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A value-added forest management policy reduces the impact of fire on timber production in Canadian boreal forests

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ABSTRACT

When fire rates are sufficiently high, fire disturbances can have negative impacts on industrial timber supplies. One can mitigate such problems at the strategic level by accounting for potential fire losses in the timber supply planning process by reducing harvest levels to maintain a buffer stock of timber. With a forest planning model based on a timber volume maximizing policy, reducing the harvest level will lead to a reduction in the harvested timber volume and likely, of revenues. One possible solution is to change the policy to increase the value of the wood that is harvested so as to minimize such reductions with less risk. We have evaluated alternative policies for three commercially-managed forests that have different burn rates in northeastern Canada. When compared with a volume-maximization policy, a revenue-maximization policy that considers sustained production and the sale of sawmilling wood products (lumber, chips and sawdust) increased mean revenues by 130% (36–770%) with > 0.90 probability and substantially decreased the area and volume harvested by 27% (11–38%) and 28% (14–36%), respectively. By reducing the harvest volume, the total number of jobs associated with forest operations decreased by 20% (10–27%) but the number of jobs per unit area harvested and volume increased. The policy also increased the harvest age and thereby enhanced the retention of a greater proportion of old-growth stands. Our study indicated that a tighter link between strategic planning and wood product processing helped identify better compromises between harvesting activities and revenues, despite the occurrence of natural disturbances.

1. Introduction

Many forest ecosystems, including the boreal forest, which represents the world's second-largest forest biome, coevolved with natural disturbances. Natural disturbance history, together with climate, surficial deposits, drainage and forest successional dynamics, generate a complex mosaic of ecosystems. As a result, the boreal forest is rich in economic (e.g., both timber and non-timber), environmental (carbon sequestration, water regulation, wild flora and fauna) and social resources (e.g., employment and recreation) (Brandt et al., 2013). The Canadian boreal forest represents 32% of forests worldwide and encompasses half of the forests of North America (Schlesinger and Bernhardt, 2013). It contributes 40% of Canada's wood supply (Bogdanski, 2008). Commercial exploitation of wood in Canada increased by 70% from 1970 to 2004. Though harvest levels began to decrease in 2005 and reached the 1970 level (120 $Mm^3\ y^{-1}$) in 2009, they resumed their increase and reached 148 $Mm^3\ y^{-1}$ in 2013 (Natural Resources Canada, 2015). Consequently, harvesting activities have expanded northwards into less productive and fire-susceptible boreal regions (Powers et al., 2013). Harvesting and transportation costs in remote northern forests have made the forest products industry less profitable and more vulnerable to timber supply disruptions caused by natural disturbances (Gauthier et al., 2014).

Forest planning consists of a three-step hierarchical process (strategic, tactical and operational steps) with an increasing level of detail and a decreasing time horizon at each step (Davis et al., 2001). The first step, strategic planning, is designed to assess the sustainability of harvesting and silviculture policies and practices over periods of up to one and a half rotations in length (Baskent and Keles, 2005) by forecasting wood supply based on data, models (e.g., stand-level yield curves), and assumptions concerning harvest and regeneration (e.g., succession rules). The objective of such analyses is to devise a forest management strategy that is designed to reduce the likelihood that ecological, social and economic resources are depleted by harvesting activities (Bettinger et al., 2009). At this step, the specific requirements of the forest industry are coarsely and conventionally described by maximizing the

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harvest of timber volume (Weintraub and Romero, 2006; Gunn, 2007), which can lead to uneconomic harvesting (Gunn, 2007).

The ability to account for risk and uncertainty in forest planning requires information which may or may not be available (Eyvindson and Kangas, 2018). Contrary to uncertainty which relates to lack of knowledge, risk is defined as an exposure to quantifiable losses. Risk analysis is a methodology designed to account for unexpected events and depends on the understanding of the potential impacts of a loss in terms of probability and their effects (Gardiner and Quine, 2000). Managers of public forests usually attempt to avoid risks, which implies that they select plans that have a high probability of success, i.e., with a high probability of achieving targeted levels of outcomes (Weber and Milliman, 1997; Savage et al., 2010) (e.g., $p \geq 0.90$). The integration of fire risk in strategic planning has been investigated since the 1980s (van Wagner, 1983), but its inclusion in strategic planning remains uncommon (Hanewinkel et al., 2011). One of the problems is the resulting size and complexity of the planning problems that need to be solved (Bettinger et al., 2009). As a risk mitigation strategy, the inclusion of fire effects in the planning process can result in a reduction of the harvest level (Armstrong, 2004; Savage et al., 2010) which forest managers are reluctant to implement because such reductions immediately affect potential income and regional economic activity (Patriquin et al., 2008; Raulier et al., 2013). Nevertheless, for the last 10 years, interest in applying risk analysis in forest fire management and strategic planning has been steadily growing (Savage et al., 2010, 2011; Miller and Ager, 2013; Gauthier et al., 2014).

In Canada, each province is responsible for the management of its forests on public land (Haley and Luckert, 1990). Forest tenure agreements on public land are negotiated in terms of volume in the provinces of Quebec and British Columbia (Rotherham and Armson, 2016). Consequently, timber supply calculations in these two provinces are based on the maximization of timber volume. The maximization of timber volume is still a guiding rule in forest management in many countries including Canada (Davis et al., 2001; Gunn, 2007). The objective of our study was to explore alternative policies with respect to their potential to reduce the impact of fire on timber supply economics through strategic planning. We hypothesized that one possible solution would be to deal with this by focusing on timber that can be used to produce high-value-added products. Increasing the value-added timber harvest is not by itself, a mitigation strategy against fire loss, but it may indirectly contribute to minimizing the loss of product value because it is positively related to log size-based wood quality recovery (Liu and Zhang, 2005). Since the harvested tree size depends on rotation age and longer rotation ages decrease the harvest flow at the forest scale (Cissel et al., 1999), the amount of timber available for harvest in successive periods will increase, which will reduce the probability of occurrence of timber supply disruptions caused by fire (Leduc et al., 2015). A change in forest policy from maximizing timber volume to maximizing product value during strategic planning should therefore indirectly help mitigate the impact of fire.

In order to examine this, we simulated the application of four different policy models. These policy models maximized: (1) timber harvest volume - a commonly-used planning objective (Davis et al., 2001; Gunn, 2007) in many countries including Canada (BFEC, 2013; Natural Resources Canada, 2015), (2) timber revenue from timber directly sold to the mills (Boychuk and Martell, 1996) and (3 and 4) revenue of primary-processed wood products - a vertically integrated model (Gunn and Rai, 1987; Rijal and Lussier, 2017). We developed timber harvest optimization models to design harvesting plans congruent with each policy. We then developed a landscape simulation model to simulate the implementation of those plans with a replanning process in interaction with fire. We used three forest management units with different mean annual burn rates located in the boreal forest region of Quebec (Canada) and compared the policies prescribed by models in terms of the impact of fire on several performance metrics. We identified risk zones corresponding to a range of outputs of performance metrics occurring with a specified probabilities produced by our simulation models.

2. Methods

2.1. Study area

In order to examine the effects of different fire rates on timber supply and forest sustainability, we selected three forest management units (FMU) that are located in the northern part of the commercially-managed forest in the province of Quebec (Canada) (Fig. 1). These three management units are located within the closed black spruce-moss bioclimatic domain (Robitaille and Saucier, 1998), but each has a different fire regime (Chabot et al., 2009; Mansuy et al., 2014), management history, species composition and age structure. Although black spruce (*Picea mariana* [Mill.] B.S.P.) dominates the forest landscape, jack pine (*Pinus banksiana* Lamb.) is more abundant in the central part of the study area (FMU 026–65) where the estimated mean annual burn rate during the 20th century was the highest (0.65% y^{-1}, Irulappa Pillai Vijayakumar et al., 2015). Balsam fir (*Abies balsamea* [L.] Mill.) abundance increases considerably in the eastern part (FMU 094–52), where the historical mean burn rate was the lowest (0.2% y^{-1}, Bouchard et al., 2008).

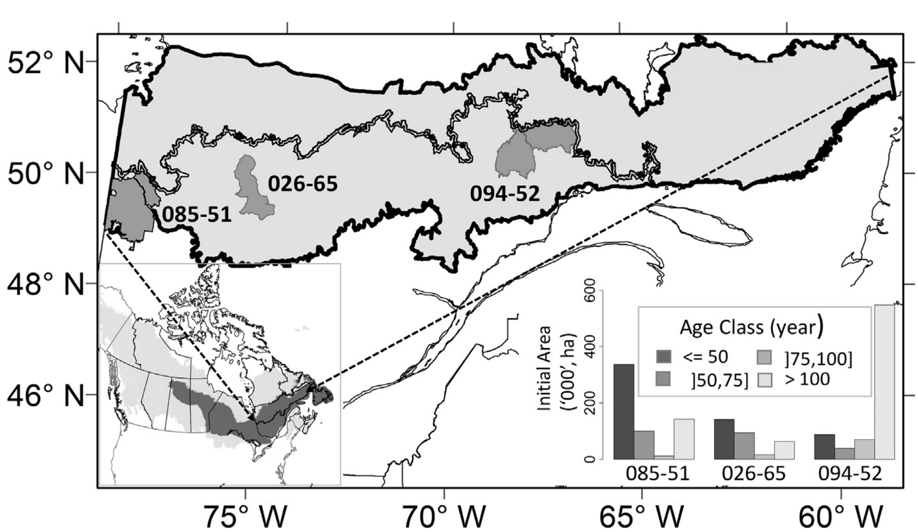

Fig. 1. Study area showing the spruce-moss forest (light grey), and three forest management units (FMUs, dark grey). The bold continuous line bounded polygon is the boreal forest and the double-line is the northern limit of commercially-managed forests in the province of Quebec (MRNFQ, 2000). The bar plots are the age class distributions of the initial forest condition in the three FMUs (2002–2004).