NATURAL REGENERATION IN NORWAY SPRUCE AND RED PINE PLANTATIONS IN DUFFERIN COUNTY ONTARIO- A CASE STUDY

by

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ABSTRACT

Keywords: Natural regeneration, *Picea abies* (L.) Karst, *Pinus resinosa* Sol. ex Aiton, stand conversion, plantations, invasive species

Norway spruce has been demonstrated to be a highly productive species in eastern temperate regions of Canada and is commonly utilized for the afforestation of poor soils. However, literature on the understory regeneration and management of mature Norway spruce plantations in Canada is lacking. Characteristics of natural regeneration were compared under two neighbouring Norway spruce and red pine plantations in southern Ontario. Regeneration counted at plots found large quantities of Norway spruce regeneration which was the dominant species of regeneration at both Norway spruce stands and neighbouring red pine stands. Most of this regeneration was also comprised of saplings greater than 1.3 meters in height. All stands had natural regeneration from outside stands, however regeneration at red pine stands was more diversified, especially in smaller height categories. Average diameters of different species were more normally dispersed than height, and somewhat related to the understory light intensity. Measurements of light intensity using a spherical densiometer were found to be consistently lower for both stands, and likely related to the abundance of tall regeneration instead of the overstory density. One-way analysis of variance (ANOVA) found no significant differences for all parameters between stand types (red pine and Norway spruce), although this was potentially in part due to small sample sizes (n= 8 for most measures). These findings suggest some potential of Norway spruce as an invasive species, however further study is required to make this claim. A review of the European literature on the topics of Norway spruce regeneration and Norway spruce stand conversion suggests Norway spruce exhibits intermediate levels of shade tolerance regenerating best in large gaps and is capable of being outcompeted by shade-tolerant species at low-light environments. Practitioners managing similar stands should target small canopy gaps and should anticipate the potential of the species to regenerate very intensively in large gaps compared to native spruce species.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1.0 INTRODUCTION

Forest plantations of red pine (*Pinus resinosa*) are a common landscape feature which can be found across much of southern Ontario. Many of these forests are secondary forests originating from government reforestation efforts to restore degraded agricultural land succumbing to soil erosion (Elliot 1998). Over time, these red pines have served as nurse trees assisting with advancing the forest into later stages of succession (Parker et al 2001; Landowner Resource Center 1999b). Norway spruce (*Picea ab*ies) is another species which has historically been used for very similar purposes beginning much earlier in Europe and has also had more recent historical usage across Canada's eastern temperate forest regions (Spiecker et al. 2004; Holst & Heimburger 1969). There appears to have once been a great deal of Canadian research interest on the topic of Norway spruce due to its demonstrated potential for productivity and tolerance for poor soils (Holst & Heimburger 1969). Norway spruce has not been planted as frequently in Ontario as red pine, however is it still recommended in modern Ontario government afforestation guides (Holst & Heimburger 1969; OMNRF 2019). This also appears to have been the case at one stand located in Mono Ontario which was planted around a similar time with a Norway spruce red pine mix shortly after the tract was acquired by the County, although current documentation is vague as to the rationale for planting. While Norway spruce is still frequently planted in eastern Canada, research interest in Norway spruce appears to have drastically declined in recent years as interests have begun to shift towards modern sustainable forest management objectives. Yet despite these changing interests, the Mono Tract Norway spruce stands have continued to grow and are now reaching later stages of maturity and succession with noticeable understory regeneration under its own canopy as well as nearby red pine plantations.

Several factors affect the growth of natural regeneration present in each stand including species composition, light availability, and gap dynamics interactions (Abbott et al 2010; OMNR 2000). Natural regeneration in canopy gaps is a commonly employed silvicultural tool across southern Ontario to advance the succession of forests. The topic of understory regeneration in red pine plantations in the Great Lakes St Lawrence Forest Region has been studied quite extensively (Parker et al. 2001 & 2008, Vander Yacht et al. 2022). However, research on understory regeneration in Norway spruce plantations is lacking in the Canadian literature, aside from the work of Mottet et al. (2008 & 2021) who also notes the lack of current literature on the subject. As such, the presence of this stand presents a valuable opportunity to further study the interactions and role of Norway spruce with other native tree and understory species in the Great Lakes St. Lawrence Forest. Results from better understanding understory dynamics in Norway spruce plantations can be used to guide management of similar stands present in Ontario.

1.1 OBJECTIVE

The objective of this study was to examine the differences in natural regeneration in the understory of Norway spruce and red pine plantations. Results from this case study will provide useful information for the future management of these plantations.

1.2 HYPOTHESES

The primary hypothesis for this experiment was that there would be no significant difference between natural regeneration in Norway spruce stands and natural regeneration present in red pine stands. The alternative hypothesis (Ha) would be that there is a significant difference the natural regeneration present between Norway spruce stands and red pine stands.

2.0 LITERATURE REVIEW

2.1 SITE HISTORY AND GENERAL BACKGROUND OF FOREST MANAGEMENT IN SOUTHERN ONTARIO

Early forest management in Southern Ontario is very much defined by the intensive timber extraction practices following European settlement which depleted several of the large stands of oak and pine native to these regions (Elliott 1998). These practices continued into the 1800s with much of the forested land being cleared for agriculture (Elliott 1998). Among these cleared areas of Southern Ontario included the townships of Mulmur, East Gaxafraxa, and Mono which are characterized by morainal origin with highly sandy rocky soils (Mach 2016). These coarse soils were quickly depleted of nutrients leading to blow-sands caused by widespread soil erosion and drought (Mach 2018; Elliott 1998). This prompted government programs to begin leasing and acquiring land as well as creating programs where trained government staff would assist private landowners with tree planting and woodlot management on their property (Mach 2016; Elliott 1998). This began in Dufferin County as early as 1905, and began in the township of Mono in 1925, and by 1952 there were in total 228 300 trees planted in this area across different forest tracts (Mach 2016). One of these tracts named the “Mono Tract” was purchased in 1960 for a total of $6000 and the 10.125 ha area was planted with a mixture of species including Norway spruce and red pine being the main components, as well as white pine and white spruce.

2.2 NORWAY SPRUCE: HISTORY AND SILVICULTURE IN EUROPE

The need for reforestation in Europe began originated from intensive forest usage and deforestation beginning in the Middle Ages and reportedly lasting into the 19th century to clear land for agriculture and produce wood and charcoal (Spiecker et al. 2004). Soils became degraded over time due to further soil erosion and agricultural usage, and regeneration of broadleaved trees was further depleted by grazing from livestock (Spiecker et al. 2004; Heinrichs & Schmidt 2009). Norway spruce *(Picea abies*) was a chosen species extensively used for reforestation beginning in the 18th century given its versatility and tolerance for these degraded sites as well as it's fast growth and wood quality (Spiecker et al. 2004; Heinrichs & Schmidt 2009). Using species such as Norway spruce and Scot's pine, large quantities of forest cover have been successfully re-established, however these forests have some shortcomings including soil acidification, susceptibility to windthrow, and susceptibility to pests (Spiecker et al. 2004; Kazda & Pichler 1998) It's also estimated that there will be poor suitability under climate change (Reventlow et al 2021; Hilmers et al 2020). As a result, the topic of "stand conversion" is a common research subject in the European literature. Stand conversion entails the process of converting monoculture stands into mixed hardwood forests and commonly utilizes native hardwood species originally endemic to these areas such as European beech (*Fagus sylvatica)* (Reventlow et al 2021; Ammer et al 2008; Spiecker et al. 2004). Research indicates that these conversions to hardwood stands can improve biodiversity, adaptability to climate change, and even increase productivity (Ammer et al. 2008). These conversion efforts also most commonly utilize lower intensity harvest strategies such as single tree and group selection in addition to underplanting mainly due to the higher operational costs of more intensive cuts which are usually only done for areas at most risk with highly unstable soils (Suadicani & Fjeld 2001; Spiecker et al. 2004). Unmanaged Norway spruce forests in their natural ranges are adapted to cycles of windthrow disturbance creating large canopy gaps which are associated with more prevalent regeneration (Tsvetanov 2018). This preference for large gaps suggests Norway spruce is somewhat mid-tolerant. This is supported by further research which demonstrates Norway spruce has lower competitive advantage in a low-light environments when compared to shade-tolerant European species such as European silver fir (*Abies alba*) under a denser canopy (Vencurik et al. 2020). Although, Norway spruce seedlings do appear to have some capacity for shade tolerance and have been found to have greater tolerance when compared to Scot's pine (Riikonen et al 2016).

2.3 NORWAY SPRUCE: UTILIZATION AND SILVICULTURE IN CANADA

Norway spruce has a long history of being used in Canadian silviculture in addition to other exotic species such as Scot's pine (*Pinus sylvestris*) and European Larch (*Larix decidua*) (Holst & Heimburger 1969). Reviews on this topic describe the early Canadian literature on Norway spruce and provide many of the research interests at the time such as genetic improvement and provenance studies (Holst & Heimburger 1969; MacArthur 1964; Fowler & Coles 1980). The history and justification for the use of Norway spruce in Canada is also described. Norway spruce was a commonly used species in Eastern North America beginning in the 1800s and continuing quite extensively during the Canadian reforestation program (1900-1965) (Holst & Heimburger 1969). The main reason being is its extremely high productivity in areas with high precipitation and poor acidic soils which has made it especially suitable across the temperate eastern regions of the Great Lakes St. Lawrence and Acadian Forests (Holst & Heimburger 1969). Much of the early literature on Norway spruce focuses on provenance and shares the similar objective of further determining which geographic regions of Europe provide seed stock which is best adapted to Canadian climates (Holst & Heimburger 1969; MacArthur 1964; Fowler & Coles 1980). This early research on Norway spruce is quite reflective of the views and priorities in silviculture at the time. Many of these studies were conducted in Quebec and the Maritime regions, however one notable and commonly referenced study was conducted at the

Petawawa Research Forest in Chalk River, Ontario (Holst & Heimburger 1969). Further studies have also been conducted in Boreal and Prairie regions such as Manitoba, however the species has been found to be less productive in boreal climates, and western prairie climates are prone to drought and intensive competition from grasses (Holst & Heimburger 1969; Klein 1977). More recent research and utilization of this species continues mostly across the Acadian Forest regions where it continues to be used in silviculture quite frequently, with recent research interests being centered around topics related to further optimization of the species ie growth and wood quality, susceptibility to white pine weevil, etc (Lenz et al 2020; Blouin et al 1994). Norway spruce management is not covered extensively in the Ontario silviculture guides, however it is a commonly mentioned and recommended species for coarse soils in Ontario afforestation guides (OMNRF 2019; White et al 2005). The topic of regeneration in Norway spruce plantations appears to be quite sparse, and as of the writing of this thesis the only research found on the topic of Norway spruce regeneration in the Great Lakes St. Lawrence Forest are two subsequent studies by Mottet et al (2010 & 2021) who also note the lack of literature on the subject. This research was conducted at the same 24 Norway spruce plantations in Quebec and not only observed the phenomenon of Norway spruce regeneration but also determined that regeneration in $4m^2$ plots within the plantation itself was considerably higher (13.3% at least one seedling per 4m2 plot) with the percentage decreasing at the borders (8.4%) and significantly decreased 10-20m outside the plantation (1.3-1.4%) (Mottet et al 2010; Mottet et al 2021). Another theme mentioned by these studies is the potential for invasiveness, although invasiveness was dismissed due to a reduced frequency of regeneration with distance, especially outside the plantation (Mottet et al 2021). No other studies have studied the potential for invasiveness in North America as accurately, this possibility is mentioned to some extent by other sources. Invasive potential of Norway spruce is mentioned in a common garden experiment conducted in Michigan by Kilgore et al (2004), although in more of a footnote context. Naturalized populations have also been documented in the United States as well in Connecticut and Michigan (Little 1979).

2.4 RED PINE: SILVICULTURE IN SOUTHERN ONTARIO AND CONVERSION TO MIXED STANDS

The history and utilization of red pine in southern Ontario silviculture very much parallels that of Norway spruce in terms of use for reforesting poor eroded agricultural sites, and advancing monoculture plantations into later stages of succession. Red pine is a native species which is known for being shade intolerant as well as its ability to occupy sandy, rocky, and infertile sites (OMNR 2000). For this reason, the species has historically been chosen for reforestation in southern Ontario due to its tolerance for degraded agricultural sites and further reported ability to “nurse” these sites into native understory forests over the course of its lifetime (McLaughlin et al. 2010; Landowner Resource Center 1999b). These red pine stands have served many purposes such as improving soil stabilization and further enrich organic matter into the soil which provides understory conditions which after approximately 70 years of repeated thinning treatments incorporate hardwood regeneration and develop into mixedwood forests (Landowner Resource Center 1999a; Landowner Resource Center 1999b; OMNR 2000). Red pine stands are managed into this advanced understory using subsequent thinning treatments (Landowner Resource Center 1999a). Canopy gap sizes can be tailored to desired regeneration species type such as smaller gaps for shade-tolerant species like maples and larger gaps for mid-tolerant and intolerant species such as oak, cherry, and white pine (Landowner Resource Center 1999b; USDA Forest Service). Literature on this area in southern Ontario is well-established with studies observing demonstrated increased seedling growth (height, width, and density) and increased species richness with larger intensity thinning treatments (Parker et al 2008; Parker et al 2001; Vander Yacht et al 2022). Although some studies also demonstrate site-specific factors at red pine plantations which can limit the growth of regeneration such as drought, nutrient availability, and lack of mycorrhizal colonization (Vander Yacht et al 2022; Tobiesson et al. 1980). There are also several recent issues with decline of mature red pine stands as well across different areas of southern Ontario, which has been theorized to be related to nutrient deficiencies and disease such as Armillaria root rot (McLaughlin et al 2010). Newer guidelines created by Simcoe County for planting new red pine stands recommend conducting soil sampling in order to determine whether the site meets requirements for nutrient levels, and it's also been suggested that these recent issues could negatively affect the progress of succession into hardwoods for many sites (McLaughlin et al 2010).

3.0 MATERIALS AND METHODS

3.1 Study Site

The study was carried out at a community forest tract located in Mono Ontario owned and managed by the municipality of Dufferin County and the Dufferin County Forest (Figure 1). This forest is located in the Great Lakes St. Lawrence Forest region. Sampling occurred at four neighbouring stands including stands 41a, 41b, 41c, and 40b (Figure 2). All stands were planted around the same time, and based on historical data are estimated to be between 61-71 years old. Stands 41a (4.72 ha) and 41b (8.68 ha) were planted with a mixed Norway spruce and red pine overstory with additional scattered seed trees of white pine (*Pinus strobus*) and white spruce (*Picea glauca*). Stands 40b (15.34 ha) and 41c (4.75 ha) were planted exclusively with rows of red pine. A random sampling of 10 trees and stumps at each stand found an average original planting spacing of around 393 cm at Norway spruce stands and 366.5 cm at red pine stands. Both stands have been subsequently thinned in recent years in 1972 and as recently as 2010 (The Corporation of the County of Dufferin 1995). Early thinning treatments when the stand was young targeted a larger basal of approximately 30 m^2/ha, however more recent treatments have targeted a more standard 20 m^2/ha (The Corporation of the County of Dufferin 1995). These harvests have removed much of the red pine at both stands as well as some Norway spruce and have opened canopy gaps. Much of what remains at Norway spruce stands is primarily Norway spruce.

Figure 1. Site location of the Mono tract forest located in Dufferin County, ON with respect to nearby areas.

3.2 Experimental Design

The data collected for this study was collected during July-August 2022. Data on natural regeneration was collected over four different measures which included the following.

1. Understory light environment
2. Composition (stems per hectare) of regeneration
3. Growth (diameter and height) of regeneration
4. Estimated percentage cover of understory vegetation

It was determined that for the purposes of this study, random stratified sampling would be a good method to select quadrats for sampling due to the preliminary nature of this study. Each of the four stands were used as individual strata, and randomized plots were selected for each site using a randomized point generator function using a buffer of 20 m. In total, this resulted in 16 plots recorded into an ArcGIS online map, and then visited in person using ArcGIS Field Maps (Figure 2). The size of these plots was 5 x 5 meters ($25m^2$). However, given the variability of GPS points, further methods were required in field to determine an exact location of the plots more accurately. Once the coordinates were reached to the best of the navigator's ability, the nearest overstory tree was chosen and marked with flagging tape as the first corner in the quadrat. The next two points were determined by measuring 5 meters North, and West of this original point. The final point was equidistant between these two previous points.

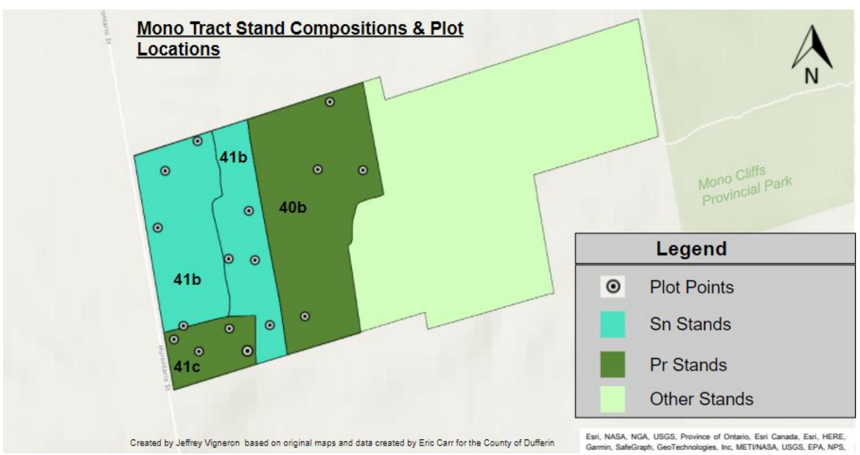

Figure 2. ARCGIS Online map of showing delineated Norway spruce stands and red pine stands, and locations of all 16

plots.

3.3 Sampling Methods

Regeneration for all tree species was tallied and diameter was measured at the base using small calipers. Regeneration was further classified into species and height classifications. Measurements of light intensity were also recorded for each cardinal direction (NSEW) using a spherical densiometer. These measurements were averaged and then multiplied by 1.004 as per the directions listed on the instrument. Data on overstory composition, understory composition, and understory vegetation were also recorded at each site as well as an estimation of percentage cover. Data on understory vegetation was collected as a percentage of the understory not occupied by tree regeneration and was grouped (Shrubs and herbs < 1.3m, and tall shrubs > 1.3m). The format for aspects of both datasheets and classifications of understory regeneration were created based on existing datasheets used by the Dufferin County Forest for the classification of understory regeneration. The datasheet used to record regeneration was further informed by a table used in a similar study by Fye & Thomas (1963) which is a similar study that also involved measuring regeneration at randomly selected plots. Both tables were further modified based on recommendations from supervisors, as well as testing in the field.

3.4 Data Analysis

Statistical analysis was performed using a one-tailed ANOVA to compare measurements at Norway spruce stands with measurements collected at red pine stands. These measurements included understory light, regeneration in each plot, diameters, and percentage cover. Due to the sample size, these measurements were performed independent of individual regeneration species found at each of the plots. It should also be noted that height measurements were not compared using ANOVA since this was measured using height classifications instead of exact heights. Statistical analysis was performed in Microsoft Excel using the data analysis function which is part of the "Analysis Toolpak" package and used a significance level of α = 0.05.

4.0 RESULTS

4.1 Statistical Significance

Findings for results of all species were tabulated together using an ANOVA test comparing the measures are provided in the table below (Table 3)

Table 3: Results of ANOVA Testing at for different measures collected data at significance level of α = 0.05

Factor Variable	***F***	***P-value***	***F crit***
Light	0.738049651	0.404756537	4.600109937
# Seedlings/Plot	0.653472741	0.432396457	4.600109937
Diameter (cm)	3.142273303	0.0773264	3.873391838
Tall Shrubs (> 1.3m)	0.05688773	0.81494021	4.600109937
Shrubs & Herbs (< 1.3m)	0.214170692	0.650629251	4.600109937

Since F > F crit and P < 0.05 for all measures, these variables demonstrate no significant difference between Norway spruce stands and red pine stands at a sample size of n = 8. Only diameter demonstrates a potential level of significance which also had larger sample sizes (n = 160 at Norway spruce plantations and n = 135 at red pine plantations).

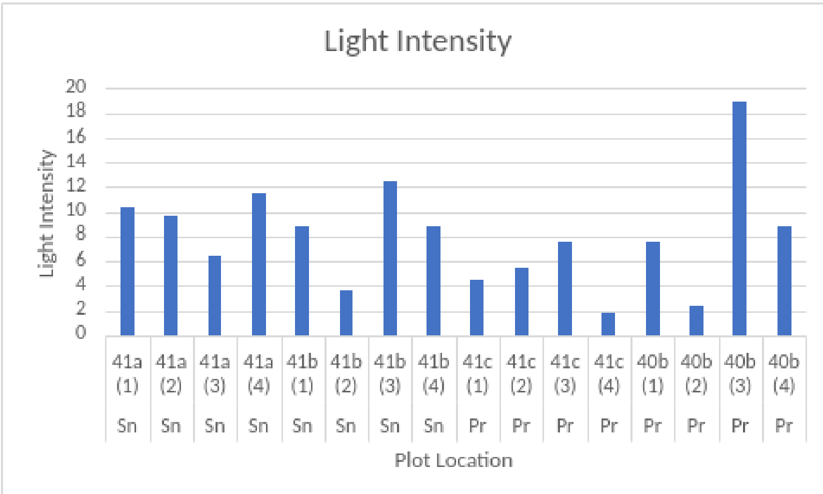

Figure 3. Percentage of full light intensity measurements collected using a densiometer at Norway spruce (Sn) and red pine (Pr) stands

4.2 Understory Light Environment

At Norway spruce stands, light intensity varied between 3.64 - 12.48 % and averaged at 8.97% (Figure 3). Measurements for light intensity at red pine stands fell between 1.82 - 18.98% and averaged at 7.12%. This data is further analysed with -respect to diameter in 4.3.2

4.3 Understory Regeneration

Results for density demonstrate very significant Norway spruce regeneration at both plantation types, with Norway spruce regeneration being present at almost all plots sampled at both sites. Norway spruce regeneration was especially prevalent at the Norway spruce stands, comprising an estimated 3075 stems/ha (75.9% of tallied stems) (Figure 4). Hardwoods were also present to a lesser extent; however, some species were present in considerable amounts including an estimated 425 stems/ha black cherry (9.7%), 275 stems/ha sugar maple (6.8%), and 25 stems/ha white ash (0.6%). Since only one plot had white spruce in the overstory, all spruce regeneration at that plot was designated as unidentified spruce (Sn/Sw) and comprised 250 stems/ha (6.2%).

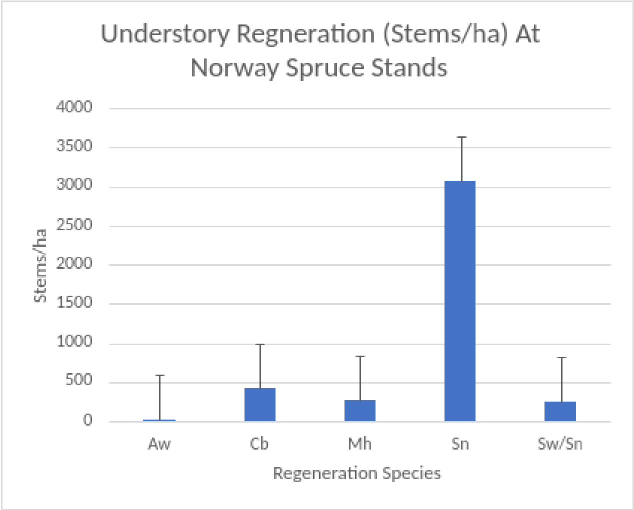

Figure 4. Estimate of stems/ha density for all tree regeneration at Norway spruce stands based on tallied seedlings at each plot

Norway spruce regeneration was present in much lesser degree at the red pine plantations, however remained the most prevalent regeneration accounting for 1200 stems per hectare (35.3%) (Figure 5). Black cherry comprised the second highest composition at red pine plantations (15.4%). Other regeneration was split amongst red pine (10.3%) white ash (10.3%), white pine (9.6%), red oak (8.1%) and sugar maple (5.9%).

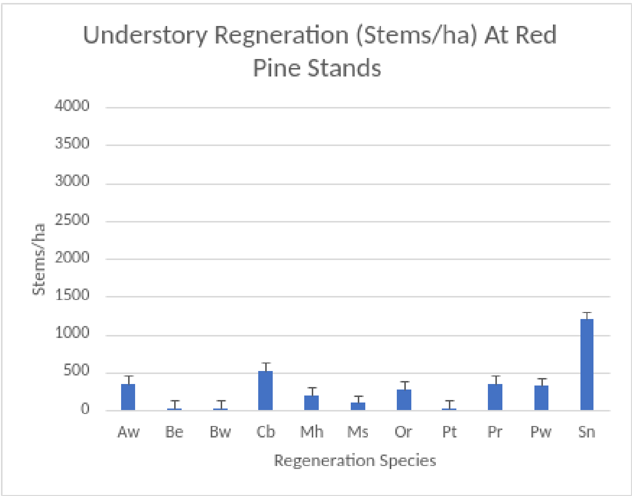

Figure 5. Estimate of stems/ha density for all tree regeneration at red pine stands based on tallied seedlings at each plot.

4.3 Height & Diameter Growth

4.3.1 Height

The overall higher prevalence of Norway spruce regeneration is further confirmed by height measurements, as Norway spruce regeneration comprised the largest number of seedlings in almost all height categories for both stands. In Norway spruce plantations, Norway spruce comprised 45.1% of all counted regeneration greater than 1.3 meters, with other notable competitors in this category including black cherry (5.6%), and sugar maple (4.3%) (Figure 6). Norway spruce regeneration greater than 1.3 meters comprised 26.5% of all seedlings, and other competition in this category included black cherry (10.33%) and white pine (7.4%). Norway spruce regeneration smaller than 1.3 meters was still quite abundant under its own canopy and comprised the largest composition for both height categories including 0-30cm (13%) and 30-1.3m (17.9%).

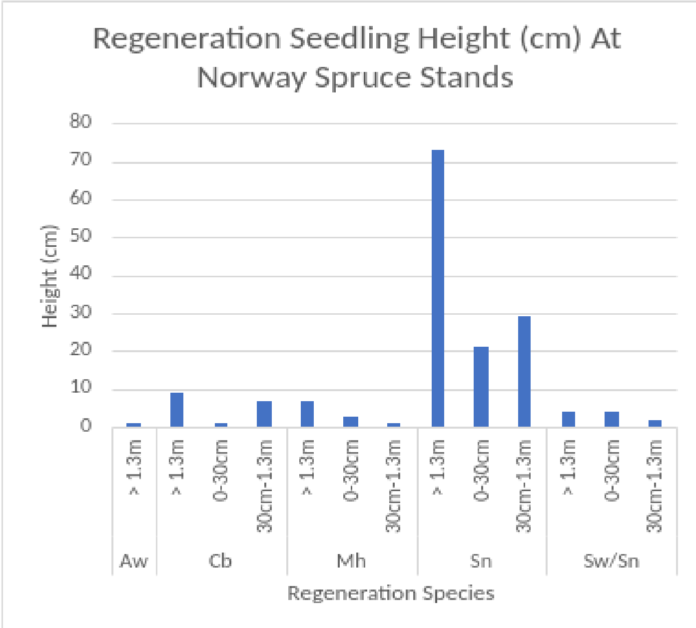

Figure 6. Total tallied height for all seedlings based on species and height classification for 3 height classifications at Norway spruce stands

Results in red pine stands were considerably lower as similarly reflected in previous section on regeneration (Figure 7). Norway spruce regeneration less than 1.3 meters was considerably less competitive at red pine stands. Notable competitors to Norway spruce for regeneration 0-30cm (6.6%) included black cherry (5.1%) white ash (5.1%) and red pine (5.1%). Notable competitors to Norway spruce for regeneration 30cm-1.3m (2.2%) included red pine (5.1%), sugar maple (4.4%), red oak (4.4%) and white ash (3.7%).

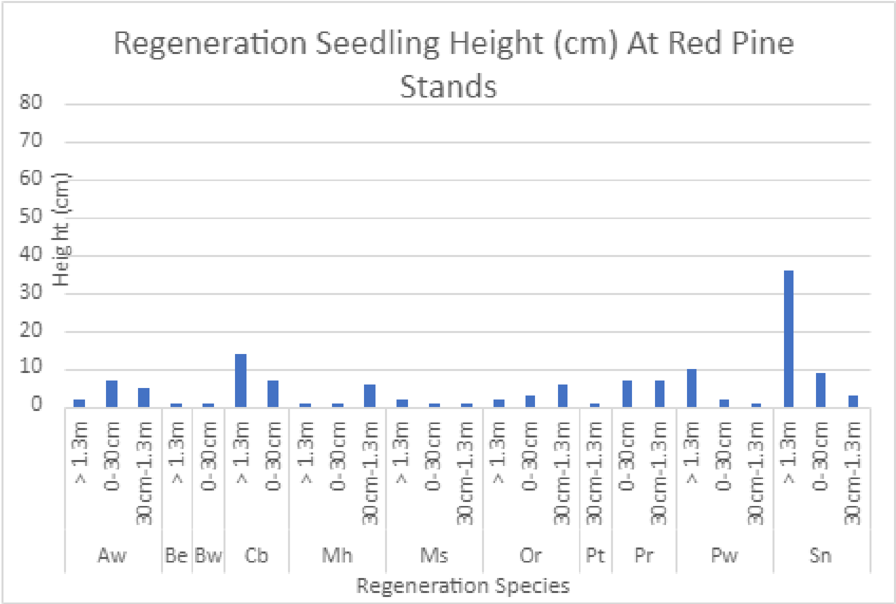

Figure 7. Total tallied height for all seedlings based on species and height classification for 3 height classifications at red pine stands.

4.3.2 Diameter

Diameter of Norway spruce was variable, however as demonstrated by the boxplot distributions the overall tendency towards higher levels of tall regeneration isn't as reflected in the diameter measurements (Figure 8). The overall measurements are far more normally distributed.

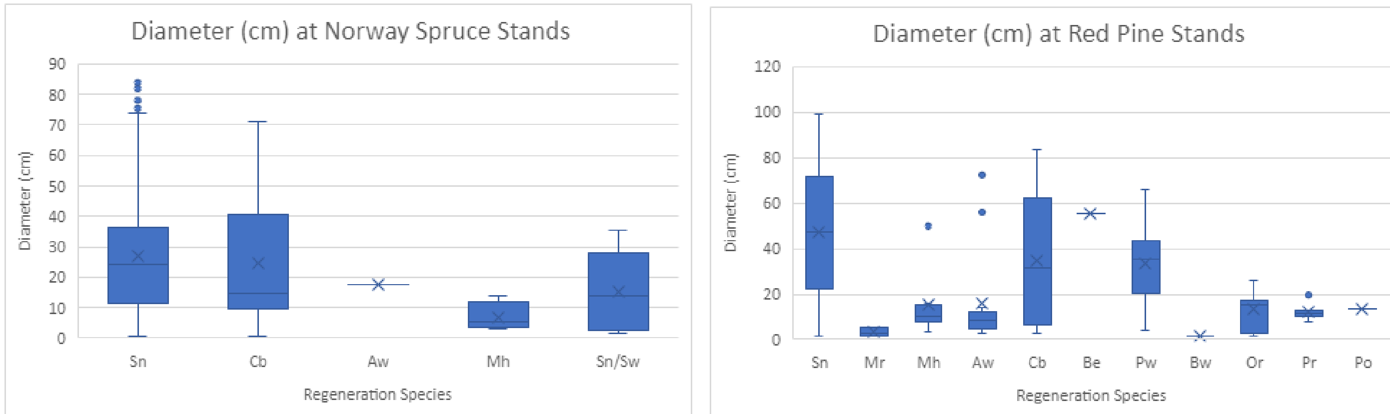

Figure 8. Distribution of diameter measurements at Norway spruce and red pine plantations.

Diameter was also plotted on scatter plots using collected data on light intensity (Figure 9 &10). While the data was found to not be statistically significant at this sample size, both graphs show some potential grouping and tendencies which could indicate beginnings of a potential relationship. Particularly a presence of tolerant hardwoods (ie sugar maple) around lower light intensities, which was observed around both Norway spruce and red pine stands although to a much greater extent at red pine stands (Figure 10). Norway spruce regeneration and black cherry were both observed over a wide margin at both stands, but over a slightly higher range at red pine stands. Much of the regeneration found at higher intensities included less shade tolerant species such as red oak and red pine.

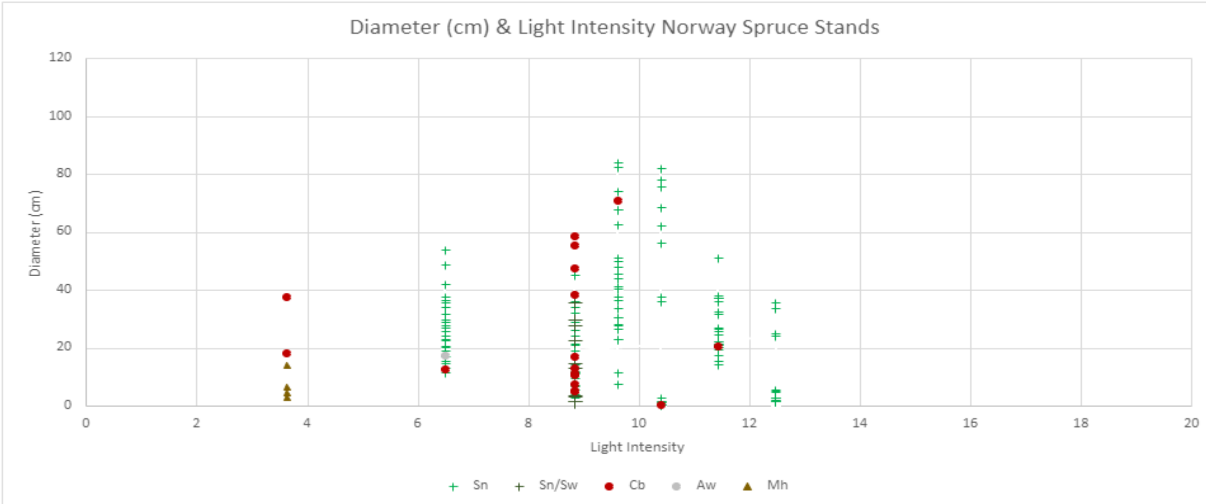

Figure 9. Scatter plot of diameter of regeneration and light intensity based on species at Norway spruce stands

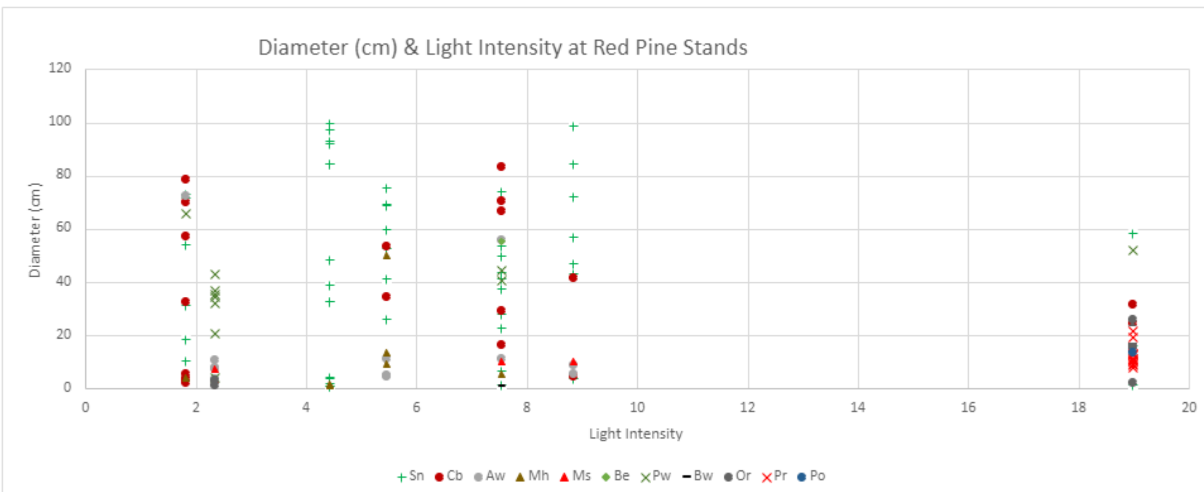

Figure 10. Scatter plot of diameter of regeneration and light intensity based on species at red pine stands

4.4 Understory Vegetation

Estimated percentage cover of understory vegetation was grouped based on height. Notes on species and vegetation classification were also recorded (Appendix VI). Understory shrubs and herbs less than 1.3 meters comprised a very similar proportion of both plantations which was averaged at 42.37% in red pine plantations and 49.5% in Norway spruce plantations.

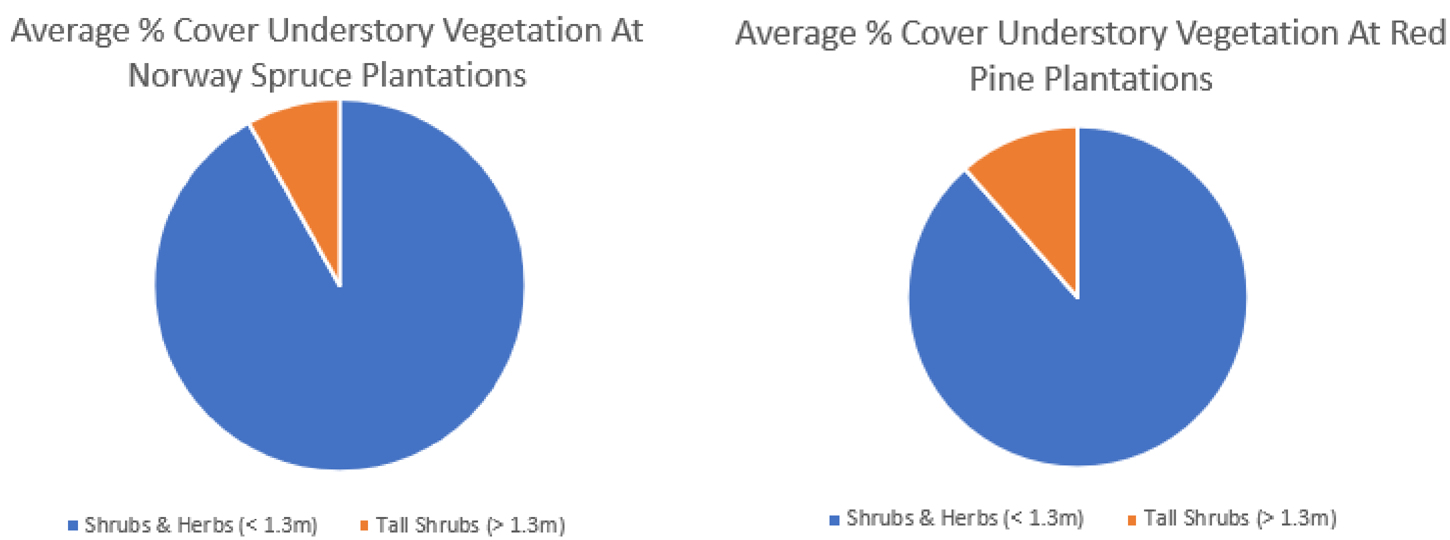

Figure 11. Average percentage cover of shrubs and herbs (<1.3m) and tall shrubs (>1.3m) at Norway spruce and red pine plantations.

Bryophytes also comprised a very significant proportion of Norway spruce stands, with the feathermoss species shaggy moss (*Rhytidiadelphus triquetrus)* being especially prevalent in this group. Vegetation at red pine stands was more varied, and contained higher proportions of ferns, graminoids, low shrubs, and forbs. Tall shrubs (>1.3m) generally comprised a smaller proportion of the understory and a very similar composition for both sites. This category comprised 5.5% of the understory at Norway spruce plantations and 4.38% at red pine plantations. Tall shrubs didn't appear to provide a significant source of competition for young seedlings and taller regeneration, however one species worth noting for being a component of many sites was alternate-leaved dogwood (*Cornus alternifolia*).

Also worth noting is the presence of some non-native species which were observed such as leafy spurge (*Euphorbia esula*), European buckthorn (*Rhamnus cathartica*), and broad-leaved helleborine *(Epipactis helleborine*), however these were not a significant proportion of many plots overall.

5.0 DISCUSSION

5.1 Overview of Results

5.1.1 ANOVA Results

As previously described, it was found that these results concluded that there were no significant differences in any of the measures sampled. This result is not surprising in part due to the small sample size of n = 8 for all measures except for diameter. Further studies at this stand using ANOVA aimed at producing statistically significant results should aim to utilize a larger sample size, with n= 30 being a commonly accepted "rule of thumb" minimum target sample size (Perezgonzalez 2016). Despite this small sample size, as previously stated in the introduction, this study was conducted with the intention of providing very basic preliminary results to compare with literature and direct future management and research at Norway spruce stands. So, despite this small sample size, many measures show potential beginnings of relationships which will be further analyzed.

5.1.2 Understory Light Environment

Not only were measurements of canopy cover at both stands found to be statistically similar, but all measurements were also found to be within a very similar interval which suggests a consistently high level of canopy cover between 81% at minimum and 97% at maximum. These results are also quite high when compared to other research on conifer plantations of similar compositions where a canopy closure of 75% is common, and more intensive treatments can result in closure of 50% or lower (Buckley et al 1999; Kim et al 1996). One major consideration which should be taken into account with regards to these relatively low measurements of light intensity is that that these measurements don't necessarily reflect a high density overstory as might normally be assumed but are instead likely due to the very abundant tall regeneration in the understory discussed beginning in section 4.3. This is an important distinction to make, as densiometer measurements are also often used to infer the overall level of canopy openness, however this is not representative in this case as while the canopy is quite dense but only at lower heights (Russavage 2021).

Operator effect is still a worthwhile consideration for this measure given the very localized grouping of the data. Literature on the accuracy of spherical densiometer measurements is variable, with some suggestion that operator effect has a minimal effect and other literature suggesting densiometer measurements can be less accurate due to being highly variable and somewhat subjective especially when performing quick measurements (Baudry et al 2014; Korhonen et al 2006). Densiometer measurement accuracy has also been found to be less accurate at lower levels of canopy openness (Russavage et al 2021).

5.1.3 Regeneration

Norway spruce was observed to be capable of producing very abundant regeneration under its own canopy as well as in the understory of nearby red pine stands. While the presence of Norway spruce regeneration is documented in the other Canadian study on Norway spruce, my results suggest a potentially greater magnitude of spread than was found in the original study (Mottet et al 2021). It is fairly well established in the European literature that Norway spruce exhibits an intermediate level of shade tolerance and in its natural range had adapted to natural windthrow disturbance and appears to regenerate best in large canopy gaps (Tsvetanov 2018). This shade-tolerance however does appear to have limitations, and while it can compete with an intolerant species like Scots pine, it appears less capable of competing with shade-tolerant species such as European beech *(Fagus sylvatica)* and European silver fir (*Abies alba*) in low-light environments (Riikonen et al 2016; Löf et al 2007; Vencurik et al. 2020). This possibility is suggested by my results with some plots containing advanced hardwood regeneration (Appendix). Mottet et al, who found a strong presence of balsam fir (*Abies balsamea)* suggesting the possibility that this species could be a similar competitor in low-light conditions (Mottet et al 2021).

Hardwood regeneration was observed to be more prevalent overall in red pine stands, and to a lesser extent in Norway spruce stands. This was observed as shade-tolerant species were more prevalent in understory of varied plots, whereas less shade tolerant species such as red oak and red pine were observed at plots with higher light intensity. The one exception to these observations was black cherry, which is often described as a species with lower shade-tolerance was found to be the second largest composition of regeneration for both stand types (OMNR 2000). Although, it appears this establishment of black cherry regeneration under canopy cover is not uncommon, even under a dense canopy (USDA n.d). Although management usually requires opening of gaps otherwise seedlings will die after a few years, which could explain the persistence and survival of these seedlings at both stand types (USDA n.d; OMNRF 2000).

5.1.4 Height and Diameter Growth

The results for height and high composition of tall Norway spruce regeneration suggest that Norway spruce regeneration is beginning to reach the stage of stem exclusion. Research conducted on Norway spruce plantations in Estonia observed a similar relationship with larger regeneration creating increased competition and changing growth characteristics of smaller regeneration height classes (Metslaid 2005). This data collected was not able to demonstrate a statistically significant correlation between height and diameter growth in response to stand type or light intensity. However, the regular management history of the stand which has consisted of several thinning treatments since the 1970s suggests at the very least that all regeneration has experienced greater growth in response to the opening of canopy gaps, albeit to a larger extent with Norway spruce. Extensive research has been conducted on Norway spruce in Europe which further supports this potential relationship with increased height and diameter of Norway spruce seedlings in response to openings in canopy gaps (Löf et al 2007; Hökkä & Mäkelä 2015). Research conducted on mixed hardwood and conifer regeneration in southern Ontario red pine plantations also demonstrates a similar relationship of increased height and diameter hardwood regeneration in response to increased canopy gaps (Parker et al 2001 & 2008).

5.1.5 Understory Vegetation

The results show some considerable amount of understory vegetation for both stands. Related research on both red pine stands, and Norway spruce stands often reports reduced levels of understory vegetation is often associated with both plantation types (Park & Carpenter 2016; Petersson et al 2019). The prevalence of bryophytes in Norway spruce stands is also shared to some extent with research in Europe which has demonstrated similar shared associations between Norway spruce with bryophytes as well as greater bryophyte diversity (Petersson et al 2021). Further study would be able to further quantify vegetation in these plantations as well as potentially other nearby hardwood stands.

5.2 Study Limitations and Recommendations

There are some anomalies in the data worth noting resulting from variations in the stand conditions such as openings caused by trails and inconsistent species planting compositions. This was the case for Plot 2 at stand 41a which despite being in a Norway spruce plantation had no Norway spruce regeneration present and instead had all hardwood regeneration originating from a small patch of mature sugar maples growing in a large trail opening. Several other mature hardwood seed sources can be observed in this stand and other stands as well, particularly from external stands which contain considerable overstory hardwoods. White spruce was not commonly observed, however random scattered trees are planted around Norway spruce stands in addition to other trees such as white pine and European larch. It is assumed that these scattered trees were intended as seed trees, however little documentation exists on the rationale for these scattered trees. Anecdotal information passed on from operational personnel at the time to the county forester (Caroline Mach) also indicates it's possible that these scattered trees are likely a result of nursery stock which was available at the time or just trees that got mixed in and ended up getting planted (pers. comm., March 27, 2023). Only one of these plots measured contained white spruce in the overstory. Spruce seedlings can be very difficult to identify at the seedling stage, and it's not uncommon to resort to using molecular markers to identify seedlings for this reason (Mottet et al 2010; Khasa & Dancik 1996). As such, many of the young seedlings at this site were recorded as Sw/Sn. It should be mentioned that the presence of some white spruce at this stand raises the possibility that white spruce was present at other plots as well and were incorrectly identified as Norway spruce. Although this is less likely, as white spruce reportedly can be difficult to regenerate via natural regeneration (Natural Resources Canada 2018).

These stands are of great interest for continued monitoring and further study. Random stratified selection provided an excellent method for this study to establish some basic information about this stand. For further study, a more thorough investigation of the regeneration capabilities using a more simplified and streamlined methodology comparable to that of Mottet et al (2010 & 2021) might be useful to quantify the degree and location of spread more accurately. As previously mentioned, a larger sample size of at least n = 30 would ensure further results are of statistical significance. Investigation into the location and approximate distance of seed sources might be useful as well to better understand whether the seedlings originate from primary overstory or secondary sources. Additionally, to properly compare results, it would be ideal to establish a proper control. It was not anticipated that there would be so much Norway spruce regeneration in the red pine stands, so a proper control wasn't established in this study due to timing constraints. However, several red pine stands of a similar age exist in the Dufferin County area which could be used for this purpose.

5.4 Potential for Norway Spruce as an Invasive Species

Based on these findings, it might be reasonable to conclude that Norway spruce regeneration has some aggressive tendencies and competitive advantages at this site over other native regeneration and other understory vegetation. These findings do raise some very valid concerns about the competitive nature of this species and whether it might be considered invasive. It can be argued that Norway spruce impedes the growth at this site, however the question of whether it's defined in terms of Ontario legislation ultimately depends on whether it can be considered “harmful or potentially harmful to the natural environment of Ontario” (Ontario Invasive Species Act 2015). As previously mentioned in the literature review, existing information about the invasiveness of Norway spruce isn’t well documented, however some information and reports of naturalization are documented both in Canada as well as the United States. As of the writing of this report, the only study conducted on the phenomenon of Norway spruce regeneration in the Great Lakes St. Lawrence Forest (and as suggested by the authors, potentially all of North America) appears to be the work of Mottet et al. (2010 & 2021). This research also documents the phenomenon of Norway spruce regeneration, and it was determined to not be invasive due to the spread of regeneration being significantly limited by distance with very limited spread outside the plantation boundaries. My findings however suggest a potentially greater degree of spread at this site given that Norway spruce seedlings were found relatively far outside the plantation boundaries in nearby red pine plantations. However, a similar phenomenon was observed as this external regeneration was considerably diminished and often outcompeted by native regeneration. Some plots on the outside edges were very much representative of this such as Plot 2 at stand 40b which contains no Norway spruce regeneration, but instead native hardwood regeneration reflective of the external stands comprised of maple, oak, etc. Overall, these findings present a good case for further investigation of invasive potential, however based on current info it wouldn’t be possible to make this determination at this point if the species is simply well adapted to the site or provides a threat to all sites as a typical generalist invasive species would.

5.3 Management Recommendations

The primary finding that should be taken from the results of this study for practitioners to take into consideration is that mature Norway spruce plantations can develop very significant regeneration which is capable of spreading into nearby plantations. Current afforestation guides published by the OMNRF and Natural Resources Canada list Norway spruce as a recommended species for poor coarse sites (OMNRF 2019; White et al 2005). As such, it’s quite likely that other Norway spruce plantations do exist in Ontario. At this time, the development of all Norway spruce stands should be monitored for the potential for invasiveness.

Potential management recommendations for this species depend on what the desired outcome of the stand is. However, it’s likely that the management approach taken by Ontario modern foresters interested in furthering a sustainable forest management approach would be to shift away from Norway spruce towards a mixed hardwood stand. Luckily, the topic of stand conversion of Norway spruce plantations to mixed hardwood has been in discussion for many years now and is quite well established in the European literature as referenced in the literature review. In summary there are two main findings of note from this literature applicable to Canadian plantations which include (1) Norway spruce will regenerate best in large gaps rather than smaller gaps, and (2) tolerant regeneration is capable of outcompeting Norway spruce regeneration in low-light environments. Assuming management wants to move away from further Norway spruce regeneration, continued succession of the stand should ideally target the further establishment and development of mid-tolerant and tolerant hardwood regeneration which could have some competitive advantage over Norway spruce regeneration in lower-light environments.

Methods such as stand tending and herbicide could be utilized for the control of Norway spruce regeneration but are also potentially resource intensive and could also harm desirable native regeneration. Removal of litter has been shown to limit seedling growth of Norway spruce quite significantly as well, which is an option that could be further explored (Nyland et al 1979). However, it's likely that such an intensive management approach won't be applied at the Mono Tract due to constant recreational use at this site including mountain bikes, dogs, and horses as well as the already existing abundant mixedwood forest diversity present at many other stands that are higher priority in terms of management.

There are some other potential aspects from European literature on Norway spruce plantations which should also be shared with all practitioners who find themselves managing Norway spruce plantations in Canada. One concern commonly discussed is the overall susceptibly of Norway spruce stands to disturbance, mainly acidification and pest outbreaks (Spiecker et al 2004). Susceptibility to pests is the greatest concern which has also been established and explored in Canadian literature on Norway spruce. Government afforestation guides mention the susceptibility of Norway spruce to several native Ontario pests and diseases including Tomentosus root rot (*Inonotus tomentosus)*, white pine weevil *(Pissodes strobi)*, spruce budworm (*Choristoneura fumiferana*), spruce canker (*Cytospora kunzei*) and heart rots (OMNRF 2019; White et al 2005). Several further studies have been conducted on this subject to optimize genetic traits such as resistance to pests like white pine weevil (Lenz et al 2020). The potential for acidification at the site studied is unclear, and potentially of less concern due to the presence of abundant woody and herbaceous vegetation. Although this could be a concern for other sites, as some degree of soil acidification observed for both Norway spruce as well as red pine in plantations in New York (Pallant & Riha 1990).

6.0 CONCLUSION

In conclusion, while the results were found to be collected over a small sample size, the overall findings demonstrate interesting conditions found in the Norway spruce plantations and the neighbouring red pine plantations. While a statistically significant difference was not able to be established at the sites, there are potentially several individual findings for each measure collected which over further study might be able to demonstrate more consistent relationships. As such, it can be stated that there is a significant difference in regeneration between Norway spruce stands and red pine stands. Most significantly and worth noting for future study are the findings that mature Norway spruce plantations are capable of producing significant understory regeneration in canopy gaps which is quite competitive locally and demonstrates the potential to spread to nearby plantations. Management of similar Norway spruce stands should aim to use recommendations found in European literature for stand conversion silviculture to mixedwood, however this situation definitely also warrants applying an adaptive management approach using continued monitoring and observation in order to further improve management techniques for Canadian Norway spruce plantations.

Putting aside the controversial nature of using a non-native species in modern silviculture, it can be argued that these initial results demonstrate some degree of success. This is a situation where it is easy to lose sight of the original intention of the stand which was to restore degraded agricultural land into productive forest which was ultimately successful. The Mono Tract currently provides a great deal of multiple-use values to the municipality including a local hotspot of recreational value to mountain bikers and horseback riders, economic value to the County as a source of wood products, and as a source of carbon sequestration along the outskirts of the greater Toronto area. It is easy to look back critically on past silvicultural decisions that were made, especially when they are very different than decisions we might make today. Yet, stands like this serve as a reminder of how far silviculture has developed in recent years and will continue to develop in future years.

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APPENDIX I: Tables of Light Intensity Data

Stand Type	Plot	Light Intensity
Sn	41a (1)	10.4
Sn	41a (2)	9.62
Sn	41a (3)	6.5
Sn	41a (4)	11.44
Sn	41b (1)	8.84
Sn	41b (2)	3.64
Sn	41b (3)	12.48
Sn	41b (4)	8.84
	Average	8.97

Stand Type	Plot	Light Intensity
Pr	41c (1)	4.42
Pr	41c (2)	5.46
Pr	41c (3)	7.54
Pr	41c (4)	1.82
Pr	40b (1)	7.54
Pr	40b (2)	2.34
Pr	40b (3)	18.98
Pr	40b (4)	8.84
	Average	7.12

APPENDIX II: Tables of Stems/ha data

Stand Type	Regeneration Species	Total # Seedlings	Estimated Stems/ha	Percentage Total
Sn				
	Aw	1	25	0.6%
	Cb	17	425	10.5%
	Mh	11	275	6.8%
	Sn	123	3075	75.9%
	Sw/Sn	10	250	6.2%

Stand Type	Regeneration Species	Total # Seedlings	Estimated Stems/ha	Percentage Total
Pr				
	Aw	14	350	10.3%
	Be	1	25	0.7%
	Bw	1	25	0.7%
	Cb	21	525	15.4%
	Mh	8	200	5.9%
	Ms	4	100	2.9%
	Or	11	275	8.1%
	Pt	1	25	0.7%
	Pr	14	350	10.3%
	Pw	13	325	9.6%
	Sn	48	1200	35.3%

APPENDIX III: Tables of height data

Stand Type	Regeneration Species	Height Class	Total # Seedlings	Percentage Total
Sn	Aw	> 1.3m	1	0.6%
	Cb	> 1.3m	9	5.6%
		0-30cm	1	0.6%
		30cm-1.3m	7	4.3%
	Mh	> 1.3m	7	4.3%
		0-30cm	3	1.9%
		30cm-1.3m	1	0.6%
	Sn	> 1.3m	73	45.1%
		0-30cm	21	13.0%
		30cm-1.3m	29	17.9%
	Sw/Sn	> 1.3m	4	2.5%
		0-30cm	4	2.5%
		30cm-1.3m	2	1.2%
Pr	Aw	> 1.3m	2	1.5%
		0-30cm	7	5.1%
		30cm-1.3m	5	3.7%
	Be	> 1.3m	1	0.7%
	Bw	0-30cm	1	0.7%
	Cb	> 1.3m	14	10.3%
		0-30cm	7	5.1%
	Mh	> 1.3m	1	0.7%
		0-30cm	1	0.7%
		30cm-1.3m	6	4.4%
	Ms	> 1.3m	2	1.5%
		0-30cm	1	0.7%
		30cm-1.3m	1	0.7%

	Or	> 1.3m	2	1.5%
		0-30cm	3	2.2%
		30cm-1.3m	6	4.4%
	Pt	30cm-1.3m	1	0.7%
	Pr	0-30cm	7	5.1%
		30cm-1.3m	7	5.1%
	Pw	> 1.3m	10	7.4%
		0-30cm	2	1.5%
		30cm-1.3m	1	0.7%
	Sn	> 1.3m	36	26.5%
		0-30cm	9	6.6%
		30cm-1.3m	3	2.2%

APPENDIX IV: Percentage Cover Data

Understory Shrubs/Herbs (Non-tree Vegetation)

Stand Type	Shrubs & Herbs (< 1.3m)	Tall Shrubs (> 1.3m)
Pr	42.375	5.5
Sn	49.5	4.375

APPENDIX V: OBSERVED TREE SPECIES AND CORRESPONDING SPECIES CODES

Species Code	**Scientific Name**	**Common Name**
Aw	*Fraxinus americana*	White ash
Be	*Fagus grandifolia*	American Beech
Bw	*Betula papyrifera*	White birch
Cb	*Prunus serotina*	Black Cherry
Ms	*Acer rubrum*	Red maple/ Soft maple
Mh	*Acer saccharum*	Sugar maple/ Hard maple
Po	*Populus sp*	Poplar
Pr	*Pinus resinosa*	Red Pine
Pw	*Pinus strobus*	White Pine
Or	*Quercus rubra*	Red Oak
Sn	*Picea abies*	Norway Spruce
Sw	*Picea glauca*	White Spruce

APPENDIX VI: OBSERVED UNDERSTORY VEGETATION SPECIES AT PLOTS

Herbaceous Plants	
Scientific Name	**Common Name**
Hieracium sp.	Hawkweed species
Aralia nudicaulis	Wild Sarsaparilla
Epipactis helleborine	Broad-leaved helleborine
Euphorbia esula	Leafy Spurge
Maianthemum canadense	Canada Mayflower
Polygonatum sp	Solomon's seal
Prunella vulgaris	Self-heal
Rhytidiadelphus triquetrus	Shaggy moss
Woodland strawberry	Fragaria vesca
Woody Shrubs	
Scientific Name	**Common Name**
Amelanchelier sp	Serviceberry species
Cornus alternifolia	Alternate-leaved dogwood
Cornus cornuta	Witch Hazel
Lonicera sp	Honeysuckle species
Prunus sp	Cherry species
Rhamnus cathartica	European Buckthorn
Ribes sp	Currant species
Sambucus sp	Elderberry Species