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Exploring adaptation to climate change in the forests of central Nova Scotia, Canada

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A B S T R A C T

The threat of climate change is now recognized as an imminent issue at the forefront of the forest sector. Incorporating adaptation to climate change into forest management will be vital in the continual and sustainable provision of forest ecosystem services. The objective of this study is to investigate climate change adaptation in forest management using the landscape disturbance model LANDIS-II. The study area was comprised of 14,000 ha of forested watersheds in central Nova Scotia, Canada, managed by Halifax Water, the municipal water utility. Simulated climate change adaptation was directed towards three components of timber harvesting: the canopy-opening size of harvests, the age of harvested trees within a stand, and the species composition of harvested trees within a stand. These three adaptation treatments were simulated singly and in combination with each other in the modeling experiment. The timber supply was found to benefit from climate change in the absence of any adaptation treatment, though there was a loss of target tree species and old growth forest. In the age treatment, all trees in a harvested stand at or below the age of sexual maturity were exempt from harvesting. This was done to promote more-rapid succession to climax forest communities typical of the study area. It was the most effective in maintaining the timber supply, but least effective in promoting resistance to climate change at the prescribed harvest intensity. In the composition treatment, individual tree species were selected for harvest based on their response to climate change in previous research and on management values at Halifax Water to progressively facilitate forest transition under the altered climate. This proved the most effective treatment for maximizing forest age and old-growth area and for promoting stands composed of climatically suited target species. The size treatment was aimed towards building stand complexity and resilience to climate change, and was the most influential treatment on the response of timber supply, forest age, and forest composition to timber harvest when it was combined with other treatments. The combination of all three adaptation treatments yielded an adequate representation of target species and old forest without overly diminishing the timber supply, and was therefore the most effective in minimizing the trade-offs between management values and objectives. These findings support a diverse and multi-faceted approach to climate change adaptation.

1. Introduction

The threat of climate change is now recognized as a legitimate and imminent issue at the forefront of the forest sector Intergovernmental Panel on Climate Change [IPCC], 2007; International Union of Forest Research Organizations [IUFRO], 2009; Williamson et al., 2009. Research on climate change and forests has greatly developed in recent years (Millar et al., 2007; Malmsheimer et al., 2008; Johnston et al., 2010), while current impacts on forests are becoming evident and widespread (Hogg and Bernier, 2006; Kurz et al., 2008).

Direct effects of the changing climate include changes in the metabolic processes and growth rates of trees, due to carbon fertilization (Schimel et al., 2001), increased temperatures, and climate-induced changes in soil and moisture regimes, leading to changes in forest productivity (McMahon et al., 2010). Increases in forest productivity attributed to elevated temperatures and longer growing seasons have already been observed in high-latitude areas (Braswell and Schimel, 1997; Bunn and Goetz, 2006). Much study has also been dedicated to changes in tree-species distribution due to shifting ranges (McKenney et al., 2007; Iverson et al., 2008), possibly leading to the restructuring of existing forest communities (Webb and Bartlein, 1992; Scheller and Mladenoff, 2005). Indirect effects of climate change on forest ecosystems result from changes in natural disturbance regimes, with more frequent and severe extreme weather events, wildfires, and insect and disease outbreaks (Dale et al., 2001; Gray, 2008).

Effects of climate change on timber supply may vary and be positive or negative depending on the region, management activities, and temporal scale (Johnston and Williamson, 2005). For example,

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many northern, high-latitude regions are predicted to experience an increase in timber supply, driven by increases in forest productivity. However, predictions of the effects of climate change on forest productivity are uncertain and variable (Heimann and Reichstein, 2008). Management actions and natural disturbances may be the controlling factors in the overall net change in forest productivity and timber supply (Scheller and Mladenoff, 2005).

Climate change is likely to hinder the ability of forest managers to reach many of their management goals and objectives (Mote et al., 2003; Ogden and Innes, 2008). Forest management objectives have traditionally been developed based on historical forest conditions and ecological sustainability (Lackey, 1995; Landres et al., 1999), and the assumption that if we maintain these conditions, forest ecosystems will continue to provide goods and services (Millar et al., 2007). Changes in global climate invalidate these assumptions and we now need to incorporate climate change into forest management paradigms. It can be argued that forests may eventually adapt to the new climate on their own, yet because we have so many societal demands on forest ecosystems we want to facilitate this adaptation in a timely manner (Spittlehouse, 2005).

In recent years, several options for climate change adaptation have been explored, such as the control of undesirable or climatically unfavored species (Parker et al., 2000), partial cutting and reduced harvest intensity (Volney and Hirsch, 2005), maximization of forest structural complexity and diversity (Noss, 2001), insect and disease control (Spittlehouse, 2005), provenance testing, and assisted migration (Johnston et al., 2009). Because of future uncertainty there is a need for flexibility and continual learning of forest management institutions and policies through adaptive management (Duinker and Trevisan, 2003; Van Damme et al., 2003; Johnston et al., 2010). There is also a growing recognition that forest-sector vulnerability to climate change needs to be addressed at the scale necessary for forest management decision-making (Nitschke and Innes, 2008; Johnston et al., 2010). However, examples of specific climate change adaptation strategies, especially at the operational scale, are rare in the literature (Johnston et al., 2010).

In central Nova Scotia, Canada, Halifax Water manages the water supply and forests of the 14,000 ha Pockwock and Lake Major watersheds (Fig. 1). These watersheds lie within the Acadian Forest Region, and are characterized by mixedwood communities of red spruce (*Picea rubens*), eastern hemlock (*Tsuga canadensis*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), balsam fir (*Abies balsamea*), and white pine (*Pinus strobus*; Loo and Ives, 2003). Poor site conditions and frequent disturbance often favor stands of black spruce (*Picea mariana*), red maple (*Acer rubrum*), white birch (*Betula papyrifera*), and aspens (*Populus* spp.).

Healthy forests that are diverse in composition and age structure, among other things, are best equipped for the continual provision of a healthy water supply (Neary et al., 2009), so an understanding of climate change, its effects on forests, and how best to manage these forests in an altered climate is a principal objective of Halifax Water. To fully understand forest vulnerability to climate change, it is critical to explore and recognize all of the biophysical processes involved at the appropriate scales, including predicted regional impacts of climate change and the adaptive capacity of forest ecosystems and management systems (Duinker, 1990; Turner et al., 2003).

In this study we take a landscape-ecology approach to incorporating adaptation into timber harvesting using the landscape disturbance model LANDIS-II (Scheller et al., 2007), capable of simulating spatially explicit landscape succession and disturbance processes. The objective of this study is to research the effectiveness of different climate change adaptations in timber harvesting for satisfying management values and objectives of maintaining a supply of timber, preserving old-growth forest (OGF), and maintaining an adequate representation of desirable tree species. We strived to conduct this research at a fine enough spatial scale to inform management decisions of Halifax Water, but broad enough to examine forest-landscape response to adaptation in an approach that is valid within the design, scope, and temporal-spatial scales of LANDIS-II. By understanding which elements of timber harvesting are most receptive to, and effective in, incorporating climate change adaptation, we may begin to bridge the gap that exists between landscape ecology and resource management (Liu and Taylor, 2002) and between the theoretical and the operationally feasible.

2. Methods

2.1. Study overview

In this study we simulated the interaction of climate change and forest management in central Nova Scotia in order to measure the effectiveness of timber-harvest adaptation to climate change. Timber harvest parameters were altered in order to develop three different climate change adaptation treatments. The three adaptation treatments were simulated alone and in all potential combinations in seven different experimental scenarios, along with one control scenario. Their efficacy was evaluated in a values-based assessment of their ability to maintain the timber supply, preserve OGF, and keep target species on the landscape.

Forest succession, growth, mortality, seed dispersal, and disturbance in the Pockwock and Lake Major watersheds were simulated using LANDIS-II, a stochastic landscape disturbance model that operates in a spatially explicit rasterized landscape, which is stratified into areas of similar abiotic conditions, called ecoregions. Tree species are represented by species-age cohorts that are aggregated by user-defined successional time-steps, whereby any raster cell of user-defined resolution can have a unique combination of tree species-age cohorts (Scheller et al., 2007).

2.2. Baseline parameterization

Site and tree-species parameters for the models were derived from the peer-reviewed literature (Baldocchi et al., 1988; Pastor and Post, 1988; Burns and Honkala, 1990; Aber et al., 1996, 1997; Goodale et al., 1998; Scheller and Mladenoff, 2005; Xu et al., 2009; Bourque et al., 2010), survey data we collected in the field, and consultation with local experts in forest ecology. Model behavior, in terms of forest composition, biomass, and age, were consistent with provincial inventory data, existing studies, and expert opinion (Townsend, 2003).

Disturbances simulated were wind, bark beetle, and timber harvest. Bark beetle disturbance was parameterized to simulate the native spruce beetle (*Dendroctonus rufipennis*) and the introduced brown spruce longhorn beetle (*Tetropium fuscum*), which are important disturbance agents in the watersheds (Table 1; Magasi, 1995). Host species were white spruce (*Picea glauca*), black spruce, and red spruce, and outbreaks were considered chronic, with low rates of mortality occurring at every time step. It was also assumed that the study area was large enough to implement outbreaks as spatially synchronous (Sturtevant et al., 2004). Four different wind disturbance regimes were parameterized using a review of historical disturbance regimes for the region (Seymour et al., 2002; Keys et al., 2003), which included frequent stand-initiating, moderate stand-maintaining, infrequent catastrophic, and gap dynamics (Table 1).

Climate change data used in the modeling were downscaled data from the Third Generation Coupled Global Climate Model (CGCM3) under the SRES-A2 emissions scenario, where