Institut de recherche sur les feuillus nordiques Inc.
Northern Hardwoods Research Institute Inc.

What factors explain variations in sapling density of tolerant hardwood?

September 2020

Technical Note

Silviculture

Introduction

Natural forest regeneration is the ability of a stand to renew spontaneously after natural or anthropogenic disturbance (Carle and Holmgren, 2003). This process is difficult to predict given its high variability (Li et al., 2011). Some studies showed that harvest intensity influences the composition of regeneration in Acadian hardwood forests (Danyagri et al., 2017). However, the forest regeneration process is poorly documented for commercial northern hardwoods species in the Acadian forest (Li et al., 2011). Predicting how sapling density of tolerant hardwood is influenced by silvicultural, environmental, and ecological factors is a challenging task in New Brunswick because of the limited availability of data in this jurisdiction. The objective of this study was to identify the silvicultural, environmental, and ecological variables that best explain variations in sapling density of commercial tolerant hardwood species (sugar maple, American beech) in the Acadian forest in northern New Brunswick. We predicted that the variation in saplings density is best explained by treatment intensity (e.g. percent basal area removed).

HIGHLIGHTS

- **We did not find that treatment intensity, expressed by the percent basal area removed and the post-treatment basal area, best explains variation in sapling density of tolerant hardwood in this dataset.**
- **The factor that best explained variation in sapling density of tolerant hardwood in this dataset was the proportion of hardwoods in the original stand.**
- **Sapling density of American beech increases with the proportion of hardwoods in the original stand.**
- **Sapling density of American beech exceeded 1500 stems/ha when the proportion of tolerant hardwoods in the original stand was greater than or equal to ~80%.**
- **Sapling density of sugar maple was not significantly influenced by the proportion of hardwoods in the original stand.**
- **Increasing the sample size is recommended to reach more comprehensive conclusions about the most important factors explaining variation in sapling density of tolerant hardwood in Acadian forests.**

Reviewed: September 2020

METHODOLOGY

We used data collected in 43 permanent sample plots (PSP) of 0.05 ha located in northern New Brunswick (Black Brook) on lands owned by J.D. Irving Limited. This PSP network was used to evaluate the stand and regeneration dynamics before and after treatment. All PSP's were established in 2002 and measured before harvesting. In the original stand (before harvesting), softwoods had the highest density of merchantable trees (min = 20 trees/ha, mean = 693 trees/ha, max = 3720 trees/ha) compared to other commercial groups (Figure S1, Appendix 1). All PSP's were treated and harvested between 2002 and 2005 with different treatment intensities.

Balsam fir was heavily targeted by these treatments in order to emulate the spruce budworm outbreaks by creating gaps in the stand. In the residual stand (after harvesting), the merchantable tree density of sugar maple (min = 20 trees/ha, mean = 181 trees/ha, max = 740 trees/ha) was higher than softwoods and other commercial hardwoods tree density (Figure S1, Appendix 1).

The same PSP's were re-measured in 2018, 14 years after harvest. Given the analytical constraints related to the small sample size, the analyses described below only address the density of saplings (regeneration with DBH between 1 cm and 9 cm) of two commercially important species, sugar maple and American beech. For each plot (N=43), silvicultural and ecological variables (Table 1) were collected or calculated from existing inventory data. Environmental variables (Table 1) were extracted from GIS layers for each plot.

To identify the silvicultural, environmental, and ecological variables that best explain variations in sapling density of tolerant hardwood species (response variable), we compared a series of GAMLSS (Generalized Additive Models for Location Scale and Shape) models. The initial list of models had been built to reach our research objective and respond to the operational concerns (silvicultural management) of industrial partners. The different models included different combinations of the predictors (silvicultural, environmental, and ecological variables) and relevant interactions between these predictors (24 candidate models). In each model, we included the plot ID as a random variable.

To avoid overparameterization, we only compared models with a maximum of 20 degrees of freedom (Table S1, Appendix 2). We also removed from the list of models the ones that did not converge (Table S1, Appendix 2). Hence, we checked the assumptions in each model and retained in the final list of models (Table S1, Appendix 2) only the ones that validated the assumptions underlying the GAMLSS technique (normality, homogeneity and deviation of residuals; Rigby et al., 2019). The most suitable GAMLSS models were selected using the second order Akaike Information Criterion (AICc) for small sample size.

METHODOLOGY

Table 1. The three categories of predictor variables used in analyses

Silvicultural variables	Environmental variables	Ecological variables
- % merchantable basal area cut - Residual merchantable basal area (m^2/ha) - % softwood in the residual merchantable basal area - % hardwood in the residual merchantable basal area - Total QMD[1] - Total QMD cut	- Ecosite[2] - Depth of the water table - Aspect, Slope - Elevation - Topographic index (TPI) - Soil characteristic - BGI[3]	- Original stand characteristics: - Total basal area - Total QMD - % hardwood - % softwood - Competition: Beech density - Competition: red maple density

[1]: Quadratic Mean Diameter
[2]: This variable was initially included, but because there was only one plot for a given category of Ecosite, this created convergence problems. We then removed this variable after checking that it did not explain variations in sapling density when using the dataset excluding this plot.
[3]: Biomass Growth Index

To provide additional and preliminary information to respond to the operational concerns (silvicultural management) of industrial partners, we described variation in sapling density (14 years after harvesting) according to the treatment intensity for all species or species groups inventoried in the sample plots (Figure S2, Appendix 1). Four categories of treatment intensity were created from the four quantiles of the percent basal area removed data, low (basal area removed ≤ 25%), medium (25% < basal area removed ≤ 50%), high (50% < basal area removed ≤ 67%) and very high (67% < basal area removed ≤ 96%) (Figure S2, Appendix 1).

RESULTS

We found that the model including the interaction between the tolerant hardwood species and the proportion of hardwoods in the original stand (%) was the best model to explain variation in sapling density of sugar maple and American beech (Table S1, Appendix 2). Also, we found a significant effect of the proportion of hardwoods in the original stand on sapling density of American beech (Table 2). However, there was no significant effect of the proportion of hardwoods in the original stand on density of sugar maple saplings (Table 2).

Table 2. Coefficients of the best predictive model for sapling density of tolerant hardwood species

Predictors	Estimate	Standard error	t-value	p-value[2]
Sapling density				
Intercept	7.342	0.112	65.703	**< 0.001**
American beech * PHOS[1]	1.319	0.178	7.418	**< 0.001**
Sugar maple * PHOS	0.233	0.224	1.039	0.302

[1]: **P**roportion of **H**ardwoods in the **O**riginal **S**tand (%)
[2]: Values in bold type indicate significance at *P* = 0.05

The density of American beech saplings significantly increased with the proportion of hardwoods in the original stand, whereas the increase in the density of sugar maple saplings with the proportion of hardwoods in the original stand was not significant (Figure 1, Table 2). On average, the 1500 stems/ha density threshold (simple density threshold; Government of New Brunswick, 2020) was exceeded when the proportion of hardwoods was greater than or equal to ~80% and ~65% for American beech and sugar maple respectively, according to model predictions (Figure 1).

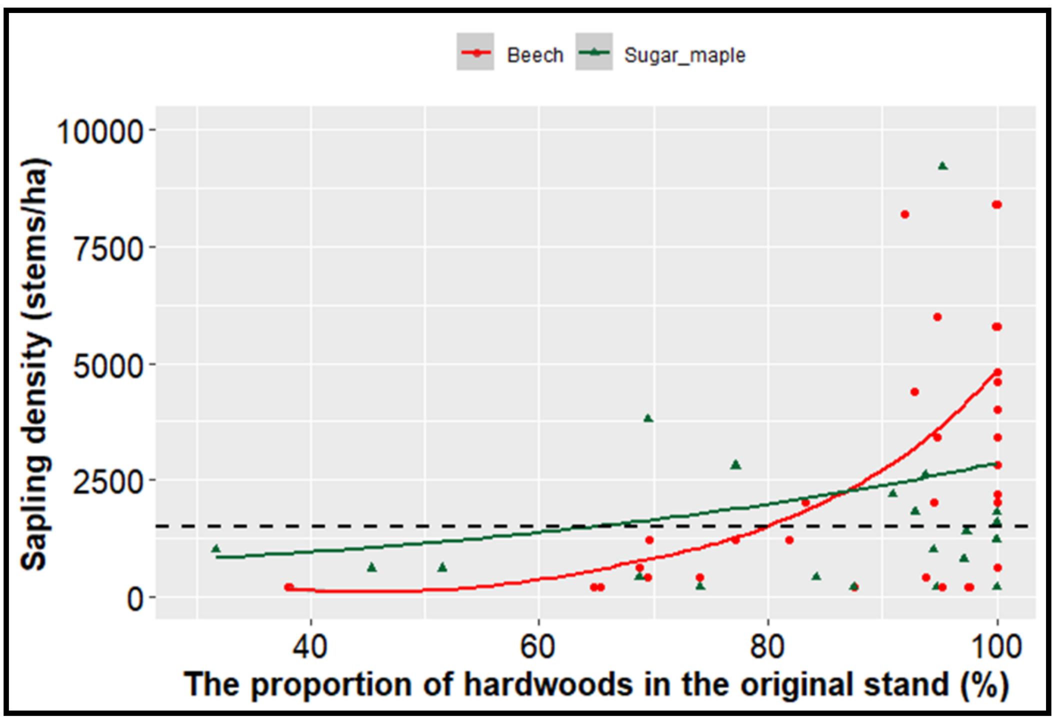

Figure 1. Effect of the proportion of hardwoods in the original stand on tolerant hardwood sapling density. The dashed line indicates the 1500 stems/ha density threshold.

DISCUSSION

Among all the silvicultural, environmental and ecological factors and contrary to our prediction, the interaction between the proportion of hardwoods in the original stand and species best explained the sapling density of tolerant hardwoods. Li et al. (2011) also found that the proportion of hardwood can influence forest dynamics (e.g. the recruitment of stems into the merchantable cohort) in New Brunswick. After harvest, the proportion of hardwoods in the residual stands has a direct influence on the regeneration of tolerant hardwoods (Nyland, 2016). Indeed, the proportion of hardwoods could influence the light availability inside the stand, by influencing the canopy cover (Nyland, 2016).

Unlike sugar maple, the density of American beech saplings is influenced by the canopy closure (Nolet et al., 2008, 2015), particularly in stands with a high proportion of hardwoods. Under these conditions, density of American beech saplings exceeds that of sugar maple (Nolet et al., 2015). Despite its shade tolerance, the establishment of sugar maple saplings is favored by the partial opening of the canopy and its density increases with light availability (Forget et al., 2007; Baral et al., 2016). Indeed, several studies recommended the application of partial harvest in stands with an abundance of pre-established sugar maple regeneration in order to increase their abundance after harvesting (Nyland et al., 2006; Kershaw et al., 2012). Under these conditions, the density of sugar maple saplings can exceed that of American beech (Nolet et al., 2008).

Moreover, unlike American beech, the sapling density of sugar maple is strongly influenced by site fertility and the strength of inter-specific competition (Kobe et al., 2002; Arii and Lechowicz 2002; Dracup and MacLean, 2018). Indeed, nutrient-poor stands (especially in basic cations) or dominated by American beech saplings are not favorable to the establishment of sugar maple saplings (Gravel et al., 2008; Bannon et al., 2015). However, in closed-canopy stands, increasing light availability may increase the density of sugar maple saplings to a greater extent than for American beech (Nolet et al., 2008). In summary, to promote the abundance of a tolerant hardwood species over another, different authors recommended to evaluate site fertility and apply adequate silvicultural treatments suited to the species of interest (Duchesne et al., 2002; Wagner et al., 2010; Sullivan et al., 2013; Danyagri et al., 2019). In this context, some studies report that application of partial harvests (with medium intensity) would favor the abundance of sugar maple saplings over American beech (Danyagri et al., 2019), especially on fertile sites (Arii and Lechowicz 2002; Kobe et al., 2002; Forget et al., 2007).

Although the effect of treatment intensity (percent basal area removed) on tolerant hardwood saplings was not detected in this study, we described variation in sapling density (14 years after harvesting) according to the treatment intensity for all species or species groups inventoried in the sample plots (Figure S2, Appendix 1).

DISCUSSION

This figure gives preliminary information indicating that the density of tolerant hardwood saplings seems to vary more than the mid-tolerant hardwoods (yellow birch, red maple), intolerant hardwoods and softwood species, notably with the low and medium treatment intensities (Figure S2, Appendix 1). Confirming this preliminary information and identifying what explains variation in sapling density for all species or species groups inventoried in the sample plots would require a larger sample size and additional statistical analyses.

Because this study was limited by its small sample size (N = 43), we recommend increasing the number of sample plots to confirm the patterns found for each species and reach more comprehensive conclusions about the most important factors explaining variation in sapling density of tolerant hardwood.

CONCLUSION

The interaction between the proportion of hardwoods in the original stand and species was the factor that explained best the variation in the density of tolerant hardwood saplings (American beech and sugar maple). Only the American beech saplings responded to increases in the proportion of hardwoods in the original stand. We recommend to further investigate the effects of site fertility (in addition to the measured variables in this study) to obtain a more comprehensive understanding of the factors shaping patterns in the density of tolerant hardwood saplings in the Acadian forest.

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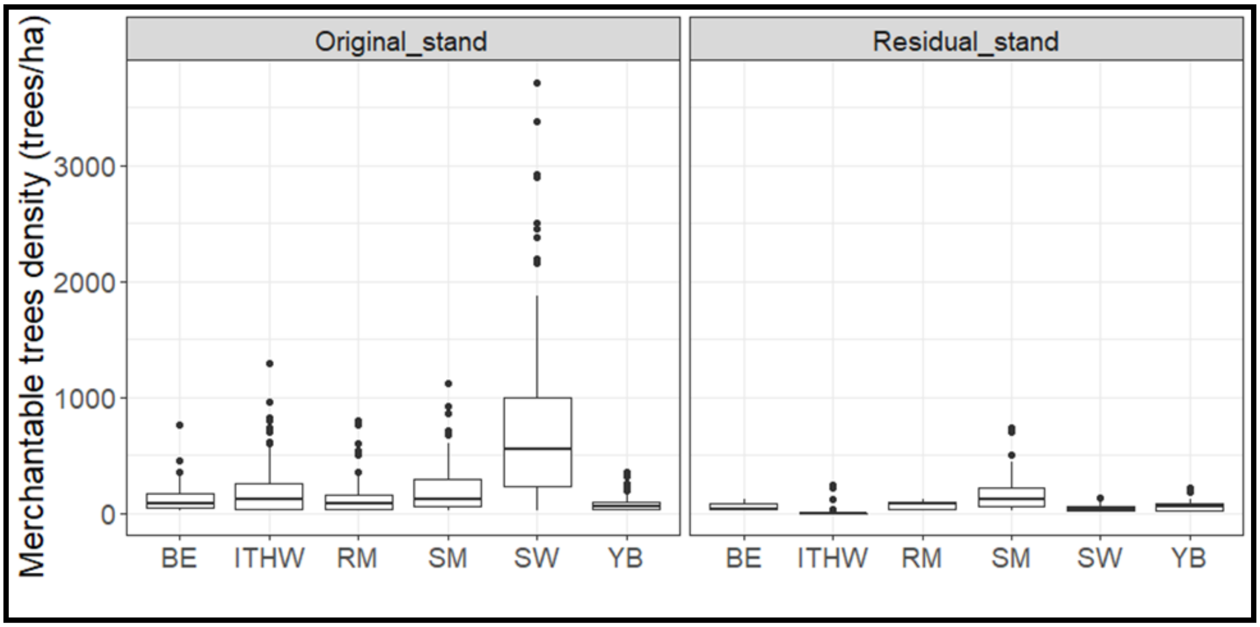

Figure S1. Box plots showing the variation of trees density by species or group of species (BE: American beech; ITHW: intolerant hardwoods (white birch, trembling aspen); RM: red maple; SM: sugar maple; SW: softwood; YB: yellow birch) across original stand (before harvesting) and residual stand (after harvesting).

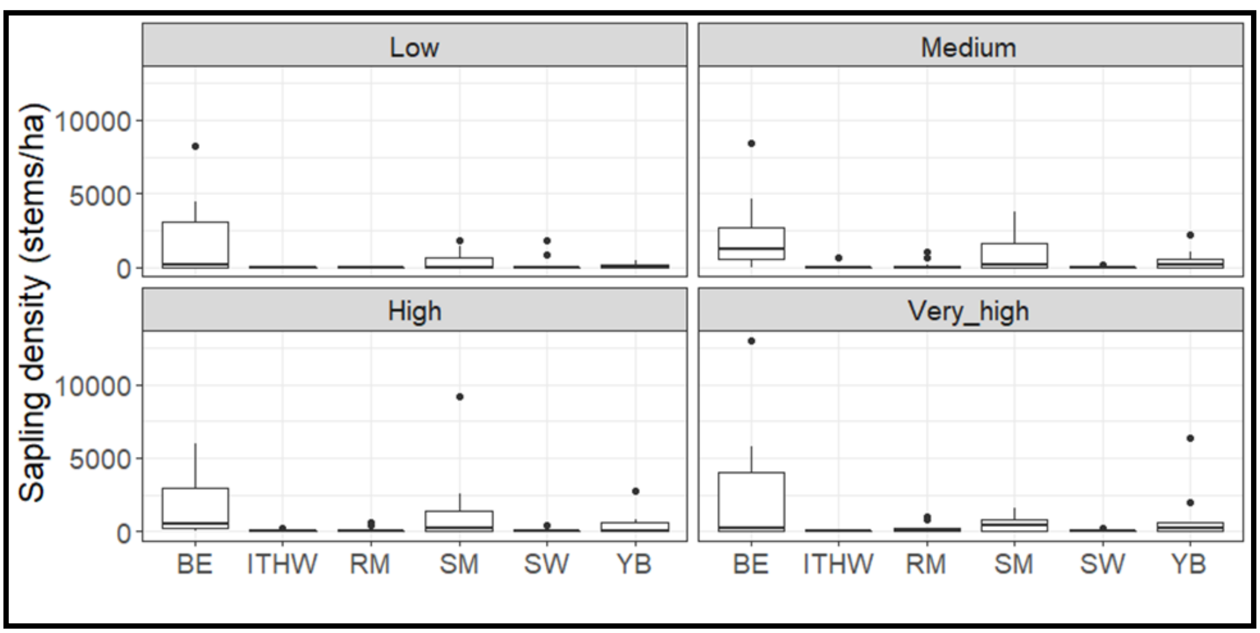

Figure S2. Box plots showing the variation of sapling density (14 years after harvesting) by species or group of species (BE: American beech; ITHW: intolerant hardwoods (white birch, trembling aspen); RM: red maple; SM: sugar maple; SW: softwood; YB: yellow birch) according to the treatment intensity (Low : basal area removed ≤ 25%; Medium: 25% < basal area removed ≤ 50%; High: 50% < basal area removed ≤ 67%; Very high: 67% < basal area removed ≤ 96%).

Appendix 2

Table S1. Final list of candidate models selected for selection by AICc. The first four models with AICc and ΔAICc values include models that respected fit assumptions of GAMLSS models (normality, homogeneity and deviation of residuals) with a maximum of 20 degrees of freedom to avoid overparameterization. The best model is shown in bold with the lowest AICc and ΔAICc value. The list of models without AICc and ΔAICc values were not retained for AICc selection because it includes non-converging models; and models that do not respect fit assumptions of GAMLSS models.

Model#	Model variables	AICc	ΔAICc
Model 1	**Species*Proportion of hardwoods in the original stand**	**1049.8**	**0.0**
Model 2	Species*Proportion of hardwoods in the original stand+ Species* Proportion of softwoods in the original stand + Species*Total QMD	1063.0	13.2
Model 3	Species*Total QMD	1073.4	23.6
Model 4	Species* Proportion of hardwoods in the original stand + Species* Proportion of softwoods in the original stand + Species*Topography Index	1509.8	460.0
Model 5	Species + Biomass Growth Index	-	-
Model 6	Species + Aspect + Slope	-	-
Model 7	Species + Total basal area + Topography Index	-	-
Model 8	Species*Total QMD + Species*Topography Index	-	-
Model 9	Species + Residual merchantable basal area	-	-
Model 10	Species*Total QMD cut	-	-
Model 11	Species*Total QMD + Species*Total QMD cut	-	-
Model 12	Species*Topography Index + Species*Elevation	-	-
Model 13	Species*Aspect + Species*Slope	-	-
Model 14	Species*Total basal area + Species*Topography Index	-	-
Model 15	Species* Proportion of hardwoods in the original stand + Species* Proportion of softwoods in the original stand + Species*Elevation	-	-
Model 16	Species + Total QMD + Elevation	-	-
Model 17	Species*Total QMD + Species*Elevation	-	-
Model 18	Species + Residual merchantable basal area + Merchantable basal area cut	-	-
Model 19	Species + Merchantable basal area cut	-	-
Model 20	Species + Merchantable basal area cut + Topography Index	-	-
Model 21	Species*Merchantable basal area cut + Species*Topography Index	-	-
Model 22	Species + Merchantable basal area cut + Elevation	-	-
Model 23	Proportion of hardwoods in the original stand	-	-
Model 24	Species + Total QMD + Elevation	-	-

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