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Economic vulnerability of southern US slash pine forests to climate change

Andres Susaeta[a,*], Damian C. Adams[a], Carlos Gonzalez-Benecke[b]

[a] School of Forest Resources and Conservation, University of Florida, FL, 32611, USA
[b] Department of Forest Engineering, Resources and Management, Oregon State University, OR, 97331, USA

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ABSTRACT

It is widely accepted that pine plantation forests will play a critical role in climate change (CC) mitigation, but their vulnerability to CC impacts raises questions about their role. We modeled the impacts of changing climatic variables on forest growth, optimal harvest age, and land expectation value (LEV) for 11 representative slash pine sites in the Southeastern U.S. under two alternative climate scenarios (RCP4.5 and 8.5). Our coupled modeling approach incorporated the 3-PG biological process model, a generalized carbon sequestration economic model, and Pressler's indicator rate formula to determine relative changes in prices, timber and carbon production. We generally found weak impacts of CC on slash pine LEVs and optimal harvest ages, but our results were sensitive to site productivity and location. CC increased LEVs in sites with low productivity for both RCPs. While a 1 °C increase led to the greatest LEV increase in Northeastern sites with low and moderate forest productivity conditions, Southeastern sites showed the greatest decreases in LEV. Higher (lower) future land values would shorten (lengthen) the current harvest age for slash pine. Changes in the rate of carbon and stumpage prices had the greatest impact on the rate of marginal economic revenues of slash pine.

Introduction

There is broad consensus in the scientific community that climate change (CC) will continue to worsen without stringent policy interventions (Moore and Diaz, 2015). Recent projections (e.g., IPCC, 2013a) suggest that global temperatures and concomitant weather impacts will increase by a considerable amount (+4.8 °C by 2100), but with high spatiotemporal variation (Collins et al., 2013). For example, by 2100 the southern United States (US) is expected to see up to +3 °C increase in mean temperatures (Kirtman et al., 2013), and +10% to 20% increase in mean precipitation in winter months (IPCC, 2013a).

We know that as forests grow, they capture atmospheric carbon dioxide (CO_2) and store it as biomass. For example, in the heavily-forested southeastern US, Han et al. (2007) predict that nearly 1/4th of the region's GHG emissions – a considerable amount – could be offset by forests. We also know that increasing forest biomass and extending the forest estate are relatively cost-effective CC mitigation approaches (Couture and Reynaud, 2011; Gren and Carlsson, 2013), and for that reason afforestation and reforestation are central to several greenhouse gas (GHG) emissions reduction programs and policies (e.g., EPA's Clean Power Plan (Soto et al., 2016), and the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC, 1998).

From the perspective of ecological and biological processes, we have a strong and improving understanding of the relationship between forests, the carbon cycle, and climate change. It is clear that climate change will impact the structure and function of forest ecosystems (Johnsen et al., 2014), though the direction and magnitude of these impacts is thought to vary considerably across the spatiotemporal gradient, and this is an area of active debate. While higher concentration of atmospheric carbon dioxide (CO_2) and temperatures are expected to increase forest pine growth in the Southern US (Wertin et al., 2012), this increase in productivity may be hampered by drought conditions and water stress (Wertin et al., 2010). CC is also associated with an increase in forest disturbance risks, which may offset any productivity gains. Wildfire frequency and intensity are expected to increase with projected increases in temperatures in the region (Liu

* Corresponding author at: School of Forest Resources and Conservation, University of Florida, 315 Newins Ziegler Hall, Gainesville, FL 32611, USA.
E-mail address: asusaeta@ufl.edu (A. Susaeta).

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et al., 2014; Susaeta et al., 2016a). Pest outbreaks, hurricanes and invasive species are also expected to increase with CC, thus affecting ecological and productive functions of forests (Haim et al., 2011; Susaeta et al., 2016b). In this way, CC can have significant impacts on this important carbon sequestration role[1] that southern forests could play in the US.

Considerably less attention has focused on the economic feasibility of this approach. Throughout much of the world, private forest ownership is the dominant form of forest land tenure. Indeed, a major threat to forests and forest C stocks is land use change. Forest carbon stocks are actually projected to fall from 2030 to 2060 due to losses in forest areas (Hugget et al., 2013).

Robust markets for forest products (e.g., timber and bioenergy) and services (e.g., C sequestration) can counter this effect, and are important policy considerations. Forests play an important role in the economic system, meeting society's needs for raw materials, mostly timber and fiber. The southern US is one of the most productive tree-growing areas in the world. Southern forests occupy 87 million hectares (ha), provide 12% of the world's industrial roundwood, 19% of the world's pulp and paper products; they also provide 53% of the sawlog and veneer products in the US, and 72% of the pulpwood in the US (Smith et al., 2009). Depending on assumptions about forest product demand and productivity of forest plantations, southern US forests are forecast to increase total timber production by 25–70% between 2010 and 2060 (Hugget et al., 2013).

A major factor in the predications of forest-based C sequestration is optimal harvest age, which has also been a primary focus of plantation forest management for several decades (Chang, 1984; Lu and Gong, 2003). The impacts of incentives, subsidies and taxes related to C sequestration and GHG emissions on the optimal harvest age have been widely examined, most notably within a Hartmann modeling framework (Creedy and Wurzbacher, 2001; Hartman, 1976; Stainback and Alavalapati, 2002; Susaeta et al., 2014; van Kooten et al., 1995). Although most of these studies found higher optimal harvest age with positive forest C prices, leading to a higher amount of C sequestered in tree biomass, other studies have indicated that the optimal harvest age may be shorter with C prices. Much of the difference in findings appears to be driven by assumptions about: the balance between two functions of the forests, i.e., sequestering C or postponing sequestered C release (Akao, 2011), the type of C process and selection of discount rates (Chladná, 2007), the type of C credit payment schemes (Guthrie and Kumareswaran, 2008), and the incorporation of carbon stocks in dead organic matter (Asante et al., 2011),

Research specifically related to optimal harvest age with CC has typically assumed increasing C prices associated with efficient climate change mitigation policies (Ekholm, 2016 Köthke and Dieter, 2010; Yu et al., 2014). Economic studies that have considered changes in forest growth induced by fluctuating climatic conditions are very limited, primarily because of inherent limitations in growth and yield models used for these analyses, which have traditionally assumed similar or even fixed climatic conditions over time. A notable exception is the work by Ferreira et al. (2016) that used a processed based model coupled with a dynamic programming approach to determine the implications of climate change on eucalyptus stand management in Portugal. Much work remains to be done in this area.

In this study, we focus on the impacts of CC on pine plantations, and use slash pine (*Pinus elliotti*) in the southern US as an example case. We integrated a process-based model (3-PG, Physiological Processes Predicting Growth, Landsberg and Waring, 1997) with a generalized stand level economic optimization model that accounts for timber and C prices (Susaeta et al., 2014) to determine optimal even-aged forest management for slash pine across different sites in the southern US under a current and two future climatic scenarios. Slash pine is major commercial species in the southern US. It has been planted on 4.2 million ha in the region and extends across a wide range. It is found as far west as eastern Texas, as far north as southern North Carolina, and as far south as south-central Florida (Barnett and Sheffield, 2004). Notably, our approach is sensitive to climatic variables that determine the impacts of future climate conditions on LEVs and optimal harvest ages. As such, we also presented an extension of our model – Pressler's indicator rate formula – to determine the impacts of relative changes of timber production, quality of forest products, and carbon and stumpage prices on the marginal economic returns of slash pine forests. This is particularly relevant in a CC context since changes in forest growth may modify harvesting decisions and significantly affect economic revenues for forest landowners, the supply of wood products, and carbon storage.

Below we specify a generalized carbon sequestration economic model and Pressler's indicator rate formula, describe the 3-PG process based model, and outline the climatic scenarios used in our analysis. We then describe slash pine forest management, the location of our representative study sites, model parameters, and our application of the generalized economic model. We report the economic impact of future climates on the profitability and current optimal harvest ages of slash pine, and discuss our findings. Finally, a concluding section summarizes the main findings and present avenues for further research.

Model specification

The generalized economic model

We employed a generalized carbon sequestration economic model to analyze the impact of carbon taxes and subsidies on optimal harvest management (Susaeta et al., 2014; see Appendix B (Eqs. (B1)–(B3) for model derivation)). This model is an important extension of the standard carbon sequestration economic model proposed by van Kooten et al. (1995), which assumes: (i) yearly payments to forest landowners for carbon sequestered by the trees as the forest stand grows and (ii) a tax (cost of carbon release) levied at the time of harvest and due to forest product decay (Appendix A). Unlike the standard approach, the generalized approach assumes that economic factors (stumpage prices, carbon prices, regeneration costs, and discount rates) and biological factors (forest growth, and fraction of carbon that is permanently stored in forest products and landfills) may change from timber crop to timber crop. As such, the generalized model avoids a major complaint of the standard model – its limited ability to account for landowner adaptation and responsiveness to market conditions. For example, with the generalized model, forest landowners may replant a different timber crop for high value forest products, with other wood properties, and a different silviculture intensity – all of which are static in a standard model.

[1] Southern forests also provide other critical ecosystem services (e.g. water availability, biodiversity, wildlife habitat, and recreation) that are essential for society. For example, forests produce 34% of the water yield in the Southern US (Lockaby et al., 2013) and host >1000 native terrestrial vertebrate species (Trani Griep and Collins, 2013).