MGM Research Note #2021-1

Survival probability models for seven western boreal tree species

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Introduction

Cortini et al. (2017) present survival probability models for western boreal tree species based on a large dataset collected from several agencies in western Canada. Application of these models in the Mixedwood Growth Model (MGM18) indicated potential issues with applying the model for jack pine in some areas and inclusion of tagging limits in the models for some species was problematic when implemented in MGM.

Methods

This analysis utilized the dataset prepared and described by Cortini et al. (2017). Tagging limit (TAG) was not included in model refitting.

Logistic models were fit for black spruce (*Picea mariana* (Mill.) BSP.), lodgepole pine (*Pinus contorta* Douglas ex Loudon), jack pine (*Pinus banksiana* Lamb.), and balsam fir (*Abies balsamea* (L.) Mill.) using PROC NLMIXED in the SAS 9.4 statistical package. Since tagging limit was not significant for white/Engelmann spruce (*Picea glauca* (Moench) Voss/*Picea engelmannii* Parry ex Engelm.), trembling aspen (*Populus tremuloides* Michx.), and balsam poplar (*Populus balsamifera* L.) the parameter estimates presented by Cortini et al. (2017) were retained.

The selected logistic model of the probability of survival [Eq. 1] included a component [Eq. 2] represented by: tree size, competition estimates by species group, climate (CMI), and the time elapsed between consecutive measurements:

Eq. [1]: $$P_{ijk} = \left(\frac{\exp(c)}{(1+\exp(c))} \right)^{L_{jk}} + \varepsilon_{ijk}$$

Eq. [2]: $$c = a_0 + a_1 * DBH_{ijk} + a_2 * DBH_{ijk}^2 + a_3 * DBALT_{ijk} + a_4 * SFBALT_{ijk} + a_5 * PBALT_{ijk} + a_6 * CMI_i$$

Where**:**
P_{ijk} = survival probability of the j^{th} tree at k^{th} measurement in the i^{th} PSP; DBH_{ijk} = Diameter at Breast Height (cm) of the j^{th} tree at k^{th} measurement in the i^{th} PSP; $DBALT_{ijk}$ = basal area of deciduous trees larger than the subject tree (m^2 ha^{-1}) of the j^{th} tree at k^{th} measurement in the i^{th} PSP; $SFBALT_{ijk}$ = basal area of spruce and fir larger than the subject tree (m^2 ha^{-1}) of the j^{th} tree at k^{th} measurement in the i^{th} PSP; $PBALT_{ijk}$ = basal area of pine trees larger than the subject tree (m^2 ha^{-1}) of the j^{th} tree at k^{th} measurement in the i^{th} PSP;CMI_i = climate (CMI) variable for the i^{th} PSP; L_{jk} = time elapsed between consecutive measurements (year) for the i^{th} PSP at the k^{th} measurement; a_o–a_6 = fixed effects parameters; and ε_{ijz} = leftover unexplained error.

Results and Discussion

Table 1 provides parameter estimates for models. Figures 1 through 6 illustrate behavior of the resulting models. Excluding TAG lead to an increase in AIC. However, models without tagging limit are preferable for implementation in MGM since inclusion of tagging limit can cause anomalous behavior of MGM and also requires knowledge of the tagging limit used in data sources. L is not shown here since it is set to a value of 1 in MGM.

Table 1. Estimates of fixed effects parameters for revised survival probability models for each modeled species.

Modeled Species	**Intercept** (a_0)	**DBH** (a_1)	**DBH^2** (a_2)	**DBALT** (a_3)	**SFBALT** (a_4)	**PBALT** (a_5)	**CMI** (a_6)
white spruce (SW)	3.7259	0.0804	-0.0012	-0.0086	-0.0112	0.0062	0.0249
black spruce (SB)	2.7493	0.1920	-0.0057	-0.0076	-0.0035	-0.0004	0.01761
lodgepole pine (PL)	2.9172	0.2273	-0.0041	-0.0188	-0.0062	-0.0113	-0.0078
jack pine (PJ)	2.6166	0.3206	-0.0069	-0.0167	-0.1027	-0.0543	-0.0066
trembling aspen (AW)	2.4327	0.1298	-0.0022	-0.0142	-0.0082	0.0070	0.0294
balsam poplar (PB)	2.2634	0.0700	-0.0006	-0.0023	-	-	0.0248
balsam fir (FB)	2.8413	0.1229	-0.0035	-0.0379	-0.0056	0.0117	0.0174

DBH=diameter at breast height; DBH^2=square of DBH; DBALT=deciduous (aspen, balsam poplar and birch) basal area larger; SFBALT=spruce/fir (white spruce, Engelmann spruce, black spruce, balsam fir and subalpine fir) basal area larger; PBALT=pine (lodgepole pine and jack pine) basal area larger; CMI=climate moisture index (calculated from annual monthly climate data for the 1981-2020 normal period obtained from ClimateNAv5.60).

Relationships between DBH and survival probability are similar for all species (Figure 1), with jack pine showing a slightly more dramatic increase in survival for trees below 10 cm compared to other species. In addition, the threshold for survival decreases for large trees is higher for white spruce and balsam poplar, followed by aspen, lodgepole pine, jack pine, balsam fir, and black spruce.

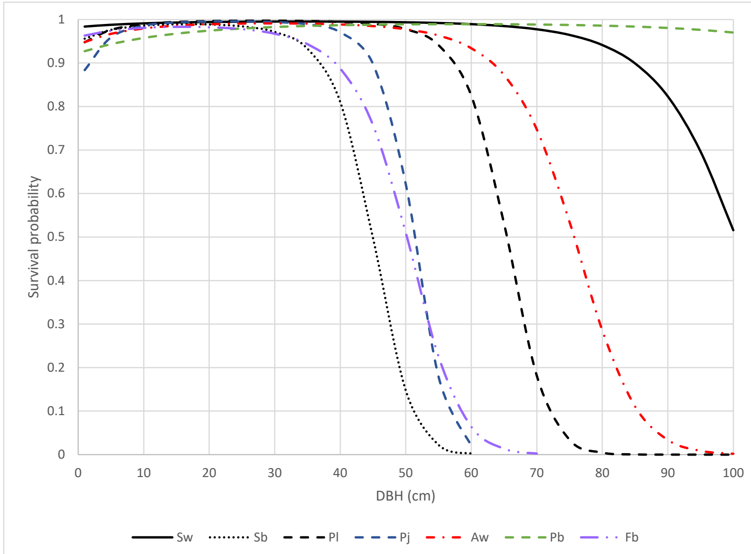

Figure 1. Predicted survival probability of each species in relation to DBH based on models shown in table 1. For other variables the following values were used: DBALT=0.4, SFBALT=0.4, PBALT=14.7, and CMI=8.6. Species are: Sw=white spruce ; Sb= black spruce ; PL= lodgepole pine ; Pj= jack pine; AW= trembling aspen ; PB= balsam poplar; and FB= balsam fir/subalpine fir.

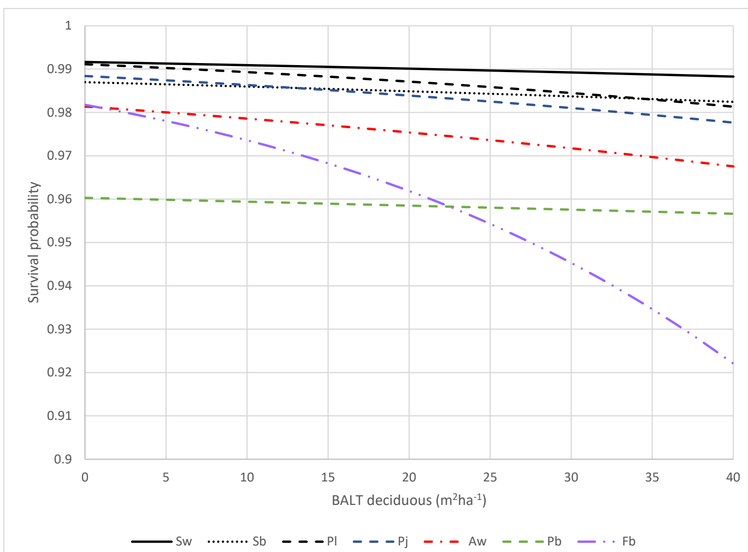

Figure 2. Predicted survival probability for each species in relation to DBALT (deciduous basal area larger) based on models shown in table 1. For other variables the following values were used: DBH=11.2, SFBALT=0.4, PBALT=14.7, and CMI=8.6. Species are: Sw=white spruce ; Sb= black spruce ; PL= lodgepole pine ; Pj= jack pine; AW= trembling aspen ; PB= balsam poplar; and FB= balsam fir/subalpine fir.

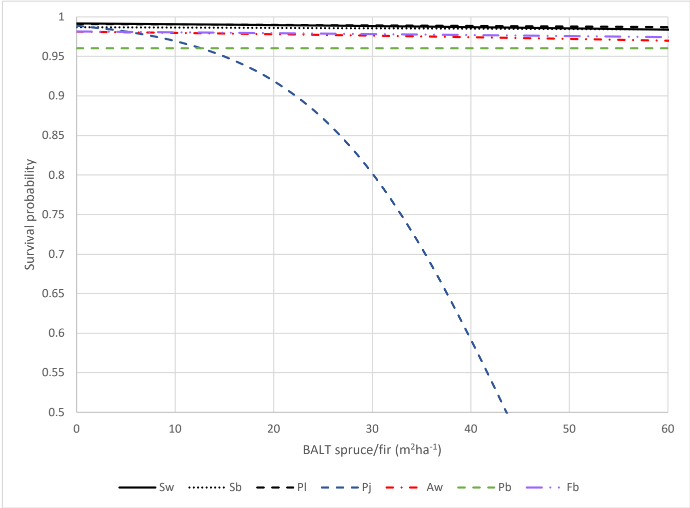

Figure 3. Predicted survival probability for each species in relation to SFBALT (spruce/fir basal area larger) based on models shown in table 1. For other variables the following values were used: DBH=11.2, DBALT=0.4, PBALT=14.7, and CMI=8.6. Species are: Sw=white spruce ; Sb= black spruce ; PL= lodgepole pine ; Pj= jack pine; AW= trembling aspen ; PB= balsam poplar; and FB= balsam fir/subalpine fir.

Deciduous basal area larger (DBALT) (Figure 2) has negative effects survival of all species with parameter estimates ranging from -0.0024 (balsam poplar) to -0.0379 (balsam fir) (Table 1). Basal area larger of spruce and fir (SFBALT) (Figure 3) is consistently negative with parameter values in table 2 ranging from -0.0035 (black spruce) to -0.1027 for jack pine. Basal area larger of pine (PBALT) is associated with improvements in survival of white spruce, trembling aspen and balsam fir and decreased survival of black spruce, lodgepole pine, and jack pine (Figure 4).

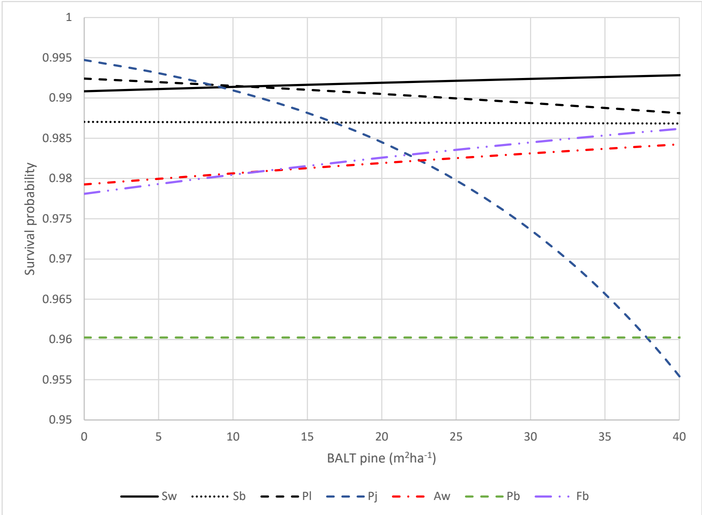

Figure 4. Predicted survival probability for each species in relation to PBALT (pine basal area larger) based on models shown in table 1. For other variables the following values were used: DBH=11.2, DBALT=0.4, SFBALT=0.4, and CMI=8.6. Species are: Sw=white spruce; Sb= black spruce; PL= lodgepole pine; Pj= jack pine; AW= trembling aspen; PB= balsam poplar; and FB= balsam fir/subalpine fir.

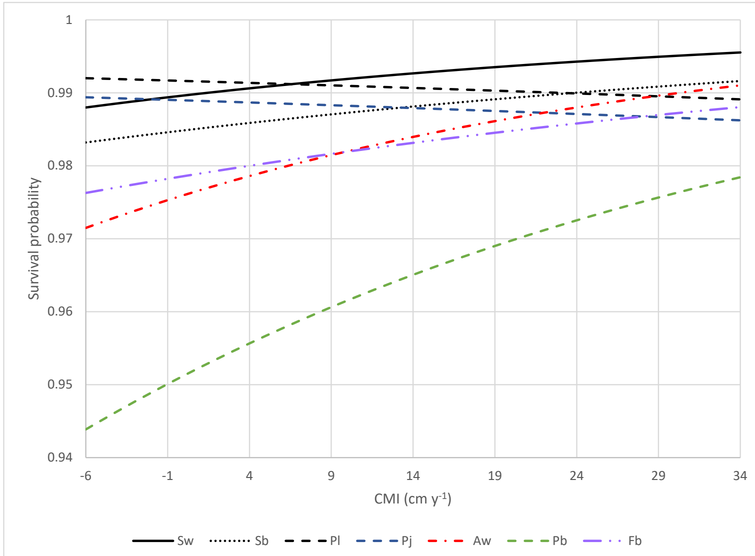

Figure 5. Predicted survival probability for each species in relation to CMI based on models shown in table 1. For other variables the following values were used: DBH=11.2, DBALT=0.4, SFBALT=0.4, and PBALT=14.7. Species are: Sw=white spruce; Sb= black spruce; PL= lodgepole pine; Pj= jack pine; AW= trembling aspen; PB= balsam poplar; and FB= balsam fir/subalpine fir.

Increases in CMI are associated with decreases in survival of lodgepole pine and jack pine but are associated with increases in survival of white spruce, black spruce, aspen, balsam poplar and balsam fir (Figure 5). Cortini et al. 2017 suggest that the difference between the pines and other species is explained by effects of current and recent growing conditions relative to species optimal conditions.

> *"The effect of climate varied between species and since the climate variable (i.e. CMI) represents the plot level average for the normal period 1981–2010, it accounted for variation in survival between plots that is related to long-term average conditions and location. Thus, the plot level survival response of each species to climate is mainly driven by the location of the plot in relation to the optimal range of temperature, precipitation and elevation.*
>
> *CMI combines temperature and an estimate of drought stress with higher values of CMI being associated with relatively cooler and wetter conditions. CMI was the best predictor of survival for all species examined in this study which confirmed the usefulness of CMI as an indicator of moisture regimes and drought severity (e.g. Hogg et al., 2005). In western North America, warmer temperatures and changing precipitation patterns and intensity have already been associated with increasing levels of drought-related mortality (Price et al., 2013). The effects of climate change on tree survival were not explicitly investigated in this study; however, the climate variable selected provided an indication of species susceptibility to climatic extremes based on plot location.*
>
> *In our models as CMI increased (i.e. cooler and wetter climate) survival probability increased with the exception of the pine species. Other studies have reported increasing levels of drought related forest mortality near species geographic and/or elevational range limits where climatic extremes such as water*

stress are often the main limiting factor (e.g. Hogg et al., 2008; Allen et al., 2010; Peng et al., 2011; Hember et al., 2016). Chen et al. (2016) also found that white spruce development is often limited by temperature-induced drought due to higher temperatures and lower precipitation, as also indicated by our results. While pine survival is highest at low CMI levels, increasing drought would be expected to eventually lead to reduced survival."

These results also reflect the much higher drought tolerance of the two pine species in comparison to the other species (Table 2).

Table 2. Summary of tolerance to shade, drought and waterlogging for 7 species examined by Cortini et al. 2017 and Comeau 2020. Tolerance scales range from 0 (no tolerance) to 5 (maximal tolerance). (From Niinemets and Valladares 2006).

Species	**Species Label**	**Shade Tolerance**	**Drought Tolerance**	**Waterlogging Tolerance**
Abies balsamea	FB	5.01	1	2
Picea glauca	Sw	4.15	2.88	1.02
Picea mariana	Sb	4.08	2	2
Pinus banksiana	Pj	1.36	4	1
Pinus contorta	PL	1.48	4.21	2
Populus balsamifera	PB	1.27	1.77	2.63
Populus tremuloides	AW	1.21	1.77	1.77

CMI has a strong negative correlation with MAT (mean annual temperature) and other variables associated with temperature. Consequently, these survival probability models are also likely reflecting better pine survival under the warmest temperatures (and lowest CMI's) represented in these data. These observed trends are also consistent with observations of increases in site index of lodgepole pine in Alberta with increasing GDD (Monserud et al. 2008).

An additional factor which may influence these observed differences between species are the influences of interactions between climate and site conditions on species distribution across sites. Under high CMI pine species are typically restricted to poorer quality soils (ie. coarse-textured and rapidly drained or wet and nutrient poor), while under low CMI pine species may occupy mesic (ie. medium textured glacial till) conditions.

References

Cortini, F., Comeau, P.G., Strimbu, V.C., Hogg, E.H., Bokalo, M., and Huang, S. 2017. Survival functions for boreal tree species in northwestern North America. For. Ecol. Manage. 402: 177-185.

Monserud, R.A., Yang, Y., Huang, S., Tchebakova, N. 2008. Potential change in lodgepole pine site index and distribution under climate change in Alberta. Can. J. For. Res. 38: 343-352.

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