What drives reproductive maturity and efficiency in serotinous boreal conifers?

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Supplementary Material

Appendix 1 Forest compositional attributes and climatic variability of the study plots

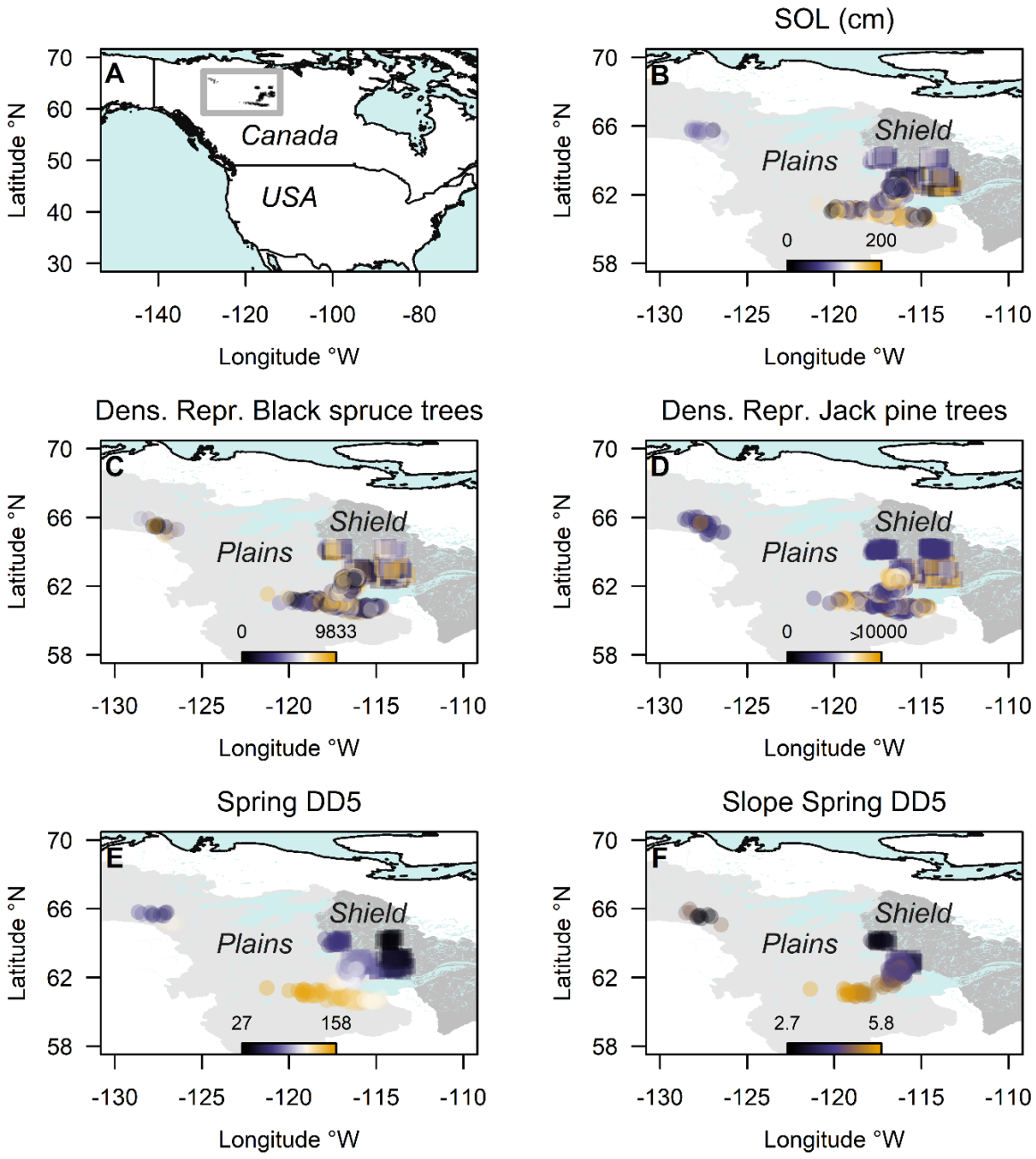
Plots in both ecozones had a similar mean age of 85-89 years and encompassed an age range from 19-29 (Shield or Plains ecozone, respectively) to > 240 years (Table S1). Site drainage was evenly distributed among wet, moist, and dry classes on the Plains, whereas 50 % of Shield plots were dry, 20 % moist and 30 % wet. Near surface ground ice (i.e., within 2 m of the soil surface) was present in one third of plots in both ecozones. SOL was thicker on the Plains than the Shield (Fig. 1b). For both species, tree density and basal area were greater on the Plains than the Shield. Within both ecozones, densities of total black spruce trees were higher than those of jack pine (Table S1).

The latitudinal gradient covered by the plots located on the Shield was narrower than that of plots on the Plains, and there was very little overlap in climatic conditions between ecozones (Fig. 1, S2). Our study region extended over an annual thermal sum range of 763 to 1277 DD5 (27 to 158 for spring (April-May) DD5). The Shield had shorter growing seasons (lower spring DD5) and colder and wetter conditions (lower T_{min} and spring-summer CMD). In both ecozones spring DD5, spring-summer CMD, and spring T_{min} decreased with increasing latitude (Fig. 1e, Fig. S2a,c). In both ecozones, the growing season length increased significantly during 2000-2015, except in the northeastern sites, located north of Great Slave Lave. During this period, 64 % of sites on the Plains and 31 % of the sites on the Shield showed a significant positive trend in spring DD5, particularly in southern locations (Fig. 1f). Spring-summer CMD increased significantly in 72 % of the sites on the Shield, whereas spring T_{min} increased significantly in 73 % of the sites on the Plains (Fig. S2b,d).

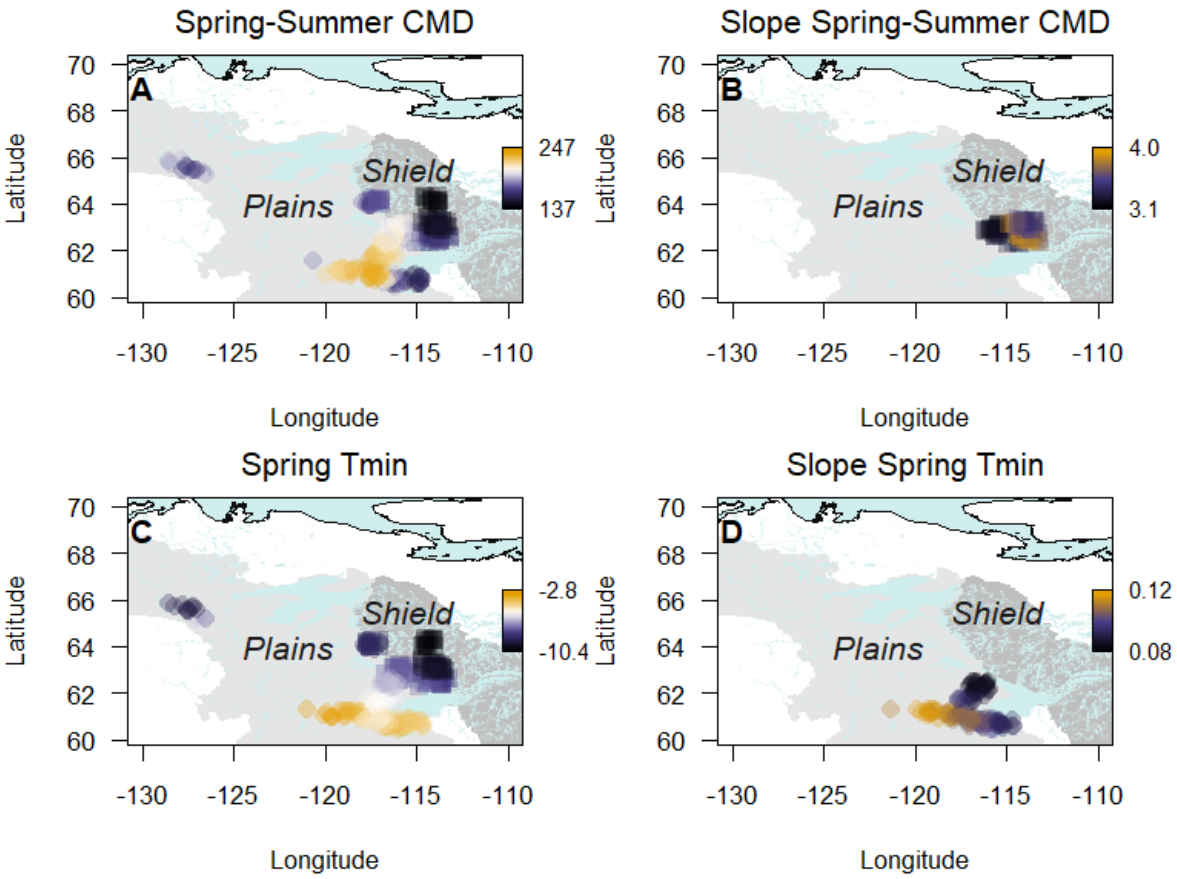
On the Plains, tree density and basal area of black spruce and jack pine increased with spring DD5 despite the decrease in dominance of both species, meaning that plot-level tree diversity increased with greater increases in spring DD5. On the Shield, basal area of both species increased with spring DD5, but not tree density. In this ecozone, the dominance of black spruce was greater where conditions were colder (lower spring DD5), whereas the dominance of jack pine increased or stayed constant where conditions were warmer (Fig. S3).

1 Supplementary Figures and Tables

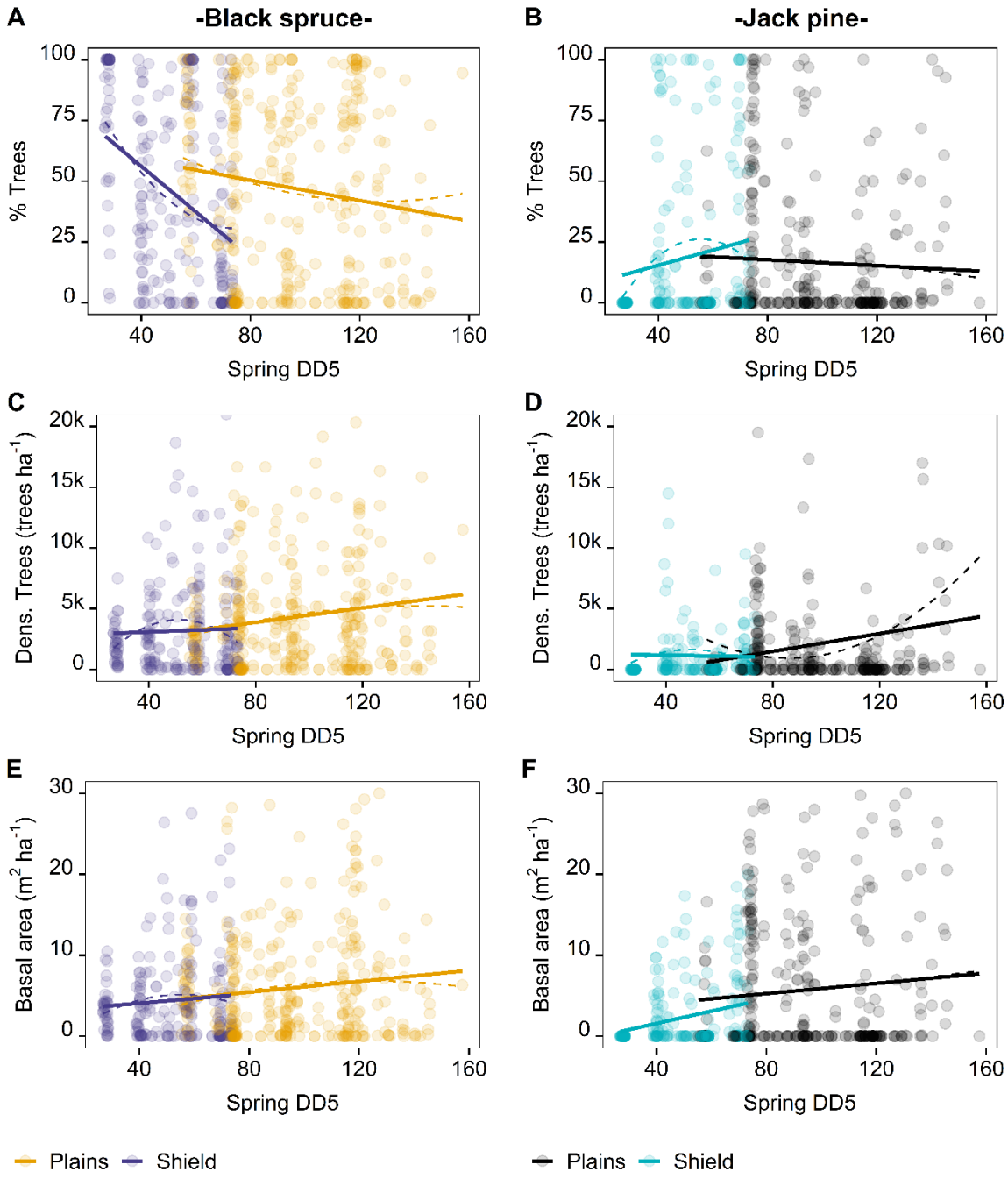
1.1 Supplementary Figures



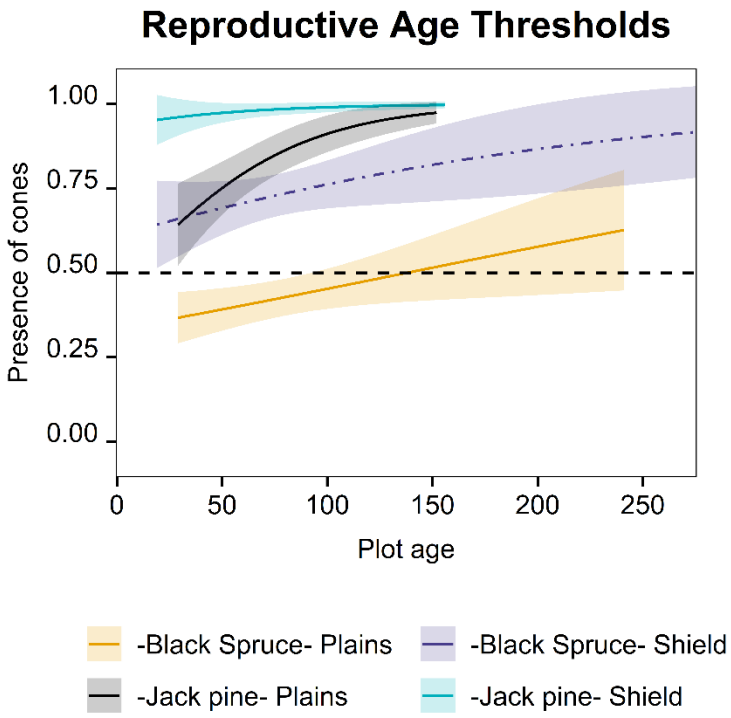
Supplementary Figure 1. Location of the study area within North America (a). Spatial distribution of soil organic layer thickness (SOL; centimeters) (b). Spatial distribution of density of reproductive black spruce trees (trees trees·ha^{-1}; Dens. Repr. Black spruce; c) and reproductive jack pine trees (trees trees·ha^{-1}; Dens. Repr. Jack pine trees; d) in the old and recently burned plots. Spatial distribution of spring growing degree days (spring DD5) for the period 1985-2015 (e) and change in spring DD5 trends (slope coefficients obtained in linear regression models) for each of the study plots for the period 2000-2015 (f). In panels b-d, pre-fire values are shown for the recently burned plots.



Supplementary Figure 2. Spatial distribution of spring-summer Hargreaves' climatic moisture deficit (CMD, mm; a) and spring minimum temperature (Spring Tmin, °C, c) for the period 1985-2015 and slope coefficients obtained in linear regression models of the change in spring-summer CMD and Spring Tmin for each of the study plots for the period 2000-2015 (b, d).



Supplementary Figure 3. Percentage of black spruce trees per plot (% Trees), tree density (Dens. Trees; trees·ha^{-1}) and basal area (m^2·ha^{-1}) as a function of spring growing degree days (Spring DD5) of black spruce and jack pine on the Plains and the Shield. Pre-fire values are used for the burned plots.



Supplementary Figure 4. Probability of cone presence as a function of plot age (reproductive age thresholds, b) for individual black spruce and jack pine trees on the Taiga Plains (Plains) and the Taiga Shield (Shield) in the Northwest Territories, Canada. Transparent ribbons indicate 95 % confidence intervals. The horizontal dashed line indicates the reproductive age thresholds (probability of cone presence on a tree > 0.5). Dash-dotted line is used for black spruce in the shield, where plot age resulted no significant in the model. Full model outputs are in Table S2c.

1.2 Supplementary Tables

Supplementary Table 1. Forest compositional attributes on the Plains and the Shield calculated from the 552 recently and old burned plots (n=340 in the Plains; n=210 in the Shield). SOL: Soil organic layer; BS: Black spruce; JP: Jack pine; BS trees (%): Proportion of black spruce trees; JP trees (%): Proportion of jack pine trees; Repr. BS trees (%): Proportion of reproductive black spruce trees; Repr. JP trees (%): Proportion of reproductive jack pine trees. Mean and standard errors are given for all variables, except for plot age where mean and range are given.

	Plains		Shield	
	Mean	SE/range	Mean	SE/range
Plot age (years)	89	29-241	85	19-275
Soil drainage: Dry/Moist/Wet (% plots)	32/33/35		50/19/31	
Presence of ice: No ice/Ice (% plots)	67/33		67/33	
SOL (cm)	46	2.7	17.4	1.6
BS trees (%)	48	2	47.2	2.6
JP trees (%)	16.6	1.5	18.3	2.3
Basal area BS ($m^2 \cdot ha^{-1}$)	6	0.4	4.5	0.4
Basal area JP ($m^2 \cdot ha^{-1}$)	5.7	0.5	2.3	0.3
Density BS ($trees \cdot ha^{-1}$)	4296	263	3148	270
Density JP ($trees \cdot ha^{-1}$)	1989	372	1102	238
Dens. Reproductive BS ($trees \cdot ha^{-1}$)	1144	76	1339	127
Dens. Reproductive JP ($trees \cdot ha^{-1}$)	780	175	636	130

Supplementary Table 2. Probability of cone presence GLMMs coefficients as a function of diameter at breast height (DBH, a) and plot age (b) for black spruce and jack pine living individuals, from old burned plots, on the Plains and the Shield.

A	**Plains**			**Shield**		
	Reproductive	Non reproductive	% Repr. trees	Reproductive	Non reproductive	% Repr. trees
n Black spruce individuals	2079	3171	40%	1462	806	64%
n Jack pine individuals	1405	1125	55%	738	76	91%

B	**-Black spruce- Plains**			**-Black spruce- Shield**			**-Jack pine- Plains**			**-Jack pine- Shield**		
Predictors	*Log-Odds*	*SE*	*p*	*Log-Odds*	*SE*	*p*	*Log-Odds*	*SE*	*p*	*Log-Odds*	*SE*	*p*
(Intercept)	-3.12	0.22	<**0.001**	-1.43	0.24	<**0.001**	-2.08	0.35	<**0.001**	1.23	1.03	0.235
DBH	0.91	0.03	<**0.001**	0.97	0.05	<**0.001**	0.59	0.04	<**0.001**	0.94	0.14	<**0.001**
Random Effects												
Plot:Site	1.97 $_{\text{plot:site}}$			1.09 $_{\text{plot:site}}$			1.07 $_{\text{plot:site}}$			1.36 $_{\text{plot:site}}$		
Site	2.03 $_{\text{site}}$			1.45 $_{\text{site}}$			2.09 $_{\text{site}}$			8.08 $_{\text{site}}$		
Observations	5250			2268			2530			814		
Marginal R^2 /Conditional R^2	0.47 / 0.76			0.56 / 0.75			0.49 / 0.74			0.51 / 0.87		

C	**-Black spruce- Plains**			**-Black spruce- Shield**			**-Jack pine- Plains**			**-Jack pine- Shield**		
Predictors	*Log-Odds*	*SE*	*p*	*Log-Odds*	*SE*	*p*	*Log-Odds*	*SE*	*p*	*Log-Odds*	*SE*	*p*
(Intercept)	-0.69	0.22	**0.002**	0.45	0.36	0.207	-0.13	0.41	0.755	2.62	1.05	-0.69
Age	0.01	0	**0.031**	0.01	0	0.109	0.02	0.01	<**0.001**	0.02	0.01	<**0.05**
Random Effects												
Plot:Site	0.61 $_{\text{plot:site}}$			0.65 $_{\text{plot:site}}$			0.50 $_{\text{plot:site}}$			0.00 $_{\text{plot:site}}$		
Site	0.64 $_{\text{site}}$			0.57 $_{\text{site}}$			0.98 $_{\text{site}}$			2.47 $_{\text{site}}$		
Observations	5250			2268			2530			814		
Marginal R^2 /Conditional R^2	0.01 / 0.28			0.01 / 0.28			0.06 / 0.35			0.06 / 0.06		

Supplementary Table 3. Number of reproductive trees GLMMs coefficients for black spruce (a) and jack pine (b) individuals on the Plains and the Shield. DT: Density of trees; BA: Basal area, SOL: Soil organic layer. The level plot age < 50 (29-50 on the Plains and 19-50 years on the Shield) are included in the intercept.

A. Black spruce	**- Plains-**			**- Shield-**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	-6.41	0.53	**<0.001**	-6.45	0.52	**<0.001**
DT Black spruce [log]	0.9	0.07	**<0.001**	0.92	0.07	**<0.001**
BA Black spruce [log]	0.41	0.05	**<0.001**	0.35	0.07	**<0.001**
Age [50-100]				0.51	0.13	**<0.001**
Age [>100]				0.49	0.14	**0.001**
SOL [1st degree]	0.09	0.05	0.052	0.08	0.04	0.058
Spring DD5	-0.22	0.06	**<0.001**	-0.17	0.05	**<0.001**
Random Effects						
Site	0.16			0		
Observations	340			210		
Marginal R^2 / Conditional R^2	0.97 / 0.98			0.99 / 0.99		

B. Jack pine	**- Plains-**			**- Shield-**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	-8.92	0.55	**<0.001**	-7.47	0.73	**<0.001**
DT Jack pine [log]	1.21	0.06	**<0.001**	1.12	0.06	**<0.001**
BA Jack pine [log]	0.52	0.1	**<0.001**			
SOL [1st degree]	-2.32	0.41	**<0.001**	-6.32	2.23	**0.005**
SOL [2nd degree]	2.28	0.75	**0.002**	-6.5	4.92	0.186
SOL [3rd degree]				-4.49	9.67	0.642
Spring DD5 [1st degree]	-0.14	0.06	**0.024**	3.05	0.81	**<0.001**
Spring DD5 [2nd degree]				0.23	0.16	0.162
Random Effects						
Site	0			0.03		
Observations	340			210		
Marginal R^2 / Conditional R^2	0.99 / 0.99			0.99 / 0.99		

Supplementary Table 4. Mean and standard error values of density of seedlings, density of reproductive trees and reproductive efficiency for black spruce (BS) and jack pine (JP) calculated from the 228 recently burned plots on the Plains and the Shield. An efficiency ratio (unitless) is calculated by dividing the reproductive efficiency of jack pine with the reproductive efficiency of black spruce. Reproductive efficiency of black spruce and jack pine and the efficiency ratios were calculated for 203 and 129 plots, respectively.

	Plains		**Shield**	
	Mean	SE	Mean	SE
Density of BS seedlings (Seedlings·ha^{-1})	36644	5077	14000	2315
Density of JP seedlings (Seedlings·ha^{-1})	84521	16665	4386	1605
Density of BS reproductive trees (trees·ha^{-1})	1114	106	1350	165
Density of JP reproductive trees (trees·ha^{-1})	489	112	489	221
Reproductive efficiency BS (Seedlings·Reproductive tree^{-1})	5587	1952	244	157
Reproductive efficiency JP (Seedlings·Reproductive tree^{-1})	17591	6668	719	239
Efficiency ratio (BS Plains/BS Shield)	**23**			
Efficiency ratio (JP Plains/JP Shield)	**24**			
Efficiency ratio (JP/BS)	**3**		**3**	