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A silvicultural decision-support algorithm for density regulation within peatland black spruce stands

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ABSTRACT

Determining the optimal density management regime for a given stand-level objective is a complex proposition faced by forest managers. Although decision-making for volumetric yield objectives has been greatly simplified with the advent of stand density management models, addressing new objectives arising from the paradigm shift towards the production of enhanced end-products and a broader array of ecosystem services remains a challenge when managing commercially-important boreal species. Consequently, the objectives of this study were to (1) develop an integrated modular-based structural stand density management model (SSDMM) and a corresponding algorithmic analogue for peatland black spruce (*Picea mariana* (Mill.) BSP.) stands, and (2) given (1), demonstrate its utility as a crop planning tool within the context of silvicultural decision-making. The SSDMM was developed using 495 tree-list measurements obtained from 137 permanent and temporary sample plots, remeasurement data from 30 Nelder plots, and published relationships derived from diameter distribution and height–diameter modelling studies, density control experiments and sawmill simulation analyses. The resultant algorithm enabled the evaluation of the rotational consequences of competing density management regimes in terms of overall productivity, log-product distributions, biomass production and carbon yields, recoverable end-products and their associated monetary value, economic efficiency, duration of optimal site occupancy, structural stability, and wood fibre attributes. The utility of employing the model as a generic modelling platform for structural yield prediction for other species is also discussed.

1. Introduction

Forested peatlands represent an important ecological resource throughout the northern portions of North America, Fennoscandia and Russia (Gorham, 1991; Lavoie et al., 2005). In Canada, monospecific black spruce (*Picea mariana* (Mill.) BSP.) stands which occupy poorly-drained organic peatland sites throughout the central portion of the Canadian Boreal Forest Region (Rowe, 1972) are an economically important societal resource. Paralleling historical trends in other jurisdictions such as Scandinavia and the Pacific Northwest region of North America, the focus of forest management has shifted towards the production of high-value end-products (e.g., select grade dimensional lumber) and the provision of a broader array of ecosystem services (e.g., bioenergy feedstocks, carbon storage, wildlife habitat, recreation activities), in order to maximize the economic and ecological value of Canada's forest resources (e.g., Emmett, 2006). Density management which includes initial spacing, precommercial thinning (PCT; reducing stand densities via the removable of unmerchantable-sized trees during the early stages of stand development) and commercial thinning (CT; reducing stand densities through the removable of merchantable-sized trees during the later stages of stand development), has been one of the principal silvicultural tools used to achieve these objectives (e.g., Zhang and Chauret, 2001; Lindh and Muir, 2004; Nilsen and Strand, 2008; Pitt and Lanteigne, 2008). However, with regards to peatland black spruce stands and other commercially important boreal conifer stand types, the availability of decision-support models for addressing this new management focus is practically nonexistent. Consequently, the objectives of this study were to (1) develop an integrated modular-based structural stand density management model (SSDMM) and an associated algorithmic analogue for peatland black spruce stands, and (2) given (1), demonstrate its utility as a crop planning tool via the comparison of competing density management regimes across a broad array of stand-level yield metrics and performance indices, reflecting volumetric, end-product, economic and ecological based outcomes. Furthermore, a number of improvements to the generic SSDMM framework which was originally described by Newton (2009) are implemented. Specifically, these included ensuring mathematical compatibility among yield estimates, accounting for intrinsic density-independent mortality, and response delay following thinning, and enabling end-users to tailor model outputs by varying merchantable specifications, product degrade factors, and cost profiles.

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Additionally, a participatory approach was used throughout model development in order to maximize the practical adoption of the model in operational forest management (senu Lawrence and Steward, 2011). This involved tailoring the model's input and output to the requirements of the end-user community and was accomplished through the employment of an interagency advisory team consisting of scientific, policy, knowledge exchange and informatics staff from the receiving organizations (e.g., government agencies and forest industrial corporations).

2. Methods and results

2.1. Modelling approach

Structurally, as illustrated in Fig. 1, the modular-based SSDMM for the peatland black spruce stand-type consisted of six interconnected prediction modules. Module A (Dynamic Stand Density Management Diagram (SDMD)) involved the development of a dynamic SDMD via the parameterization and integration of a key set of static and dynamic yield–density relationships based on the traditional SDMD modelling approach (Newton, 1997). Module B (Diameter and Height Recovery) employed a (1) Weibull-based parameter prediction equation (PPE) system to recover the grouped-diameter frequency distribution from stand-level variables (as predicted from Module A), and (2) composite height–diameter prediction equation for estimating tree heights by diameter class. Module C (Taper Analysis and Log Estimation) utilized a dimensional compatible taper equation, derived from the literature, to predict log products (number of pulp and saw logs) and stem volumes. Module D (Biomass and Carbon Estimation) used a set of allometric-based composite biomass equations to predict the mass of each above-ground component (bark, stem, branch and foliage) from which carbon-based equivalents were derived. Module E (Product and Value Estimation) employed a set of sawmill-specific (stud and random length mill processing configurations) equations derived from the literature to predict chip and lumber volumes and associated market-based monetary values. Module F (Fibre Attribute Estimation) engaged a set of composite equations to estimate average wood density and mean maximum branch diameter for sawlog-sized trees. An algorithmic analogue of the resultant modular-based SSDMM was developed and its utility exemplified by simultaneously contrasting a set of complex density management regimes involving CT treatments, in terms of productivity, log-product distributions, biomass production and carbon yields, recoverable end-products and associated values, economic efficiency, duration of optimal site occupancy, structural stability and wood fibre attributes. In terms of presentation: (1) only a brief description of the methods and results associated with some of the component relationships which were previously presented in separate incremental contributions are included (i.e., parameter prediction equation system (Newton and Amponsah, 2005), relative density isolines delineating the zone of maximum forest production (Newton, 2006a), asymptotic size–density relationship (Newton, 2006b), and the composite height–diameter function (Newton and Amponsah, 2007)); (2) analytical results are embedded in the methods given the hierarchical and sequential nature of the model building approach used; (3) in cases were data limitations negated the parameterization of some of the underlying relationships, approximate equivalents derived from the literature were utilized and supporting references included (i.e., taper, biomass, end-product recovery and value, and fibre

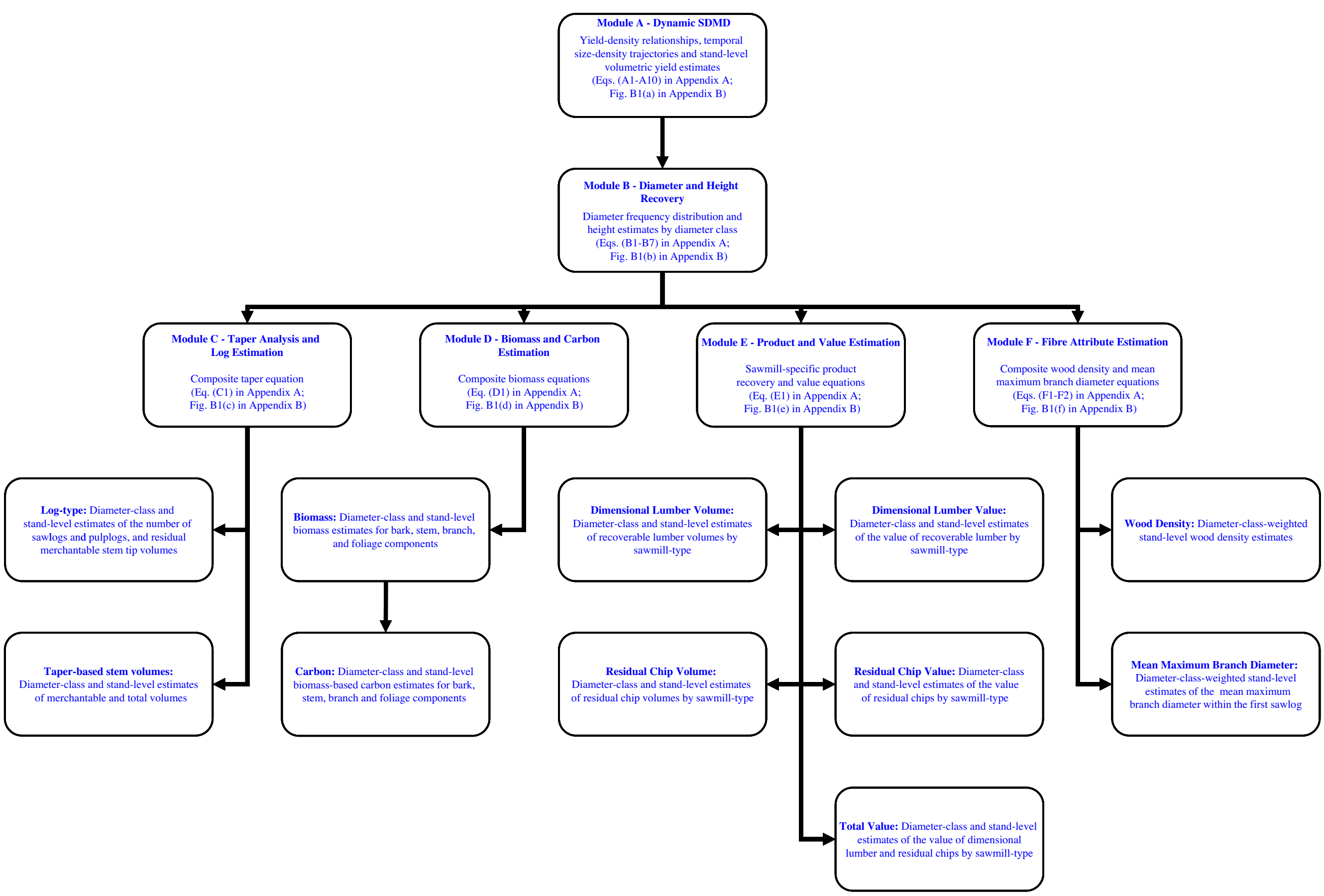

Fig. 1. Schematic illustration of the modular-based SSDMM. Modular-specific descriptions of the computational framework employed are given in Appendix B.