MGM Research Note #2021-3

Updated height and diameter growth models for black spruce in western Canada.

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Introduction

Forest growth models play a vital role in sustainable forest management by assisting forest managers in: (1) assessing alternative silvicultural systems; (2) determining the influence of disturbance agents (eg. like insects or disease); (3) estimating sustainable yield of forest products; and (4) generalizing trends (Weiskittel et al. 2011).

In western Canada, the Mixedwood Growth Model (MGM; https://mgm.ualberta.ca/) is an example of a deterministic, distance-independent individual tree-based stand growth model capable of modelling pure or mixed stands of lodgepole pine, jack pine, white spruce, trembling aspen, and black spruce. The unique architecture of MGM underscores its ability to model multi-cohort stands, thinning and partial cutting, and discrete spatial treatments such as understory protection. Within MGM submodels predict height growth, compatible diameter growth (based on the relationship between height growth and diameter growth), survival, and maximum size-density relationships. This research note summarizes results from a recent update of the height and diameter growth models for black spruce.

Methods

This analysis utilized the dataset prepared and described by Cortini et al. (2017) (Fig. 1). Analysis reported here focusses on data for black spruce (*Picea mariana* (Mill. BSP.) which included data from 4,139 remeasured permanent sample plots.

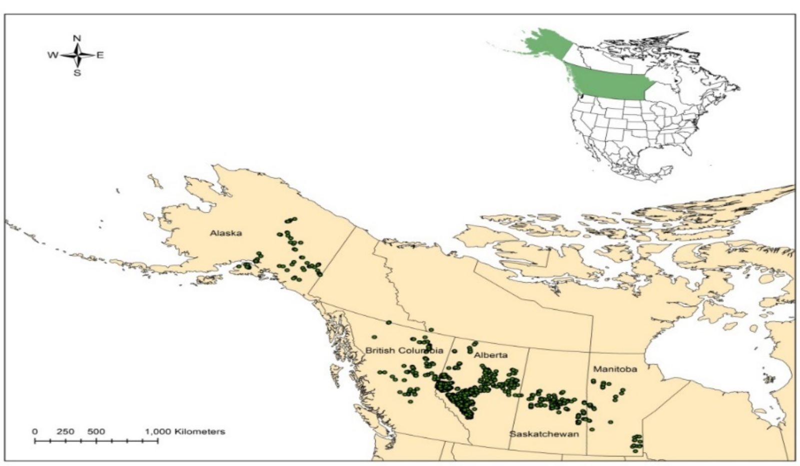

Fig. 1. Locations of permanent sample plots (PSPs) used in model fitting. (Each black symbol represents the location of one Permanent Sample Plot).

The approach currently used for modelling height growth (HIncr) in MGM is the potential height modifier approach (Eq. 1). In this approach, an assumed potential height increment (PHI) is obtained from height-age curves using the dominant and co-dominant trees in a stand, which then represents the height growth of a tree in the absence of competition. Potential height increment (PHI) is an important component of MGM because it represents the starting point for growth modelling before the growth of individual trees is determined by the modifying factors.

$$\mathrm{HIncr}_{\mathrm{ijk}} = \mathrm{PHI}_{\mathrm{ik}} * \mathrm{A}_{i} \quad (1)$$

where HIncr is the height increment (m) of each individual tree, PHI is the potential height increment (m) which is the growth of a site index (top height) tree with a height equal to the current height of the subject tree of the same species and site index (Nunifu 2003), and A_i is a modifier which adjusts for reductions in height growth adjustment due to overtopping competition.

For most species, the Mixedwood Growth Model (MGM) uses a compatible system of functions to estimate diameter growth (DIncr) from height growth (HIncr). Compatible diameter growth functions are based on the assumption that trees adjust their growth allocation based on changes in tree size and stand conditions (Sumida 2015; Trouvé et al. 2015), as represented in eq. 2 below:

$$\frac{\mathrm{DIncr}}{\mathrm{HIncr}} = \eta \quad (2)$$

where η is the slope, which is the tree's ability to increase in DIncr relative to HIncr based on changes in forest conditions (Sievanen 1993). The diameter growth model is estimated in MGM as follows:

$$\mathrm{DIncr} = \mathrm{HIncr}\ \mathrm{X}\ \eta \quad (3)$$

The focus here was to develop a suitable function for η , to provide a "compatible diameter growth model", that can be used in MGM to estimate diameter increment.

The modeling function gnls in the nlme library in R (version 3.6.0) (R core team 2019) was used to fit these models. The models were fitted by including a variance weighting function to control heteroscedasticity (Pinheiro and Bates 2000). Among all functions tested, the power and exponential functions were found to be effective for reducing heteroscedasticity for compatible diameter and height growth models respectively. In addition to the variance functions, the continuous autoregressive structure (CAR(1)) was selected to model autocorrelation because it accounts for unequal time intervals.

Results

Results indicate that all parameters included in the final height and compatible diameter growth models were significantly different from zero ($\alpha = 0.05$). While competition had a negative effect on height growth (Eqs. 4 and 5), it also reduced the ability of trees to allocate growth to diameter relative to height (Eqs. 6 and 7), as shown by the negative coefficients in height and compatible diameter growth models. Among the three competition types, spruce/fir competition (stSFBaGt) had the strongest negative influence on height and compatible diameter growth.

The final compatible height increment (HIncr) model as represented in Eqn (1) was $\text{HIncr}_{ijk} = \text{PHI}_{ik} * A_i$ and the modifier A_i equations are shown below (Eqs. 4 and 5)

a) For juvenile black spruce (≤4 cm dbh)

$$A_i = \text{Exp}(-1 * ((0.02640888 * .\text{stDBaGt}) + (0.08004063 * .\text{stSFBaGt}) + (0.03360386 * .\text{stPlBaGt}))) \quad (4)$$

b) For Mature black spruce (>4 cm dbh)

$$A_i = \text{Exp}(-1 * ((0.02640888 * .\text{stDBaGt}) + (0.08004063 * .\text{stSFBaGt}) + (0.03360386 * .\text{stPlBaGt}))) \quad (5)$$

The final compatible diameter increment (DIncr) equations are shown below (Eqs. 6 and 7):

a) For juvenile black spruce (≤4 cm dbh)

$$\text{DIncr} = .\text{HtIncr} * (0.9285128 + \text{Exp}(-0.2663871 * \text{Exp}(.\text{Dbh} \wedge 0.0218894)) * \text{Exp}(-1 * ((0.0076929 * .\text{stDBaGt}) + (0.0910156 * .\text{stSFBaGt}) + (0.0027382 * .\text{stPlBaGt})))) \quad (6)$$

b) For Mature black spruce (>4 cm dbh)

$$\text{DIncr} = .\text{HtIncr} * (0.9285128 + \text{Exp}(-0.2663871 * \text{Exp}(.\text{Dbh} \wedge 0.0218894)) * \text{Exp}(-1 * ((0.0076929 * .\text{stDBaGt}) + (0.0910156 * .\text{stSFBaGt}) + (0.0027382 * .\text{stPlBaGt})))) \quad (7)$$

where:

.Dbh= tree Diameter at breast height (cm);

.stDBaGt= Basal area (m^2/ha) of deciduous trees larger than the subject tree;

.stSFBaGt= Basal area (m^2/ha) of spruce-fir trees larger than the subject tree;

$.stPBaGt_{ijk}$ = Basal area (m^2/ha) of pine trees larger than subject tree.

Figures 2 and 3 illustrate the effects of competition on height and compatible diameter increment respectively, for juvenile and mature black spruce. Figure 4 shows the effect of tree size (DBH) on compatible diameter increment, with larger-sized trees allocating less growth to diameter than smaller-sized trees.

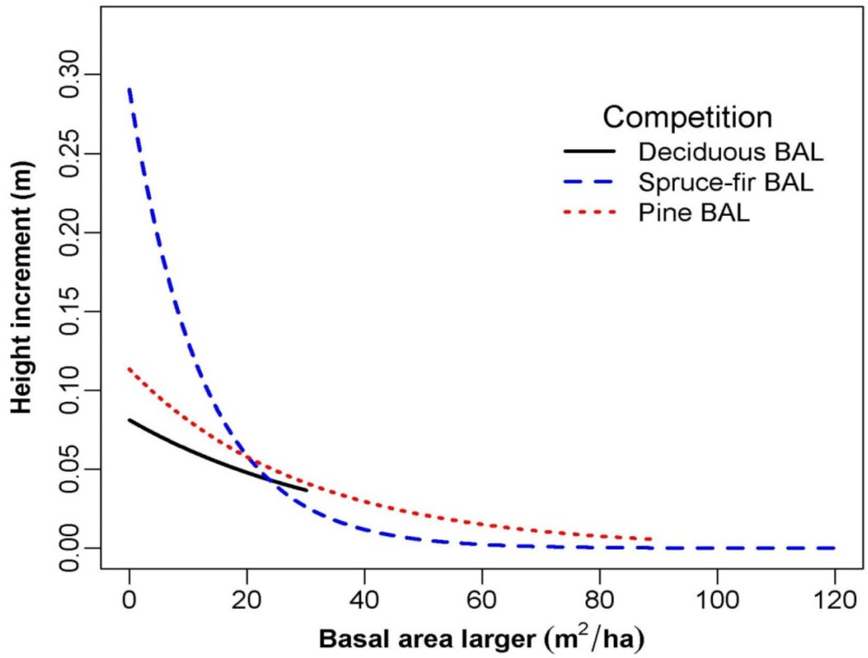

Fig. 2. Deciduous, spruce/fir and pine competition effects on height increment of juvenile and mature black spruce. To illustrate these trends non-focus variables were set to mean values.

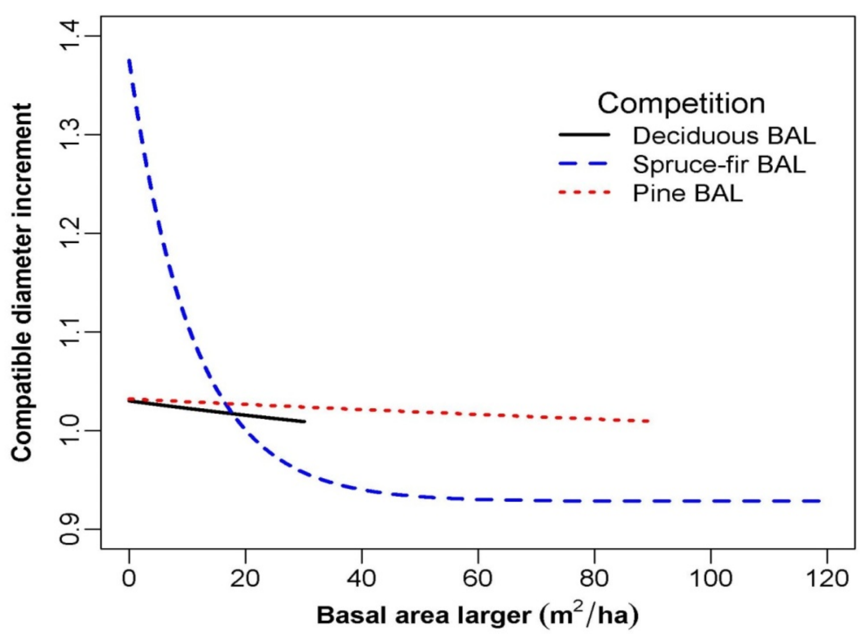

Fig. 3. Deciduous, spruce/fir and pine competition effects on diameter increment of juvenile and mature black spruce. To illustrate these trends non-focus variables were set to mean values.

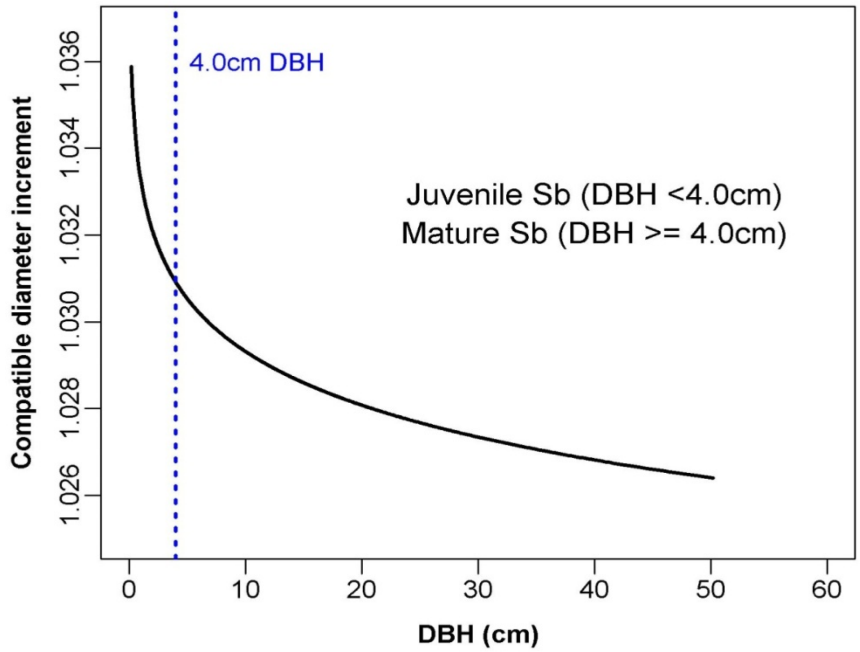

Fig. 4. Tree size effects (represented by diameter at breast height, DBH) on diameter increment of juvenile and mature black spruce. To illustrate these trends non-focus variables were set to mean values.

Discussion and conclusions

These results are consistent with other studies (Lègarè et al., 2004; Girona et al., 2017) which reported that competition is a major factor influencing the growth of black spruce. Larger-sized competitors can deplete underground resources (soil water, nutrient, etc.) as well as above ground resources (sunlight), thereby reducing height and diameter growth of trees. However, the stronger effect of intraspecific competition over interspecific deciduous and pine competition, could be attributed to higher crown density (and light interception) by spruce and fir species and to strong niche overlap. Black spruce trees growing in dense stands and larger-sized trees allocated less growth to diameter over height in order to maintain a stable height: diameter ratio relationship (Rich et al. 1986; Meng et al. 2006).

The height and compatible diameter increment functions developed in this study have been incorporated into MGM, and are used in MGM21 for black spruce. They are useful in projecting growth for both pure and mixed-species stands, and in assisting forest managers develop more realistic projections of stand volume per hectare for different silvicultural treatment and management scenarios.

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