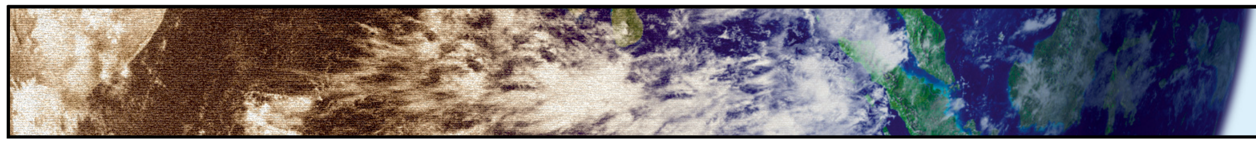

Fire - Are we facing an increase in wildfires?

PRESENT PAST

Anthony L. Westerling
Sierra Nevada Research Institute, University of California, Merced, USA; awesterling@ucmerced.edu

Large wildfires in a diverse array of forests are typically associated with drought during the fire season (Krawchuk and Moritz 2011). Drought occurrence is driven by variability in both temperature and precipitation. Climate change is expected to increase temperature over land, with greater increases in continental interiors and high northern latitudes. However, precipitation is more varied and uncertain, with increases projected in the tropics and high latitudes, and decreases in mid-latitudes (Dai 2010). Warming combined with changes in precipitation is projected to produce permanent severe drought conditions by mid-to-late century for much of the Americas, Africa, Southern Europe, Central and Southeast Asia, and Australia, although uncertainty is high (Dai 2010). Changes of this magnitude could substantially alter ecosystems, with wildfire constituting a mechanism effecting abrupt changes in response to more gradual climate forcings. The lack of analogues for transitions of this speed and magnitude limit the capacity to robustly model climate-fire-vegetation interactions in coming decades.

Ecosystems highly sensitive to recent climate trends include cool, moist forests with infrequent, stand-replacing fire where warming has led to longer fire seasons and/or increased evapotranspiration. Examples include substantially increased fire in mid-elevation Rocky Mountain forests of the USA (Westerling et al. 2006) and Canadian and Alaskan boreal forests (Soja et al. 2007) (Fig. 1). High-severity burned area in Siberian boreal forests may also have increased, but historical baseline data are less reliable (Soja et al. 2007). Fire is likely to further increase in these forests with continued warming (e.g. Krawchuk et al. 2009; Wotton et al. 2010; Westerling et al. 2011). However, as climate shifts and fire becomes more frequent, changes in regeneration and productivity for forest species could transform vegetation assemblages and the fire regimes they can support (Soja et al. 2007; Krawchuk et al. 2009; Westerling et al. 2011). An additional uncertainty for these ecosystems is how fire may interact with other disturbance types such as bark beetle outbreaks that alter the structure of forest fuels.

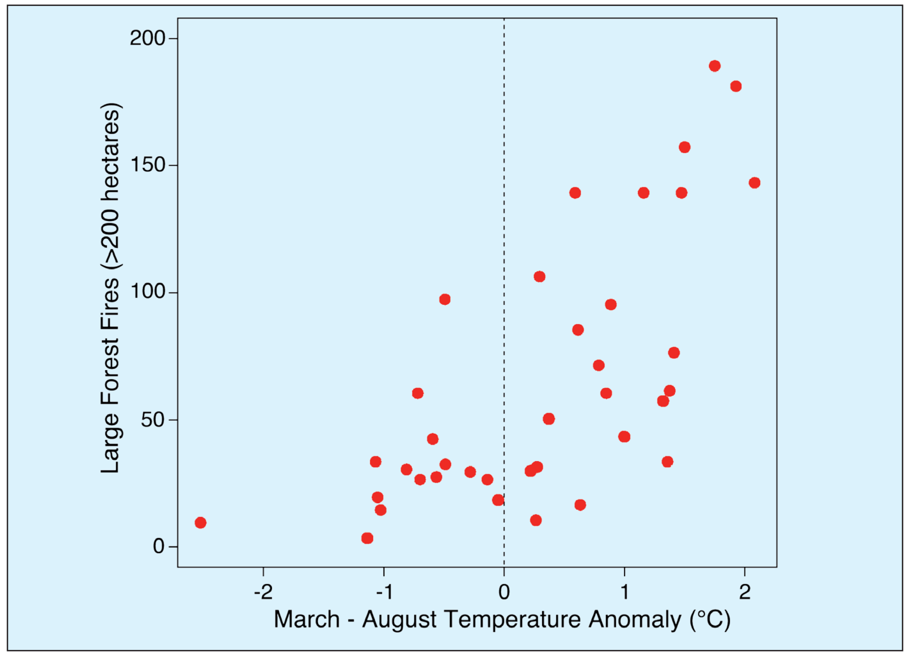

Figure 1: The number of large forest wildfires (vertical axis) versus average March through August temperature anomalies (horizontal axis) for 1972-2008 in Western US forests. Anomalies were constructed subtracting the long-term mean for 1972-1990. Fires are all large (> 200 ha) fires reported by the United States' Bureau of Indian Affairs, National Park Service, and Forest Service as burning in forests. All fires were classified as "action" fires on which suppression was attempted (fires used to manage vegetation were excluded). See Westerling et al. 2006 and Westerling et al 2011 for data and methodology.

Dry, warm forests may still be sensitive to warming that exacerbates periodic drought. Large areas burned in conjunction with recent drought and warming in mountain forests of the southwestern United States (Williams et al. 2010). The largest fires there coincided with reduced precipitation, higher temperatures and earlier spring snowmelt (Westerling et al. 2006). Land use and fire suppression in southwestern forests also led to fuel accumulation and changes in fuel structure. The interaction of fuel changes with climate change and variability likely contributed to increased fire and fire severity, but the relative importance of these causes is not known (Williams et al. 2010). Recurrent severe drought could convert large portions (>50%) of Southwestern U.S. forests to non-forest vegetation due to fire, beetles and other climate-related dieoff (Williams et al. 2010), substantially altering fire regimes.

As in higher latitude forests, drought-driven increases in fuel flammability drive increased fire in tropical forests. However, short-term reductions in precipitation, rather than elevated temperatures, are the dominant influence on wildfire in tropical forests due to their higher temperatures (Goldammer and Price 1998). While on average increased aridity is projected for Amazon, Mexico and Congo forests across many climate models, the greater uncertainty associated with projected patterns of precipitation make future fire predictions in these tropical forests more uncertain as well.

Diverse forests in many regions of the globe have the potential for increased fire in the coming decades due to changes in temperature, precipitation or both. Changes in climate and disturbance may substantially alter vegetation in ways that feed back to or limit changes in forest wildfire.

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Full reference list online under:
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Sandy P. Harrison[1] and Patrick J. Bartlein[2]
[1]School of Biological Sciences, Macquarie University, North Ryde, Australia; sandy.harrison@mq.edu.au
[2]Department of Geography, University of Oregon, Eugene, USA

Wildfire, the most widespread form of vegetation disturbance, has multiple influences on climate, and places an increasingly large socio-economic burden on society. Remote-sensing and historical records provide insights into how climatic, environmental and human factors influence the incidence of wildfire. These sources only cover the last few decades – a period when climate variations were much smaller than the changes expected during the 21st century and, globally, there were no radical changes in human activities. Luckily, there are other sources of information about changes in regional wildfire regimes in response to both large climatic changes and fundamental shifts in human activities. These sources include measurements of the isotopic composition of atmospheric gases trapped in ice cores, fire scars on living and fossil trees, and biomarkers and charcoal preserved in sediments. Of these, the most abundant are sedimentary charcoal: there are well over 800 site records worldwide, some providing high-resolution data for the last few millennia and some records spanning several glacial-interglacial cycles (Fig. 1).

Globally, fire is low during cold, glacial intervals and high during warm, interglacial intervals (Daniau et al. 2010a). The incidence of fire tracks the shift in global temperature during the last deglaciation (Power et al. 2008). It also tracks the rapid temperature changes (Dansgaard-Oeschger cycles) during the last glaciation with a lag of <50-100 years (Daniau et al. 2010a; Mooney et al. 2011). On centennial to multi-millennial time-scales and regional to global space-scales, temperature is the major driver of changes in biomass burning: increasing temperature leads to increased fire through increasing plant productivity and hence fuel production (Daniau et al., unpublished data). The effect of precipitation change is more complex. Fire peaks at intermediate precipitation levels at all temperatures: fire is low in dry environments because of lack of fuel and in wet environments because the fuel is too damp to burn. The impact of a precipitation change will depend on whether a site lies in a dry "fuel-limited" or a wet "drought-limited" environment. These climate-fire relationships are not unique to the paleorecord: similar relationships are found in global analyses of remotely sensed burnt area (Daniau et al., unpublished data).

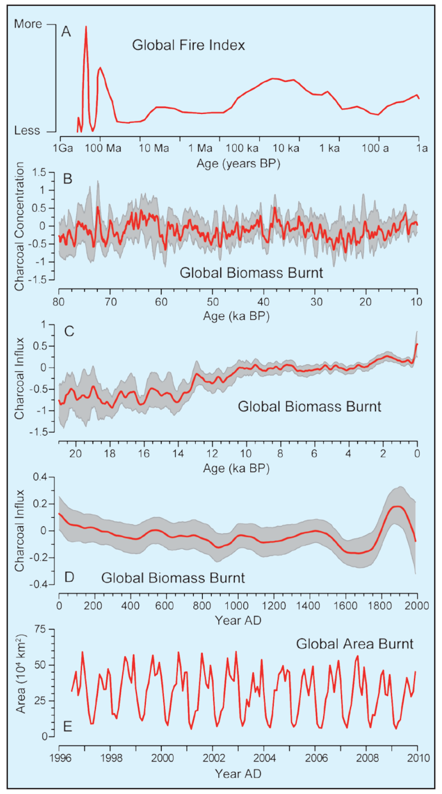

*Figure 1: The incidence of wildfire varies on multiple timescales. The record for the past billion years (1 Ga) (**A**) is a qualitative index of global fire based on discontinuous sedimentary charcoal records (Bowman et al. 2009). The record for the past 80 ka (**B**) is a global composite of 30 sedimentary charcoal records (Daniau et al. 2010a), that for the past 21 ka (**C**) is a global composite of ca. 700 sedimentary charcoal records (Daniau et al., unpublished data) and that for the past 2 ka is a global composite of ca. 400 sedimentary charcoal records (**D**; Marlon et al. 2008). The biomass burnt record in B, C and D is expressed as z-score anomalies from a long-term mean. Global area burnt from 1997 to 2009 (**E**) is derived from satellite-based remote sensing (GFED v3.1; Giglio et al. 2010).*

The paleorecord shows surprisingly little evidence of human impact on regional fire regimes. Colonization of uninhabited islands, such as New Zealand, may be marked by an increase in fire, as may cultural transitions, such as the European colonization of Australia (Mooney et al. 2011). However, there are examples of both colonization and cultural transition that are not accompanied by changes in fire. The transition from Neanderthal to Modern Humans in Europe was not accompanied by a change in fire regime (Daniau et al. 2010b); similarly, changes in fire regimes in the Americas are not synchronous with the dramatic collapse of indigenous populations after European colonization (Power et al., unpublished data). The largest human impact occurred around the end of the 19th century – the expansion of industrial-scale agriculture in many parts of the world, which resulted in substantial landscape fragmentation, coincides with decreases in fire in the affected regions and a large global decrease in biomass burning (Marlon et al. 2008; Wang et al. 2010).

Direct extrapolation of paleo-evidence to predict the future would be unreliable: the past is not an analogue for future climate and environmental changes because the combination of causal factors is different and regional land-use patterns have changed radically. But paleorecords show there are predictable relationships between climate and natural fire regimes. These relationships mean we can draw lessons from the paleorecord that have implications for fire in the 21st century. The paleorecord indicates that *global* warming will result in a *global* increase in fire; this will be mitigated in some regions by precipitation changes which either reduce fuel loads (warmer and drier climates) or increase fuel moisture (monsoonal climates). Human activities resulting in continued landscape fragmentation (e.g. urbanization, tropical deforestation) could reduce the influence of climate – but mitigation measures involving afforestation may lead to an increase in wildfires.

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