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Value-added forest management planning: A new perspective on old-growth forest conservation in the fire-prone boreal landscape of Canada

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ABSTRACT

The maintenance of old-growth stands is important for sustaining natural forest ecosystems, but fire disturbances and commonly-used timber harvest practices exert adverse impacts on the retention of old-growth forests. Forest management planning prescribes harvest levels based on the planning policy and models, but the impact of the management strategies on the retention of old-growth forests has not been well studied. The objectives of this study were to examine: a) the impact of implementing three different harvest policies on the retention of old-growth forest and b) the impact of implementing a policy of maintaining a targeted minimum of 20% old-growth area on the harvest revenue that would be generated over a long planning horizon. To simulate the implementation of these policies, we developed three strategic timber harvest-scheduling models. The first model (Model 1) maximizes harvest timber volume; Model 2 maximizes the net present value (NPV) of the timber harvested; and Model 3 maximizes the NPV of value-added products at the primary processing mills. The value-added products we considered were lumber, chips and sawdust. The models were solved for three forest management units with different fire regimes. Solutions to models that did not include a strict constraint on old-growth forest area retention did not retain the targeted level of old-growth forest over a 150-year planning horizon. When an old-growth constraint was implemented, Model 3 produced the greatest revenue with the least variation by 5-year period over the planning horizon. The probability of finding a feasible solution to our optimization Model 3 with an old-growth forest constraint increased to 0.87–1.0 compared with 0.71–0.83 using Model 1, and 0.78–0.87 using Model 2. We conclude that the value-added policy model increases the probability of sustaining the bioeconomy while preserving forest ecosystems initiated by disturbance.

1. Introduction

The production of high-value timber is an important aspect of commercial forest management that aims to sustain a forest-based bioeconomy and wood products industry in the face of changing forest production and world markets (Toppinen et al., 2010). The timber supply available at any time depends upon past management activities (e.g. silviculture treatments and harvest schedules), the disturbance regime that was experienced during the preceding periods, and long-term forest site productivity. Long-term timber supplies are routinely projected using linear programming models that produce optimal solutions that specify harvest plans and silviculture schedules in interaction with forest structure, growth dynamics and forest management objectives. The harvest plans are periodically revised at specified time intervals (e.g. 5 or 10 years; Savage et al., 2010) to account for unpredicted changes in forest structure and production or to accommodate the effects of disturbance events on timber supply (Jensen and Bard, 2003). Periodic replanning over a rolling planning horizon in which only the planned activities for the first period are implemented (e.g. BFEC, 2013) ensures a long-term flow of harvests.

Traditional forest management planning is largely based on sustained-yield harvest policies that maximize harvest volumes which favour an even flow of harvest volume by period over a planning horizon (Davis et al., 2001; Gunn, 2007). In addition, the classical Faustmann model (Faustmann, 1849) that maximizes stand-level net present value (NPV) of the harvest is also used in forest level management planning

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(Davis et al., 2001). Such harvest policies account for dynamic growth processes, but they do not account for ecosystem conservation or industrial sustainability over long planning horizons. Alternative forest harvest policies and modelling frameworks based upon explicit economic principles in an integrated framework within the wood processing industry (e.g. Barros and Weintraub, 1982; Gunn and Rai, 1987) have also been suggested, but there remain conflicts between the production of commodities and the provision of ecological services (Mönkkönen et al., 2014).

Conservation of the ecological integrity of managed forests is an important aspect of sustainable forest management for which the maintenance of mature and old-growth forest stages is important (Esseen et al., 1997). The rotation age in eastern Canada ranges from 70 to 100 years (Bouchard and Garet, 2014), which poses threats to old-growth forest stands. Ecosystem-based forest management practices have been developed to maintain natural ecosystem integrity by narrowing the gap between the natural processes of stand development dynamics (*viz.,* initiation, stem exclusion, re-initiation and old-growth (Oliver, 1980)) and commercial forest management (Gauthier et al., 2009). From an ecological stand point, old-growth stands have higher structural and functional diversity than younger stands (Chambers and Beckley, 2003). Consequently, the total area of old-growth stands on the landscape scale is a key indicator of structural diversity (Powelson and Martin, 2001; Fall et al., 2004). When the effects of disturbances such as stand replacing fire are accounted for in a volume-maximizing model, both the rotation cycle and the old-growth forest area decrease (Martell, 1980; Savage et al., 2011). Moreover, when economic parameters are included in such models, rotation ages decrease further, depending upon the discount rate (Clark, 2005), which also reduces the proportion of old-growth forests.

Harvest activities and the disturbance regime affect forest age structure (e.g. Fall et al., 2004; Barclay et al., 2006; Didion et al., 2007; Bergeron et al., 2017) and, not surprisingly they have economic consequences (Binkley et al., 1994). Management solutions can restore or maintain the targeted proportions of old-growth forest area by retaining a portion of the old-growth stands (Seymour and Hunter, 1999), by lengthening the rotation cycle (Burton et al., 1999; Koskela et al., 2007), or by the use of silviculture treatments that retain or support the creation of some structural characteristics that are similar to old-forests (Bergeron et al., 1999), or triad management (Messier et al., 2009; Tittler et al., 2012). However, the economic impact of using such alternative solutions to retain old-growth stands has not been well studied. Although, old-growth forests have been defined in many ways (Wirth et al., 2009), in this paper, we consider a stand to be an old-growth stage when it enters its old-growth phase as defined by Oliver (1980) or when post-disturbance cohorts start dying (Franklin et al., 2002; Kneeshaw and Gauthier, 2003). This consideration matches forest-harvesting activities that result in gap creation that may be similar to the gap (shape, size and frequency) dynamics of natural disturbance in terms of canopy openness, which is a key attribute of ecosystem-based forest management (Hunter, 1993). It is consistent with the definition used by the Ministère des Forêts, de la Faune et des Parcs du Québec (MFFPQ). Forest management policies that ensure the preservation of at least some specified proportion of old-growth forest areas are often recommended in order to conserve forest ecosystems (e.g. in Quebec, Jetté et al., 2013; Bouchard et al., 2015) but the adoption of such policies may reduce harvest volumes. In some cases, the formulated optimization problems do not have feasible solutions, which results in zero (no) harvest volume during some planning periods (Conrod, 2010; Savage et al., 2011). Such fluctuations or zero-harvest situations jeopardize economic opportunities. Managers should aim to minimize such potential adverse impacts on economic opportunities when the old-growth forest area constraint is strictly implemented. One possible option may be to employ alternative harvest policies that increase efficiency in revenue production (Rijal and Lussier, 2017), which implies high-value harvest prescriptions rather than timber volume production, as dictated by classical volume-maximizing models.

The objectives of this study were to; (a) examine the impacts of implementing three different harvest planning policies on the preservation of old-growth forest area, and (b) evaluate the effects of those policies on the revenues from timber harvest to the sawmill, while meeting the old-growth forest level strict requirements. The first policy maximizes the harvest volume subject to constraints on the long-term even-flow of harvest volume over the planning horizon. The second policy maximizes the NPV from the sale of the harvest log volume subject to the same constraints. The third policy maximizes the NPV for the first two periods from the sale of value-added products subject to the even-flow of high-value products over the planning horizon. We treated processed products at the primary processing mill, namely, lumber, wood chips and sawdust, as value-added products. We used data for three commercially-managed boreal forests in the province of Quebec, Canada and developed three harvest scheduling optimization models, one for each policy that accounts for the potential impacts of fire on supply.

2. Methods

2.1. Study area

The boreal forest region is the most fire-prone in the province of Quebec. It has been subjected to increased anthropogenic disturbance as timber-harvesting activities have been gradually extended northward (Powers et al., 2013). We selected three forest management units (FMUs) from the fire-prone boreal region (Fig. 1). These FMUs have distinct initial age structures (which are dominated by immature and old-growth stands), an indicator of varying harvest and fire regime histories. These three management units are in the black spruce-feather moss bioclimatic domain within the continuous boreal forest subzone (Robitaille and Saucier, 1998). Black spruce (*Picea mariana* (Mill.) BSP) dominates the region. Jack pine (*Pinus banksiana* Lamb.), a species that is well adapted to fire, is present in the central part of the study area (FMU 026-65). This FMU represents the most flammable forest in the boreal region (mean annual burn rate: 0.48% year^{-1}; details follow) of Quebec and has a relatively longer history of harvesting activities. The forest is dominated by immature (≤ 50-years-old) stands (43% of total area) and a lower proportion (21%) of old-growth (≥ 100-years-old; Jetté et al., 2013) compared with the historical proportion of old-growth forest area (Bouchard et al., 2015; Annex C). The eastern forest management unit (094-52) is dominated by old-growth forest (73%; Table 1). This condition may be due to the relatively recent introduction of harvesting activities (< 30 years; Bouchard and Pothier, 2011) and a low annual burn rate (0.06% year^{-1}) compared with the other two FMUs. It has substantial proportion of balsam fir (*Abies balsamea* (L.) Mill.) followed by black spruce. The western forest management unit (085–51) has been intensively harvested since the 1970s (Belleau and Légaré, 2009) and is characterized by a dominance of immature (51%) stands. This FMU has an intermediate mean annual burn rate of 0.13% year^{-1}.

2.2. Data

We used (a) forest inventory, (b) financial, (c) fire and (d) spatial data. The forest inventory (2002–2004) data were obtained from the MFFPQ. We constructed strata-based yield tables by dividing each FMU into aspatial strata based upon landscape unit and cover type to represent biogeographically specific growth potentials. A landscape unit is defined as “a portion of landscape characterized by a recurrence of environmental attributes (type of relief, average altitude, nature and proportion of the main surficial deposits, hydrography) and vegetation factors” (Robitaille and Saucier, 1998, page 3). The landscape unit allows for a specialization of forest composition and growth variability based on soil and bioclimatic parameters. The forest management units

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