Forest Policy and Economics 46 (2014) 47–55

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Increasing resilience of timber supply: How a variable buffer stock of timber can efficiently reduce exposure to shortfalls caused by wildfires

Frédéric Raulier [a,*], Narayan Dhital [a], Pierre Racine [a], Rebecca Tittler [b], Andrew Fall [c]

[a] Centre d'Étude de la Forêt, Faculté de Foresterie, de Géographie et de Géomatique, Université Laval, 2405 rue de la Terrasse, Québec, Québec, G1V 0A6, Canada
[b] Centre d'Étude de la Forêt, Université du Québec à Montréal, C.P. 8888, Succ. Centre-Ville, Montréal, Québec, H3C 3P8, Canada
[c] School of Resource and Environmental Management, Simon Fraser University, Burnaby, British Columbia, V5A 1S6, Canada

ARTICLE INFO

Article history:
Received 22 November 2013
Received in revised form 28 March 2014
Accepted 20 June 2014
Available online 7 July 2014

Keywords:
Timber supply planning
Sustainability
Risk assessment
Forest fire
Boreal forest
Contingency inventory

ABSTRACT

On a forest management unit in the boreal forest of eastern Canada, we used a landscape simulation model to evaluate a strategy to protect timber supply planning against the risk of failure due to wildfires. This strategy involves associating such risk to intolerable timber supply disruptions with a probability of occurrence $(1-\alpha)$. We increased the chance of planning success by controlling a buffer stock of timber, which varied as a function of the probability of failure (direct management of a buffer stock). We assessed the robustness of this protection strategy by considering three fire regimes (current and two greenhouse gas forcing scenarios). The maximum risk of failure was strongly affected by the age structure of the forest, while the median risk was more closely linked to the fire regime. The median rate of harvest success was more strongly affected by the planned level of supply. Direct management of a buffer stock of timber was more efficient than reducing the planned timber supply level by a fixed percentage throughout the planning horizon. Timber supply was used in the present study but this approach could be applied to other ecosystem services to improve the resilience of forest management.

1. Introduction

Sustainable forest management aims to satisfy social and economic objectives while maintaining forest ecosystem diversity and function (Seymour and Hunter, 1999; Luckert and Williamson, 2005). Within the context of sustainable forest management, forest management planning must demonstrate that the forest can be managed sustainably over a very long period of time (= strategic forest management planning; Gunn, 2007). A timber supply problem is used for this purpose and is normally solved with linear programming (Gunn, 2007; Bettinger et al., 2009). By definition, the optimal solution corresponds to the maximum periodic harvest level that respects all the constraints of sustainability and resource availability. This solution lies at the border of a feasibility domain delimited by the constraints of the problem, making the solution vulnerable to uncertainties in inputs or hypotheses and exposed to the risk of violating the constraints (Bertsimas and Sim, 2004), and hence has low resilience. Many different techniques exist to account for uncertainties in planning and to protect against such failure (see Verderame et al., 2010, for a review), but current timber supply calculations remain so complex that only a deterministic planning method (i.e. linear programming) is considered for practical purposes (Gunn, 2007; Bettinger et al., 2009). This situation, where risks are simply ignored, corresponds to the default strategy of "passive acceptance" (Tomlin, 2006).

Stand-replacing disturbances (e. g., fire, insects and windstorms) are key drivers of natural forest dynamics because they reinitiate the process of forest succession. Severe disturbances, especially fire, are controlled by climate (Parisien et al., 2011), and thus are strongly variable in space and time (stochastic processes). This stochasticity may affect timber supply and should thus be taken into account during forest management planning (Van Wagner, 1983; Peter and Nelson, 2005; Kolström et al., 2011; Hildebrandt and Knoke, 2011), at least to assess the vulnerability of the targeted timber supply to shortfalls. In practice, it is not considered for two reasons (Armstrong, 2004; Savage et al., 2010). First, as discussed above, the process of timber supply calculation is already very complex. Second, timber supply calculations are redone periodically (every 5–10 years) and the occurrence of a major disturbance event triggers a new timber supply calculation (e.g. Savage et al., 2010). This periodic replanning is generally considered to be adequate when it involves a constant reduction of the harvest level to compensate for disruptions of supply caused by fire (Armstrong, 2004; Savage et al., 2010). This reduction results in setting aside a contingency inventory (Tomlin, 2006) to provide sufficient flexibility at times of unexpected timber losses (Peter and Nelson, 2005), and has been termed a *buffer stock* of timber (Boychuk and Martell, 1996; Peter and Nelson, 2005).

* Corresponding author. Tel.: +1 418 656 2131x6742; fax: +1 418 656 5262.
E-mail address: frederic.raulier@sbf.ulaval.ca (F. Raulier).

http://dx.doi.org/10.1016/j.forpol.2014.06.007
1389-9341/

However, reducing the timber supply level by a fixed percentage throughout the planning horizon to manage a buffer stock (indirect management) may be ineffective because the quantity of merchantable wood fluctuates through time due to a forest age structure naturally disequilibrated by disturbance (Armstrong, 1999). The forest age structure describes the distribution of forest area by stand age classes. There are specific periods in the planning horizon when the volume of harvestable wood is closer to the planned level of supply. During these periods, the timber supply is more vulnerable to disruptions caused by fire (Peter and Nelson, 2005). At such times, a buffer stock might be useful to protect timber supply (direct management of a buffer stock). However, at other times, the available supply could well sustain losses caused by fire without a buffer stock.

This varying exposure to risk can be linked to the concept of value-at-risk (VaR) used in econometrics (Stambaugh, 1996). The VaR measures the downside risk an investment is exposed to over a specific period of time. It is equal to the difference between an expected profit and the profit corresponding to an α percentile of the cumulative probability distribution of possible profits. In connection with timber supply, the VaR could be defined as the difference between a minimum acceptable level of supply (*sensu* Peter and Nelson, 2005) and the lowest level that could occur at a specific period of the planning horizon with a probability of $(1 - \alpha)$. VaR can therefore be used as an indicator to measure the level of exposure of different scenarios (Stambaugh, 1996). Despite their potential usefulness, neither VaR nor any other financial valuation techniques are commonly used in forest management planning to increase the robustness of the decision-making process toward risk (Hildebrandt and Knoke, 2011).

The objectives of this study were thus (a) to test the applicability of VaR to timber supply planning, with particular emphasis on decreasing the risk of timber supply disruptions due to wildfires, and (b) to rate this protection strategy against that of reducing the planned harvest level by a constant proportion across the whole planning horizon (direct vs. indirect management of a buffer stock of timber).

2. Material and methods

2.1. Study area

The study area is a forest management unit located in western Quebec, Canada (FMU 85-51). It covers an area of 10,830 km^2 with abundant wetlands, peatlands, and water bodies (4580 km^2). The forest is fairly homogeneous and is dominated by stands of pure black spruce (*Picea mariana* (Mill.) B.S.P.). The FMU can be subdivided into two broad forest zones on the basis of dominant soil deposits: thick organic deposits in the north and clay-rich tills in the south (Robitaille and Saucier, 1998). Mean annual temperature varies from −2.5 °C to 0 °C and total annual precipitation is 700–800 mm. The length of the growing season ranges from 150 to 160 days (Robitaille and Saucier, 1998).

The current mean burn rate has been estimated at 0.25% year^{-1} for the period from 1920 to the present (Bergeron et al., 2004). For the study area, Gauthier et al. (2004) described three main successional pathways dominated respectively by black spruce, jack pine (*Pinus banksiana* Lamb.), and trembling aspen (*Populus tremuloides* Michx.), the largely predominant pathway being the one dominated by black spruce in poorly-drained areas. A successional pathway is a typical pattern of vegetation succession through time due to particular site conditions, stand composition before disturbance, and stand-reinitiating disturbance. Gauthier et al. (2004) subdivided each of these pathways into three age cohorts as a function of the time since the last stand initiating fire with transitions between cohorts at roughly 150 (expected longevity of black spruce) and 275 years (expected time for the complete disappearance of first-cohort trees).

2.2. Forest stratification and data aggregation

As is common in Canada's boreal forest, the company responsible for forest management in the study area wanted to apply an ecosystem-based management (EBM) strategy to their next management plan to help meet certification standards (Forest Stewardship Council, 2004). For this area, Gauthier et al. (2004) suggested targeting a forest age structure based on the natural fire regime and forest dynamics (multi-cohort approach), aggregating harvest blocks to reproduce a natural disturbance pattern at the landscape scale, and maintaining cumulative clear-cutting and natural disturbance rates below the historical range of disturbance (Bergeron et al., 1999).

Thus, two levels of forest stratification were used to emulate this EBM strategy: operating areas and successional pathways. Operating areas, used to concentrate (at a finer scale) and distribute (at a coarser scale) harvesting activities over the territory, were delimited on the basis of stand composition and physical limits such as rivers and lakes (Annie Belleau, biologist, MRN, pers. comm.). Their size varied from 30 to 150 km^2 to emulate the observed distribution of fire size within the management unit (Bergeron et al., 2004, their Fig. 8).

Successional pathways were based on the forest stratification carried out by the Quebec Ministry of Natural Resources (MRN) for the 2008–2013 planning period. Stated briefly, stand polygons were delineated from a mosaic of aerial photos and grouped into management strata according to photo interpreted stand composition, age, and cover density. Strata were biometrically characterized with 2696 sample plots located in stands with similar photo interpreted properties and within the constraints of the hierarchical ecological forest classification of Robitaille and Saucier (1998). The successional pathway of a stratum was then assigned from the yield curve compiled by the MRN using the stand yield model of Pothier and Savard (1998). For this purpose, Dhital et al. (2013) used the cohort description of Nguyen-Xuan (2002) based on stand structural attributes to assign a successional pathway and cohort to the sample plots in the study area, then used these plots to calibrate two identification keys and a logistic model to predict successional pathway and cohort from species yield volume proportions and stand age. Finally, we regrouped strata with the same successional pathway by operating area, and the yield curve of a successional pathway in a given operating area was estimated from weighted-area averages of the MRN yield curves. In total, there were 321 strata (107 operating areas × 3 successional pathways).

2.3. Harvest planning

Timber supply calculations were carried out with a Model II formulation. In a Model II, decision variables identify the areas where individual harvesting practices are planned at a specific time period of the planning horizon, in opposition to a Model I formulation where they correspond to individual sequences of harvesting practices applied over the planning horizon to a specific stratum (e.g. Davis et al., 2001, pp. 608–611). Like Armstrong (2004: Eq. (4)), the objective of the model was to maximize the planned supply level for the first 5-year period of calculation using the following equations:

Let

a	stand age
s	successional pathway (1..3)
o	operating area (1..107)
h	harvesting method combined with a regeneration method (1..6)
p	period (1..30)
c	cohort number (1..3)
T_c	Timber production area belonging to cohort c, ∀ c, following the targeted forest structure