Yield prediction for mixed species stands in boreal Ontario[1]

by Margaret Penner[2]

ABSTRACT

Wood supply of the major industrial species groups (spruce–pine–fir [*Picea–Pinus–Abies* spp.] and poplar [*Populus* spp.]) in the boreal forest of Ontario is forecasted to fall below demand in the relatively near future. This has lead to more interest in the growth and yield of mixedwood forests. Mixedwood stands are defined for forest management planning as stands in which 26% to 75% of the canopy is softwood. With an average growth rate one-third higher than the average for all forest types combined, mixed species stands have potential to mitigate some of the shortfalls. This paper reviews the history of yield curve development in Ontario and some of the current initiatives in mixedwood modeling. The Forestry Research Partnership, a partnership between Tembec, the Ontario Ministry of Natural Resources, the Canadian Forest Service, and the Canadian Ecology Centre, was formed in 1999. One of the first projects of the Partnership was to update the provincial yield curves. These updated curves provide good estimates of yield for mixedwoods on upland, drier sites but mixedwoods on moister sites need to be further stratified by leading species. Mid-rotation activities such as density regulation and partial harvesting in the selection or shelterwood silvicultural systems are generally tree-level activities. These are more compatible with tree-level models. Ontario is calibrating the Forest Vegetation Simulator (FVS) for use in Ontario and this shows particular promise in mixedwood modeling.

Key words: mixedwood growth, yield tables, FVS

RÉSUMÉ

L'approvisionnement en matière ligneuse dans le cas des principaux groupes d'espèces industrielles (épinette-pin-sapin [*Picea–Pinus–Abies* spp.] et peuplier [*Populus* spp.]) dans la forêt boréale de l'Ontario est prévu tomber en deçà du niveau de la demande dans un proche avenir. Cette situation a entraîné un plus grand intérêt pour la croissance et le rendement des forêts mélangées. Les peuplements mélangés sont définis au niveau de la planification forestière comme des peuplements ayant de 26% à 75% de leur couvert constitué de conifères. En tenant compte d'un taux de croissance d'un tiers supérieur à la moyenne de tous les types de forêt combinés, les peuplements d'espèces mélangées ont la possibilité d'atténuer certaines des pénuries prévues. Cet article révise l'historique de l'élaboration des courbes de rendement en Ontario et de certaines des initiatives actuelles de modélisation des peuplements mélangés. Le Partenariat en recherche forestière, un partenariat comprenant Tembec, le Ministère des Richesses naturelles de l'Ontario, le Service canadien des forêts et le Centre canadien d'écologie, a été mis en place en 1999. L'un des premiers projets du Partenariat a été de mettre à jour les courbes de rendement de la province. Ces nouvelles courbes permettent des estimés fiables du rendement des peuplements mélangés sur les stations en élévation et plus sèches, mais les peuplements sur les stations plus humides doivent être stratifiés plus en détail en fonction de l'espèce dominante. Les activités à la mi-révolution comme la régularisation de la densité et la récolte partielle selon un régime de sélection ou de coupes progressives sont généralement effectuées au niveau de l'arbre. Celles-ci sont plus compatibles avec les modèles en fonction des arbres. L'Ontario procède au calibrage du simulateur de végétation forestière pour la province et cela s'avère particulièrement prometteur dans la modélisation des peuplements mélangés.

Mots clés :: peuplements mélangés, croissance, tables de rendement, FVS

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Introduction

Mixedwood stands in Ontario are defined as those having between 26% and 75% of the canopy in softwoods (OMNR 2002). Estimates of the extent of boreal mixedwoods forests range from 22% (OMNR 2002, Appendix 1) to 45% (Towill *et al.* 2004) of forested lands of Ontario while mixedwoods in Quebec comprise 20% of the productive forest land (Prévost 1996) and 30% in British Columbia (Comeau 1996). Ontario boreal mixedwoods contain a wide variety of species, but can generally be characterized as having one of the following as the leading species[3]: black spruce (*Picea mariana* (Mill.) BSP), trembling aspen (*Populus tremuloides* Michx.), or jack pine (*Pinus banksiana Lamb.*). MacDonald (1996a) defined a boreal mixedwood site as an area with climatic, topographic, and edaphic conditions that favour the production of closed canopies dominated by trembling aspen or white birch (*Betula papyrifera* Marsh) in early successional stages, black or white spruce in mid-successional stages, and balsam fir (*Abies balsamea (*L.) Mill.) in late successional stages. Mixed-species stands may arise following stand-replacing disturbances, by partial disturbances, such as selective cutting or endemic impacts of insects and disease, or by succession due to different regeneration and mortality rates by species. Some forest areas are mixedwoods at the time of stand establishment, while others are dominated by a single species, then, as the stands become overmature, the dominant species succumbs to natural mortality and the stand becomes a mixture of minor species.

Using the most recent state of the forest report (OMNR 2002, Appendix 1), Ontario's mixedwoods represent over one billion cubic metres (m^3) of gross total volume and have an average mean annual increment (MAI) of 2.0 m^3/hr/yr, one third higher than the growth rate of 1.5 m^3/ha/yr for all forest types combined.

Boreal mixed-species stands have received little attention in the past as most harvesting was focused on conifer-dominated stands. As many of the accessible, available conifer-dominated stands have been harvested, an increasing part of the wood supply is coming from mixed-species stands.

Yield predictions for mixed-species stands are complicated for a number of reasons, including the wide range of mixed-species stands, the available input data and inter-species interactions. Mixed-species stands have more than one species and may or may not include a wide range in ages and sizes. Mixed-species stands are not well handled by the forest resources inventory (FRI), which records age, height, and site attributes only for the leading species and has traditionally not included any information on multi-tiered or multi-aged stands. Each species in a mixed-species stand has its own species-specific growth and mortality rates and each species pair may have unique interactions. Vanclay's (1994) book provides an excellent tutorial on mixed-species growth modeling.

New inventory methods and growth, yield and succession prediction tools are required for these mixed-species forests. In this paper, I provide a historical summary of inventory and growth and yield in Ontario followed by the current measurement and inventory policies, including a description of a number of initiatives that are underway that will aid in yield prediction for mixed-species stands. These initiatives include the formation of a growth and yield business unit (government, industry, education) that funds sample plot installation and remeasurement, a new enhanced FRI and recent revisions to the forest management planning model. Then the variety of mixedwood modeling approaches in Ontario is described including stand- and tree-level modeling initiatives.

Historic Context

The first cooperative yield study of northwestern Ontario's mixedwood began in 1948. Several pulp and paper companies jointly requested that the Canadian Forest Service provide growth and yield information on the boreal mixedwood in the Nipigon District (Bedell and MacLean 1952). The companies agreed to collect the data while the Ministry of Natural Resources (OMNR) assumed responsibility for data compilation and analysis. In 1974, Petawawa National Forestry Institute used the data to prepare yield tables for American Can of Canada Ltd. and Kimberly-Clark of Canada Ltd. (Evert 1975). The same dataset was used for yield tables (Payandeh and Field 1986) and variable stocking yield tables (Payandeh and Wang 1996). None of these yield tables was used widely in forest management planning but the growth plots continued to be measured, some to this day, and are a significant source of long-term growth data (Fig. 1).

In the early 1950s, demand for wood fibre began to increase. This increased demand required predictions of stand level growth in order to intensify forest management activities. In 1956, W.L. Plonski published normal yield tables for black spruce, jack pine, aspen and white birch in Northern Ontario. These yield tables were expanded to include tolerant hardwood and white and red pine stands in Ontario (Plonski 1960) followed by the publishing of a metric version (Plonski 1981). Since then, Plonski's yield tables, or a variant of them, have been used for forest management planning on public lands in Ontario.

Plonski's yield tables were based on temporary sample plots and, with the exception of tolerant hardwood stands, the yield tables are for even-aged single-species stands. These yield tables have remained useful for years due to harvesting of natural disturbance-origin, largely conifer-dominated stands with no mid-rotation silviculture. Traditionally, harvest-level calculations were area-based so any potential biases or errors in yield prediction had little effect on allowable cuts. These yield tables are still applicable to even-aged, pure species stands without mid-rotation silviculture, but an increasing proportion of the wood supply in Ontario's boreal forest is coming from mixedwood stands not covered by the yield tables.

In the 1990s, several models were evaluated for their application to northern hardwoods stands including Fiber 3.0 (Bankowski *et al.* 1995a), Silvah (Bankowski *et al* 1995b) and NE-Twigs (Bankowski *et al.* 1996). NE-Twigs showed the best results leading, in part, to interest in the Lake States version of the Forest Vegetation Simulator (FVS), which uses compo-

[3]The leading species is the species with the greatest proportion of the basal area.

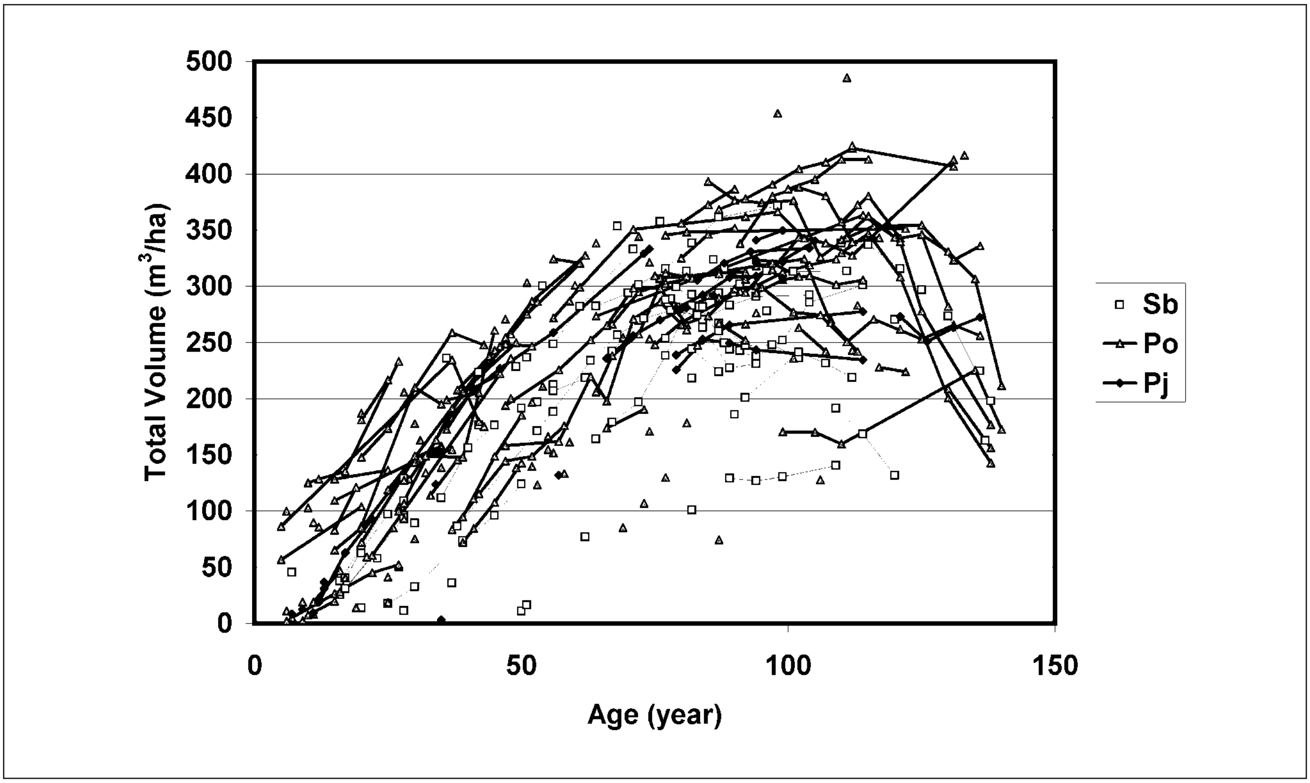

Fig. 1. Some of the mixedwood plots have been measured for over 50 years. The mixedwood forest types in Ontario consist mainly of black spruce (Sb), trembling aspen (Po), and jack pine (Pj) leading stands.

nent models from Lake States Twigs. The FVS developments are described later.

Density management diagrams (DMDs) have been used in Ontario for making silvicultural decisions (Archibald and Bowling 1995, Smith 1996, Smith and Woods 1997). DMDs have generally been applied to even-aged, single-species stands although there have been some advances in size distribution modeling and intensity of management (Newton and Amponsah 2005) and mixedwoods (Swift *et al.* 2007). Separate DMDs are available for jack pine (Archibald and Bowling 1995) and red and white pine (Smith and Woods 1997). Smith (1996) developed a conceptual mixed species DMD for Ontario but this was never quantified. DMDs are not generally recommended for yield prediction (Farnden 2002).

State of the Forest

For some management units, particularly those with a history of selective harvesting of best conifers, mixedwoods can represent over half of the landbase. Some areas of Ontario are facing wood supply shortages due, in part, to land withdrawals for parks and to age-class imbalances. In the boreal forests of Ontario, wood supply of the major industrial species groups (spruce–pine–fir [*Picea–Pinus–Abies* spp.] and poplar [*Populus* spp.]) is forecasted to fall below demand in the relatively near future. One of seven strategies to rationalize demand and improve supply is to use local yield tables since the MNR policy is to take a conservative approach wherever data on the resource is incomplete (OMNR 2003). Mixedwoods have generally been underutilized and are potentially part of the solution to meeting wood supply shortages. As a result, an increasing percentage of Ontario's harvest is from mixedwood stands. There has also been a profound shift from viewing mixedwoods as something that needed to be rehabilitated to a pure conifer stand to accepting mixedwoods as a desirable condition; as an intentional management goal. This paradigm shift led to an Ontario publication of a boreal mixedwood guide (OMNR 2003). Structural and species diversity in mixedwood forests may provide better habitat than stands dominated by single tree species stands for some wildlife species. Also, there is some evidence that some species mixtures may be more productive. Smith and Nigh (1989) found the effect of competition on jack pine was the same whether the competitors were jack pine or black spruce, while black spruce was less affected by competing jack pine than competing black spruce. This is supported by Chen *et al.* (2003), who found that mixtures of shade-intolerant and shade-tolerant species with different growth patterns may be more productive than single-species stands, while mixtures of two shade-intolerant species were less productive than single-species stands.

Current Measurement and Inventory Policies

According to Vanclay (1994), permanent growth plots (PGPs) should have three qualities essential for growth modeling: i) individual trees must be unambiguously identified, ii) plots should be homogeneous, and iii) plots should sample extremes of site and stand conditions. Immediately, one of the complications associated with modeling mixedwood stands emerges. There are very few homogenous mixedwood PGPs.

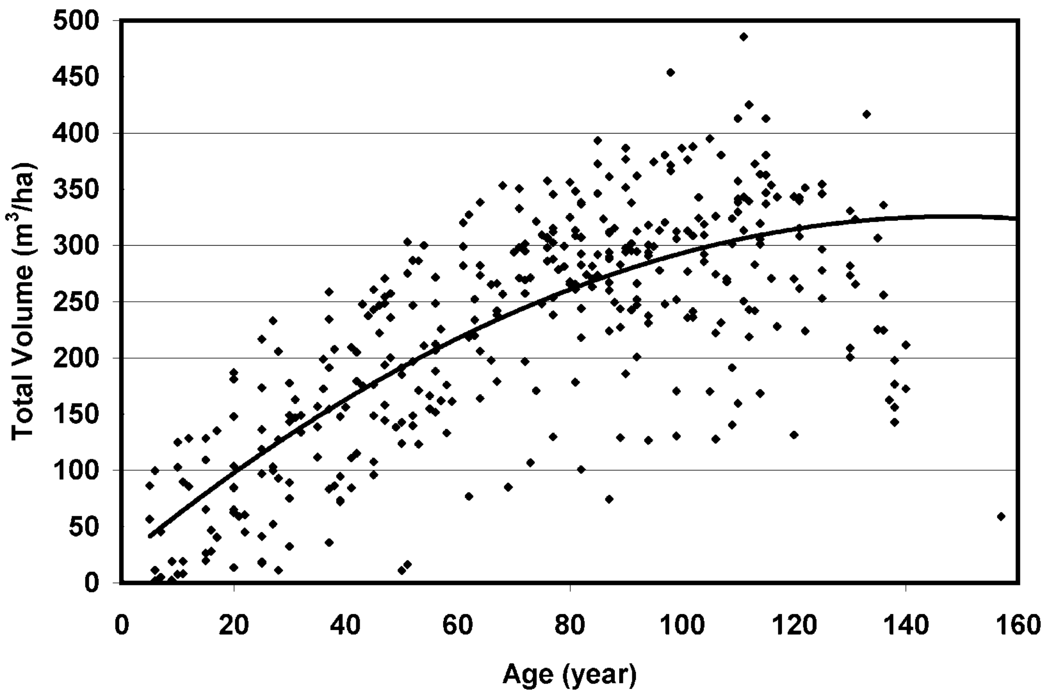

Fig. 2. An example of fitting a smoothing curve to data from a systematic sample (continuous forest inventory). Note only point data are required.

Canada's oldest PGP is in the Petawawa Research Forest, Ontario (Burgess and Robinson 1998). Since its establishment, PGPs have continued to be installed and remeasured. Historically, PGPs were placed in fire-origin, pure-conifer, fully stocked stands on productive sites and, unlike current PGPs, individual trees were not always tagged. Following a review of Ontario's growth and yield program (Kurz *et al.* 1991), the OMNR began installing more strategically placed PGPs. Since 1999, the Forest Co-op Growth and Yield Business Unit has established approximately 400 PGPs per year. The first year of full remeasurement was 2005. As with the OMNR PGPs, these are selectively placed to ensure cells of a forest unit, management intensity, development stage, and site matrix are filled. Thus, the PGPs meet Vanclay's three qualities with the exception of homogenous plots for mixedwood PGPs.

Over the last decade in Ontario, companies have been responsible for the Forest Resources Inventory (FRI). In the fall of 2005, the OMNR announced it was taking back the responsibility for FRI and assigned an annual budget of approximately $10 million for the development of an enhanced inventory. As mentioned, the current FRI provides species composition, site class, age, height, and stocking for a single canopy layer. The specifications of the new, enhanced FRI are still being finalized, but there will the provision for including information on more than one canopy layer as well as a move from stocking to crown closure. The characterization of the layers will still be based largely on the dominant species group.

In Ontario, allowable cut is calculated in terms of harvest volume/year and then translated into an allowable harvest area. In the past, allowable cut was calculated directly as an allowable harvest area. The move to a volume-based harvest level has prompted renewed interest in growth and yield modeling as evidenced by the commitment to PGPs as well as funding of yield curve development by the Forestry Research Partnership, a partnership between the OMNR, Canada Forestry Service, Tembec, and the Forest Ecology Centre) and the Enhanced Forest Productivity Program of the OMNR. Following a survey of mixedwood stakeholders the Mixedwood Silviculture Program at the Ontario Forest Research Institute identified four key areas of importance, one of which is growth and yield modeling (MacDonald 1996b).

Mixedwood Modeling in Ontario

Currently, mixedwood growth and yield estimates are obtained using a variety of approaches: 1) yield from landbase averages; 2) stand-level models; and 3) tree-level models. Stand- (or forest-) level models use summary variables such as basal area and average dominant height to predict changes in stand-level attributes while tree-level models use individual tree data to predict changes in tree level attributes (Munro 1974). Current approaches often overlap with previous work. However, there are innovative approaches.

Landbase averages

One possibility for yield tables is to obtain a representative forest inventory. For example, one forest company in Ontario invested heavily in the establishment of a continuous forest inventory (CFI) system through locating plot clusters on a 2 ? 2 km grid. Because the plots are a representative sample of the landbase, yield curves could be obtained simply by fitting a curve or smoothing function to the data (Fig. 2). This approach works well for predicting the yields by age class for the stands currently existing on the landbase. However, it is not well suited for predicting future yields if there are any trends in silviculture and site quality with age. To illustrate this, assume that all the best sites were harvested 60 years ago and are now in the 60-year age class, the next best sites harvested 40 years ago and so on and the average rotation age is 60 years. For an average yield curve, site is confounded with age. If yield curves are based on the current averages of all age classes, all other things being equal, average yield curves will overestimate yields at older ages and underestimate yields at younger age classes for a stand of average site class. The advantage of this approach is that it is simple to apply and provides unbiased results for the current forest. The disadvantages include an inability to predict growth and results of management.

Stand-level yield models

Given the recent efforts in installing and remeasuring PGPs, the Forestry Research Partnership initiated a project to develop new yield curves (http://www.forestresearch.ca/partnership_projects/130-009.htm). These are essentially a refinement of Plonski's yield curves to reflect an expanded database and to incorporate management intensity (see Bell *et al.* 2006). Two stratification schemes were used to generate yield curves: forest unit or leading species. In the forest management planning manual (OMNR 2004), a forest unit is defined as "an aggregation of forest stands for management purposes which have similar species composition, develop in a similar manner, (both naturally and in response to silvicultural treatments) and are managed under the same silvicultural system." The leading species was previously defined as the species with the greatest proportion of the basal area. The predictions were validated using an independent data set. Yield curves were developed for the all of the Northeast standard forest units except the white (*Pinus strobus* L.) and red pine (*Pinus resinosa Ait*) forest unit, the tolerant hardwood forest unit and spruce (*Picea s*pp.) bogs (see Watt *et al.* (2001) for a description of the all of the forest units).

Results of the validation are given in Fig. 3 for three forest units representing different stand types. The Pj2 forest units consists of mixed jack pine and black spruce stands growing on dry to moist sandy to coarse loamy soils of glaciofluvial origin. The MW1 forest unit consists of mixed coniferous-deciduous stands comprised of trembling aspen, white birch, jack pine and black and white spruce on dry to moist sandy to coarse loamy soils. The MW2 forest unit consists of mixed coniferous – deciduous stands comprised of trembling aspen, white birch, black and white spruce and balsam fir on fresh to moist, medium loamy to clayey soils. In general, the forest unit yield curves were less biased than the leading species yield curves for the stands dominated by a single species (e.g., Pj2 0a). The forest unit yield curves were unbiased for upland mixedwoods (MW1) but were less accurate than the leading species yield curves (0b). However, the forest stratification did not work well for the moister mixedwoods (MW2) (0c). In particular, the hardwood-dominated stands within the MW2 were underpredicted using the forest unit approach. The results indicate another complexity of mixed-species stands. An approach may work well in some conditions (in this case, well-drained soils) and not as well in other conditions (in this case stands that are mixed in terms of light tolerance and age).

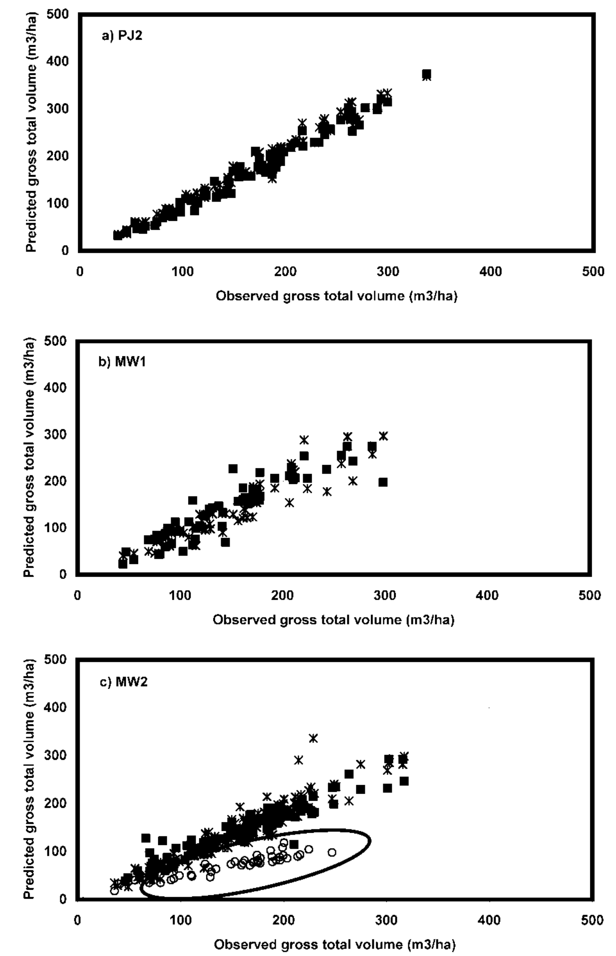

Fig. 3. The predictions using a stand level yield prediction model on an independent dataset are given by forest unit. Predictions by forest unit are indicated by ■ and predictions by leading species are indicated by ×. The predictions are relatively unbiased except for the hardwood-dominated stands in figure c (○), which are consistently underpredicted. The Pj2 forest unit consists of mixed jack pine and black spruce stands growing on well-drained soils. The MW1 forest unit consists of mixed coniferous-deciduous stands comprised of trembling aspen, white birch, jack pine and black and white spruce on well-drained soils. The MW2 forest unit consists of mixed coniferous – deciduous stands comprised of trembling aspen, white birch, black and white spruce and balsam fir on moist soils. The results indicate the forest unit stratification worked well for most forest units but the MW2 required further stratification by leading species.

The advantage of this stand-level approach is that it uses inventory data as inputs and incorporates all the permanent plot data. The predictions are good (precise and accurate) for many forest units. The forest unit stratification does not work well for forest units that are mixed in terms of light tolerance and ages. The disadvantage of this approach is that it is limited by data availability. In particular, little data are available for partially harvested stands, older plantations, mixed species plantations, and low planting densities.

Tree level

The main tree-level modeling initiative in Ontario is FVS (http://www.fvsontario.ca). Initially, the US Lake States version was converted to metric within the PROGNOSIS^{BC} shell. This version was tested (Lacerte *et al.* 2004) against data from Ontario. Overall, the model predictions were consistent with expected trends although some predictions were significantly biased. Several components have now been calibrated for Ontario including the large tree diameter outside bark at breast height (dbh; 1.3 m above ground) growth equations, height from dbh equations, and small tree-growth equations. The model requires a tree list as input. Therefore, a tree-list generator was developed to create tree lists from various types of inventory data (i.e., fixed-area or variable-radius plots). A custom interface was developed for the two main silvicultural systems, outside of clearcutting, in Ontario: single-tree selection (tolerant hardwoods) and shelterwood (red and white pine, tolerant hardwoods). Additional work is required on the height growth model, mortality and regeneration.

The advantage of this modeling approach is the potential ability to model uneven-aged, mixed species stands better than stand level yield curves and to simulate commercial thinning and more complex silvicultural systems including single-tree selection. Little mid-rotation silviculture occurs in the boreal forest in Ontario since commercial thinning is not a recommended practice (OMNR 1997). However, this is generally considered to be a result of lack of documented evidence of the effect of thinning rather than any detrimental effects of thinning.

The disadvantage of tree-level modeling is the fairly onerous input data requirements. For forest management planning in Ontario, yield predictions are based on the inventory. For tree-level modeling, stem species and diameter distributions need to be inferred from the FRI. If tree-level description can be reliably estimated from stand-level variables, in principle, the data could be projected directly by a stand-level model (Garcia 2001).

Future Improvements and Technological Advances

Data collection and model refinement (at all scales) are ongoing efforts. The use of new technologies in forest inventory may not only improve the accuracy and precision of current inventory attributes, but may also allow estimation of additional attributes. For instance, initial testing of LiDAR (Light Detection and Ranging Radar) for enhancing forest inventory yielded promising results in terms of producing digital elevation models and tree canopy height models (http://www.forestresearch.ca/ partnership_projects/120-502.htm). Further testing is underway to extract additional parameters including basal area, volume and diameter distributions as well as to determine appropriate acquisition intensities and operationalize LiDAR data processing. Potentially LiDAR (along with optical species determination) may be able to provide the detailed tree-level inputs required by FVS. Imputation is another potential method of obtaining more detailed data both for static inventory estimates and model inputs (Temesgen *et al* 2003).

Provincial modeling efforts are focusing on improving FVS^{Ontario}. Dr. Art Groot of the Canadian Forest Service is coordinating the development of IVY-fibre, a tree-level process model that includes wood quality and climate variables and will be capable of predicting growth under different climate scenarios. Work on the refinement of taper models (e.g., Sharma and Yang 2004, Zakrzewski and MacFarlane 2006) will also improve yield predictions.

Concluding Comments

The importance of mixedwoods in Ontario is not unique. Most other jurisdictions in Canada have significant areas in mixedwood stands and are devoting more resources to managing and predicting the development of these resources (e.g., Grover and Fast 2007). In Ontario, recent initiatives in growth and yield modeling and mixedwood modeling in particular have been prompted by three relatively recent developments: forecasted wood supply shortages, an enhanced forest resources inventory, and an expanded database of permanent growth plots. For the short term, forest unit or stand level yield curves were developed for mixedwood forest units. These have provided good predictions for extensively managed mixedwoods with the exception of the wetter mixedwoods, which required further stratification by forest unit. These yield curves are now available for use in forest management planning.

In the longer term, work is underway to calibrate the tree level model FVS^{Ontario}. This model allows more silvicultural options, including partial harvesting as well as providing more detailed predictions of tree sizes. FVS^{Ontario} requires a stem size-class distribution, something not currently available from the inventory. The stem size-class distribution can potentially be predicted from inventory attributes using nearest-neighbour imputation. In the longer term, the use of LiDAR to enhance the inventory and provide a tree list is being investigated.

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