. W., & Stephens, S. L. 2009. Interactions among wildland fires in a long-established Sierra Nevada natural fire area. Ecosystems, 12(1), 114–128.
https://doi.org/10.1007/s10021-008-9211-7

Collins, B. M., & Stephens, S. L. 2007. Managing natural wildfires in Sierra Nevada wilderness areas. Frontiers in Ecology and the Environment, 5(10), 523–527.
https://doi.org/10.1890/070007