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Climate and Wildfire in Western US Forests

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Climate change is generating higher temperatures and more frequent and intense drought (Cayan et al. 2010; Peterson et al. 2013). Globally, 1980s, 1990s, and 2000s have each in turn been the warmest in history (Arndt et al. 2011). In the U.S., 2012 was the warmest year on record (Blunden and Arndt 2013), and drought has become more widespread across the Western U.S. since the 1970s (Peterson et al. 2013). Climate projections suggest increased likelihood of heat waves in the western U.S. and droughts in the Southwest (Wuebbles et al. 2013) and the fire season and area burned are expected to increase substantially by mid-century across the Western U.S. due to expected climate change (Yue et al. 2013).

Climate—primarily temperature and precipitation—influences the occurrence of large wildfires through its effects on the availability and flammability of fuels. Climatic averages and variability over long (seasonal to decadal) time scales influence the type, amount, and structure of the live and dead vegetation that comprises the fuel available to burn in a given location (Stephenson 1998). Climatic averages and variability over short (seasonal to interannual) time scales determine the flammability of these fuels (Westerling et al. 2003).

The relative importance of climatic influences on fuel availability versus flammability can vary greatly by ecosystem and wildfire regime type (Westerling et al. 2003; Littell et al. 2009;

Krawchuck and Moritz 2011). Fuel availability effects are most important in arid, sparsely vegetated ecosystems, while flammability effects are most important in moist, densely vegetated ecosystems. Climate scenarios' changes in precipitation can have very different implications than changes in temperature in terms of the characteristics and spatial location of wildfire regime responses (namely, changes in fire frequency, average area burned, and fire severity).

While climate change models generally agree that temperatures will increase over time, changes in precipitation tend to be more uncertain, especially in arid midlatitude regions (Dai 2011; Moritz et al. 2012; Gershunov et al. 2013). In ecosystems where wildfire risks have been strongly affected by variations in precipitation, there is less certainty about how these wildfire regimes may change. Yet in ecosystems where wildfire risks have been sensitive to observed changes in temperature, climate change is likely to lead to substantial increases in wildfires. As climate change alters the potential spatial distribution of vegetation types, ecosystems and their associated wildfire regimes will be transformed synergistically.

The type of vegetation (i.e. fuels) that can grow in a given place is governed by moisture availability, which is a function of precipitation (via its effect on the supply of water) and temperature (via its effect on evaporative demand for water) (Stephenson 1998). As a result, the spatial distribution of vegetation types and their associated fire regimes is strongly correlated with long-term average precipitation and temperature (e.g., Westerling 2009). Climatic controls (temperature and precipitation) on vegetation type along with successional stage largely determine the biomass loading in a given location, as well as the sensitivity of vegetation in that location to interannual variability in the available moisture. These factors in turn shape the response of the wildfire regime in each location to interannual variability in the moisture available for the growth and wetting of fuels. Cooler, wetter areas (forests, woodlands) have greater biomass, and wildfires there tend to occur in dry years. Warmer, drier areas (grasslands, shrublands, pine savannas) tend to have less biomass and wildfires there tend to occur after one or more wet seasons or years (Swetnam and Betancourt 1998; Westerling et al. 2003; Crimmins and Comrie 2004).

is thus much more sensitive to variability in temperature in some locations than in others. In the western U.S., cool, wet, forested locations tend to be at higher elevations and latitudes where snow can play an important role in determining summer moisture availability (Sheffield et al. 2004). Above-average spring and summer temperatures in these forests can have a dramatic impact on wildfire, with a highly nonlinear increase in the number of large wildfires above a certain temperature threshold (Figure 1). Westerling et al. (2006) concluded that this increase is due to earlier spring snowmelt and a longer summer dry season in warm years. They found that years with early arrival of spring account for most of the forest wildfires in the western United States (56 percent of forest wildfires and 72 percent of area burned, as opposed to 11 percent of wildfires and 4 percent of area burned occurring in years with a late spring).

Fire severity tends to be highest, with large infrequent stand-replacing fires that burn in the forest canopy, in cooler, more moist forests at generally higher elevations and/or latitudes, such as the lodgepole pine forests in the northern and central Rocky mountains (Baker 2009). Prior to the era of extensive/intensive livestock grazing (post 1850s) and active fire suppression by government agencies (post 1900s), warmer, drier forests tended to have mixed or low severity, more frequent fire with more of the fire concentrated in surface fuels (grass, shrub, forest litter) and less tree mortality (Allen et al. 2002). Increased fuel loads due to historic fire suppression and ongoing land use changes, combined with more extreme climatic conditions, have resulted in high severity fire in some forests where it was rare prior to the 20th century (Miller et al. 2009).

The frequency of large (>1000 acre) forest fires and the area burned in those fires has continued to increase steadily over the last three decades as temperatures have risen throughout the region (Figure 2). Forests of the northern and central Rocky mountains where fire typically burned with high severity but was infrequent, have been the most sensitive to changes in temperature, accounting for the largest share of the increase in burnt forest area (Figure 2, Westerling et al. 2006). As discussed below, projections of additional increases in future temperatures imply further increases in fire activity. However, warming and fire frequency may increase past critical thresholds, with some forests no longer able to sustain large high-severity fires. That is, fuel availability may become a limiting condition on fire in areas where climatic controls on fuel flammability were recently the dominant constraint on fire.

Climate is generally semiarid with summer-dry conditions to the northwest, and summer-wet to the southeast (Bailey 1996), and generally moister and cooler conditions relative to regions at lower latitudes. Elevation ranges from 3000 to 7000 ft in the southern and central portions, and 3000 to over 9000 ft in the northern portion. Mixed evergreen-deciduous forests dominate montane and subalpine elevations in the north, with strong topographic controls on moisture fostering diverse forest vegetation zones to the south (Bailey 1996; Cleveland 2012). Forests with characteristically infrequent high-severity, stand-replacing fires account for the largest area (mixed spruce-fir, lodgepole pine), with significant forest area characterized by mixed- (e.g., Douglas-fir) and low- (e.g., ponderosa pine) severity fire regimes prior to the historical fire suppression era (Schoennagel et al. 2004).

Some northern Rockies ponderosa pine forests, usually associated with low-severity surface fire regimes, may have experienced occasional high-severity, stand-replacing fires during extended droughts of past millennia, as inferred from sedimentary charcoal studies (Pierce et al. 2004). However, the patch sizes of these ancient high severity fires within ponderosa pine-dominant or mixed forests are unknown for almost all forests of these types, and it is possible that current large, high-severity patch sizes and subsequent geomorphic responses may be unique over the late Holocene, as similar sedimentary charcoal studies in Colorado pine and mixed conifer forested watersheds suggest (Bigio et al. 2010). In the only detailed, highly systematic study of tree age structures and fire scar evidence at stand to landscape scales in northern stands of ponderosa pine (i.e., in the Black Hills of South Dakota), Brown et al. (2008) found that about 3 percent of the landscape experienced high-severity fires during the three and one-half centuries prior to 1893, and overall, frequent, low severity surface regimes appear to have dominated those landscapes.

In northern forests where infrequent, large high-severity fires occurred, these events likely were driven by extended drought associated with high-pressure atmospheric blocking patterns

(Romme and Despain 1989; Renkin and Despain 1992; Bessie and Johnson 1995; Nash and Johnson 1996; Baker 2009). Paleo studies support a strong influence of climate on fire-return interval (e.g., Whitlock et al. 2003, 2008; Milspaugh et al. 2004), with fuel controls playing a much lesser role (Higuera et al. 2010).

Burned area is historically concentrated in a relatively small number of very large fire events (Balling et al. 1992; Schoennagel et al. 2004; Baker 2009). From 1972-1999, 66 percent of burned area in the northern Rockies occurred in only two years (1988 and 1994), and 96 percent of burned area in the Greater Yellowstone area occurred in one fire year (1988) (Westerling et al. 2011a). This pattern is consistent with climatic controls on the flammability of plentiful fuels being the dominant constraint on the occurrence and spread of large wildfires (Littell et al. 2009); namely, large areas burn in rare dry years.

The effect of changes in the timing of spring on wildfire has been particularly pronounced in the higher-latitude (> 42° North), mid-elevation (1680-2590 m) forests of the Rocky Mountains, which account for 60 percent of the increase in forest wildfires in the western United States (Westerling et al. 2006). Higher elevation forests in the same region had been buffered against these effects by available moisture, while lower elevations have a longer summer dry season on average and were consequently less sensitive to changes in the timing of spring.

The frequency and extent wildfire is projected to continue to increase in coming decades until fuel availability and continuity becomes limited and supplants climatic controls on flammability as the dominant constraint on the spread of large wildfires by mid-century in the Greater Yellowstone region (Westerling et al. 2011a) and in the Rockies more generally. Increased burned area of similar magnitude has been projected by the National Research Council (2011), applying models from Littell et al. (2009) (see also Climate Central 2012).

Colorado and Utah also experience high geographic and interannual variability in temperature and precipitation due to elevation, topography, and latitude. In general, the region is characterized by summer-dry areas NW of the Rocky Mountains under the influence of the subtropical high, and summer-wet areas SE of Rocky Mountains and in S portions of CO and UT, due to monsoons from the Gulf of Mexico and Gulf of California (McWethy et al. 2010).

A number of low-elevation forests (e.g., below 2100 m in the central Colorado Front Range; Sherriff and Veblen 2008) with grass or other fine-fuels in the understory record regional fires during dry summers when preceded by increased spring-summer moisture availability up to 4 years prior, that enhance fine-fuel accumulation and contribute to fire spread when subsequently cured (Donnegan et al. 2001; Grissino-Mayer et al. 2004; Brown et al. 2008; Sherriff and Veblen 2008; Gartner et al. 2012). Moister, higher-elevation forests lacking grass understories do not record this wet-dry signature in the fire record (Sibold and Veblen 2006; Brown et al. 2008; Schoennagel et al. 2011). Documentary records of area burned in ecoregions encompassing CO and UT showed that moist antecedent conditions are associated with greater area burned (and were more important than warmer temperatures or drought conditions in the year of fire) in grasslands, shrublands and arid low-elevation woodlands with grass or shrub understories, but only fire-year conditions were significant in moister high-elevation and/or westslope forests (Knapp 1995; Westerling et al. 2003; Collins et al. 2006; Littell et al. 2009).

Littell et al. (2009) found that area burned in the southern Rockies (1977-2003) was positively related to winter temperature, and negatively related to spring temperature, along with spring and summer precipitation and lagged drought;($r^2 = 0.77$; Littell et al. 2009). Predictions for UT/NV Mountains were linked to lagged spring temperature, but were much less robust ($r^2 = 0.33$). The Southern Rockies only accounted for <1 percent of recent increase in wildfire activity since 1985, in contrast to the Northern Rockies, which accounted for 60 percent, primarily related longer fire seasons and snowpack reduction (Westerling et al. 2006).

Average annual summer and winter temperatures are expected to increase dramatically in CO and UT by 2050, yet models show low agreement for precipitation (Fig. 5.1 in Ray et al. 2010). However, Seager et al. (2007) predict that the Southwest (125°W-95°W, 25°N-40°N, which includes most of CO and UT) will become more arid during the next century as annual mean precipitation minus evaporation becomes more negative. Similarly, Gutzler and Robbins (2011) predict that higher evaporation rates due to positive temperature trends will exacerbate the severity and extent of drought in the semi-arid West.

Brown et al. (2004) predict that reduced relative humidity will increase the number of days of high fire danger at least through the year 2089 compared to the base period, however, the Colorado Rockies and Front Range showed no change in predicted fire risk thresholds, suggesting little change in wildfire activity. This contrasts with a Spacklen et al. (2009) study that predicts higher temperature will increase annual mean area burned by 54 percent by 2050s relative to the 1980-2004 period, with the entire Rocky Mountains showing large increases (78 percent) and high interannual variability.

The National Research Council (2011) predicts that burn area in parts of western North America may increase by 200 to 400 percent for each degree (°C) of global warming relative to 1950-2003, adapting methods developed by Littell et al. (2009) to use temperature and precipitation as the predictor variables. Across CO and UT, the southern Rocky Mountain Steppe Forest is predicted to experience the greatest increase in mean annual area burned (>600 percent), with the least in the Nevada-Utah Mountains (only 73 percent).

The Southwestern United States (Arizona and New Mexico) is generally a semi-arid region. Considerable topographic relief, however, results in a very diverse biotic landscape and consequent differences in vegetation and wildfire. These differences are often expressed along relatively short distances (10s of kilometers) and elevational gradients from desert basins to forested mountains. Natural fire regimes along these gradients vary from essentially no spreading wildfires in the pre-21st century historical record (e.g., lower Sonoran desert), to frequent, low-severity surface fires (e.g., mid-elevation ponderosa pine forests, with intervals between widespread fires ranging from 2 to 20 years), to low-frequency, high-severity, stand-replacing fires (high-elevation spruce-fir forests, with intervals between large crown fires ranging from 150 to 300+ years) (Swetnam and Baisan 1996, 2003; Margolis et al. 2007, 2009).

Seasonal climate of the Southwest is characterized by bimodal precipitation, with winter-cool season and summer-warm season maxima, with a pronounced dry season during most years in late spring to early summer. The peak of fire activity tends to occur in this warm/dry season (May through June—still true?), with a maximum area burned in the driest weeks of June, and the maximum number of fire ignitions in July when monsoonal moisture and convective activity generates large numbers of lightning strikes (Crimmins 2006; Keeley et al. 2009). Human-set fires are also important in Southwestern landscapes, both in the distant past (i.e., by Native Americans), and in the modern era. During some seasons and years human-set fires exceed areas burned by lightning set fires, especially during some recent years when extraordinarily large fires were set accidentally or purposely during spring-summer droughts. Paleo and modern records of fire and climate show the strong importance of both prior cool-season and current spring-through-summer moisture indices to fire activity in this region (especially regionally synchronized fire events in the paleorecord and total area burned per fire season/year in the modern record (Swetnam and Betancourt 1998; Westerling et al. 2002; McKenzie et al. 2004; Crimmins and Comrie 2004; Crimmins 2006; Holden et al. 2007; Littell et al. 2009; Williams et al. 2013).

Because comprehensive documentaries of wildfire only go back a few decades, paleo proxy records of past fire and climate activity have been developed to provide annual to millenial scale perspectives on fire, vegetation and inferred climate variability (Swetnam and Baisan 1996; Swetnam and Brown 2010; Falk et al. 2011; International Multiproxy Paleofire Database; Anderson et al. 2008; Frechette et al. 2009; Bigio et al. 2010).

These paleorecords demonstrate the follow specific findings:

1) Widespread surface fires were ubiquitous in ponderosa pine forests and mixed-conifer forests across the region before the advent of extensive livestock grazing in the late nineteenth century and active fire suppression by government agencies beginning about 1910. High-severity, stand-replacing crown fire occurred in some dense pinyon-juniper woodlands (Romme et al. 2009), shrublands, and higher elevation spruce-fir forests (Margolis et al. 2007; Margolis and Balmat 2009) in the pre-1900 period, but large, high-severity fires were rare in ponderosa pine forests. Although some evidence of high-severity fire in ponderosa pine and mixed-conifer forests has been found in charcoal sediments (e.g., Frechette et al. 2009; Bigio et al. 2010), and small patch size (<200 ha) high-severity fires have been reconstructed in a few tree-ring studies (Swetnam et al. 2001; Iniquez et al. 2009), we lack any clear evidence at this time that large patch size (>200 ha) high-severity fires occurred in ponderosa pine-dominant forests in the past were as extensive as those occurring today (Cooper 1960; Allen et al. 2002).

2)

3) Extreme droughts and regional fire activity are highly correlated over the past four centuries in the available tree-ring record. Lagging patterns are evident in lower elevation forests and woodlands, with wet conditions in prior 1 to 3 years, coupled with dry conditions during current year often leading to extensive regional fire years in the past (Swetnam and Betancourt 1998).

4)

5) Decadal-scale variation in past fire activity is evident in parts of the Southwest, with occasional periods of 1 to 2 decades of either decreased or increased local to regional fire activity (Swetnam and Betancourt 1998; Grissino-Mayer and Swetnam 2000; Brown and Wu 2005; Margolis and Balmat 2010; Roos and Swetnam 2011). Many studies have shown some association between these annual-to-decadal-scale patterns and climatic variations (e.g., Swetnam and Betancourt 1990, 1998; Kitzberger et al. 2007; Brown and Wu 2005).

6)

7) There are relatively few long-term, sedimentary charcoal-based records of fire activity in the Southwest compared to other more mesic regions with more lakes and bogs. The available records do show, however, decadal-to-centennial-scale variations in fire and vegetation that are likely associated with climatic variations on those time scales (e.g., Anderson et al. 2008). One striking finding in a comparison of tree-ring and charcoal-based fire histories is the unprecedented lack of fire in the most recent century (due to livestock grazing and fire suppression) in a record of more than 7,000 years (Allen et al. 2008).

The longest modern records for the Southwest show a similar pattern to that observed in some other forests across the western US during the 20th-21st centuries, namely, some large fires occurred during early decades of the 20th century, there were lower levels of fire activity during the mid-20th century (but with several large events, > 5000 ha during the 1950s drought), and after the late 1970s a rather sharp rise in numbers of large fires and area burned occurred (e.g., Rollins et al. 2001; Holden et al. 2007)

The post-2000 period includes several fires in forested landscapes that exceed in area any other wildfire in this two state region over at least the past 100 years (e.g., most notably, the 189,651 ha [468,640 acre] Rodeo-Chediski Fire in central Arizona in 2002, and the 217,741 ha [538,049 acre] Wallow Fire in east-central Arizona and west-central New Mexico in 2011 and the 63,000 ha [156,593 acre] Las Conchas Fire in New Mexico in 2011). Since the late 1990s, large areas of forest and woodland have experienced extensive tree mortality due to a combination of direct drought-induced physiological stress and mortality, and attacks by phloem-feeding bark beetles (Allen and Breshears 1998; Breshears et al. 2005). Williams et al. 2010 summarize the mortality extent across the Southwest by these agents (drought, fire, bark beetles) and they estimate that nearly 20 percent of forested areas experienced high levels of tree mortality between 1984 and 2010.

About 13 percent of California's forest area is composed of forest types with naturally high-severity (30 percent-80 percent crown-burned) fire regimes with mean fire return intervals (MFRI) of 15-100 yr (predominately cedar/hemlock/Douglas-fir, red fir), while nearly 70 percent is comprised of forest types that experienced frequent, low-severity prehistoric fire regimes (MFRI ≤ 10 yr, crown burned ≤ 5 percent; predominately mixed conifer, mixed California evergreen, redwood and ponderosa pine) (Stephens et al. 2007). A policy of fire suppression and land use changes reduced the annual burned area in California forests from pre-settlement levels by more than 90 percent in the 20th century (Stephens et al. 2007). Miller et al. (2009) document trends toward increasing fire severity in the Sierra Nevada, and hypothesize that both fire suppression and increased precipitation over the 20th century increased fuel densities, contributing to increased fire severity. The frequency of large fires, total area burned, mean fire size and fire severity have all increased in northern California forests since the mid-1980s (Westerling et al. 2006; Miller et al. 2009) (Figure 1). Because a large portion of the interannual variability in northern California forest wildfire burned area is due to variability in ignitions from clustered lightning strikes, only a modest fraction of observed interannual variability in burned area can be explained by climate alone (Preisler et al. 2011; Westerling et al. 2011b).

Wildfire is predicted to increase substantially in northern California forests in the Sierra Nevada, Southern Cascades, and Coast Ranges under some climate change scenarios. Westerling and Bryant (2008) project 100 percent-400 percent increases in the probability of large fire occurrence over much of the Sierra Nevada, Coast Ranges and Southern Cascades under a relatively warm, dry climate scenario (GFDL SRES A2). A study by the National Research Council (2011), applying regression methods from Littell et al. (2009) for fire aggregated by ecosystem provinces similarly found increases exceeding 300 percent for a 1°C temperature increase. Westerling et al. (2011b) find increases in burned area ranging from 100 percent to over 300 percent for much of northern California's forests across a range of climate and growth and development scenarios using three climate models (NCAR PCM1, CNRM CM3, GFDL CM 3.1) for the SRES A2 emissions scenario. Spracklen et al. (2009) find increases in burned area on the order of 78 percent by midcentury for the GISS GCM under the SRES A1b emissions scenario, which is similar in magnitude to Westerling et al. (2011b) for midcentury for northern California forests under GFDL SRES A2 scenarios. Conversely, increases in California forest wildfire frequency and burned area are more modest under a lower (SRES B1) emissions scenario, with end of century burned area roughly the same as midcentury (Westerling and Bryant 2009; Westerling et al. 2011b; Yue et al.

The direct effects of anthropogenic climate change on wildfire are likely to vary considerably according to current vegetation types and whether fire activity is currently more limited by fuel availability or flammability. In the long run, climate change is likely to lead to changes in the spatial distribution of vegetation types, implying that transitions to different fire regimes will occur in locations with substantial changes in vegetation. Most long-term projections of changing wildfire activity have not successfully incorporated dynamic changes in vegetation types and fuels characteristics in response to climate and disturbance. We can use existing fire-climate-vegetation interactions to understand the likely direction and magnitude of climate-driven changes in fire activity over the next few decades. Beyond that, we may be able to use these models and our understanding of current ecosystems to assess when changes in climate and disturbance regimes will begin to lead to qualitative changes in ecosystems. Given the lack of analogues to projected climate changes--especially the substantial changes in the latter half of the 21st Century that are projected to result from continued high emissions of greenhouse gases--precise modeling of future changes in vegetation and disturbances like wildfire becomes significantly more challenging for later in this century and beyond.

The overall direction and spatial pattern of changes in precipitation under diverse climate change scenarios varies considerably across both future greenhouse gas emissions scenarios and global climate models (Dettinger 2006). In ecosystems where climatic influences on fire risks are dominated by precipitation effects, this implies greater uncertainty about climate change impacts on wildfire in those locations (Westerling and Bryant 2007). Overall, greater warming will lead to more evaporation of moisture from soils and the live and dead vegetation that fuels forest wildfires. Given the substantial interannual variability in precipitation characteristic of western U.S. climate, it is likely that fire activity will at least increase in drought years in coming decades, across a broad range of future climate scenarios.

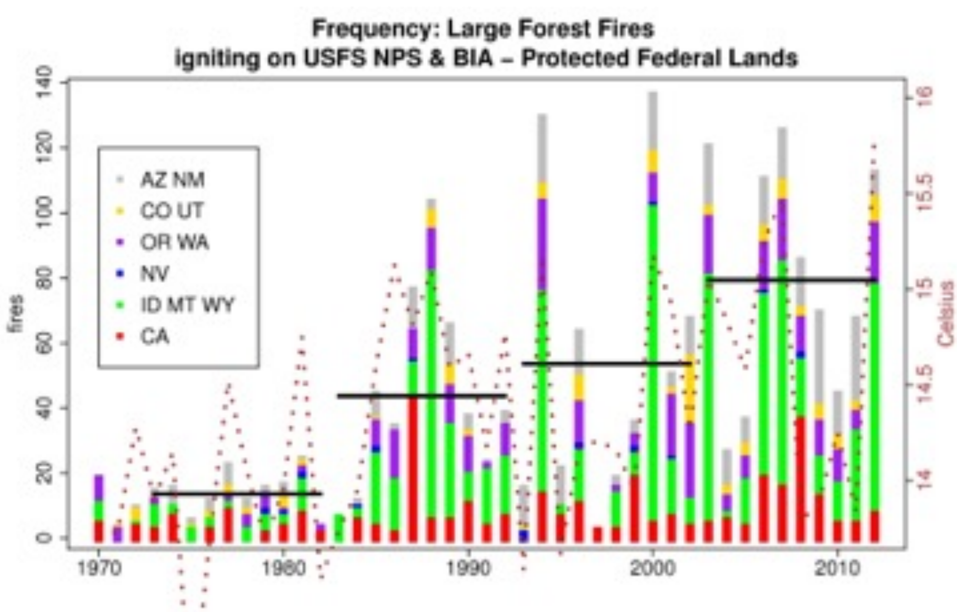
Climate scenarios (even those with rapid reductions in global greenhouse gas emissions) project increases in temperature substantially greater than those observed in recent decades (IPCC 2007), which have been associated with substantial increases in wildfire activity in western U.S. forests (Gillett et al. 2004; Westerling et al. 2006; Soja et al. 2007; Williams et al. 2013; Figures 1&2). Strategies for adapting to a warmer world will therefore need to consider the impacts of climate change on wildfire.

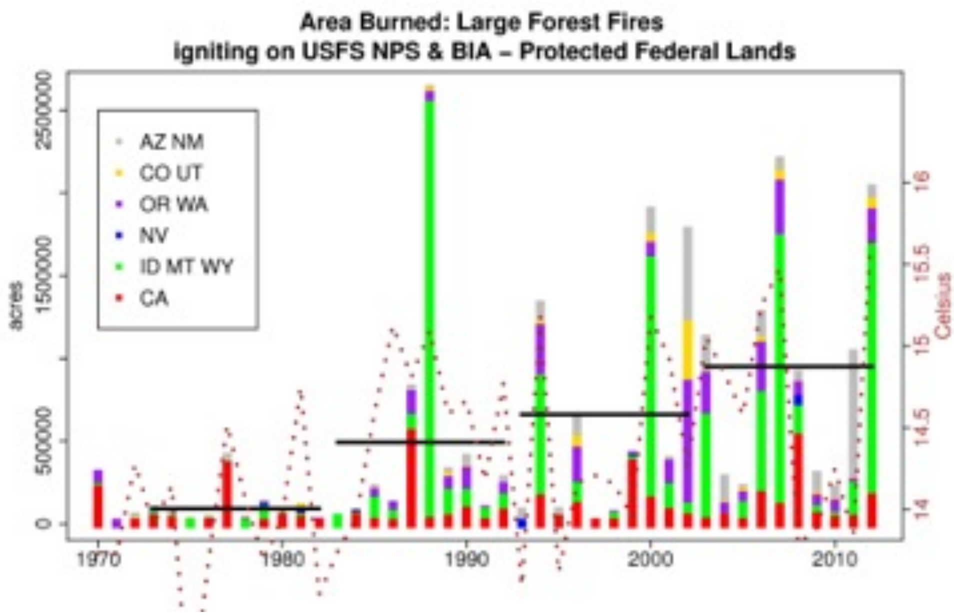
The effects of climatic change on wildfire will depend on how past and present climates have combined with human actions to shape extant ecosystems. Climate controls the spatial distribution of vegetation, and the interaction of that vegetation and climate variability largely determines the availability and flammability of the live and dead vegetation that fuels wildfires. In moist forest ecosystems where snow plays an important role in the hydrologic cycle and fuel flammability is the limiting factor in determining fire risks, anthropogenic increases in temperature may lead to substantial increases in fire activity.

In dry ecosystems where fire risks are limited by fuel availability, warmer temperatures may not increase fire activity significantly. Warmer temperatures and greater evaporation in some places could actually reduce fire risks over time if the result is reduced growth of grasses and other surface vegetation that provide the continuous fuel cover necessary for large fires to spread. The effect of climate change on precipitation is also a major source of uncertainty for fuel-limited wildfire regimes. However, in some places these are the same ecosystems where fire suppression and land uses that reduce fire activity in the short run have led to increased fuel loads today as formerly open woodlands have become dense forests. This increases the risk of large, difficult-to-control fires with ecologically severe impacts.

The combined long-term impact of diverse human activities has also been linked to a projected increase in the risks of large wildfires in many places and in ways that cannot be easily reversed. Even if prompt action is taken now to reduce future emissions of greenhouse gases, the legacy of increased atmospheric concentrations of these gases means that the risk of large fires will remain high and will continue to increase in many forests. Surrounding communities will need to adapt. The capacity for adaptation is strongly influenced by the size and diversity of the economy a community can draw upon.

Category	Emphasis	Reference
Adaptation framework	General options for wildlands	Millar et al. 2007
	Options for protected lands	Baron et al. 2008, 2009
	Adaptation guidebooks	Peterson et al. 2012, Snover et al. 2007, Swanston and Janowiak 2012
Vulnerability analysis	Climate change scenarios	Cayan et al. 2008
	Scenario exercises	Weeks et al. 2011
	Forest ecosystems	Aubry et al. 2011, Littell et al. 2010
	Watershed analysis	Furniss et al. 2010
Genetic management	Seed transfer guidelines	McKenney et al. 2009
	Risk assessment	Potter and Crane 2010
Assisted migration	Framework for translocation	McLachlan et al. 2007, Riccardi and Simberloff 2008
Decisionmaking	Silvicultural practices	Janowiak et al. 2011b
	Climate adaptation workbook	Janowiak et al. 2011a
Priority setting	Climate project screening tool	Morelli et al. 2011b





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Figures and Tables

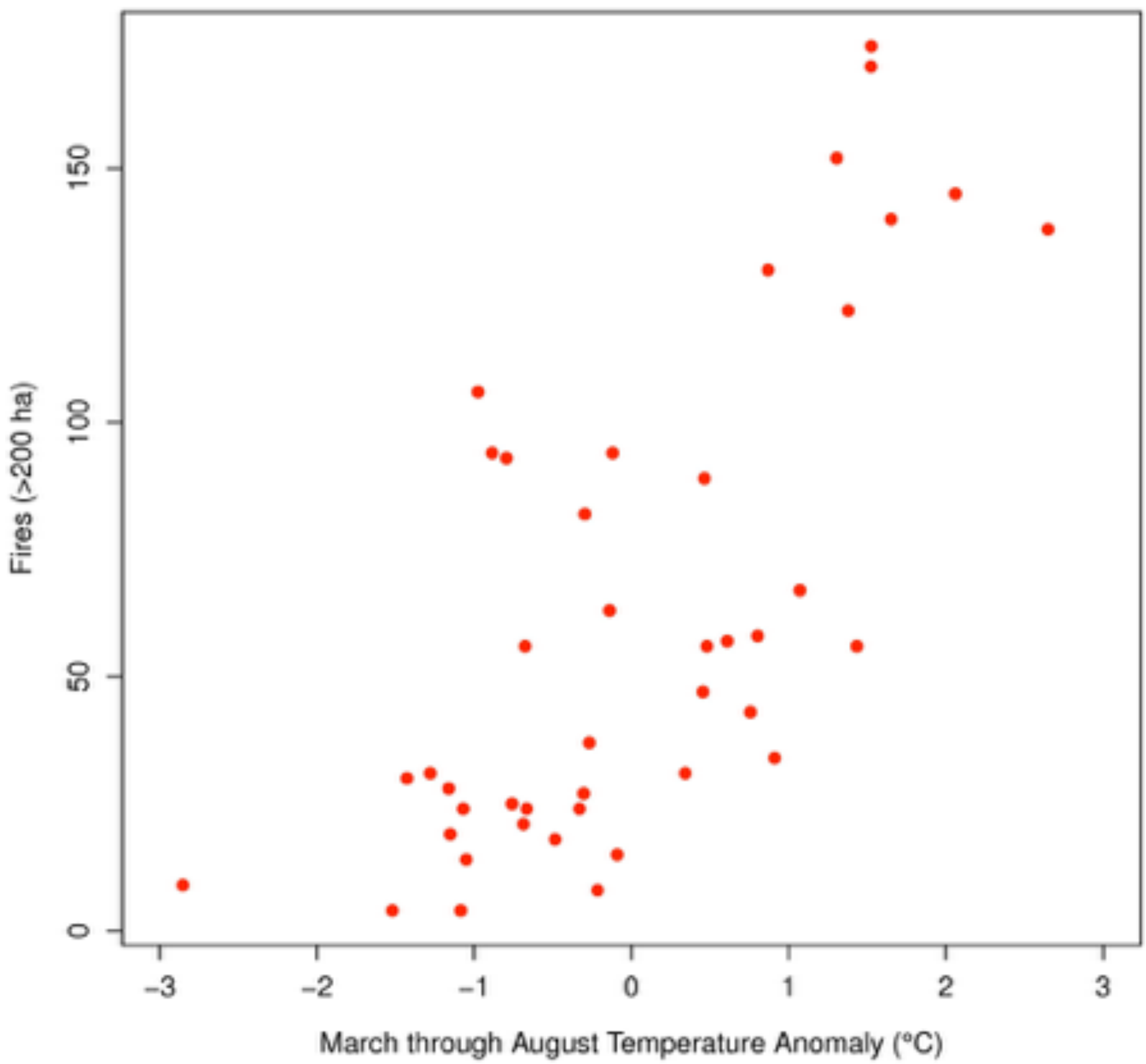

Figure 1. Scatter plot of annual number of large (> 200 ha) forest wildfires versus average spring and summer temperature for the western United States. Forest Service, Park Service, and Bureau of Indian Affairs management units reporting 1972 - 2004. Fires reported as igniting in forested areas only. Source: Westerling 2009.

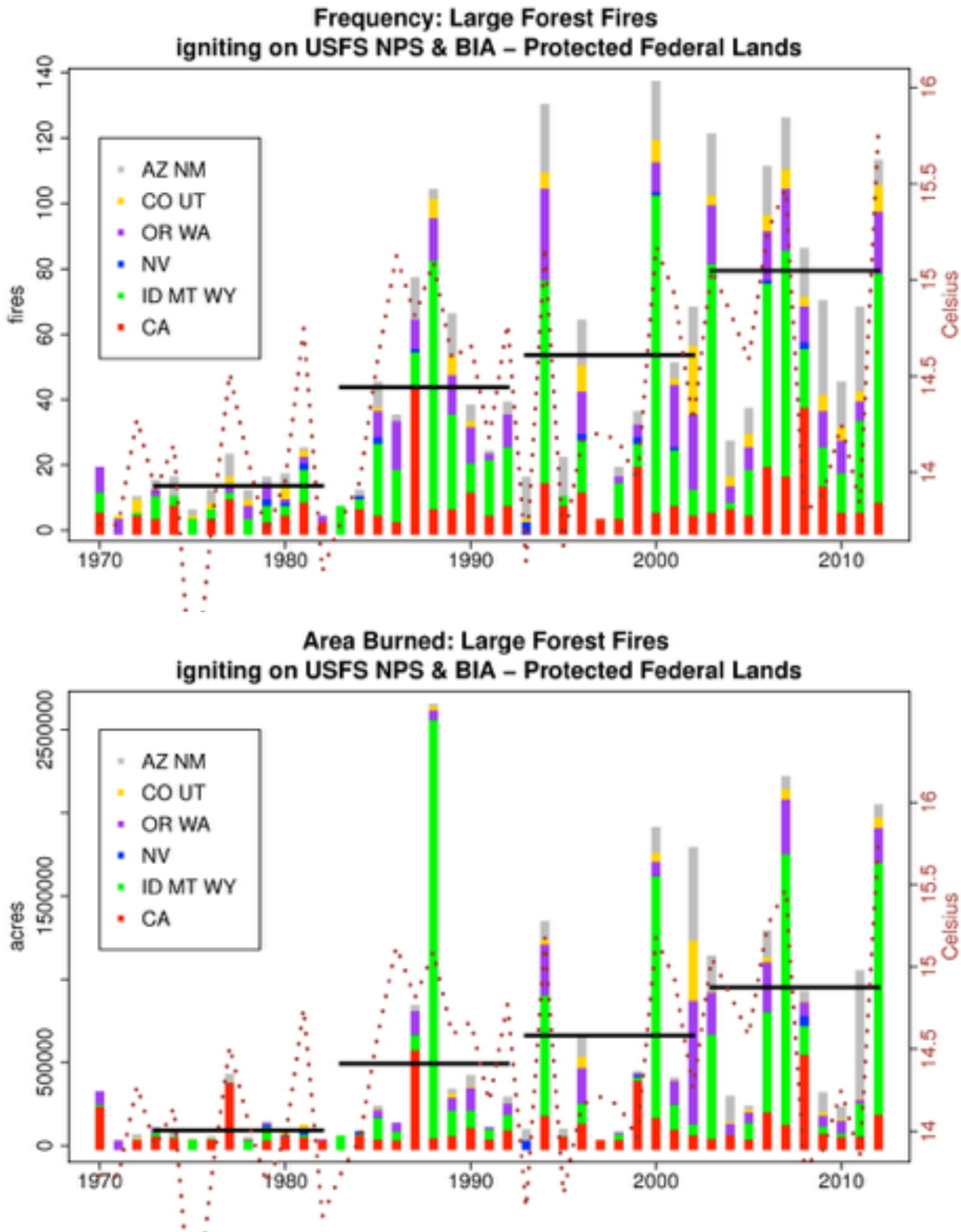

Figure 2. Frequency of (top panel) and area burned in (bottom panel) large (>1000 acre) forest fires. Fires are action fires for which suppression was attempted, reported by USFS, NPS and BIA as burning on federal lands in primarily forest vegetation. Fires are

grouped by states (colored bar sections) with average regional spring and summer temperature overlayed (dashed line). Horizontal solid lines indicate averages for the last four decades. Large fires in the last decade are over 480% more frequent and burn 930% more area than fires in the first decade. Average annual area burned on these lands has increased by over 285,000 acres per decade for the last three decades, to just under 1 million acres per year at present.