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Mega-fires, tipping points and ecosystem services: Managing forests and woodlands in an uncertain future

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ABSTRACT

Global evidence posits that we are on the cusp of fire-driven ‘tipping points’ in some of the world’s most important woody biomes including savannah woodlands, temperate forests, and boreal forests, with consequences of major changes in species dominance and vegetation type. The evidence also suggests that mega-fires are positive feedbacks to changing climates via carbon emissions, and will be responsible for large swings in water yield and quality from temperate forests at the regional scale.

Two factors widely considered to have contributed to our current proximity to tipping points are changing climates and human management – the latter most obviously taking the form of allowing fuels to build up, either through policies of fire suppression or failure to implement sufficient fuel reduction fires – to the point where wildfire intensity increases dramatically. Much of the evidence comes from Australia and the USA, but domains such as Africa and the boreal north provide additional insights.

Forests adapted to regimes of low-moderate intensity fires may not face the same challenges as the iconic ash forests of Australia and the coniferous forests of Yellowstone or the west coast of the USA that are adapted to high intensity fire. However the often modest physical barriers (including distance, topography and climate) between forests adapted to more frequent, low-moderate intensity fires on the one hand, and less frequent, high intensity fires on the other, are easily overcome by confluences of continually increasing fuel loads and changing climates that serve to increase both fire frequency and intensity.

For temperate forests, we can mitigate the extent of large-scale, high intensity fires and their consequences if we carefully use fuel reduction fires and other standard forest management practises such as thinning. Mitigation will require assessing impacts on biodiversity of smaller, low-intensity fires at intervals of 5–10 years (to reduce fuels and mitigate fire size and intensity), against those of large-scale, high intensity wildfires at increasing (but unknown) frequency. Mitigation will require that forests be managed contiguously, not via different agencies with different objectives according to land tenure. Managing requires that governments and the communities they serve acknowledge the limitations of fire-suppression. Mitigating the incidence and effects of large-scale, high intensity fires through embracing the use of managed fire in conjunction with judicious use of fire suppression offers opportunity to avoid potentially large changes in vegetation and biomass (e.g. abundance of dominant species, biodiversity, fuel structure and loads), as well as in water yield and quality and carbon carrying capacity.

1. Introduction

It hardly needs saying that the world has seen increasing incidence of large-scale, mostly high-intensity and destructive wildfires (or in Australia, bushfires). As this article was being completed, President Barack Obama had just declared as a ‘major disaster’ the Waldo Canyon fire that ravaged areas of Colorado. A state of emergency had been declared amid media reports of “two deaths… the destruction of 346 homes, … some 35,000 residents have been forced to evacuate” (Reuters 2012). The general increase in wildfire globally (e.g. Krawchuk et al., 2009) and in the western USA (e.g. Westerling et al., 2006; Running et al., 2006) has been well documented in the past 10–15 years and similar headlines and stories of destruction have been written for dozens of major fires >10^5 Ha or so in the heavily populated areas of the USA, Australia, Canada and Europe.

Forest fires in tropical countries and the boreal north seldom make as many headlines as those in the temperate zone. However tropical forest fires at scales of >10^6 Ha produce truly global impacts inasmuch as they can result in measured step increases in global atmospheric concentrations of CO_2 (Page et al., 2002), and

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in smoke plumes and hazes that affect whole regions and many countries. In a commentary prompted by the many major fires around the world in 1997/8/9, Levine et al. (1999) suggested: "wildfires of 1997 and 1998 made the world aware of the environmental and human health impacts associated with these fires. In Southeast Asia alone, tens of millions of people were exposed to high levels of fire-produced gases and particulates for weeks at a time. The poor atmospheric visibility resulting from these fires was responsible for the crash of a commercial airplane and the collision of two ships at sea". While not a focus here, recent analysis suggests smoke from landscape fires causes the death of almost 340,000 people every year (Johnston et al., 2012).

Human activity and climate dominate fire regimes globally. The accounts written by Stephen Pyne (e.g. Pyne, 1991, 1995) make plain this truism. As just a few examples, Veblen et al. (1999) for Patagonia, Flannery (2002) and Gammage (2011) for Australia, Archibald et al. (2012) for Africa, Mollicone et al. (2006) for Russia, and many for global scales including Marlon et al. (2012), Pechony and Shindell (2010), and Krawchuk et al. (2009), have emphasized the role of people. Levine et al. (1999) described the "dramatic increase in wildfire size, frequency and related environmental impacts" in 1997 and 1998 for countries such as Indonesia, Brazil, Mexico, Canada, USA, France, Turkey, Greece and Italy as well as the Russian Federation and China's northeastern Inner Mongolia Autonomous Region. Human activities were in large part responsible, either directly or indirectly. Since 1997 data has been available that allows analysis of fires in Russia. Shvidenko et al. (2011) estimated that for the period 1998–2010, an average of >8 M Ha burnt each year, with more than 90% of this area being in Asian Russia, mostly the southern part. They noted that aggravation of the problems of "catastrophic fires" were caused by "substantial decline in forest governance" and "destruction of the professional nature-protected (sic) systems (particularly, by practical elimination of the state forest guard)". Their comments about forest management in Russia echo those made 5 years earlier by Mollicone et al. (2006).

Climate though, is also influenced by fire, especially large-scale (e.g. >10^5 Ha) fires of high intensity (here referred to as mega-fires). Apart from the obvious emissions of CO_2, these fires also produce aerosol particles that play significant, albeit poorly understood roles in the climate system. Argued wildfire effects on climate include: cooling on the earth's atmosphere from more numerous and smaller droplets and increasing cloud albedo (Lohman and Lesins, 2002; Chubarova et al., 2011); increased absorption of radiation and atmospheric and surface temperatures as a result of black carbon (e.g. ash and soot) of tropical origin released in the atmosphere and deposited on surfaces (see Ramanathan and Carmichael, 2008); increased albedo and biophysical cooling due to the nature of regrowth after high intensity fires (Beck et al., 2011). In one of very few comprehensive analyses of the effects of wildfire on climate, Randerson et al. (2006) integrated effects on aerosols, greenhouse gases (both during the fire and thereafter from soil), black carbon and albedo. Their analysis of the Donnelly Flats fire in Alaska suggested that initially positive radiative forcing became negative in the long-term (assuming an 80 year fire cycle) due to the long-term changes in albedo that might take 50+ years to return to pre-fire conditions. While discussions about the human activity-climate relationship (and the role of fire therein) in the Amazon or south-east Asia (e.g. Cochrane and Laurance, 2008; Murdiyarso and Adiningsih, 2007) inevitably require consideration of both direct (slash and burn agriculture, logging and land clearing) and indirect (climate change) effects of human activity, there is broad consensus that fire regimes in these regions affect many aspects of the climates of the regions and beyond. One of the more remarkable effects is the increased incidence of lightning (Altaratz et al., 2010) as a result of smoke contributions to convection.

Companion papers on bushfires and wildfires help set the scene for this synthesis. The frequency, scale and impacts of mega-fires around the world are well described in other papers in this volume (e.g. Attiwill and Adams, 2012; de Groot et al., 2013; Williams, 2013).

Here I examine three of the key issues in relation to mega-fires. First, I summarize recent literature on fire-related 'tipping points' in major biomes with an emphasis on consequences for dominant woody species. This is followed by analysis of the effects of large scale (>10^5 Ha), high intensity fires on carbon and water as two of the most important ecosystems services provided by forests. Finally I summarize evidence from temperate forests in southern Australia, western USA, and other regions, that through management we can mitigate mega-fires and their impacts on vegetation type (and biodiversity), carbon and water.

2. Fires and tipping points in major biomes: consequences for dominant woody species

Knowledge of the effects of fires on vegetation dynamics usually depends on hard-to-maintain long-term observations post-fire and/or long-term data derived from remote sensing. With these points in mind, recent studies highlight likely changes in vegetation structure and species composition that could result from climate- and human-driven changes in fire regimes.

2.1. Savanna woodlands and forests

Savanna woodlands are perhaps better known for the number of fires than for the size or intensity of individual fires relative to temperate or boreal forests (see Fig. 1 for an example from Australia – compare the relative size of fire burnt areas in the tropics that are mostly savanna and those south of the Tropic of Capricorn that are mostly temperate forests and woodlands). Even so, some analysis suggests fire size is increasing, at least in more mesic savannas (e.g. Yates et al., 2008). Savannas are also known globally for their importance in supporting large numbers of people and their industries, especially raising livestock. This was graphically and recently illustrated by Archibald et al. (2012) who showed how reduced connectivity, due to 'agropastoralist societies', reduced the total area burnt within African savannas in the past 200 years. Globally, savannas are examples of ecosystems in which fire plays a major role in determining tipping points or thresholds or, more simply, switches between distinct vegetation types – grassland, woodland, forests. The greatly improved ability to remotely monitor and measure fires and vegetation condition has led to significant improvements in understanding of the scale of changes in savannah vegetation, including a first quantitative analysis for South America (Romero-Ruiz et al., 2010) and much improved ability to model changes through time (e.g. Bond et al., 2005).

Two recent papers in *Science* (Staver et al., 2011; Hirota et al., 2011) focused on the likelihood of tipping points. In a commentary, Mayer and Kahlyani (2011) noted (see Fig. 2) that: "both reports identify an unstable state at 50 to 60% tree cover; either trees take hold and promote their own growth hydrologically (and suppress fire), or grasses take hold and promote their expansion through fire". Mayer and Kahlyani (2011) focused their analysis of the implications of the work on the Southern Hemisphere: "large areas of savanna in Africa could shift to forest (if fire and grazing are suppressed), and large areas of forest in South America could convert to savanna".

These recent modeling studies are reflected and supported, at least in part, by other work. Murphy and Bowman (2012) and Hoffman et al. (2012) highlighted a number of features of savannah systems that encourage development of tipping points, including