Carbon dynamics in Sierra Nevada wildfire use areas

California Fire Science Consortium
"Informing Our Future With Fire"

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Actively using wildfires to restore dry, frequent fire-adapted forests in the western U.S. is an important management tool to meaningfully increase the scale of forest restoration and fuel reduction treatments. Using lightning-ignited wildfires to meet forest management objectives (also termed managed wildfire, wildfire for resource benefits, or Prescribed Natural Fire) has been particularly successful in Yosemite National Park, which has implemented a wildfire use policy since 1972. In a well-studied, remote basin in the southern part of the Park—Illilouette Creek Basin—reintroducing fire has been overwhelmingly positive (i.e., reduced fuel loads, reduced future fire spread and severity, increased land cover diversity, and increased water yield). Here, we add to this body of knowledge by investigating the impacts of wildfires on carbon stocks in two basins in the Sierra Nevada (Illilouette Creek basin in Yosemite and San Joaquin basin in the Ansel Adams Wilderness), compared to a nearby basin that has remained largely unburned (Badger basin in Yosemite).

MANAGEMENT IMPLICATIONS

- Live carbon stocks decreased by 22-48% in Sierra Nevada basins that have been managed with wildfire, but surviving carbon stocks are more likely to resist future fires.
- Areas burned at high severity had the greatest losses in forest carbon, regardless of the number of fires that the area had experienced.
- Our fire-deprived forests are exceeding the maximum amount of carbon that they can sustainably store.
- Increasing wildfire use management in areas where it is feasible is an important tool to increase the ability of carbon stocks to resist or recover from future fire.

Fire history of basins and carbon calculations

We used two spatial scales of data over two time periods to explore how the frequency and severity of fires affected aboveground carbon stocks. At the plot-level, we used a network of 37 forestry plots that were first sampled in Illilouette Creek basin in 2002 then remeasured in 2021 or 2022. Within this 20-year period, nine fires burned in the basin, though only two of these fires burned plots: six plots burned once and eight plots burned two times, and plots burned at various severities from low to high. At the landscape-level, we calculated aboveground carbon change in 30 m pixels between 1985 and 2021 using remotely-sensed data in three basins (Illilouette, San Joaquin, and the unburned Badger basin). During this 37-year period, 29 fires burned in Illilouette (with 0 to 4 fires overlapping) and seven fires burned in San Joaquin (with 0 to 3 fires overlapping).

We calculated aboveground carbon in different carbon "pools" at each plot or pixel and investigated the relationship between carbon stock change and fire history (frequency and severity). The live pool included live trees and shrubs, and the dead pool included dead trees, coarse and fine woody debris, litter, and duff. The fraction of carbon that makes up living and dead plant tissues and material varies by species and pool, but is typically around 50% of the biomass.

Fire frequency and severity effects on carbon stocks

On average and at both spatial and temporal scales, live carbon stocks decreased and dead carbon stocks remained the same or increased. The moderate loss (-22%) in carbon stocks at plots in Illilouette over 20 years was driven primarily by large losses in live tree carbon in about one third of the plots, most of which had burned at high-severity most recently and/or had burned two times. At the landscape-scale over 37 years, in the two basins that have allowed beneficial fires to burn, live carbon decreased by an average of 25% (Illilouette) and 48% (San Joaquin; Fig. 1B). The higher percentage of live carbon loss in the San Joaquin basin is likely due to tree mortality in a patch of the basin that burned at high severity in the large 2020 Creek Fire. At both scales, fire severity was found to be a more important influence on carbon change than fire frequency: areas that burned at high-severity resulted in the largest losses in aboveground carbon, regardless of the number of fires that the area had experienced. Plots that burned at low severity had a higher proportion of their carbon stocks in a fire-resistant pool (defined as live, large trees) compared to unburned plots (Fig. 1A), indicating that low-severity fire may increase the ability of surviving carbon stocks to resist future fire impacts.

In a nearby basin that has not burned since at least 1930 (when fire records in Yosemite began being documented), the average density of aboveground carbon in 2021 was more than double the carbon density in the other two basins (425 MgC/ha [190 tons/acre] in Badger compared to ~195 MgC/ha [87 tons/acre] in Illilouette and San Joaquin). Between 1985 and 2021, this unburned basin had a modest loss (-9%) in live carbon and slight gain (3%) in dead carbon. While this basin is storing a substantial amount of carbon today, the high amount of fuels makes this basin susceptible to a large high-severity fire, in which it would lose much of that stored aboveground carbon very quickly.

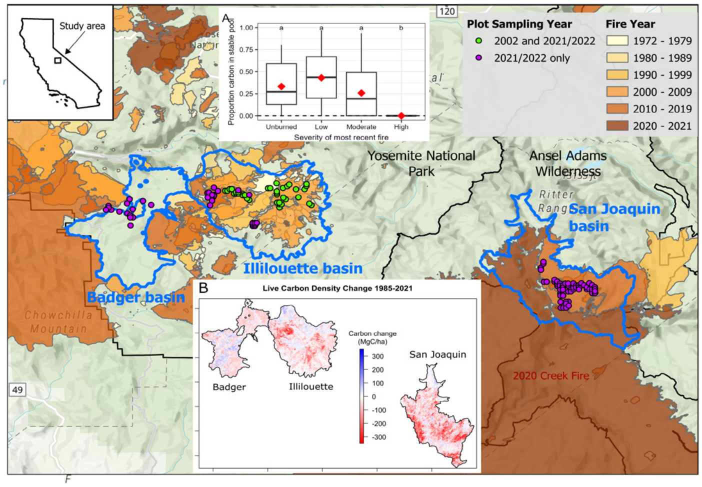

Fig. 1. Map of the three study area basins and fire history: Badger is largely unburned, Illilouette has had many fires since 1972 (onset of Yosemite National Park's wildfire use policy), and San Joaquin has had a few fires since 2003 (onset of Inyo National Forests' wildfire use policy). Inset panel A shows the plot-level relationship between the proportion of carbon that was in large, live trees (a measure of carbon stability – the ability of carbon stocks to resist future disturbances), measured across all plots in 2021/2022. Inset panel B shows the remotely-sensed landscape-level change in live carbon stocks between 1985 and 2021 in all three basins.

Implications for management

Restoration of dry, mixed-conifer forests solely by reintroducing beneficial lightning-ignited fire is a slow process, and comes at some short-term costs to aboveground carbon stocks. However, the surviving carbon stocks are likely more resistant to future fires, particularly when live, large-diameter trees are spared. Managers of similar forests should expect moderate carbon losses as trees—which store the greatest amount of carbon in forest systems—are killed or consumed by fire. Today, our fire-deprived forests are exceeding the maximum amount of carbon that they can sustainably store, and we expect to see further declines in carbon stocks as these ecosystems rebalance to increased fire activity and a warming and drying climate after more than a century of fire exclusion and loss of Indigenous burning. Some of these carbon losses may be offset by conducting mechanical thinning treatments (in which the carbon continues to be stored in forest products), producing biochar from slash, and managing to enhance the growth and health of large, fire-resistant trees.

Additional Information

This brief is based on the following article:

Nesbit, Kristin A., Brandon M. Collins, Zachary L. Steel, John J. Battles, Michael L. Goulden, and Scott L. Stephens. 2025. Multi-scale assessment of wildfire use on carbon stocks in the Sierra Nevada, CA. Fire Ecology 21 (49). https://doi.org/10.1186/s42408-025-00389-w

This brief was written by Kristin Nesbit, reviewed by Katanja Waldner and produced by the CFSC

For additional information, contact: kristin.nesbit@berkeley.edu, cafirescience@gmail.com