Taking time to consider the causes and consequences of large wildfires

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Over the past several decades we have witnessed record-setting wildfires across nearly every continent (1), with recent months as no exception. Widespread burning across western North America includes some of the largest wildfires on record in Washington State, with 2015 total area burned on track to exceed observations of the past two decades (2). Because wildfires have immediate and long-term impacts on social and ecological systems (3), these events motivate critical questions about the precedence, causes, and consequences of large wildfires, and ultimately what the future may hold under varying global-change scenarios. In PNAS, Calder et al. (4) offer a unique perspective informing these questions in subalpine forests in northern Colorado, a region that has experienced extensive fires in the past two decades, as part of the trend of increased fire activity across the western United States (5). Calder et al.'s (4) insights come from 2,000 y of fire history, developed from sediment-charcoal records from 12 lakes spanning a 100,000 ha study area. By combining these records over space and time, the authors develop a composite fire history record that reveals the timing and regional synchrony of past wildfire activity. Their results help elucidate the precedence of regionally extensive wildfires, the long-term dynamics that govern fire activity during climatic warming, and the potential implications of warmer conditions for fire regimes in the 21st century. Such paleoecological perspectives highlight that our understanding of wildfires—and the way we interact with and plan for them—is strongly shaped by the timescales we consider (6, 7) (Fig. 1).

The nature of wildfire in most subalpine forests is that a single large event or a year with regionally extensive burning is inherently rare in any one location (8). Wildfires in these forests typically occur every one to several centuries at a given point on a landscape, making them literally a once-in-a-lifetime experience when witnessed by humans. The extreme fire behavior and extensive tree mortality associated with these events makes them genuinely dramatic. When combined with their immediate and often negative impacts on human health and livelihood, it's easy to view any single wildfire as a disaster or harbinger of change. This perspective helps drive fire management practices that focus on fire suppression, at increasingly high costs [e.g., regularly exceeding $1.5 billion annually in the United States (2)]. However, as research following the 1988 fires in Yellowstone National Park has shown, when viewed over decades, centuries, and millennia, events that appear devastating in the moment are "business as usual" for many subalpine forest ecosystems (6, 9, 10).

Calder et al. (4) provide a similar perspective for subalpine forests in the Colorado Rocky Mountains, where our understanding of fire history is largely based on tree-ring records of stand-replacing fires that extend back four centuries (e.g., ref. 11). The composite record presented by Calder et al. (4) is consistent with tree-ring records in their study region, both suggesting that over the past four centuries an individual forest stand burned approximately every 300 y on average. This correspondence helps validate the use of charcoal from lake sediments for developing long-term records of fire history, and it provides an important benchmark for assessing fire activity in the past and into the future.

By extending the fire history record in their study region back 2000 y, Calder et al. (4) effectively use the past as a natural experiment to study the response of subalpine forest fire regimes to climatic warming. They focus on the Medieval Climate Anomaly (MCA), a period that occurred about 1,000 y ago (750–1100 C.E.) when mean annual temperatures were probably similar to today, but ~0.5 °C warmer than previous or subsequent centuries (12). Before and after the

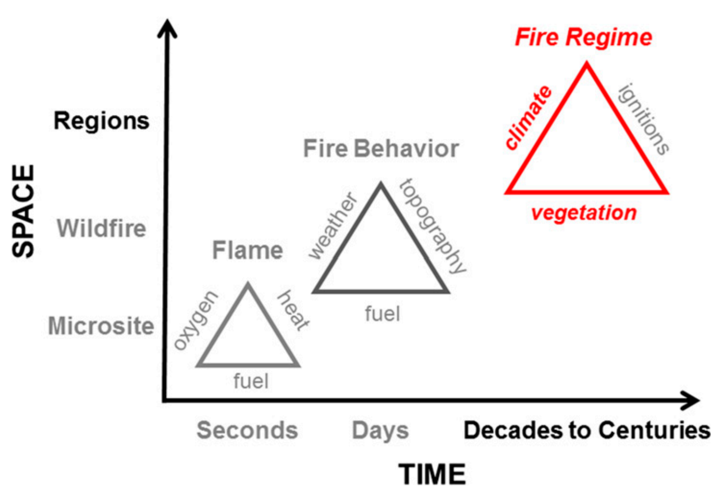

Fig. 1. Conceptual model describing the controls of fire across spatial and temporal scales, adapted from Moritz et al. (8). Much of fire science focuses on understanding fire behavior, which is sensitive to weather, fuels, and topography. Fire regimes describe the characteristic patterns of wildfires over large spatial and temporal scales, and they are sensitive to changes in climate, vegetation, and ignitions. Calder et al. (4) use paleoecological records to study fire regimes in a large subalpine landscape over the past 2,000 y. By combining space and time, their work reveals how climate warming can promote regionally extensive wildfire activity, and it suggests important feedbacks among climate, vegetation, and fire that are relevant for anticipating fire-regime responses to 21st century climate change.

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MCA, Calder et al. (4) found that an average of 33% of their study sites burned in any given century, but during the early MCA, 83% of their sites burned. This corresponds to a 260% increase in the rate of burning, relative to the past 400 y, the period we know best from tree-ring records (11). Increased fire activity during the MCA has also been documented from syntheses of lake-sediment records across the western United States (13) as well as in Alaskan boreal forests (14), suggesting a widespread response to warmer conditions. The findings of Calder et al. (4) imply that high fire activity of recent decades will likely continue into the future as temperatures increase. Equally important, because regional pollen records indicate that subalpine forests persisted through the period of high fire activity (15), their findings suggest the potential for forest resilience to increased burning in the future.

Documenting fire history provides important context, but in itself it is not sufficient to anticipate potential future fire regimes. Increased burning in the past several decades has been well linked to varying aspects of climate change, including warmer, drier summers and an increase in the length of the fire season (1, 5). The mechanisms involved include changes in the fundamental controls of fire behavior, such as an increased incidence of extreme fire weather and fuel drying (1) (Fig. 1). These modern empirical relationships make increased fire activity during a warmer MCA largely intuitive, but Calder et al. (4) found an additional pattern, suggesting that the modern link only tells part of the story of how fire regimes respond to climatic change.

Peak burning documented by Calder et al. (4) at the start of the MCA subsided centuries before paleoclimate records suggest a return to cooler conditions. If climate warming continued, what then explains reduced burning? Calder et al. hypothesize that this dynamic may be a consequence of widespread burning, reflecting a hysteresis in fire–climate relationships at centennial time scales: the impact of climate on regionally extensive fire activity is altered, depending on the previous history of fire in a region. Specifically, the authors suggest the possibility that widespread burning decreased landscape-scale fuel availability and continuity, such that regionally extensive wildfires were less likely for centuries after peak burning in the MCA. This finding assumes a reduction in vegetation, from burning or slowed forest regeneration, possibly because of reduced seed sources or poor seedling survival. Further evaluating these mechanisms requires documenting vegetation dynamics and thus landscape flammability. Evidence from Alaskan boreal forests suggests similar mechanisms linking fire-caused vegetation dynamics to a reduction in landscape flammability, inferred from observations over short time scales (16), modeling efforts simulating fire-vegetation dynamics over centuries (17), and paleoecological records of pollen and charcoal spanning the past 2,000 y (14). The work by Calder et al. (4) thus provides further paleoecological evidence that hints at intriguing feedbacks among climate, fire, and vegetation that could limit fire activity under climatic warming.

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The potential for such stabilizing feedbacks to limit fire activity under a warming climate is critical to understand in more detail, because it is increasingly clear that for much of the globe, 21st century climate will be highly conducive to burning (18, 19). For example, climate projections for the Greater Yellowstone Ecosystem suggest 1988-like summer conditions will be commonplace by the late 21st century (19). Whether or not this results in widespread burning at a similar frequency will depend strongly on vegetation response to both fire and climate. Because these dynamics unfold over decades to centuries, paleoecological records offer a critical piece of information. Ultimately, diagnosing the underlying causes and mechanisms governing climatically induced shifts in fire regimes requires combining detailed paleoecological records with modern ecological studies and process-based modeling (20). The paleoecological record presented by Calder et al. (4) suggests that subalpine forests in the central Rocky Mountains have been resilient to increased fire activity when temperatures were 0.5 °C warmer than most of the 20th century. A key unknown for the future is how forests and fire will respond to even warmer conditions than experienced during the MCA.

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