Early survival and growth of planted hardwoods

in the Acadian Forest

by

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Bachelor of Science in Forestry, Nanjing Forestry University, 2017

A Report Submitted in Partial Fulfillment
of the Requirements for the Degree of

Master of Forestry

in the Graduate Academic Unit of Forestry and Environmental Management

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This report is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

January 2019

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ABSTRACT

Establishing advanced tolerant hardwood regeneration in the Acadian forest may play a more important role due to climate change. However, very little is known about establishing tolerant hardwoods through planting in Acadian forest. A small planting trial of 392 hardwood seedlings including red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britt.) were planted in the Noonan Research Forest (NRF) beginning in 2015. We examined effects of caging, plant fraction (a measure of competition), and leaf production, combined with partial harvest, on early growth and survival of planted seedlings. Leaf number in the late summer 2018 had the greatest influence on height and RCD growth rate within the growing season while competition had the greatest influence on leaf number in the late summer 2018. Caged seedlings had larger size and higher survival rate. Caging or fencing combined with partial harvest and intensive competition control in the early stage are recommended to improve early growth and survival.

ACKNOWLEDGEMENTS

I would first like to thank Dr. John Kershaw for his support, advice, and insight with this report, and thank you for the energy and time put into the statistical course. You are truly and inspiration and a mentor. I would also like to thank Mr. Jasen Golding for his dedication about the trial design and all the materials that were used to accomplish this report. I would like to extend a special thank you to Prof. Anthony Taylor for the advice to insights to this report. Lastly, thank you to Ting-Ru Yang and Yung-Han Hsu for helping me with the R programming.

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1. INTRODUCTION

The Acadian Forest is an ecotone between the northern hardwood forest and the boreal forest and is found in northern Maine, New Brunswick, Prince Edward Island, and Nova Scotia (Loo and Ives 2003; Rowe 1972). The Acadian forest contains approximately 32 tree species (Rowe 1972; Loo and Ives 2003) which include about half hardwood species and half softwood species. Red spruce (*Picea rubens* Sarg.) is common and considered the forest's defining softwood species (Taylor et al. 2017). Other common species include balsam fir (*Abies* balsamea (L.) Mill.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), white ash (*Fraxinus americana* L.), American beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.*),* white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carrière), northern red oak (*Quercus rubra* L.), white birch (*Betula papyrifera* Marshall), trembling aspen (*Populus tremuloides* Michx.), black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench) Voss), tamarack (*Larix laricina* K. Koch), red pine (*Pinus resinosa* Ait.), eastern cedar (*Thuja occidentalis* L.) and jack pine (*Pinus banksiana* Lamb.). The Acadian Forest region is located between 43° and 48° N latitude and contains thousands of kilometers of coastline. The prevailing westerly winds from the continent often brings cold Artic air to the region; however, the Atlantic Ocean humidifies and moderates this region in terms of precipitation and temperature to make the winters milder and the summers cooler than the continent area.

Natural disturbances in the northern hardwood forest are typically small-scale disturbances caused by wind, ice storms and insect damage, toppling single trees or small groups of trees creating forest gaps (Lorimer 1977; Seymour, White, and deMaynadier 2002; Zelazny et al. 2007), while natural disturbances in the boreal forests are large-scale stand replacement events (Bergeron and Harvey 1997). The combined influence of these varied disturbances and the unique climate in this region produces a variety of stand structures in the Acadian Forest from simple pure even-aged stands to complex multi-cohort, multispecies stands (Zelazny et al. 2007).

Human induced disturbance is currently the most common disturbance agent in the Acadian Forest (Zelazny et al. 2007; Loo and Ives 2003; NSDNR 2011). Native Americans widely used fire and other tools to clear land, control vegetation, and hunt big game (Pyne 2001). European settlers cleared vast areas of forest for agriculture in the 1700s and early 1800s (Lorimer 1985; Oliver 1980; Oliver and Larson 1996). Much of the forests of today are second growth forests that regenerated following land abandonment in the 1850s (Oliver and Larson 1996; Seymour, White, and deMaynadier 2002). Before European settlement, this region was largely forested by beech, pine, oak, cedar, birch, and hemlock. However, the species composition of the Acadian forest has changed dramatically from its pre-European state due to human impacts and natural factors. During European colonization, cedar and spruce were the predominant species used for shipbuilding, and white pine was harvested in great numbers for making ship masts, especially following the US Revolution. Balsam fir was never targeted for harvesting until the 1980s (Forbes et al.1998), and recent cutting practices have seen this species, along with red maple, increase in abundance (Archambault, Delisle, and Larocque 2009; Seymour, White, and deMaynadier 2002; Seymour et al. 1986). The hardwood forest structure and composition has been further impacted by exotic diseases (Taylor, McPhee, and Loo 2013).

In recent decades, regeneration of shade tolerant and mid-tolerant hardwoods, including red oak, sugar maple, and yellow birch, has declined and became more challenging (Bédard and Huot 2006; Gauthier 2002; Matonis, Walters, and Millington 2011). Declining regeneration of desired hardwood species is a phenomenon that has been observed throughout eastern North America (Kershaw et al. 2012; Archambault, Delisle, and Larocque 2009; Fredericksen et al. 1998). There are many possible explanations for this: browsing from mammals such as white-tailed deer (*Odocoileus virginianus),* moose (*Alces alces*) and squirrels (*Sciuridae*); the need for longer rotations than those used for spruce plantations in New Brunswick; the use of herbicide; and competition with other intolerant hardwood species and invasive vegetation at the early growth stage. However, the increasing borealization of the Acadian forest, as a result of industrial forest management practices is likely a major contributor (Salonius 2007; Salonius and Beaton 1999). The emphasis on softwood plantations and move to more mechanized harvesting has resulted in less soil disturbance, and a reduction in mechanical site preparation, which favors balsam fir advanced regeneration at the expense of tolerant and mid-tolerant hardwood regeneration, which often requires more exacting conditions for regeneration (Salonius and Beaton 1999).

While softwoods dominate the industrial forest plantations throughout the region, hardwoods are an important part of the Acadian forest. Furthermore, the climate of the Acadian Forest Region is projected to warm over the coming decades and become increasingly suited to warm-adapted hardwood species (Taylor et al. 2017). Planting tolerant hardwood species may be a mechanism to address the increasing difficulties with tolerant hardwood regeneration and may create forest conditions that are more resilient to climate change.

Because of the historic focus on planting softwoods in the Acadian Forest Region and the past abundance of natural hardwood regeneration, little is known about establishing tolerant hardwoods through planting in this region. Most hardwood species can be planted successfully, but plantation establishment is generally more difficult and expensive than conifer plantations, especially when considering shade tolerant hardwood species rather than fast-growing, shade intolerant hardwood species such as hybrid poplar (Althen 1977). Weed control during the early years of establishment is necessary and will greatly improve seedling growth and survival (Pijut 2003; Althen 1977). Jamie et.al (2010) found that the use of herbicide, fire, or other methods of vegetation control, combined with the shelterwood or single tree selection harvest system, contributed successfully to establishing red oak regeneration. Browsing by white-tailed deer is one of the major causes of hardwood regeneration failure (Tilghman 1989). Horsley et al. (2003) found a negative trend between hardwood seedling height and deer population levels in northern Pennsylvania. Tree gridling by mice and browsing by rabbits are also factors that can cause establishment failure (Althen 1977). Increasing moose population poses a further browsing threat to young hardwood species (Banks 2017). Common practices to protect seedlings from deer browsing include caging and fencing. Althen (1977) found that the best practice to protect against rodent damage is the elimination of competing vegetation which provides hiding cover from predators in the summer and tunnels for movement under the snow in winter.

Many of the above described studies occurred outside of the Acadian Forest region. To our knowledge, no systematic studies of hardwood planting and the factors influencing the growth and survival of planted hardwood seedlings exist for the Acadian Forest. To help address this knowledge gap, the Faculty of Forestry and Environmental Management at the University of New Brunswick established a hardwood planting trial in the Noonan Research Forest in 2015. This report summarizes the early growth and survival of those plantings and makes recommendations for future planting trials.

2. METHODS

In this study, we developed a small field trial of planted hardwoods in the Noonan Research Forest (NRF, Fig. 1) to examine seedling survival and early growth. Three tree species were initially planted: red oak, sugar maple, and yellow birch. To determine if browsing was a factor influencing growth and survival, we built wire cages around some seedlings. Seedlings were planted in the summer of 2015 and 2016. Seedlings were measured at the time of planting, at the end of the first growing season, and at the end of the second and third growing seasons.

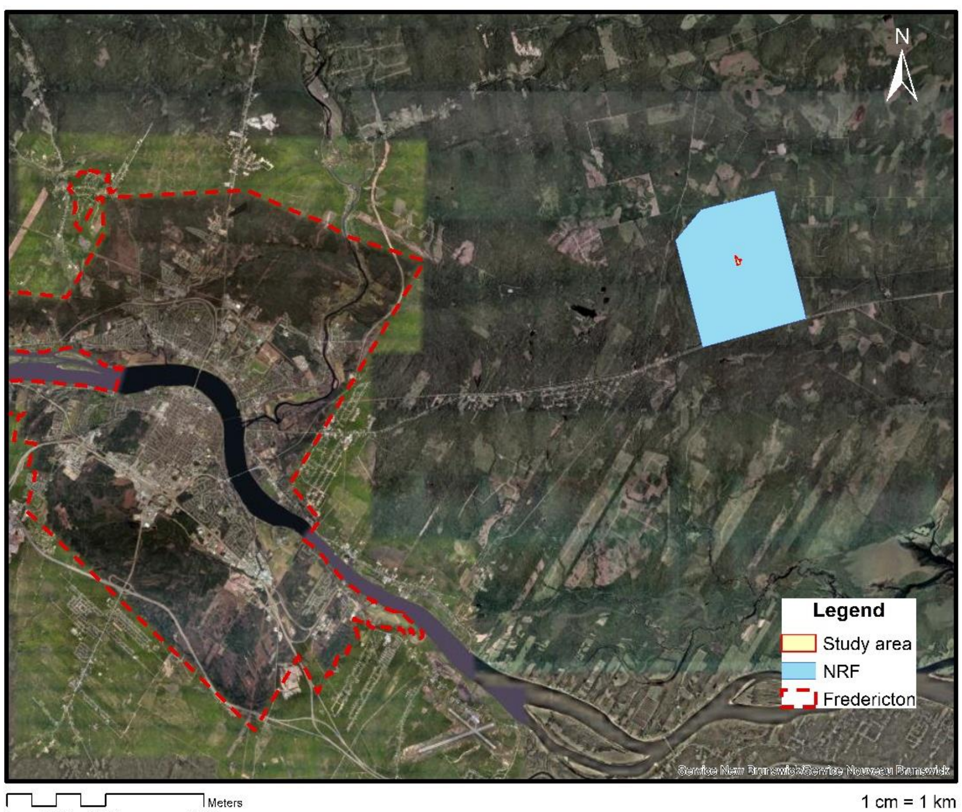

Figure 1 Location of Noonan Research Forest and study area in relation to Fredericton, NB.

2.1 Site Description

This study was conducted on a 2-hectare recently harvested area located in the NRF. The area was harvested in 2014 by clearcut harvesting in the upper half of the study area and partial cut harvesting in the bottom half of the study area (Fig. 2). The pre-harvested area was dominated by red spruce, balsam fir, some shade-intolerant hardwood species (such as white birch and red maple) and a few white pine. The bottom half of the block was partially harvested using strip cuts leaving behind red spruce and white pine as the primary residual species. Approximately 5m wide strips were cut and alternating residual strips of 5 – 10m were left with some removal of intolerant species within the residual strips.

This area is in a dry-mesic condition with pit-and-mound topography. The study area is relatively flat with elevation less than 100m. It is considered an upland site type within the NRF with moderately well-drained and slightly rocky soil conditions. The study area is located within the Grand Lake Lowlands – Maquapit eco-district, which is moderately dry and has the warmest climate in the province of New Brunswick (Zelazny et al. 2007). Mean annual temperature is 5.8 °C, while mean January and July temperatures are -9.4°C and 19.4°C respectively. Mean annual precipitation is 1095mm with an average annual frost-free period of 140 days (Environment Canada 2018).

Herb and shrub plant species invaded and dominated the understory rapidly following harvest which made it difficult for subsequent monitoring and data collection.

Competition from herbs and shrubs was intense in the study area. Specifically, Alleghany blackberry (*Rubus allegheniensis* Porter) and raspberry (*Rubus idaeus* L.) invaded the understory rapidly and competed strongly with the planted hardwood seedlings (Fig. 3). In addition to these two shrub species, the planted hardwood seedlings also faced strong competition from local intolerant hardwood tree species, grasses, and other invading early successional vegetation (Fig. 3).

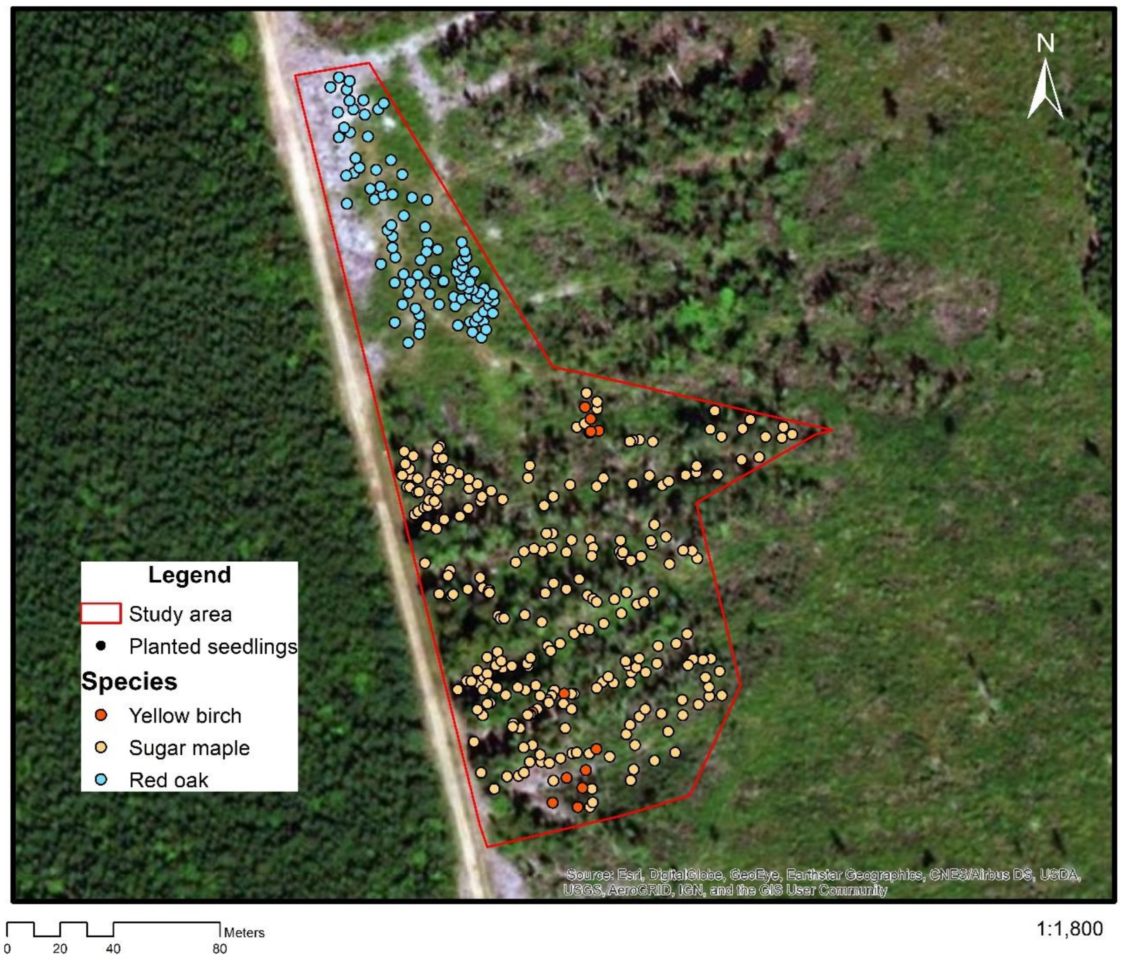

Figure 2 Locations of planted seedlings within the planting trial at Noonan Research Forest. The red line shows the boundary of the planting area.

Figure 3 Photo showing example of typical competing vegetation associated with planted hardwood seedlings at the Noonan Research Forest.

2.2 Planting Trial Development

In the summer of 2015, 294 tolerant hardwood (193 sugar maple, 16 yellow birch, and 85 red oak) seedlings were planted in the NRF (Fig. 2). Sugar maple and yellow birch are considered more shade tolerant than red oak (Burns and Honkala 1990). Red oak can tolerate drier conditions than the other two species. Sugar maple and yellow birch seedlings were planted in the partial harvest area (bottom half of the study area) in both the cut strips and under the canopy of the residual strips. Red oak seedlings were planted in the clear-cut area (upper half of the study area). Planting was carried out haphazardly with no predetermined spacing with the ultimate goal of spreading the seedlings over the site, but utilizing available planting sites (primarily places where mineral soil was accessible). Eleven sugar maple and 47 red oak seedlings had wire cages built around them (Fig. 4). There were no caged yellow birch seedlings. Selection of trees to cage was not based on any statistical design and, similar to planting location, was haphazard. In the summer of 2016, we planted another 98 sugar maple seedlings without cages, randomly throughout the strip-cut area.

Seedlings were natural germinants that were transplanted from a private source in Stanley, New Brunswick, which is about 55 km north of the study area. Germinants were extracted with shovels, kept in containers overnight, watered and planted the following day to ensure survivability. Initial seedling heights were about 10 - 20cm. There were no pre- or post-management activities such as site-preparation, scarification, or cleaning during the planting and seedlings were left to grow naturally following planting.

Figure 4 Sugar maple and orange marker flag surrounded by the wired cage.

2.3 Data Collection

Seedlings were assessed annually after planting. In the summer 2018, data were collected twice, once in the early summer (late May) and then again in late summer (mid-August). During the summer 2017, survival and height (HT) were measured for all seedlings. In the summer 2018, root-collar diameter (RCD) and the number of leaves were also measured. Height (HT) was measured to the nearest 0.1cm using a meter stick. Root collar diameter (RCD) was measured to nearest 0.001 inch using a Vernier caliper, and then converted into the nearest 0.01 cm.

To assess the level of competing vegetation, a spherical camera (Nikon KeyMission 360; Fig. 5) was used to take a photo just above the seedling tip. The photo was projected as a fish-eye hemispherical photo and plant fraction (PF) was determined (Fig. 6). Plant fraction was defined as the proportion of pixels covered by vegetation and was used as an indicator of intensity of competing vegetation.

Figure 5 The Nikon KeyMission 360 camera and a yellow birch seedling. This photo was taken before the measurements, the camera will then be put above the seedling tip.

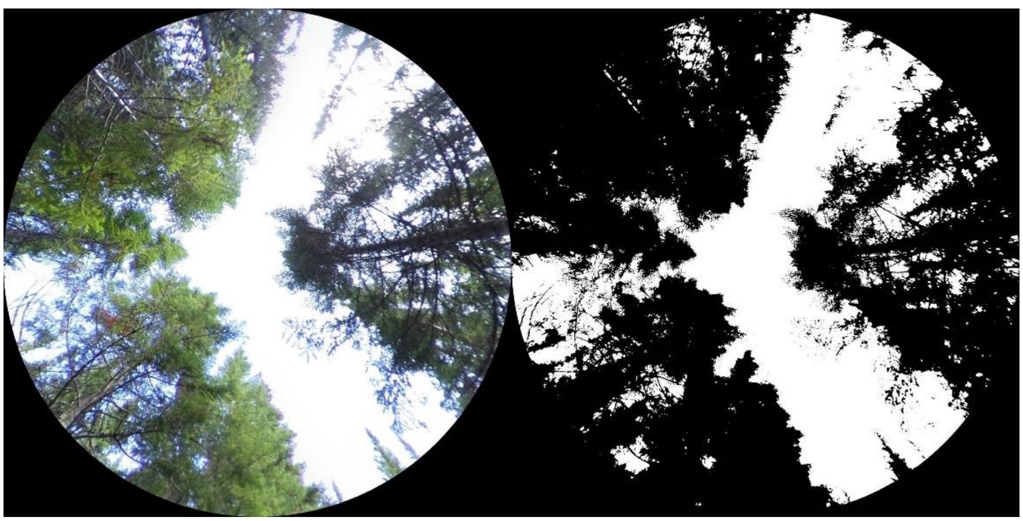

Figure 6 The conversion and calculation of Plant fraction (PF). The color photo was classified as sky(white) or vegetation (black) and PF was calculated as the proportion of black pixels in the right-hand picture.

2.4 Statistical Analysis

For this report, only the 2018 data are analyzed in depth. This planting trial suffers from many statistical design flaws and was not intended to be an experiment, but rather an attempt to gain experience planting tolerant hardwoods in the Acadian Forest. While the trial lacks statistical rigor, the insights gained from the trial can be used to help design future experiments. Because of the lack of experimental control, imbalance of data among species and caging treatment, normal linear models were not appropriate for analyzing the data that resulted from this study. Instead, we used generalized boosted regression models (Ridgeway 2007) to assess relative influence of factors thought to be important for seedling growth and survival. Survival, RCD and HT growth, and Number of Leaves were modeled independently. RCD and HT growth were modeled as ratios of seedling size at the end of the growing season to seedling size at the beginning of the growing season:

$$XGR = \frac{X\_L}{X\_E}$$

where, XGR = growth ratio of seedling factor X (X denotes RCD or HT); X_E = seedling size early in the growing season; and X_L = seedling size late in the growing season. All analyses were conducted with Rstudio Programming software (RStudio team, 2016) using the package GBM (Greenwell et al. 2018).

2.4.1 Growth Ratio

RCD and HT growth ratios (RCDGR and HTGR, respectively) were modeled using a

Gaussian distribution within GBM (Ridgeway 2007). Factors explored in the Growth Ratio GBM included Species, Caging, RCD in the early summer 2018 (RCD_E), height in the early summer 2018 (HT_E), PF in the early summer 2018 (PF_E), number of leaves in the early summer 2018 (LeafN_E), RCD in the late summer 2018 (RCD_L), height in the late summer 2018 (HT_L), PF in the late summer 2018 (PF_L), and number of leaves in the late summer 2018 (LeafN_L). Because of the limited number of observations and the limited number of independent variables, all relevant parameters were included in the initial call to GBM and we did not explore any parameter reduction techniques or additional model performance validation. The GBMs were run using a 70:30 training: testing split and 100 trees were generated for each random sample. Influence was calculated as a loss function based on the presence and absence of the factor in a set of trees. GBMs only identify influential factors and not the nature of their effects. To explore the effects of the influential factors we used scatter plots and lowess regressions to highlight trends across the range of data.

2.4.2 Survival

Survival is a binary response variable (0 = dead, 1 = live), and was modeled using a Bernoulli distribution. The same set of factors as used in the Growth Ratio GBMs were used in the Survival GBM with the same data split and influence calculations.

2.4.3 Leaf Number

LeafN_L in the growing season emerged as one of the consistently influential factors in the above GBMs. As a result, we examined the factors that influenced leaf number as well. As with growth ratio, leaf number was modeled as a Gaussian distribution, and the same factors used above were included in the GBM analysis except for the size variables in late summer (LeafN_L was the factor being modeled and RCD_L and HT_L were, like LeafN_L, a product of the season's growing conditions).

3. RESULTS

3.1 Average Seedling Size and Survival Rates

Averages and associated standard deviations for seedling HT and RCD are shown in Table 1 and Figure 7. Overall, caged seedlings were larger (Table 1), on average, than non-caged seedlings. In the early summer, the caged sugar maple seedlings had the largest height, while the caged red oak seedlings had the largest RCDs (Fig. 7). At the beginning of the summer, seedling heights were more equal with yellow birch being taller but differing only by 8cm from the non-caged sugar maple and 11cm from the non-caged red oak. By the end of the summer, yellow birch seedlings had much larger HTs than the other species (although there were only 16 yellow birch seedlings planted and 10 yellow birch survived into the late summer). On average, yellow birch seedlings were 42cm taller than non-caged sugar maple and 47cm taller than non-caged red oak by the end of the summer (Table 1). While the caged heights of sugar maple and red oak were greater than the non-caged heights, the non-caged yellow birch were still more than double the height of the caged sugar maple and red oak at the end of summer (Fig. 7). Differences in RCD were less pronounced than differences in HT both early and late in the summer (Table 1, Fig. 7). Initially RCD differed by less than 0.1cm between caged and non-caged seedlings; however, that gap widened for sugar maple by the end of summer (almost 0.2cm difference) while it remained unchanged for red oak (0.02cm). As with HT, yellow birch had the greatest increase in RCD over the summer (Table 1, Fig. 7). Seedling survival was based on the presence of leaves, which explains why there are more seedlings surviving in late summer than in early summer due to slower bud break of some individuals and the potential for human error (easier to miss small leaves early in the growing season). Red oak had the largest difference in survival estimates between early and late summer due to the much later leaf appearance on the red oak seedlings.

Table 1 Average seedling height and root collar diameter (RCD) (standard errors in parentheses) and number of survived seedlings by species and caging treatment for the hardwood planting trial at Noonan Research Forest.

Parameter	Species[1]	Early Summer			Late Summer		
		Number	Caged	Non-Caged	Number	Caged	Non-Caged
Height (cm)	SM	74	34.19 (5.488)	15.09 (0.597)	105	31.30 (8.548)	18.54 (1.056)
	RO	67	16.38 (0.591)	12.59 (0.552)	84	22.58 (1.566)	14.15 (0.648)
	YB	4	---	23.18 (3.577)	10	---	61.05 (11.814)
RCD (cm)	SM	74	0.34 (0.029)	0.32 (0.009)	105	0.55 (0.114)	0.38 (0.015)
	RO	67	0.46 (0.015)	0.42 (0.015)	84	0.68 (0.030)	0.64 (0.032)
	YB	4	---	0.43 (0.065)	10	---	1.21 (0.262)

[1]SM = sugar maple, RO = red oak, and YB = yellow birch.

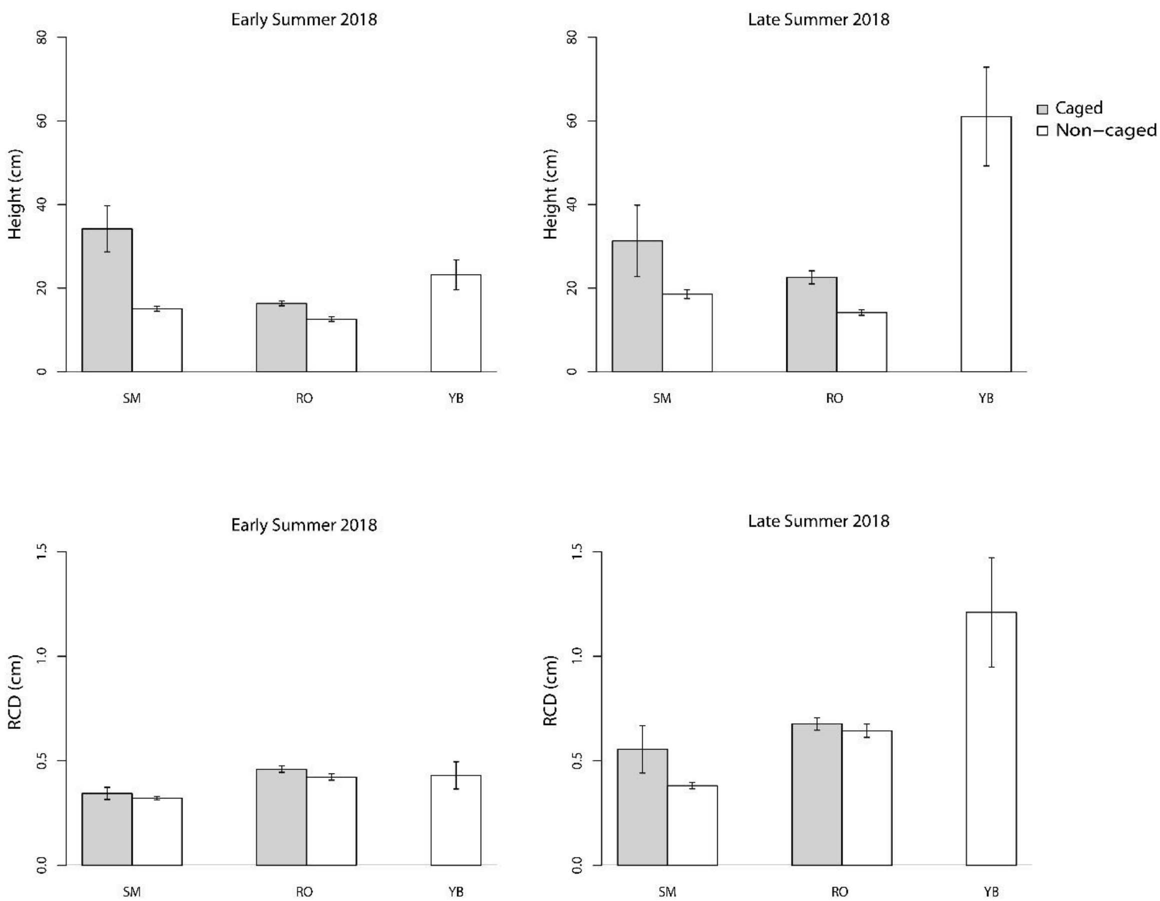

Figure 7 Average seedling height and root collar diameter (RCD) in early and late summer by species (sugar maple (SM), red oak (RO), and yellow birch (YB)) and caging treatment. Standard errors are shown in the error bar.

3.2 Height Growth Ratio

Figure 8 shows the relative influence of the tested factors on height growth ratio (HTGR) within the 2018 growing season based on the GBM model. The LeafN_L and the HT_E had high relative influence (>20) on HTGR within this growing season. PF_E, PF_L and RCD_E had a relatively higher influence (>10) on HTGR than the species and LeafN_E (<5). Cage had minimal influence (<1) on height growth ratio in 2018.

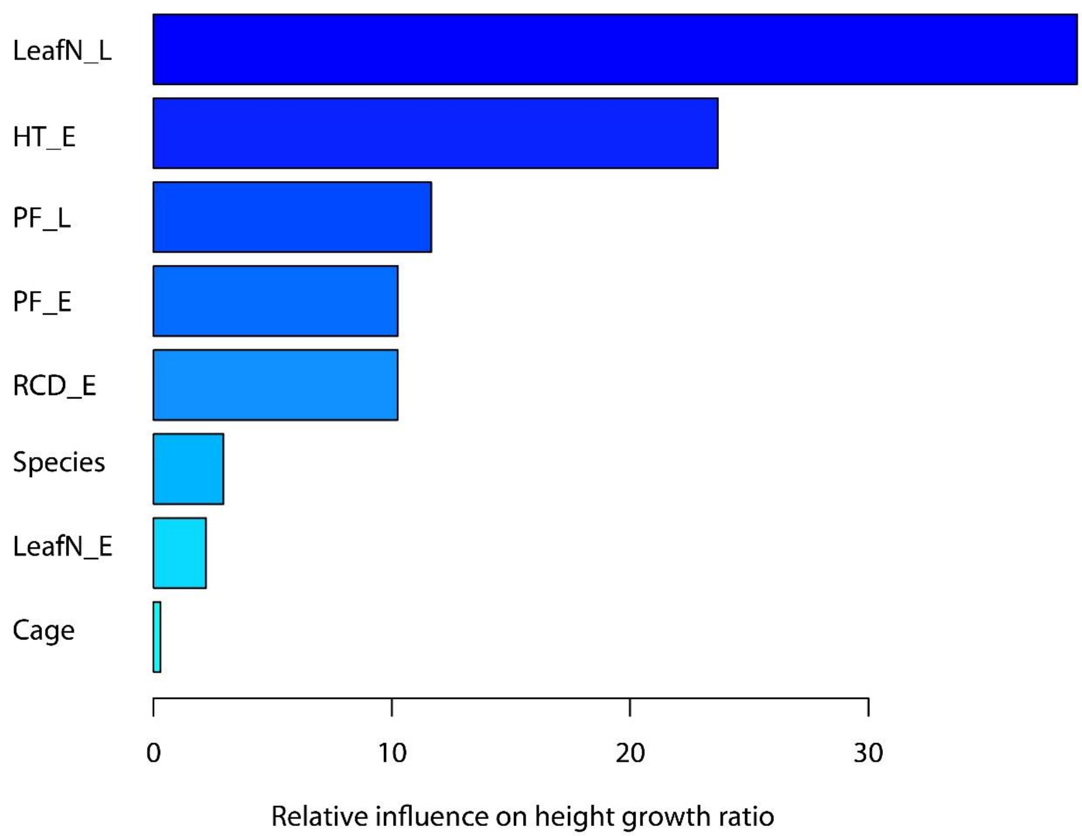

Figure 8 Relative influence by factor for height growth ratio (HTGR) in the 2018 growing season.

Figure 9 shows scatterplots of height growth ratio by the 4 most influential factors on height growth ratio. HTGR increased with increasing LeafN_L up to about 20 leaves, then decreases slightly with more leaves. As the LeafN_L increases the HTGR increases up to about 20 leaves, then decreases when LeafN_L > 20. Above 20 leaves, the sample sizes are quite small and lots of variation across the different species exist. Sugar maple appears to continue to increase with increasing leaf number while yellow birch decreases (Fig. 9). HTGR decreases as the HT_E increases. Again, the HTGRs for the larger initial seedling heights are only represented by a few seedlings (Fig. 9). Red oak tended to have higher HTGRs than sugar maple; however, species was not very influential in the GBMs (Fig. 8). Both PF_L and PF_E were more equally represented across the range of PF values (Fig. 9); however, there was strong species segregation within the range of PF (Fig. 9). Red oak planted in the clearcut portion of the study area had lower PFs than sugar maple planted in the partial harvest area. HTGR decreased for red oak with increasing PF_L while sugar maple increased in HTGR as the PF_L increased. Both species had small and consistent reductions in HTGR with increasing PF_E. There was a lot of variation observed in sugar maple. Sample sizes for yellow birch were too small to discern any clear trends and added much variability for all four factors.

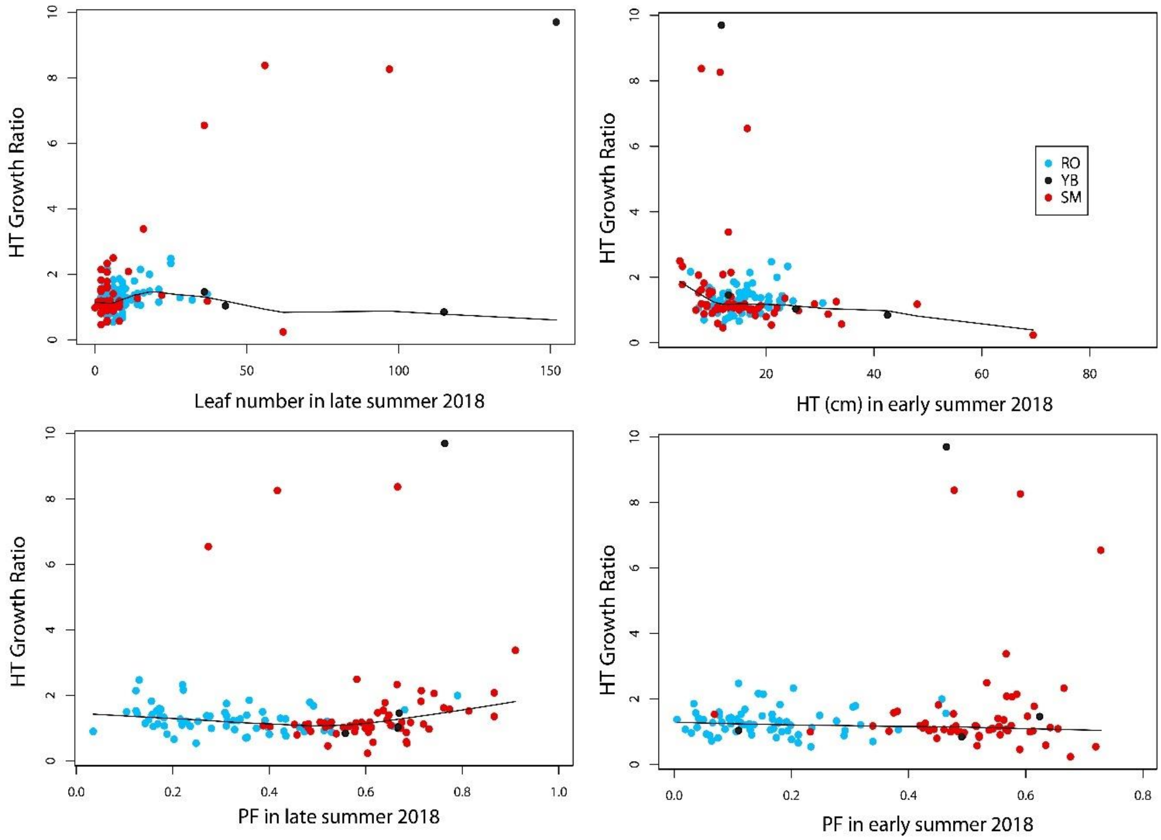

Figure 9 Scatterplots of height growth ratio (HTGR) versus the 4 most influential factors as determined by generalized boosted modeling by species. The black line indicates the locally weighted scatterplot smoothing (LOWESS) regression line. (RO = red oak, SM = sugar maple, YB =yellow birch).

3.3 Relative Root-Collar Diameter

Figure 10 shows relative influence of the tested factors on RCD growth ratio (RCDGR) within the 2018 growing season based on the GBM model. The LeafN_L had the greatest influence (>40) on the RCDGR within this growing season. All other factors had less than half of the relative influence that LeafN_L had (Fig. 10). RCD_E, PF_L, HT_E, and

PF_E had relative influences values between about 10 and 20, and the remaining variables had less than 5 relative influence.

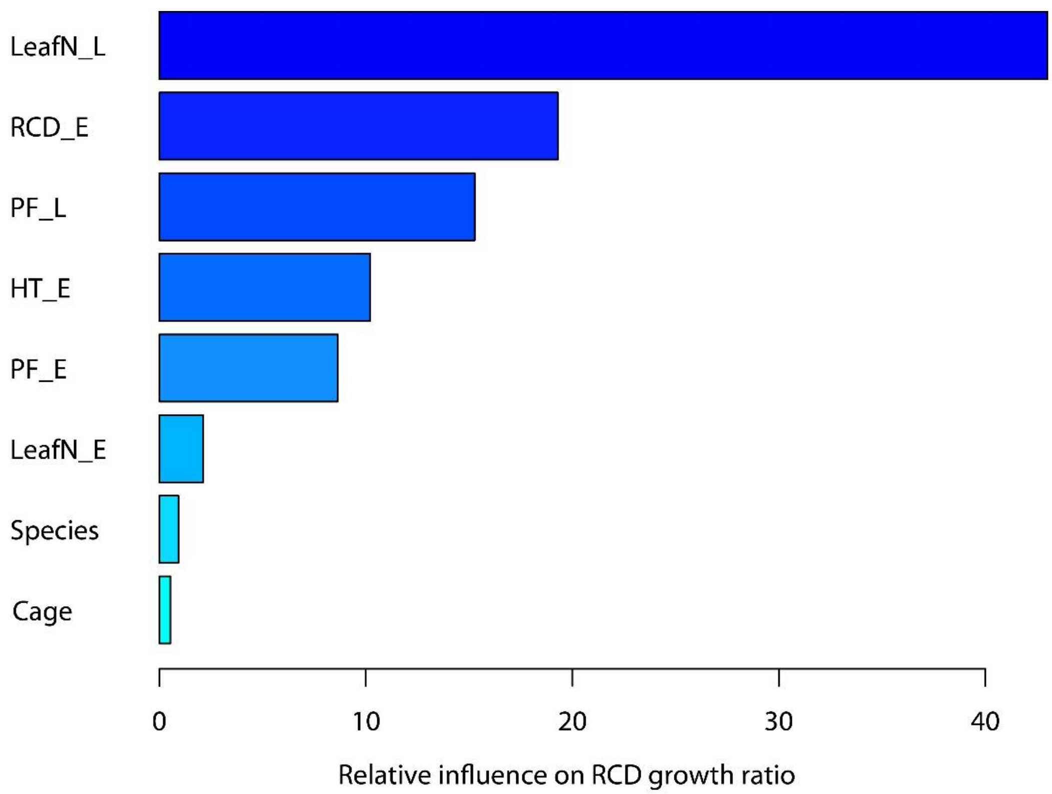

Figure 10 Relative influence for root collar diameter growth ratio (RCDGR) in the 2018 growing season.

Figure 11 shows the scatterplots of RCDGR versus the 4 most influential factors as determined from the GBM. RCDGR increased with increasing LeafN_L. RCDGR slightly decreased with increasing PF_L with the same levels of segregation between red oak and sugar maple as described above for height. RCDGR of red oak decreased as

PF_L increased, while RCDGR for sugar maple remained relatively constant across the range of PF_L. RCD_E and HT_E had a relatively flat pattern with RCDGR. RCDGR decreased with increasing RCD_E and increased with increasing HT_E, though trends were very minor, and species differences (red oak versus sugar maple) apparent.

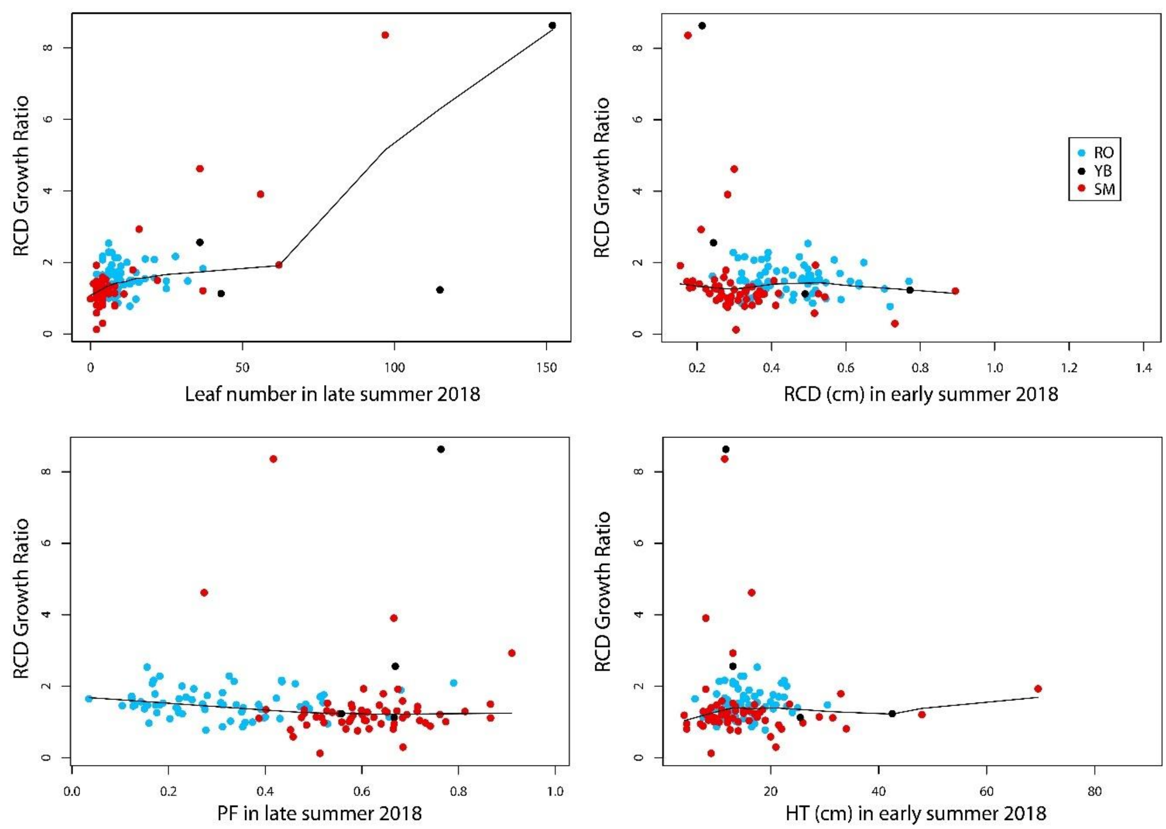

Figure 11 Scatterplots of root collar diameter growth ratio (RCDGR) versus the 4 most influential factors as determined by generalized boosted modeling by species. The black line indicates the locally weighted scatterplot smoothing (LOWESS) regression line. (RO = red oak, SM = sugar maple, YB = yellow birch).

3.4 Leaf number in the late summer 2018

Figure 12 shows the relative influence of the tested factors on leaf number in late summer 2018 (LeafN_L) based on the GBM model. PF_E and PF_L had the greatest influence on LeafN_L (> 20) while HT_E, and RCD_E where almost equal with relative influence values of around 20 (Fig.12). Increasing PF generally resulted in decreased LeafN_L (Fig. 13) while increasing seedling size (RCD_E and HT_E) resulted in increased LeafN_L (Fig. 13). All trends were slight, and much variability existed between species and within species (especially with sugar maple and yellow birch).

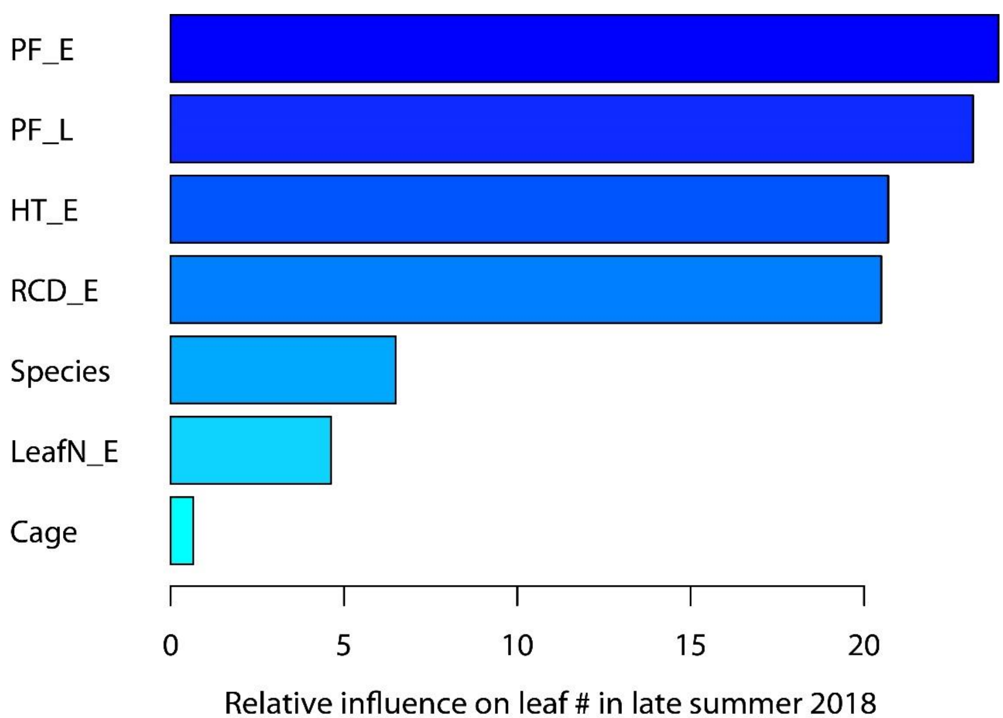

Figure 12 Relative influence for leaf number in late summer (LeafN_L) in the 2018 growing season.

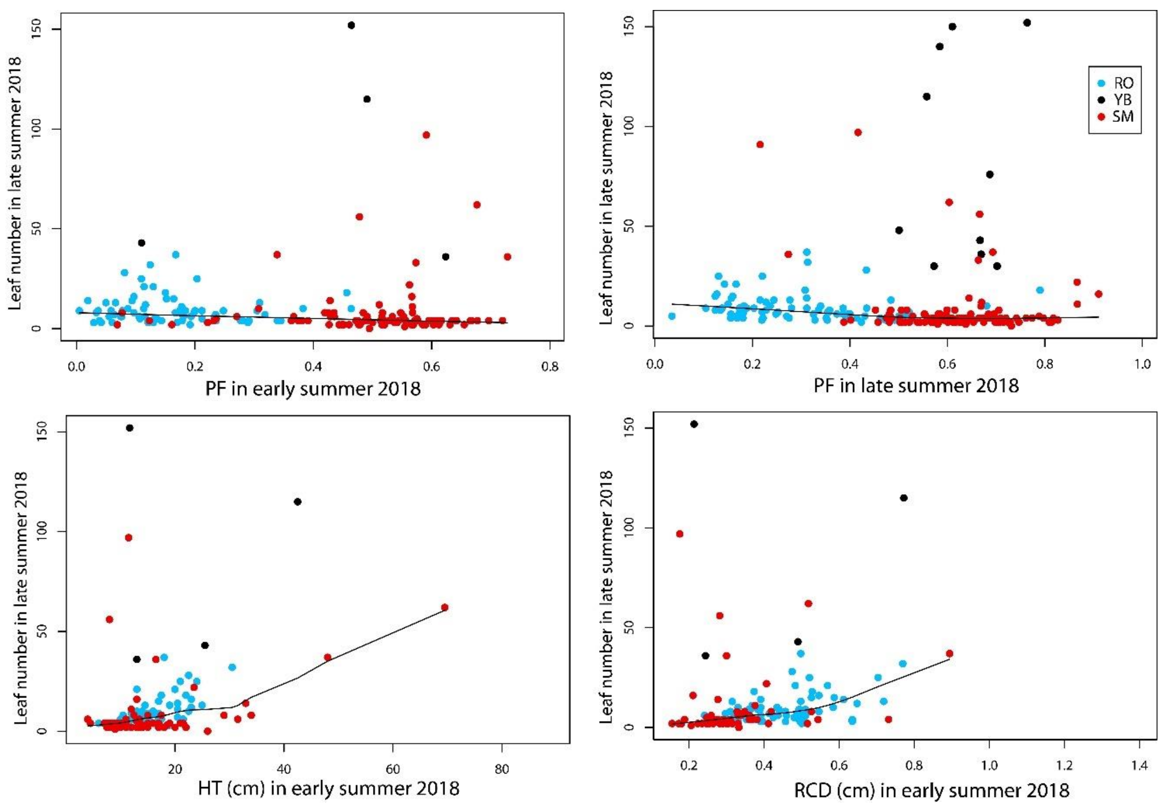

Figure 13 Scatterplots of leaf number in late summer (LeafN_L) versus the 4 most influential factors as determined by generalized boosted modeling by species. The black line indicates the locally weighted scatterplot smoothing (LOWESS) regression line. (RO = red oak, SM = sugar maple, YB =yellow birch).

3.5 Survival

Survival rates of seedlings by species and associated standard errors are shown in Table 2 and Figure 14. As mentioned above, survival in late summer was higher than early summer due to the later leaf appearance on some individuals. The late summer survival rates are considered more accurate because of this. Overall, caged seedlings had higher survival rates than the non-caged seedlings except for red oak in the late summer. Red oak had the highest survival rate than the other two species. Non-caged sugar maple had the lowest survival rates in both early summer and late summer (Table 2 and Fig. 14).

Table 2 Seedling survival rates (standard errors in parentheses) and number of surviving seedlings by species and caging treatment for early and late summer 2018 measurements at Noonan Research Forest.

Parameter	Species[1]	Early Summer			Late Summer		
		Number	Caged	Non-Caged	Number	Caged	Non-Caged
Survival Rate	SM	73	0.667 (0.142)	0.295 (0.031)	105	0.909 (0.091)	0.426 (0.033)
	RO	67	0.918 (0.040)	0.579 (0.081)	84	0.936 (0.036)	0.952 (0.033)
	YB	4	---	0.250 (0.112)	10	---	0.625 (0.125)

[1]SM = sugar maple, RO = red oak, and YB = yellow birch.

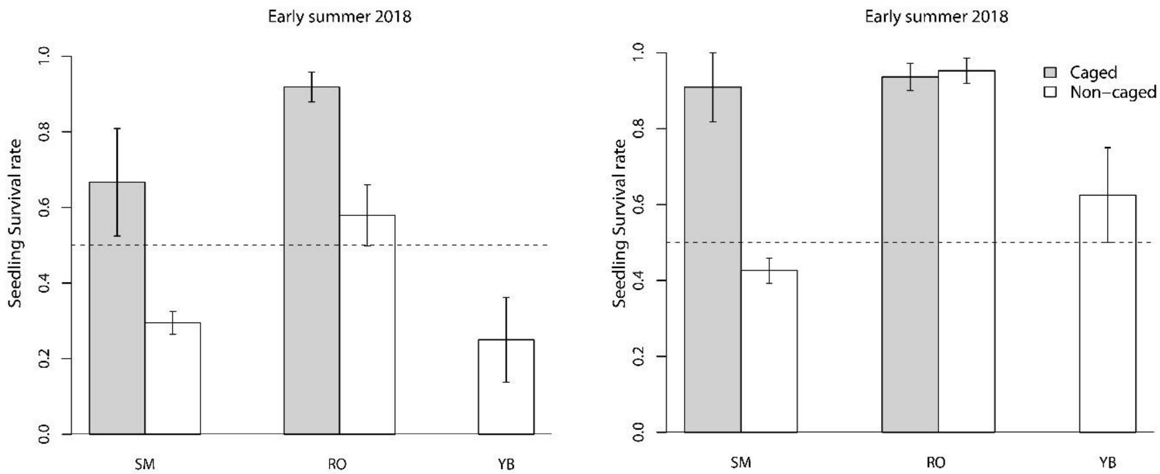

Figure 14 Average seedling survival rates by species and caging treatment in early and late summer 2018. The dash line indicates 50% survival rate. Standard errors are shown in the error bar. (SM = sugar maple, RO = red oak, and YB = yellow birch).

Figure 15 shows the relative influence of the tested factors on survival rate in the late summer 2018 based on the GBM model. HT_E had the greatest influence (>35) on survival. PF_L, LeafN_L, and LeafN_E had relatively high influence (>15) on survival, while PF_E had very low influence (<5) on survival, and RCD_E, species, and cage had almost no influence on survival.

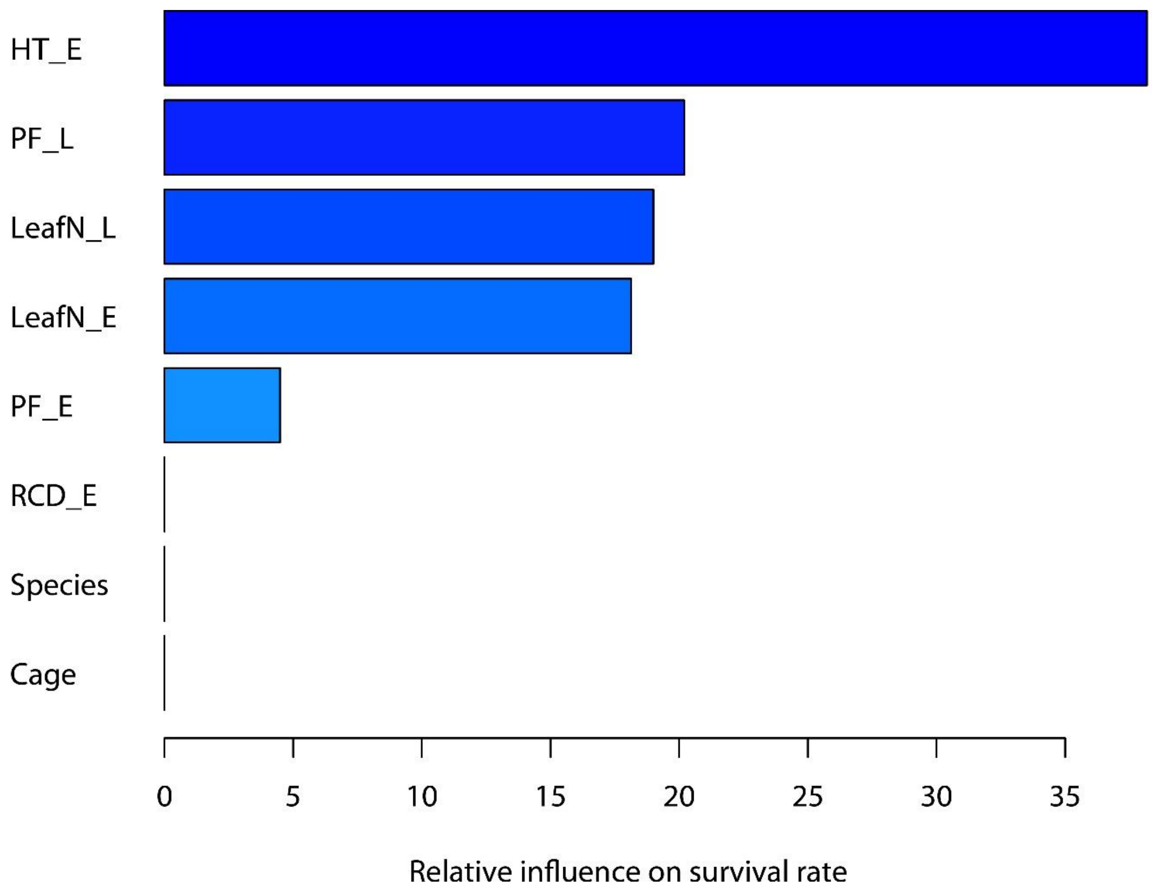

Figure 15 Relative influence for late summer Survival in the 2018 growing season .

4. DISCUSSION

Our study is meant to examine the viability of tolerant hardwood planting in the Acadian Forest, and to determine the practices and factors that will benefit the survival and early growth of planted tolerant hardwood seedlings. The study had several statistical challenges that prevented conventional analyses with linear models; however, the generalized boosted models consistently identified the same set of factors influencing growth and survival. All species were facing intense competition with intolerant hardwood species and other invasive vegetation.

The caged seedlings had faster height growth rates (Fig. 7) and higher survival rates (Fig. 14) than those that were non-caged. Caging is thought to control browsing. Although there were observed differences associated with caging treatment, the factor did not emerge in the GBM analyses as being influential on growth or survival. This may be related to the fact that seedlings were larger in the caged treatments at the beginning of the growing season (Table 1). Leaf number in late summer (LeafN_L) had the greatest influence on HTGR (Fig. 8) and RCDGR (Fig. 10). Competition, as measured by PF early (PF_E) and later (PF_L) in the growing season had the greatest influence on LeafN_L (Fig. 12). Taller seedlings are likely to have lower PFs because they are situated higher in the vegetative canopy. This can be particularly important early in the growing season when much of the height growth occurs (Kozlowski, Kramer, and Pallardy 1991; Oliver and Larson 1996). HT_E was the most influential factor for survival (Fig. 15).

Caging also may indirectly influence overall tree size through decreased browsing. So, while caging produces larger seedlings with greater survival rates, the within season effects may be masked by interactions with and correlations between other factors that exert greater influence on seedling growth and survival.

Leaf production was positively correlated with both increased root collar diameter growth (Fig. 13) and height growth (Fig. 11). Since foliage is the source of photosynthate, this makes sense – more leaves = more photosynthesis = more seedling growth. At the same time, more competition (increased PF_E and PF_L) resulted in fewer leaves. Lower numbers of leaves in lower light conditions would result in lower photosynthesis and thus lower growth rates and potentially lower survival rates.

Height in the early summer was the single most important factor influencing survival (Fig. 15). Because survival was assessed on the basis of presence/absence of leaves there were large differences between survival estimates in early summer versus late summer. The inconsistent survival assessments may explain why caged sugar maple seedlings had lower average heights in late summer relative to early summer. Smaller seedlings may have later leaf appearances than the larger seedlings, and seedling were only measured if they were considered alive. Human error might also contribute to this result. The RCD measurement has less human error because of the more precise measuring tool (caliper), less browsing pressure, and the absence of viewing angle issues.

Our results consistently suggest that the control of competing vegetation and the reduction of browsing pressure are critical for improving the survival and early growth of planted tolerant hardwood seedlings. Browsing by white-tailed deer is one of the major reason for hardwood regeneration failure (Tilghman 1989). Horsley et al. (2003) also found a negative trend between hardwood seedling height and deer population levels in northern Pennsylvania. Even though, we found that caging did not significantly impact height and diameter growth, seedling size was greater with caging, indicating that caging has an indirect positive effect on seedlings, perhaps through a reduction in browsing. White-tailed deer is the dominant deer species in the Acadian forest and there is a relatively high population in the Noonan area. There are also moose and hares that contribute to hardwood browsing impacts as well. Due to the lack of herbs and adequate food sources in the long winter, the hardwood twigs and buds from the seedlings then become a favored food source for many browsing species. Elie et al. (2009) found that the browsing by hare *(Lepus Americanus*) reduced the survival rate and growth of yellow birch seedling in Quebec. Fencing or caging is recommended for hardwood planting as the first step to reduce the risk of failure, especially for the low browsing-tolerant species such as sugar maple.

During the growing season, the planted seedlings faced intense competition pressure from intolerant hardwoods and invasive vegetation which had a negative impact on the growth of the planted hardwood seedlings (Figs. 8 and 10). The partial harvest on our study area was considered to be a control for competition by limiting the sunlight available to the pioneer species compared to the clearcut. However, sugar maple, which was only planted in the partial cut area, had the highest PF values (Figs. 9 and 11). Direct control of the competition from intolerant hardwood and invasive species should have better results than using either the shelterwood system and partial harvesting (Miller, Brose, and Gottschalk 2017). Competition control is probably more favorable for the private landowners when comparing the cost to the deer fencing, but may increase browsing pressure on planted seedlings (Frank, Rathfon, and Saunders 2018; Dalgleish et al. 2015).

This study only examined results for the first two years following planting. Continued monitoring of these seedlings is required for evaluation of the long-term success of planting tolerant hardwoods in the Acadian Forest. Enabling the seedlings to rapidly grow in height will reduce the competition pressure as the seedlings become taller than the dominant competing vegetation. Rapid height growth also may reduce browsing pressure as the buds become out of reach for most browsing species.

5. FUTURE WORK

Much of the variability in survival and growth is still not explained by the current results, so that future work remains a critical component to understanding planted tolerant hardwood success. As for the existing planting trail, summarized here, annual assessments over the next 5 years are recommended, following the same procedures as used in the data collection in the summer 2018. The results indicate that competition is the primary factor impacting seedling growth and survival; therefore, it is recommended that competition control should also be implemented in the study area in the coming summer to examine actual benefits from the competition control. Because of the size of the study area, we recommend controlling vegetation directly around seedlings rather than area-based control. Randomly choosing half of the seedlings by species and caging treatment would be the ideal method for implementation as this would avoid some of the previous statistical problems created by haphazardly choosing seedlings for treatment. Competition control should be implemented in mid-May and reassessed and possibly retreated in mid-August. The results over the next 2 years should be used to inform future experimental trials.

Any future trials should adhere to conventional statistical experimental design. In the current study, we were unable to assess effects of clearcutting versus strip cutting because of species segregation. Partial harvesting is likely to have an effect on seedling performance and survival and we recommend that this be a part of any future planting study. Harvesting should be carried out in blocks large enough to contain all of the other factors of interest. Replicate blocks (at least three) of each harvest treatment need to be established. Species, browse control, and competition control are recommended treatments within each harvest treatment. Combinations of these treatments should be replicated within each harvest block to create a randomized complete block design. The new trial should comprise a balanced number of seedlings among species, caging, and competition control treatments. Regular seedling spacing is recommended for efficient data collection, seedlings should be planted dense enough that future treatments, such as thinning or pruning, could be overlaid (this will also require sufficient treatment combination replicates). Seedlings should be marked clearly by flags (the color coding by species was very useful in the current study). Root collar diameter, total height, number of leaves, and survival should be assessed annually. We recommend early and late summer measurements for the first few years. The presence of browsing should also be recorded and, if possible, cause of death noted. By following these recommendations, the new planting trail should be much more statistically rigorous.

6. CONCLUSION

Hardwood planting will be a challenge in the Acadian Forest. Minimizing the browsing pressure is the primary recommendation when trying to establish tolerant hardwoods by planting. Caging or fencing also are recommended. Partial harvesting reduces competing vegetation, but manual competition control may be required to maximize early diameter growth. Fertilization is not necessary and may benefit the understory competition more than the planted seedlings (Frank, Rathfon, and Saunders 2018). Overall, hardwood planting is probably a viable option in the Acadian Forest but will require new guidelines and silvicultural practices to insure survival and growth of planted seedlings. Larger, replicate trials are recommended before final operational guidelines are developed.

Bibliography

Althen, F. W. von. 1977. “Hardwood Planting in Ontario.” The Forestry Chronicle 53 (4): 209–14.

Archambault, Louis, Claude Delisle, and Guy R. Larocque. 2009. “Forest Regeneration 50 Years Following Partial Cutting in Mixedwood Ecosystems of Southern Quebec, Canada.” Forest Ecology and Management 257: 703–11.

Banks, Brian. 2017. “The Mystery of Our Disappearing Moose,” 2017. http://brianbanks.ca/the-mystery-of-our-disappearing-moose/.

Bédard, Steve, and Michel Huot. 2006. “Long-Term Silviculture Research on Northern Hardwoods in Québec (Canada). In: Irland, L.C., Camp, A.E., Brissette, J.C., and Donohew, Z.R. (Eds), Long-Term Silvicultural & Ecological Studies - Results for Science and Management.” GISF Research Paper 005. Global Institute of Sustainable Forestry: School of Forestry and Environmental Studies, Yale University.

Bergeron, Yves, and Brian D. Harvey. 1997. “Basing Silviculture on Natural Ecosystem Dynamics: An Approach Applied to the Southern Boreal Mixedwood Forest of Quebec.” Forest Ecology and Management 92 (1–3): 235–42.

Burns, Russell M., and Barbara H. Honkala. 1990. “Silvics of North America. Volume 2. Hardwoods.” Agriculture Handbook 654. US Department of Agriculture.

Dalgleish, Harmony J., Nathanael I. Lichti, Nicholas Schmedding, and Robert K. Swihart. 2015. “Exposure to Herbivores Increases Seedling Growth and Survival of American Chestnut (Castanea Dentata) through Decreased Interspecific Competition in Canopy Gaps.” Restoration Ecology 23 (5): 655–61.

Elie, Jean-Gabriel, Jean-Claude Ruel, and Jean-Martin Lussier. 2009. “Effect of Browsing, Seedbed, and Competition on the Development of Yellow Birch Seedlings in High-Graded Stands.” Northern Journal of Applied Forestry 26 (3): 99–105.

Environment Canada. 2018. “Canadian Climate Normals 1981-2010.,” 2018. http://climate.weather.gc.ca/climate_normals/.

Frank, Graham S., Ronald A. Rathfon, and Michael R. Saunders. 2018. “Ten-Year Responses of Underplanted Northern Red Oak to Silvicultural Treatments, Herbivore Exclusion, and Fertilization.” Forests 9 (9): 571.

Fredericksen, Todd S., Brad Ross, Wayne Hoffman, Mike Lester, Jan Beyea, Michael L. Morrison, and Bradley N. Johnson. 1998. “Adequacy of Natural Hardwood Regeneration on Forestlands in Northeastern Pennsylvania.” Northern Journal of Applied Forestry 15 (3): 130–34.

Gauthier, Martin-Michel. 2002. “Regeneration Response Following Strip Cutting in a Shade Tolerant Hardwood Stand of Southwestern New Brunswick.” Unpubl. BScF Thesis, Fredericton, NB, Canada: University of New Brunswick.

Greenwell, Brandon, Bradley Boehmke, Jay Cunningham, and https://github.com/gbm-developers GBM Developers. 2018. “Package Gbm: Generalized Boosted Regression Models.” https://cran.r-project.org/web/packages/gbm/index.html.

Horsley, Stephen B., Susan L. Stout, and David S. deCalesta. 2003. “White-Tailed Deer Impact on the Vegetation Dynamics of a Northern Hardwood Forest.” Ecological Applications 13 (1): 98–118.

Kershaw, John A., Jr., Marek Krasowski, Thom Erdle, Jasen Golding, Lee Salmon, M. B. Lavigne, and Anthony R. Taylor. 2012. “Response of Tolerant Hardwood Stands to Partial-Cut Harvesting in the Acadian Forest: A Synthesis of Current Knowledge and Future Perspectives.” Unpublished Report. Tolerant Hardwood Task Force: New Brunswick Department of Natural Resources.

Kozlowski, Theodore T., Paul J. Kramer, and Stephen G. Pallardy. 1991. The Physiological Ecology of Woody Plants. San Diego, CA: Academic Press.

Loo, J., and N. Ives. 2003. “The Acadian Forest: Historical Condition and Human Impacts.” Forestry Chronicle 79 (3): 462–74.

Lorimer, Craig G. 1977. “The Presettlement Forest and Natural Disturbance Cycle of Northeastern Maine.” Ecology 58 (1): 139–48.

Lorimer, Craig G. 1985. “Methodological Considerations in the Analysis of Forest Disturbance History.” Canadian Journal of Forest Research 15 (1): 200–213.

Matonis, Megan S., Michael B. Walters, and James D.A. Millington. 2011. “Gap-, Stand-, and Landscape-Scale Factors Contribute to Poor Sugar Maple Regeneration after Timber Harvest.” Forest Ecology and Management 262 (2): 286–98.

Miller, Gary W., Patrick H. Brose, and Kurt W. Gottschalk. 2017. “Advanced Oak Seedling Development as Influenced by Shelterwood Treatments, Competition Control, Deer Fencing, and Prescribed Fire.” Journal of Forestry 115 (3): 179–89.

NSDNR. 2011. “The Path We Share, a Natural Resources Strategy for Nova Scotia 2011-2020.” Report DNR 2011-01. Nova Scotia Department of Natural Resources.

Oliver, Chadwick D. 1980. “Even-Aged Development of Mixed-Species Stands.” Journal of Forestry 78 (4): 201–3.

Oliver, Chadwick D., and Bruce C. Larson. 1996. Forest Stand Dynamics. Updated. New York: Wiley.

Pijut, Paula M. 2003. “Planting and Care of Fine Hardwood Seedlings: Planting Hardwood Seedlings in the Central Hardwood Region.”

Pyne, Stephen J. 2001. Fire: A Brief History. Seattle, WA: University of Washington Press.

Ridgeway, Greg. 2007. “Generalized Boosted Models: A Guide to the Gbm Package.”

Rowe, J.S. 1972. “Forest Regions of Canada.” Publication 1300. Canadian Forestry Service.

Salonius, Peter. 2007. “Silvicultural Discipline to Maintain Acadian Forest Resilience.” Northern Journal of Applied Forestry 24 (2): 91–97.

Salonius, Peter, and K.P. Beaton. 1999. “Restoring Shade Tolerants in an Acadian Mixedwoods Site of Degraded Species Diversity.” In Proceedings of the IUFRO Interdisciplinary Uneven-Aged Management Symposium, 247–58. Corvallis, Oregon: Oregon State University.

Schuler, Jamie L., and Daniel J. Robison. 2010. “Performance of Northern Red Oak Enrichment Plantings in Naturally Regenerating Southern Appalachian Hardwood Stands.” New Forests 40 (1): 119–30.

Seymour, Robert S., Peter R. Hannah, J. Grace, and David A. Marquis. 1986. “Silviculture: The Past 30 Years, the next 30 Years. Part IV. Northeast.” Journal of Forestry 84: 31–38.

Seymour, Robert S., Alan S White, and Philip G. deMaynadier. 2002. “Natural Disturbance Regimes in Northeastern North America — Evaluating Silvicultural Systems Using Natural Scales and Frequencies.” Forest Ecology and Management 155 (1–3): 357–67.

Taylor, Anthony R., Yan Boulanger, D.T. Price, Dominic Cyr, Elizabeth McGarrigle, Werner Rammer, and John A. Kershaw Jr. 2017. “Rapid 21st Century Climate Change Projected to Shift Composition and Growth of Canada’s Acadian Forest Region.” Forest Ecology and Management 405 (2017): 284–94.

Taylor, Anthony R., D.A. McPhee, and Judy Loo. 2013. “Incidence of Beech Bark Disease Resistance in the Eastern Acadian Forest of North America.” The Forestry Chronicle 89: 690–95.

Tilghman, Nancy G. 1989. “Impacts of White-Tailed Deer on Forest Regeneration in Northwestern Pennsylvania.” The Journal of Wildlife Management 53 (3): 524–32.

Zelazny, V., G.L. Martin, M. Toner, M. Gorman, M. Colpitts, H. Veen, B. Godin, B. McInnis, C. Steeves, and M. Roberts. 2007. “Our Landscape Heritage: The Story of Ecological Land Classification in New Brunswick.” Ecosystem Classification Working Group: New Brunswick Department of Natural Resourc

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