ARTICLE IN PRESS

Forest Ecology and Management xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Climate change and fire management in the mid-Atlantic region

Kenneth L. Clark [a,*], Nicholas Skowronski [b], Heidi Renninger [c], Robert Scheller [d]

[a] Silas Little Experimental Forest, Northern Research Station, USDA Forest Service, 501 Four Mile Road, P.O. Box 232, New Lisbon, NJ 08064, USA
[b] Northern Research Station, USDA Forest Service, 180 Canfield St., Morgantown, WV 26505, USA
[c] Rutgers University, Department of Biological Sciences, 195 University Ave., Newark, NJ 07102, USA
[d] Department of Environmental Sciences and Management, Portland State University, P.O. Box 751, Portland, OR 97207, USA

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Forest composition
Wildfire
Prescribed burns
Carbon sequestration
Mitigation

ABSTRACT

In this review, we summarize the potential impacts of climate change on wildfire activity in the mid-Atlantic region, and then consider how the beneficial uses of prescribed fire could conflict with mitigation needs for climate change, focusing on patters of carbon (C) sequestration by forests in the region. We use a synthesis of field studies, eddy flux tower measurements, and simulation studies to evaluate how the use of prescribed fire affects short- and long-term forest C dynamics. Climate change may create weather conditions more conducive to wildfire activity, but successional changes in forest composition, altered gap dynamics, reduced understory and forest floor fuels, and fire suppression will likely continue to limit wildfire occurrence and severity throughout the region. Prescribed burning is the only major viable option that land managers have for reducing hazardous fuels in a cost-effective manner, or ensuring the regeneration and maintenance of fire-dependent species. Field measurements and model simulations indicate that consumption of fine fuels on the forest floor and understory vegetation during most prescribed burns is equivalent to <1–3 years of sequestered C, and depends on pre-burn fuel loading and burn intensity. Overstory tree mortality is typically low, and stands have somewhat reduced daytime C uptake during the next growing season following burns, but may also have reduced rates of ecosystem respiration. On an annual basis, net ecosystem productivity is negative the first year when consumption losses are included, but then positive in following years, and stands can reach C neutrality within <2–3 years. Field data and model simulations suggest that increases in prescribed burning in fire-prone areas would have little appreciable effect on long-term forest C dynamics in some fire-prone forest types. Large-scale conversion to young pine plantations for fiber and biofuels will potentially increase the risk of wildfires, as had occurred previously in the late-19th and early-20th centuries in the region.

Published by Elsevier B.V.

1. Introduction

Wildfire occurrence and severity are driven by a variety of factors, including climate and weather conditions (Liu et al., 2013; Morton et al., 2013; Potter, 2012), fuel loading and arrangement (Agee and Skinner, 2005; Ottmar et al., 2007; Rollins, 2009), and natural and human-caused ignitions (Hawbaker et al., 2013). Climate change may have a major impact on wildfire activity (Hessl, 2011), and increases have been projected for a number of regions in North America (Liu et al., 2013). In contrast to the Western US and Canada, where changes in climate are projected to significantly increase the frequency and area burned by wildfires (Spracklen et al., 2009; Westerling et al., 2006; Wimberly and Kennedy, this issue; Wotton et al., 2010), wildfire activity has been relatively low and only moderate increases are projected for the mid-Atlantic region (Liu et al., 2013; Morton et al., 2013; NIFC, 2013). Forest recovery following agricultural abandonment (Pan et al., 2011), successional trends towards older, more mesic, closed-canopy forests (Abrams, 2003; Little, 1979; Nowacki and Abrams, 2008), and less flammable fuel beds in the understory and litter layer (Kreye et al., 2013) have reduced wildfire size and severity considerably compared to historic fire regimes and the regional peak in the late 1800's and early 1900's (Brose et al., 2013a; Forman and Boerner, 1981; Little, 1979). Wildfire suppression activities are facilitated by the extensive road network that exists in the region (Forman and Boerner, 1981; Scheller et al., 2011), and complex spatial patterns of land use, forest ownership and forest fragmentation (Drummond and Loveland, 2010) will likely continue to constrain the spread of wildfires in the region. These factors could moderate any potential increases in enhanced fire weather conditions, drought, potential changes to forest structure and fuel loading due to insect invasions, and other stresses associated with climate change in the mid-Atlantic region.

In addition to direct suppression activities, prescribed fire is the primary management practice used by agencies to mitigate

* Corresponding author. Tel.: +1 609 894 0325.
E-mail address: kennethclark@fs.fed.us (K.L. Clark).

0378-1127/$ - see front matter Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.foreco.2013.09.049

wildland fires in the mid-Atlantic region. Prescribed burning is the most cost-effective method for reducing hazardous fuels in areas such as the New Jersey Pinelands National Reserve, where it has been used for this purpose since the late 1930's (Clark et al., 2009; Little and Moore, 1949; NJFFS, 2006). More recently, prescribed fire use has been expanded to restore historic fire regimes and encourage the regeneration of canopy oaks (*Quercus* spp.) and other fire-tolerant species in the region (Arthur et al., 2012; Brose et al., 2013b; Hutchinson et al., 2012). Benefits of reintroducing fire on the landscape for the maintenance of biodiversity are well-established (e.g., Fan et al., 2012; Jordan et al., 2003; Phillips et al., 2012). In some forests, early-successional species are largely dependent on the occurrence of frequent, low intensity fires (Burton et al., 2011; Jordan et al., 2003), prompting efforts for the reintroduction of fire on forested landscapes throughout the mid-Atlantic (Nowacki and Abrams, 2008; Phillips et al., 2012). However, a more liberal "let it burn" policy for wildland fire use cannot be considered a viable management option in the region, because of high population densities, proximities to urban population centers, the extent of wildland urban interface (WUI) areas, legal liability issues, aesthetic concerns and the emissions of fine particulates (PM 2.5) and other pollutants in or near non-attainment areas (Urbanski, 2013).

Wildland fire management strategies, including a suppression-only strategy, are directly linked to the storage of carbon (C) on the landscape, and can affect the emissions of carbon dioxide (CO_2) and other greenhouse gasses, leading to potential feedbacks with climate change (Urbanski, 2013, Weise and Wright, 2013). Forests will continue to play a key role in C storage and sequestration throughout the region (He et al., 2012; Pan et al., 2011; Woodall et al., 2013), and obvious conflicts exist between the use of prescribed fire and the management of forests to mitigate climate change by maximizing rates of C sequestration (e.g., Loehman et al., 2013). For example, a prescribed fire will result in a short-term flux of CO_2 and other greenhouse gasses to the atmosphere during fuel combustion, as well as reduced rates of C sequestration during stand recovery, but may prevent the occurrence of a high-intensity wildland fire that would result in a much greater alteration to C pools and longer-term impacts to forest productivity. Forest managers will likely be required to formally evaluate the trade-offs between the short- and long-term impacts of fire management strategies on both forest C pools and sequestration rates in the near future. Therefore, a better understanding of the overall spatial and temporal effects of fire management in the mid-Atlantic is critical for maximizing the benefits of fire for hazardous fuel reduction, maintaining biodiversity, and ecosystem functioning, while minimizing impacts on long-term rates of C sequestration to mitigate climate change.

Research efforts in eastern forests indicate that prescribed burning has relatively minor effects on overstory tree mortality (Hutchinson et al., 2005, 2012; Skowronski et al., 2007; Stephens et al., 2012), and aboveground biomass (Chiang et al., 2008). Single and repeated prescribed burns can reduce sapling and seedling density, but also can have the desired effect of stimulating regeneration of fire-tolerant species, depending on fire intensity and seasonality (Brose, 2010; Brose et al., 2013b; Hutchinson et al., 2012; Waldrop et al., 2010). Several studies have illustrated that initial consumption losses from the forest floor and understory vegetation total less than 5 Mg C ha^{-1} during prescribed fires, after which C storage in vegetation is not strongly affected (Boerner et al., 2008; Clark et al., 2009, 2010a; Chiang et al., 2008; Skowronski et al., 2007). Little appreciable long-term effects on forest floor mass, coarse wood or standing dead trees have been observed in a number of studies in oak-dominated stands (Boerner et al., 2009; Hartman, 2004; Polo et al., 2013; Waldrop et al., 2010). Litter layer composition may change through time with repeated burning, resulting in a reduction in fine litter and an increase in woody fuels (Hartman, 2004; Waldrop et al., 2010). Prescribed burning also has little effect on soil organic matter and nitrogen (N) content (Boerner et al., 2009; Hubbard et al., 2004; Nave et al., 2011; Neill et al., 2007; Wang et al., 2012), unless burns are conducted very frequently (Williams et al., 2012). Decreases in soil microbial biomass and microbial N can occur following burning, leading to reduced N mineralization (Gray and Dighton, 2009; Wang et al., 2012), but in other studies little effect of burning on soil microbial properties has been reported, even under frequent burning treatments (Williams et al., 2012). The short-term effects prescribed fires on ecosystem CO_2 flux immediately following prescribed fires, and the longer-term impacts of fire management on rates of C sequestration are not as well characterized. In this review, we use the results of climate simulations, field measurements of fuel loading and consumption, net exchange of CO_2 measured from flux towers before and after prescribed burn treatments, and model simulations to evaluate current and future uses of prescribed fire in the mid-Atlantic. We focus on the trade-offs between hazardous fuel reduction and C sequestration in wildfire-prone forest types, and extend some of our conclusions to the use of prescribed fire to restore historic fire regimes in oak-dominated stands in the region. Our objectives are: (1) to summarize the effects of projected climate change on wildfire activity in the mid-Atlantic over the next 50 years, and highlight some of the uncertainties with current projections, and (2) to evaluate the potential short- and long-term impacts of fire management activities on forest C dynamics in selected forest types in the mid-Atlantic region.

2. Regional description and background

The mid-Atlantic region includes four physiographic provinces; Coastal Plain, Piedmont, Ridge and Valley, and Plateau. Interactions between climate, geology, and geologic history have led to high species diversity in the region, with tree diversity alone totaling at least 135 species (www.fia.gov; Prasad et al., 2011). Dominant forest types are oak-hickory, N. hardwood, mixed pine and oak-pine (Phillips et al., 2012; www.fia.gov). Forests currently cover 64% of the mid-Atlantic, and are concentrated in western Virginia, eastern W. Virginia, northwestern Pennsylvania, portions of southern and northern New Jersey, and southern and eastern New York. Nearly all large contiguous tracts of forest contain too many roads to be considered wilderness, although some areas are >90% forested. Changes from historic fire regimes and regeneration following extensive deforestation in the 1800's are having profound effects on forest structure and composition throughout the mid-Atlantic (Brose et al., 2013a; Forman and Boerner, 1981; Nowacki and Abrams, 2008; Phillips et al., 2012). Fire suppression activities, in concert with intense grazing pressure by white-tail deer (*Odocoileus virginianus*) (Nuttle et al., 2013), defoliation by Gypsy moth (*Lymantria dispar* L.), changes in gap dynamics (Buchanan and Hart, 2012; Nuttle et al., 2013) as well as other factors, have reduced the regeneration of oaks and other fire-tolerant species, and is favoring the regeneration of more mesic species across the region (e.g., Abrams, 2003; Royse et al., 2010; Woodall et al., 2013). Many of the resultant closed-canopy forests have relatively low understory biomass, high fine litter turnover rates (Piatek et al., 2010), and low surface fuel loads (Graham and McCarthy, 2006; Waldrop et al., 2007) consisting of less flammable litter (Kreye et al., 2013).

Pine-dominated, oak-pine, and to a lesser extent oak-hickory forests continue to be the most wildfire prone forests in the mid-Atlantic, and are typically the focus of fire management activities. New Jersey and Virginia currently have the highest number of wildfire ignitions, and Virginia, W. Virginia, and New Jersey have

Please cite this article in press as: Clark, K.L., et al. Climate change and fire management in the mid-Atlantic region. Forest Ecol. Manage. (2013), http://dx.doi.org/10.1016/j.foreco.2013.09.049