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Modeling climate change, urbanization, and fire effects on *Pinus palustris* ecosystems of the southeastern U.S.

Jennifer K. Costanza [a,*], Adam J. Terando [b,c], Alexa J. McKerrow [d], Jaime A. Collazo [e]

[a] North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, NC 27695, USA
[b] Southeast Climate Science Center, U.S. Geological Survey, Campus Box 7617, Raleigh, NC 27695, USA
[c] Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, NC 27695, USA
[d] Core Science Analytics and Synthesis, U.S. Geological Survey, Campus Box 7617, Raleigh, NC 27695, USA
[e] U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, NC 27695, USA

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ABSTRACT

Managing ecosystems for resilience and sustainability requires understanding how they will respond to future anthropogenic drivers such as climate change and urbanization. In fire-dependent ecosystems, predicting this response requires a focus on how these drivers will impact fire regimes. Here, we use scenarios of climate change, urbanization and management to simulate the future dynamics of the critically endangered and fire-dependent longleaf pine (*Pinus palustris*) ecosystem. We investigated how climate change and urbanization will affect the ecosystem, and whether the two conservation goals of a 135% increase in total longleaf area and a doubling of fire-maintained open-canopy habitat can be achieved in the face of these drivers. Our results show that while climatic warming had little effect on the wildfire regime, and thus on longleaf pine dynamics, urban growth led to an 8% reduction in annual wildfire area. The management scenarios we tested increase the ecosystem's total extent by up to 62% and result in expansion of open-canopy longleaf by as much as 216%, meeting one of the two conservation goals for the ecosystem. We find that both conservation goals for this ecosystem, which is climate-resilient but vulnerable to urbanization, are only attainable if a greater focus is placed on restoration of non-longleaf areas as opposed to maintaining existing longleaf stands. Our approach demonstrates the importance of accounting for multiple relevant anthropogenic threats in an ecosystem-specific context in order to facilitate more effective management actions.

1. Introduction

Understanding how ecosystems will respond to future anthropogenic drivers such as climate change is critical to management for resilience and sustainability (Millar and Woolfenden, 1999; Stein et al., 2013). In ecosystems in which wildfire is a fundamental process, knowing how climate change could alter future wildfire regimes is key to developing conservation and management strategies that promote persistence over time and space (Stephens et al., 2013). Recent studies suggest that future changes in climate could have substantial impacts on wildfire regimes, resulting in major ecosystem impacts (Overpeck et al., 1990; Dale et al., 2001; IPCC, 2007). Climate change is already affecting wildfires in some cases. For example, in the western U.S., earlier snowmelt due to recent increases in spring and summer temperatures have led to higher wildfire activity, and this trend is expected to become more pronounced in the future (Westerling et al., 2006; Litschert et al., 2012). However in other regions, climate change is likely to lead to a decrease in wildfire activity (Moritz et al., 2012). This uncertainty in the magnitude and direction of wildfire responses to climate change limits any generalized predictions across ecosystems that could be used to inform management strategies.

In addition to affecting ecosystems, climate change acts in concert with other drivers, including land use conversion (Staudt et al., 2013). In particular, conversion to urban and suburban land

* Corresponding author. Present address: Department of Forestry and Environmental Resources, North Carolina State University, 3041 Cornwallis Road, Research Triangle Park, NC 27709, USA.
E-mail address: jennifer_costanza@ncsu.edu (J.K. Costanza).

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uses is a major driver of ecosystem change worldwide and may be more important than global climate change in some regions (Grimm et al., 2008). Conversion to urban land uses affects a variety of ecosystem properties, including water quality and predator–prey relationships (Anderies et al., 2007; Tu, 2013). In addition, urbanization can affect wildfire dynamics as well as the ability to conduct prescribed fires (Costanza et al., 2013; Hawbaker et al., 2013). Of particular concern is how the combination of climatic and land use changes will affect the role of fire in fire-dependent ecosystems. However, to date, few studies have undertaken the detailed accounting of all of the primary anthropogenic drivers that is necessary to better predict the consequences of climate and land use change in fire-dependent ecosystems (one exception is Paveglio et al. (2013)). A better understanding of how these multiple drivers will affect wildfires will allow for more effective management.

Here we investigate how a rapidly warming and urbanizing world affects the critically endangered longleaf pine ecosystem that is dependent on wildfire and fire management. This ecosystem, located in the southeastern U.S. from southern Virginia to Texas, and named after the keystone tree species (*Pinus palustris*), is particularly sensitive to changes in fire frequency. Low severity but highly frequent fires help to maintain the open, park-like savanna structure that provides habitat for a rich diversity of plant and animal species. However, the majority of wildfires in the ecosystem have been suppressed in recent years through direct human action or indirectly through land use change (Frost, 2006). A combination of wildfire suppression, timber harvesting, and land conversion has resulted in a severely degraded and fragmented system which is now only found over about 3% of its historic range (Frost, 1993; VanLear et al., 2005). With this degradation has come declines in the species that are strongly dependent on this ecosystem, including the federally-endangered Red-cockaded Woodpecker (U.S. Fish and Wildlife Service, 2003). In response, widespread improvement of degraded stands via prescribed burning, as well as restoration of converted stands using prescribed burning combined with other management actions have been proposed (VanLear et al., 2005; America's Longleaf, 2009). Specifically, a major conservation goal for the longleaf pine ecosystem is a doubling of the extent of fire-maintained, open longleaf stands (from 1.5 million ha to 3 million ha), and increasing the total extent of the longleaf pine ecosystem by 135% (from 3.4 million ha to 8.0 million ha) (America's Longleaf, 2009).

To plan for and accomplish this ambitious conservation goal, resource managers need information about the future role of both wildfires and managed fires in the longleaf pine ecosystem. Because wildfire suppression is extensive in the Southeast, prescribed burning is currently the major means by which fires affect the longleaf pine ecosystem, and is the primary strategy for maintaining and restoring the ecosystem. In fact, more prescribed burning is conducted in the Southeast than any other region of the country (Haines et al., 2001). However, current prescribed burning management programs still do not implement enough burning to accomplish ecosystem-wide restoration of longleaf pine (VanLear et al., 2005; Costanza et al., 2013). Several regional initiatives have begun to address ways to implement more burning over larger extents in the Southeast (Southeastern Regional Working Group, 2012). Recent plans suggest doubling current burning levels, with primary emphasis on maintaining open longleaf stands, and a secondary goal to improve and restore degraded stands (America's Longleaf, 2009). However, decision makers need to know whether proposed management strategies to double prescribed burning efforts and focus on maintaining open stands will be sufficient given possible future climatic and land use changes. For example, an altered wildfire regime in the longleaf pine ecosystem due to climate change could make management more difficult, especially if wildfires become more frequent. Wildfires in long-unburned areas where fuels have built up due to past fire suppression could lead to undesired effects such as high mortality of longleaf pine trees (Varner et al., 2005, 2007). In addition, growth of urban areas will lead to permanent conversion of longleaf and other habitats, which cannot be restored.

In this study, we simulated the future effects of potential prescribed burning regimes on the longleaf pine ecosystem in a landscape subject to the anthropogenic drivers of climate change and urban growth. We first examined how greenhouse gas emissions trajectories and urban growth would affect the wildfire regime. Our wildfire projections were developed by exploiting the observed relationship between climate and wildfire to build an empirical model that was deployed in a suite of climate models. We next simulated scenarios of prescribed burning in the context of climate change and urban growth. Our prescribed burning scenarios varied both the annual amount of burning and the extent to which the focus of burning was on maintaining open longleaf stands versus restoring fire-suppressed stands. We asked these questions:

1. What effect could climate change and urbanization have on the fire regime in longleaf pine stands, and how will the amount of fire-maintained, open longleaf pine change as a result?
2. Can recommended prescribed burning strategies achieve conservation goals for the longleaf pine ecosystem given these drivers?

The results of this research will help inform whether proposed management strategies focused on prescribed burning are likely to be successful in accomplishing their goals of doubling the extent of open, fire-maintained longleaf stands and more than doubling the total extent of the ecosystem. Thus, our work will provide critical information for sustainable management of the longleaf pine ecosystem and the species that depend on it.

2. Methods

2.1. Study area

We modeled longleaf pine dynamics across a portion of the Southeast Coastal Plain of the U.S. that corresponds to the Dougherty Plain ecoregion (EPA, 2004). This region covers 2.94 million ha (29,400 km^2) in portions of southwestern Georgia (GA), southeastern Alabama (AL) and the Florida (FL) Panhandle (Fig. 1). Longleaf pine ecosystems cover 9% of the study area (Southeast Gap Analysis Project (SEGAP), 2008). Agricultural lands (row crops and pastures) and loblolly pine (*Pinus taeda*) plantations are the most abundant land cover types in the region today, comprising 42% and 23% of the landscape, respectively (SEGAP, 2008). Agriculture and pine plantations are predominant across much of the Southeast; therefore, reestablishing longleaf in those areas will be particularly important for longleaf pine restoration efforts. The remaining portions of the study area are a mixture of other plant communities, including bottomland hardwood forests. A majority of the region is privately owned (96%), with the public land occurring in relatively small state management areas, mainly along rivers.

The study area within the Southeast Coastal Plain experiences a humid continental climate. Mean monthly temperatures range from 9.4 °C in January to 27.5 °C in July while maximum precipitation occurs in July (5 mm/day) with a slight minimum occurring in the spring (2.9 mm/day in May). As with almost all areas of the planet, significant warming is projected to occur in the 21st century. Results from an ensemble of statistically downscaled global climate models (Stoner et al., 2012) show average daily maximum