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Spatial distribution of carbon in natural and managed stands in an industrial forest in New Brunswick, Canada

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Abstract

Industrial forest could be managed to enhance carbon (C) sequestration together with other ecological and socio-economic objectives. However, this requires quantifying C dynamics of all major forest types within the management area, over the whole forest rotation. We used data from permanent sample plots and temporary forest development survey plots to generate volume yield curves and used the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) to estimate C yield and dynamics over a rotation for major forest types in northern New Brunswick, Canada. We compared C yields of natural versus managed and hardwood versus softwood forest under different silviculture treatments over the entire rotation. Carbon in 40–80-year-old and > 80-year-old tolerant hardwood stands averaged about 115 and 130–142 t ha^{-1}, respectively, while softwood spruce (*Picea* sp.)–balsam fir (*Abies balsamea* (L.) Mill.) 40–80 and > 80 years old averaged 90 and 88–94 t C ha^{-1}. Among 10 stand types, total C ranged from 50 to 109 t ha^{-1} at age 50 years, 92–138 t ha^{-1} at age 100, and 79–145 t ha^{-1}at age 150 years. C in most stand types declined from age 100 to 150 years, except for eastern white cedar (*Thuja occidentalis* L.), sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton). At age 100 years, planted softwood stands had 94–135 t ha^{-1}, versus 92–117 t ha^{-1} for natural softwoods and 127–138 t ha^{-1} for natural hardwoods. Planted white spruce (*Picea glauca* (Moench) Voss) and natural sugar maple and yellow birch sequestered the most C. The total C (above and belowground biomass and deadwood, excluding soil carbon) on the 428,000 ha test landbase was 35 million tonnes, or an average of 82 t ha^{-1}.

Keywords: Forest carbon; Sequestration; Timber supply models; Forest management; Indicators; Tolerant hardwood; Spruce; Balsam fir; Dead organic matter

1. Introduction

Quantification of forest carbon (C) has recently gained in importance to forest managers, largely due to the Kyoto Protocol and global warming (Kurz and Apps, 1999; Phillips et al., 2000; Sohngen and Mendelsohn, 2003; Nelson and de Jong, 2003; Baral and Guha, 2004). Increased atmospheric carbon dioxide (CO_2) is considered to be responsible for global warming and climate change (Heath and Smith, 2000; Phillips et al., 2000). Forest managers are interested in quantifying forest C stocks on their landscapes and influence of management on C sequestration (Heath and Smith, 2000; Smith and Heath, 2001).

Forest ecosystems act as atmospheric filters of CO_2. Forests sequester C from the atmosphere through the process of photosynthesis and store C in woody biomass. Mortality transfers C from biomass to forest soils, coarse woody debris (CWD), litter and other forms (Lee et al., 2002). There are opportunities to increase the amount of C in forest ecosystems through intensive management or longer harvest rotations (Hoen and Solberg, 1994; Van Kooten et al., 1995; Murray, 2000; Sohngen and Mendelsohn, 2003). Should managers choose, or be obligated, to quantify C stock changes on forest landscapes, a quantifiable measure of C is needed for integration into current management planning.

Several studies have quantified stand-level C in forested ecosystems (e.g., Granier et al., 2000; Law et al., 2001; Hazlett et al., 2005; McDowell et al., 2005; Smith et al., 2006), and others have done so at a larger regional or landscape scale (Dixon et al., 1994; Turner et al., 1995; Brown and Schroeder, 1999; Kurz and Apps, 1999; Bhatti et al., 2001; Banfield et al., 2002; Zheng et al., 2004; Fredeen et al., 2005; Liski et al., 2006). Scattered information regarding C dynamics for a limited number of stand types is insufficient to consider C

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sequestration with other management objectives in industrial forests.

Our objective was to establish a framework to generate C yield curves based on existing permanent sample plot and stand development survey data for major forest types in an industrial forest, over an entire rotation following different silviculture treatments. In particular, C yields are compared for natural versus managed and softwood versus hardwood forest. The C yield curves generated with this procedure could be directly used for C accounting under forest management scenarios, or be used to actively manage forest to enhance onsite C sequestration. C yield analysis of major forest types could assist forest managers to prioritize silviculture treatments intended to increase C sequestration, without modifying the entire forest management plan.

In this paper, we use a C simulation model to generate stand-level complete C temporal dynamics for all major forest stand types within the management zones. ''Complete C'' yields can then be used in timber supply models that can optimally time management interventions to capture stand mortality and to design sustainable resource management. Timber supply models are often flexible enough to accommodate conflicting objectives, such as managing for both timber and C through alternative harvesting scenarios. C yield data also permit calculation of the spatial distribution of C on the landscape, as a function of stand age and cover type.

We used the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3, developed from the CBM-CFS, and CBM-CFS2—Kurz et al., 1992; Kurz and Apps, 1999), stand volume yield curves, and forest inventory data to simulate living and dead C dynamics for natural and managed stand types. The objectives of this paper are to (1) develop C yield curves for living biomass and DOM pools; (2) compare C yield curves for natural versus managed, and hardwood versus softwood stand types; and (3) apply these curves to determine the spatial C distribution on a 428,000 ha Crown Forest Management Area (FMA) in New Brunswick, Canada. Our C yield curves project C content in five living biomass pools and nine dead biomass pools over a 275-year period.

In Neilson et al. (submitted for publication), we use these data in a decision-support framework to optimize timber harvesting and C sequestration planning, and evaluate a number of forest management scenarios which use the 'business-as-usual' approach as the control. Results suggested that maximizing C for 80 years would lead to a 5% forest C increase (1.67 million tonnes C across the FMA) above the business-as-usual scenario (Neilson et al., submitted for publication). Similarly, maximizing C from 2002 to 2012 would result in a 3% increase by 2012. A scenario to double the supply of softwood timber could, by 2062, increase softwood harvest by 94%, and total harvest by 47%, but would decrease the forest C pool by 9% from 2002 to 2082 (Neilson et al., submitted for publication).

2. Materials and methods

2.1. Study area

Our study area was the Upsalquitch FMA (Fig. 1), licensed to Bowater Maritimes Inc. in northern New Brunswick (47°25′–48°04′N, 65°45′–67°40′W). It includes portions of three ecoregions (Zelazny et al., 1989; New Brunswick Department of Natural Resources and Energy (NBDNRE), 1998), with 91% in the Northern Uplands, 3% in the Southern Uplands, and 6%

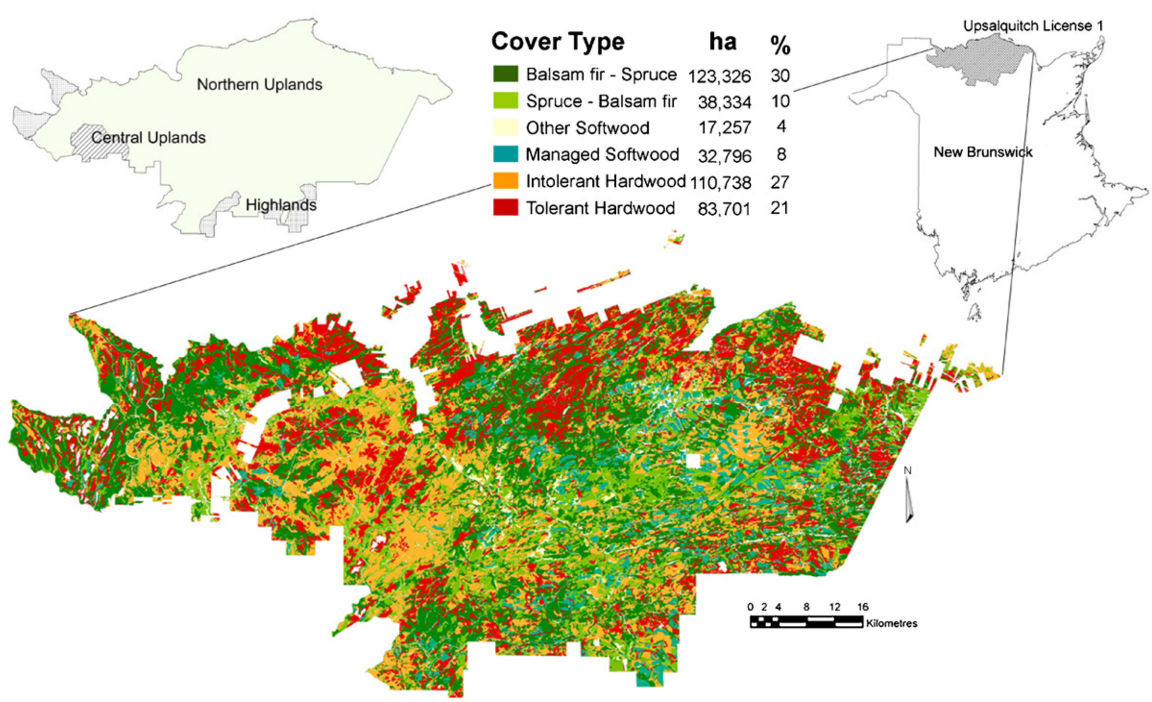

Fig. 1. Cover types of the Upsalquitch Forest Management Area with area and percent of total area listed, reference year 2002.