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Survival functions for boreal tree species in northwestern North America

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ABSTRACT

Logistic survival probability models were developed for seven tree species in northwestern North America using Permanent Sample Plot (PSP) data from: six Canadian provincial and territorial governments, the government of Alaska (USA), and four forestry companies; for a total of 1,250,257 trees within 11,673 PSPs. The survival probability of: white/Engelmann spruce (*Picea glauca* (Moench) Voss/*Picea engelmannii* Parry ex Engelm.), black spruce (*Picea mariana* (Mill.) BSP.), lodgepole pine (*Pinus contorta* Douglas ex Loudon), jack pine (*Pinus banksiana* Lamb.), trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and balsam fir (*Abies balsamea* (L.) Mill.) was modeled using tree size (dbh), competition estimates (basal area of the larger trees by species group), climate normal, tagging limits and the time elapsed between consecutive measurements. Survival increased nonlinearly with tree size and the effect of competition on tree survival was related to the shade-tolerance of the species and to stand composition, with shade intolerant conifer species (i.e. lodgepole and jack pine) being more negatively affected by competition compared to shade intolerant deciduous species (trembling aspen and balsam poplar) and shade tolerant spruce species (white and black spruce). Competition from larger spruce (*Picea* spp.), fir (*Abies* spp.) and deciduous species (e.g. *Populus* spp. and *Betula* spp.) had stronger influences on survival than pine species (*Pinus* spp.). Intraspecific competition also had significant effects on survival of the majority of the species. Climate Moisture Index provided better results than other climate variables for most species and survival probability increased with increasing values of CMI (i.e. relatively cooler and wetter climate), while for pine species survival probability decreased with increasing CMI and showed higher levels of survival on warmer and drier sites for the range of conditions included in our data. The predictive equations developed in this study could be used to improve the predictive ability of existing growth and yield models such as the Mixedwood Growth Model.

1. Introduction

Tree mortality reduces stand density and affects competition and understory conditions which will influence growth of remaining trees and regeneration, and can have major impacts on stand yield. A substantial body of literature in boreal forests has already demonstrated the strong effects of competition, tree size, and tree age on survival probability (e.g. Yao et al., 2001; Yang et al., 2003; Luo and Chen, 2011; Reyes-Hernandez and Comeau, 2014). This is particularly evident in trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamifera* L.) mixed stands with white spruce (*Picea glauca* (Moench) Voss).

Climate, site, and genetics also influence the probability of survival of trees (Caspersen and Kobe, 2001). Climate has been shown to influence survival probabilities of aspen, spruce and pine in the boreal forest (Peng et al., 2011; Luo and Chen, 2013; Dawson, 2013). Bell et al. (2014) reported that stand conditions, such as density, influence the effects of drought on aspen decline. Luo and Chen (2013) suggest that mortality in young stands is highly sensitive to climate induced drought stress, and that late successional species such as white and black spruce or moist site species such as balsam poplar are even more sensitive than trembling aspen or jack pine. In contrast, in their analysis of data for pine and spruce stands in the Hinton area of Alberta, Thorpe and Daniels (2012) found that climate did not significantly affect tree

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survival in this region, and that competition and tree size are the major factors influencing survival probability. This suggests that the effect of climate may vary considerably according to region, forest type and site conditions.

The objective of this study was to develop improved models of survival probability for white/Engelmann spruce (*Picea glauca* (Moench) Voss/*Picea engelmannii* Parry ex Engelm.), black spruce (*Picea mariana* (Mill.) BSP.), lodgepole pine (*Pinus contorta* Douglas ex Loudon), jack pine (*Pinus banksiana* Lamb.), trembling aspen, balsam poplar, and balsam fir (*Abies balsamea* (L.) Mill.) based on data from an extensive network of permanent sample plots in northwestern North America. The models considered the effects of: tree size, competition, climate, and time elapsed between consecutive measurements. The resulting predictive equations could be used to improve the predictive ability of existing models such as the Mixedwood Growth Model (MGM, Bokalo et al., 2013).

2. Materials and methods

Six Canadian provincial and territorial governments (Alberta, British Columbia, Yukon, Manitoba, Northwest Territories, and Saskatchewan), Alaska (USA), and four forestry companies (i.e., Alberta-Pacific Forest Industries Inc., Millar Western, Weyerhaeuser and West Fraser) provided the Permanent Sample Plot (PSP) data used in this study. The available data spanned from latitude 49.0°N to 67.9°N and from longitude −151.6°W to −95.4°W, with elevations ranging from 6 m to 2356 m (Fig. 1).

These plots ranged in size from 0.04 to 0.10 ha with smaller subplots being used for saplings in some cases. Most PSPs included only trees with dbh above 5.0 cm (60%), while in some cases all trees taller than 1.3 m in height were measured, while a few plots included data only for trees above 7.0 (15%) or 9.0 cm in dbh (11%). Tagging limits were investigated in the survival probability models to account for the effect of the different measuring protocols.

The database included tree data (e.g. species, dbh, height, dead/alive status) for a total of 11,673 PSPs established and measured between 1931 and 2015. The total number of trees was 1,250,257 and the total number of observations equaled 2,572,122. Seven major tree species were selected for the analysis and included: white/Engelmann spruce (SW), black spruce (SB), lodgepole pine (PL), jack pine (PJ), trembling aspen (AW), balsam poplar (PB), and balsam fir (FB) (Table 1).

Historical climate data was generated using ClimateNA v5.10 (Wang et al., 2012) and nine candidate variables were selected, including: mean annual temperature (MAT, °C), mean warmest month temperature (MWMT, °C), mean coldest month temperature (MCMT, °C), mean annual precipitation (MAP, mm), mean summer precipitation (MSP, mm), growing degree-days above 5 °C (DD5), summer heat-moisture index (i.e. SHM = (MWMT + 10)/(MSP/1000)), annual heat-moisture index (i.e. AHM = (MAT + 10)/(MAP/1000)), and Climate Moisture Index (CMI, Hogg et al., 2013). For these climate variables the average value by location (PSP) for the normal period 1981–2010 was tested in the model (Table 2). Based on the 1981–2010 normal period, mean annual

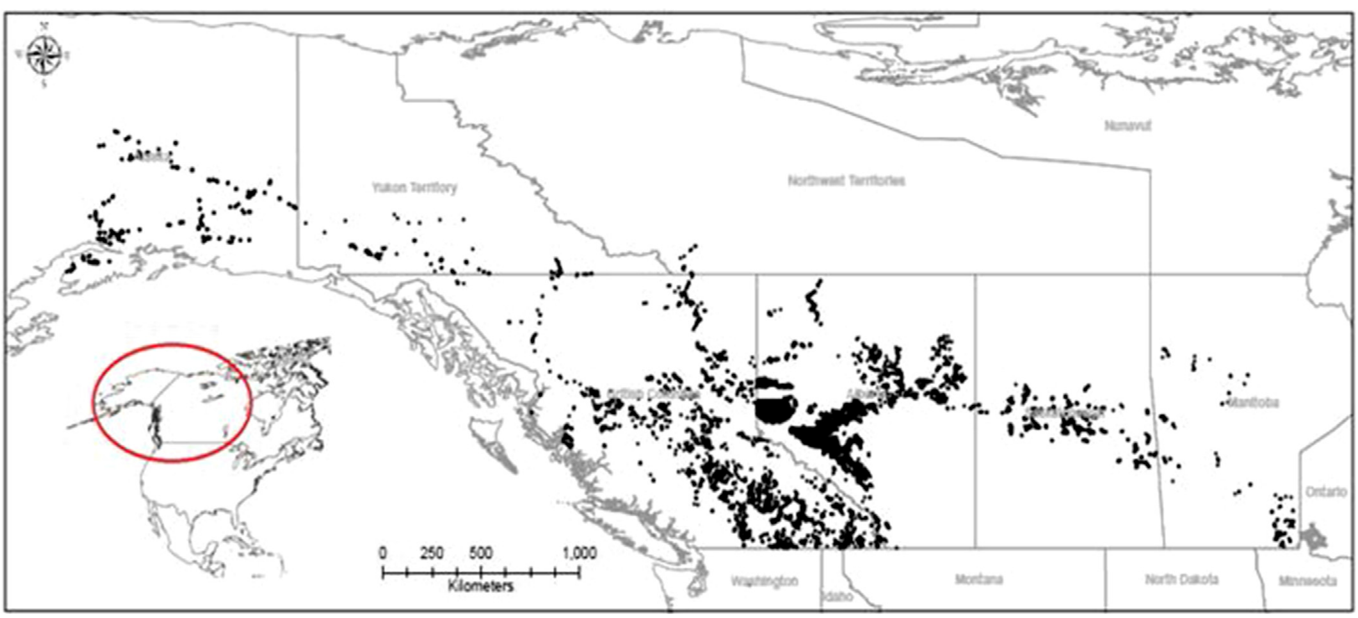

Fig. 1. Locations of permanent sample plots (PSPs) used in model fitting. (Each black dot represents the location of one Permanent Sample Plot).

Table 1
Ranges in locations of permanent sample plots (PSP's) for each species.

	Latitude			Longitude			Elevation		
Species.	*Min*	*Aver.*	*Max*	*Min*	*Aver.*	*Max*	*Min*	*Aver.*	*Max*
	Degrees			Degrees			Meters		
White spruce (SW)	49.0	55.1	67.9	−151.6	−120.2	−95.5	6	885	2356
Black spruce (SB)	49.5	54.6	67.5	−151.4	−117.8	−95.5	16	952	1787
Lodgepole pine (PL)	49.0	53.1	62.4	−136.6	−118.6	−113.6	214	1148	2356
Jack pine (PJ)	49.1	53.6	60.0	−123.4	−102.5	−95.4	205	401	1123
Trembling aspen (AW)	49.0	55.0	67.0	−151.6	−118.3	−95.5	24	783	1867
Balsam poplar (PB)	49.4	54.8	65.3	−151.3	−118.2	−95.5	22	908	1709
Balsam fir (FB)	49.6	54.6	58.7	−120.0	−116.8	−95.6	237	1126	1830