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Editorial

Introduction to the regional assessments: Climate change, wildfire, and forest ecosystem services in the USA

1. A perspective on fire, forests, and climate

Fires have influenced and shaped vegetation ever since the climate evolved to provide both ignition sources and oxygen (Bowman et al., 2009). Fire has been one of the most frequent and impactful disturbances to ecosystems globally, and thus one of the major regulators of forest composition, function and dynamics (Spurr and Barnes, 1973; Bond and Keeley, 2005). Any consideration of forests under a changing climate regime, therefore, must be viewed through a prism of fire interactions. Notwithstanding the importance of understanding how fire interacts with climate and imparts forest change, fire has been inadequately addressed in past assessments of climate impacts (National Assessment Synthesis Team, 2001).

The recent interest in fire and climate has been fueled by growing scientific consensus that, across much of the US, wildfires are likely to become larger, more intense, and increasingly difficult to contain with climate change (Brown et al., 2004; Westerling and Bryant, 2008; Krawchuk et al., 2009; Littell et al., 2009; Littell et al., 2010; National Research Council, 2011; Westerling et al., 2011a,b). The increase in intense fires is a phenomenon that is evident throughout the world (Lohman et al., 2007; Attiwill and Binkley, 2013); but, is particularly apparent in the western US, where an increase in large fires appeared markedly in the mid 1980s coincident with increased spring and summer temperatures and earlier snow melt (Westerling et al., 2006). The last two decades have continued to see record wildfire seasons and escalating fire suppression costs (data from National Interagency Fire Center). Society's ability to respond to climate change, mitigate negative consequences when possible, and adapt to those impacts that we are unable or unwilling to change will depend on a better understanding of the complex relationships between fire, vegetation and climate.

2. A call for assessment

The papers contained in this special issue were crafted to provide scientific input on the topic of climate, fire, and forests into the third National Climate Assessment (<www.globalchange.gov/ncadac>; Melillo et al., 2014). The National Climate Assessment (NCA) is in many ways the United States' analog to assessments generated by the IPCC. The NCA is mandated by the US Global Change Research Act of 1990, §106. It is a periodic assessment, prepared at least every four years, of the effects of global change on the natural environment, including land and water resources and biological diversity. The assessment is also mandated with analyzing current, and projecting major trends in global change for the next 25–100 years. In preparing for the National Climate Assessment, a request for information (RFI) was published in the Federal Register on July 13, 2011 to solicit input from those outside of the Federal government.

Prior to the third NCA, two assessments have been published: Climate Change Impacts on the United States (National Assessment Synthesis Team, 2001), and Climate Change Impacts in the United States (Karl et al., 2009). Each assessment described the current trends in fire disturbance and projected the effects of future fire disturbance. Both assessments highlighted the need to understand better the interactions of fire, climate and forest processes. Our goal was to not only answer this need with the best available science, but to also provide information on how management could affect this interaction, and vice versa.

We addressed our task by forming science teams in regions of the continental US for which forests were important (grassland and shrub/grasslands are not directly addressed), and for which fire was an important disturbance that would be altered by predicted climate changes. The following series of articles reviews the variation in fire and climate relationships among those regions and among forest types within regions. We chose a regional approach in order to recognize and characterize the variation in natural history, climate, and socio-economic influences that affects forests and fire regimes in the US. Too often, management options are applied uniformly without adequate consideration of the regional and local factors that may influence their effectiveness. As the following papers show, forests across the US differ in terms of the legacy of past fire suppression, the ecosystem service costs of increasingly large and severe wildfires, and the feasibility and benefits of active forest and fire management activities, such as thinning and prescribed fire.

Each of the following articles follows the same general structure, including: a description of the region and the forests that are considered, a discussion of projected changes in climate and how these are likely to impact fire and forests, and a synthesis of what is known about the consequences of various management approaches (e.g., suppression, fuel treatments including prescribed burning) on ecosystem services (e.g., C sequestration, fire impacts on water quantity and quality, air quality impacts, and biodiversity). The temporal scale for the assessments will approximate the next 50 years. We limited the temporal scale for two reasons. First, climate scenarios become more uncertain as models project farther in the future. Second, the next several decades are critical, and can be dynamic, from a management perspective. Many forest plans require an Adaptive Management approach, whereby the

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outcomes from management actions are monitored, and future management actions will be adjusted as our scientific understanding improves. The papers also address profitable areas of inquiry in which greater scientific understanding would likely lead to alternative management approaches or result in a greater precision in understanding the consequences of implementing management alternatives.

3. Climate projections for the US

The direction and magnitude of climate change will vary across the US among and within regions, precluding simple projections of alterations to fire regimes. We present climate forecasts from Liu et al. (2013), which are based on dynamically downscaled projections of the Hadley Center Climate Model (HadCM3) using the A2 emissions scenario, a relatively high emissions scenario (NARCCAP; Mearns, 2007, updated 2011; Mearns et al., 2009). In these figures, "future" climate (averages of 2041–2070 data) is presented relative to "present" climate (averages of 1971–2000 data). Under the A2 scenario, future maximum air temperature is projected to increase across the US in all seasons (Fig. 1). Temperature increases of 1.5–3 °C are projected for winter and spring seasons nationwide. Even greater warming (3–5 °C) is projected for the summer, with the largest increases (more than 4 °C) projected for the central third of the US. The same pattern remains in fall; but it is somewhat muted compared to summer months. Future precipitation projections are far more variable spatially (Fig. 2), and less certain (Meehl et al., 2007). The

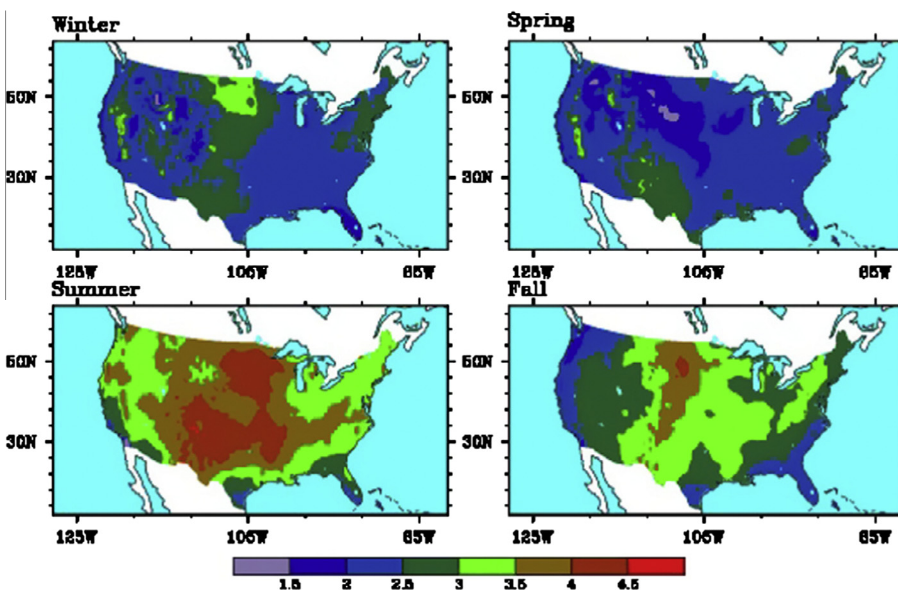

Fig. 1. Projected changes in seasonal maximum temperature (in °C) between 2041–2070 and 1971–2000. The data were obtained from the NARCCAP (Mearns et al., 2009). (Reprinted with permission from Liu et al., 2013.)

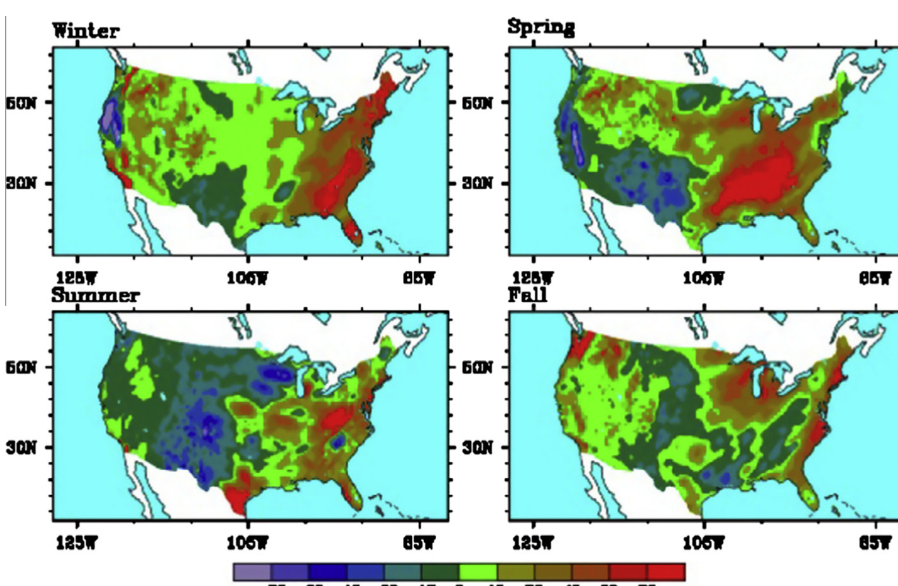

Fig. 2. Projected changes in precipitation (in mm) between 2041–2070 and 1971–2000. The data were obtained from the NARCCAP (Mearns et al., 2009). (Reprinted with permission from Liu et al., 2013.)

most significant increases occur in the eastern US, primarily in the winter and spring. Precipitation is projected to decrease in the Pacific Northwest in winter, and the southern Plains and Southwest in the spring and summer.

These same data have been used for projecting fire potential trends in North America (Liu et al., 2013; Fig. 3). Liu et al. (2013) used the Keetch–Byram Drought Index (KBDI; Keetch and Byram, 1968, revised 1988), an indicator of soil moisture deficit. Fig. 3 shows current average KBDI values and projected changes to KDBI in the future. Currently the drought index is high (above 400) to extreme (above 600) in the west, except for the Pacific Northwest, throughout much of the year. A high drought index also occurs in the Gulf region in summer and fall. In the future, drought will increase in the Southwest and Rocky Mountains in all seasons; and drought will increase in the East, Southeast, and Plains in summer and fall. The magnitude of the increase is sufficiently large to change fire potential level from low to moderate or from moderate to high. The exception occurs in the Pacific Northwest, where drought decreases in winter and spring, though projections show increases in drought during the summer fire season.

4. Future fire regimes and forest ecosystem services across regions of the US

Because temperature is forecast to increase almost everywhere, all the regions except the mid-Atlantic region project increases in wildfire activity, despite the variability in precipitation forecasts. The magnitude and impact of future wildfire activity will likely be most pronounced in the three westernmost regions, which have already seen increases in fire occurrence, area burned, and fire season length due to warmer temperatures (Hurteau et al., 2014; Rocca et al., 2014; Wimberly and Liu, 2014). In the mid-Atlantic, increases in precipitation and humidity, as well as forest fragmentation and fire suppression, are likely to offset increases in temperature, resulting in only small to moderate changes to wildfire activity (Clark et al., 2014). As discussed in the regional papers that

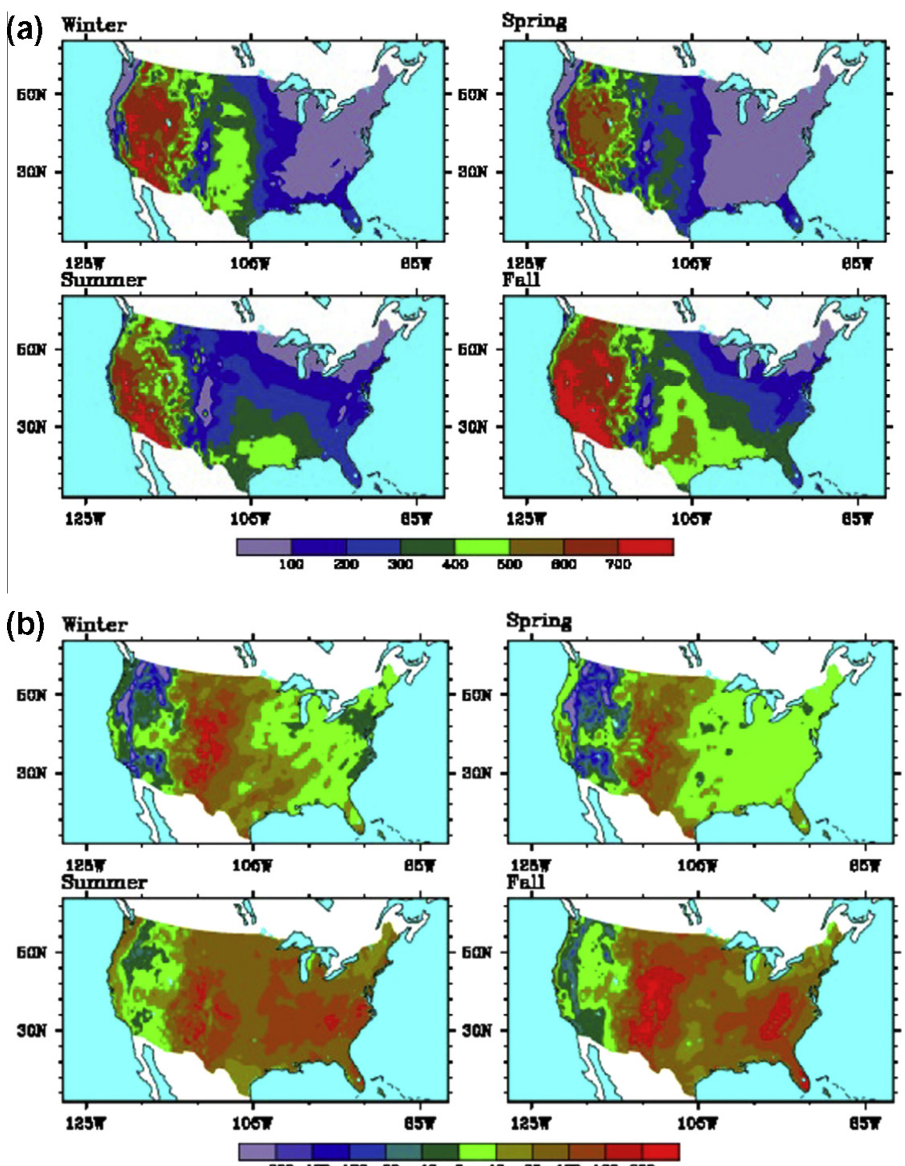

Fig. 3. Spatial patterns of (a) current average KBDI by season for the period of 1971–2000 in the continental US and (b) projected changes in seasonal KDBI between 2041–2070 and 1971–2000. KBDI values above 400 are considered high fire potential, and above 600 are considered extreme. (Reprinted with permission from Liu et al., 2013.)

follow, management options for addressing future changes in wildfire activity are limited, and alternative approaches will have costs and benefits that vary by region and by forest type within region.

Across the US, considerable uncertainty remains about how changing climate and increasing human encroachment into the wildland–urban interface may constrain the use of prescribed burning in the future; however, some trends emerge across the regions. In the Southeast, where the majority of burning occurs as prescribed fire, the most significant impact of a future climate is likely to be the reduction in appropriate burn windows for implementation of prescribed fire (Mitchell et al., 2014). Prescribed burning in the Southeast is, by far, applied to more forests than any region in the US. Any decrease in prescribed burning is likely to result in decreased biological diversity particularly in the Coastal Plain, a global hotspot of diversity that depends on frequent fire. In other regions, efforts to restore fire as a process are increasing, and often include some type of forest structural treatment prior to prescribed burning. Prescribed burning is a critical element of these treatments; thinning without accompanying surface fuel reduction is often ineffective and can increase fire severity in some situations (Rocca et al., 2014; Wimberly and Liu, 2014).

Interactions between climate change, forest management, and the ecosystem services provided by US forests, such as biodiversity and C sequestration, are explored in the regional papers that follow. In dry western forests dominated by ponderosa pine, for example, both prescribed fire and mechanical treatments have the potential to help restore and maintain historical forest structure, promote native diversity, lower the risk of severe air quality events, and resist long-term loss of C stocks (Hurteau et al., 2014; Rocca et al., 2014; Wimberly and Liu, 2014). In contrast, in wetter forests of the West, which have been less impacted by fire suppression, mechanical treatments likely have fewer benefits. In such forests, allowing wildfires to burn where possible would benefit forest species, though they carry a cost of potential increases in erosion and episodes of poor air quality. More research is needed to evaluate tradeoffs between management alternatives in the West, especially where reductions in C stocks associated with fuels treatments would be counterbalanced by reduced wildfire C losses (Hurteau et al., 2014). In the pine barrens of the mid-Atlantic, an increase in prescribed burning would have little appreciable effect on long-term forest C dynamics, while serving as a cost-effective strategy for reducing hazardous fuels and mitigating the potential ecological impacts of a changing climate (Clark et al., 2014). In the Southeast, the decrease in prescribed burning and increase in wildfire have the potential to reduce quality and quantity of surface water released from forests at times when demand will increase due to drought (Mitchell et al., 2014). While the Southeast has among the highest potential for C storage and sequestration, a potential reduction in C sequestration capacity due to increasing disturbance from drought, insect outbreaks and fire is possible (Mitchell et al., 2014).

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