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Improving sustainability of value-added forest supply chain through coordinated production planning policy between forests and mills

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ABSTRACT

Commonly-used sustained yield harvest policies ensure sustained supply of harvest timber volume over a planning horizon. However, implemented policies gradually decapitalize forest values over time that threatens the sustainability of ecosystem and wood industries. Different business units of a forest-product supply chain have different ways of valuing forestry resources, different supply and demand policies, and corresponding business policy models to implement them. The objective of this study was to evaluate ecological and economic impacts to participating business units of a supply chain when implementing different business policies. We constructed six business models in a linear programming framework and solved them using data from commercially-managed forests. Our empirical results showed that compared to a base model (Model 1; unilateral decision by forest business unit), the best model (Model 6; integrated harvest and production planning) reduced the median harvest volume and area by 25% (12–31%) and 24% (7–40%), respectively, but increased net revenue by 88% (6–218%) over a 150-year planning horizon. Hence, efficiency increased by 158% (20–373%) per unit of harvest area and 163% (23–364%) per unit of harvest volume. Furthermore, when the models were simulated using a hard constraint to preserve at least 20% of old-growth forest area, the revenue was least affected (15%; 11–19%) by Model 6 compared to Model 1 (26%; 14–45%). We conclude that vertically-integrated harvest policy that embeds forest values in the planning model reduces the gap between the business units, and enhances ecosystem conservation with the least fluctuation of harvest and revenue by period over a planning horizon.

1. Introduction

Timber supply, defined as the amount of timber available for harvest from a specific area over time, is an important component of commercial forest management and industrial planning. Traditional forest management is mainly guided by a volume-maximizing harvest policy that maintains a constant level of timber harvest volume through a planning horizon (Davis et al., 2001; Gunn, 2007). It respects the sustainability (non-declining) of forest commodity supply but has received criticism for ecological sustainability (Millennium Ecosystem Assessment, 2005) and the policy often prescribes noneconomic harvest characteristics (Gunn, 2007). There are many studies that show the necessity of including economic parameters in planning models to account for the value of harvest since the 1980s (e.g., Barros and Weintraub, 1982; Gunn and Rai, 1987; Wear and Parks, 1994). However, the sustained-yield policy is still a deep-rooted guiding principle in timber harvest planning including Canadian forest management (Natural Resources Canada, 2007). In addition, Faustmann's (1849) classical model, which maximizes the stand-level net present value (NPV), is also used in forest management (Gunn and Rai, 1987). These sustained yield (volume)-based policies account for the growth process, however, neither of them account for industrial sustainability. On the other hand, there are a number of industrial productions planning models, but they do not account for forest regenerations and growth processes (Gunn, 2007). Their objectives and spatiotemporal scales of hierarchical planning horizons vary considerably (D'Amours et al., 2008).

A pathway of product movement, through which the harvested timber flows and is processed, consists of multiple business units from the stump to its end-use including intermediaries. Incremental level of their values through the chain vary. This term is often called with a catchword – "value-added supply chain," and consists of a set of business units (links) involved in the path (La Londe and Masters, 1994). The activities offered at each unit correspond to the value-added transaction of the products. Christopher (2005) defines a supply chain as a network of organizations that are involved through upstream and

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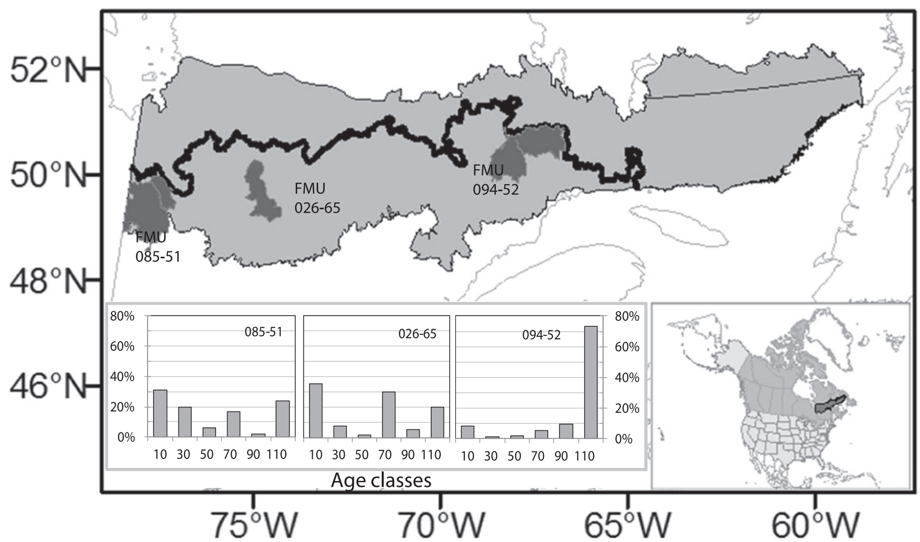

Fig. 1. Study area, showing the boundary of spruce-moss forest (light gray), and three forest management units (FMUs) (dark gray). The bold continuous line shows the northern limit of commercial forests in Quebec (MRNFQ, 2000).

downstream linkages for the different processes and activities that produce value in the form of products and services ultimately delivered to consumer. Normally, each unit involved in the chain acts independently (Thomas and Griffin, 1996).

Forest product supply chains may be considered hierarchical in their design because forest business units act as principals or leaders. While this is considered an upper-level problem, wood industry acts as an agent or follower and hence a lower-level problem (Laffont and Martimort, 2009; Paradis, 2016). The forest business unit often assumes that all of the harvest products (limited to timber in this analysis) from the forest would be consumed by the consumers (e.g., wood industry) regardless of cost, quality and potential net revenue. In a bi-level decision process (which may be extended to multi-level), each business unit independently optimizes its own objectives, but one is affected by another action (Colson et al., 2007). This situation is the most common across managed forests in Canada. This is the reason in part why the actual harvest is generally lower than planned annual allowable cut (AAC) (Natural Resources Canada, 2013). When harvest planning in principal does not include econometric values to agent, part of the AAC is noneconomic to the agent (Gunn, 2007).

Another alternative policy consists of integrated structure among the business units. The policy accounts for supply chain values in a single management framework (Ferber and Gutknecht, 1998) and decisions are taken jointly (Gereffi, 1999). As an agent-based model, both are informative in such a way that they determine the parameters across the chain (Gereffi, 1999). Because the forest products value chain is often hierarchical with the forest as upper level and industry as lower level (Paradis, 2016), the value chain among the business units are often described as having a vertically-integrated structure. In practice, most of Crown forest lands in Canada are vertically integrated with forest industry (Barros and Weintraub, 1982) for forest operation and management, but decision processes in harvest allocations are solely made by government authorities unilaterally (e.g., in Quebec, BFEC, 2013; Bouchard et al., 2016).

Forest management should thrive to maximize economic efficiency to a supply chain, i.e., high revenue sharing from harvesting to the participating business units. In the same time, conservation of ecological integrity of forests is an important element of sustainable forest management and it is being an increasing concern of commercially-managed public forests. While sustained revenue generated by the harvest prescriptions is considered an indicator of sustainability of forest industry, harvest rate and proportion of old-growth forest area maintained by the forest management policy may be considered the indicators of maintaining forest ecosystem (Seymour and Hunter, 1999) and structural diversity (Fall et al., 2004; Powelson and Martin, 2001).

Instead, conflicts exist between the production of commodity and ecological services, and they are not new (Mönkkönen et al., 2014; Nalle et al., 2004). There is no such study that has examined the possible outcomes of both ecological and economic values of the forest and the benefits sharing among the participating business units of the supply chain in an integral framework.

We hypothesized that an appropriate strategic planning model can be a better alternative that yields higher level of co-benefits by increasing economic efficiency and lowering harvest disturbances. The main objective of our study was to comparatively examine the impacts of implemented business policies on sustainability of forest economics and ecosystem. We considered the problem to two business units in a supply chain, namely: a) a forest business unit (forest owner), and b) a primary processing mill. We constructed six business planning models corresponding to three business policies in which decision processes of harvest and procurement planning would be taken by: a) the forest business unit acting as a principal, b) two business units acting independently, and c) two business units jointly acting as an integrated agent. Our analyses consisted of simulated implementation of harvest policies models that were constructed in a linear programming solution framework and solved them based on empirical data for commercially-managed boreal forests of eastern Canada.

2. Method

2.1. Study area

We selected three forest management units (FMUs) located in the boreal region of Quebec Province, Canada (Fig. 1, Table 1). Each FMU represents commercially-managed public forests lying in a single administrative jurisdiction in Quebec's provincial forest management. Forests in the region have varying management histories and disturbances regimes. The commercial harvesting activities in the western forest started in the 1970s (Belleau and Légaré, 2009). In contrary, the harvesting activities in the eastern forest is relatively new (< 30 years; Bouchard and Pothier, 2011). Although, there are different silvicultural methods, cutting all of the mature trees and ensuring protection of regeneration and soil dominates in the region ("Coupe avec Protection de la Regéneration - CPRS") (MFFPQ, 2016). Fire is a ubiquitously important disturbance agent across the boreal region. However, the fire return interval is relatively long in the eastern forest (1700 years) compared to the central (200 years) and western (750 years) forests (BFEC, 2013). The harvesting and variability of disturbance regimes have created forests of complex age-structures and species compositions in the boreal landscape. We covered varying initial age structures by