The Development of Spruce and Pine Plantations After Early Silviculture Treatments

by

Megan McKinley

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Supervisor: John Kershaw, PhD, Forest Mensuration

Examining Board: Greg Adams, MScF, Research and Development
Jasen Golding, MFE, Senior Teaching Associate

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ABSTRACT

A plantation establishment trial was initiated in 1994 with two scarification treatments (two passes of a Marden drum chopper, and a control), three herbicide treatments (two applications over the first two years following planting, three applications at years 1, 2, and 4 following planting, and a control), and four species (jack pine, black spruce, white spruce, and Norway spruce). Subplots of 18 trees in each species×scarification×herbicide treatment combination (100 tree blocks) were measured over time. This report presents the results at age 21. In this study, herbicide application had the greatest influence on tree growth, resulting in the influence of species and drum chopping to be insignificant. Jack pine responded greatest to the administration of three herbicide treatments by 63.6cm in mean height, and 0.872cm in mean diameter at breast height (DBH) at age 21 compared to the next largest species for each growth response. Each species achieved ≥ 74% survival when herbicide was applied, except for Norway spruce that had the lowest survival of 62% overall. Black spruce had the greatest survival when no treatments were applied.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

AHS – Agricultural Health Study

BS – Black spruce

DBH – Diameter at breast height (1.3 meters)

Efsa – European Food Safety Authority

EPA – Environmental Protection Agency

GBM – Generalized Boosted Regression Model

IARC – International Agency for Research on Cancer

JP – Jack pine

NS – Norway spruce

RCD – Root collar diameter

WHO – World Health Organization

WS – White spruce

Introduction

The discipline of silviculture is the management and study of forests to produce desired attributes and products (Puettmann 2009). Silviculture may be applied during any period of the stand development process. Early stand tending may include, but is not limited to, site preparation, artificial regeneration, and herbicide treatments. Plantations help satisfy the rising demand for wood products by increasing the long-term supply of timber compared to naturally regenerated stands (Netzer 1978). Various silviculture treatments are applied within plantations to help further increase the amount of timber produced over time. Herbicide applications are one example, and they are performed at the early stages of stand development, often during the first two to three years following stand initiation (Rolando 2017) or prior to plantation establishment.

Herbicide is used in conifer release programs to control competing vegetation (Thompson 2000). Competing tree species are the major cause of suppressed growth in plantations (Campbell et al. 2013). An abundance of light, soil moisture, favorable temperature conditions, and lack of competition and lack of overtopping, promote the survival and rapid early growth of conifer seedlings (Evans 2009). For example, at age 50, jack pine and black spruce plantations have 50% and 35% improved gross total volume compared to the regeneration of mixed natural stands, respectively (Morris 2014). Furthermore, herbicide can increase the wood volume yield for major commercial tree species by 30-300% (Wagner 2004).

Glyphosate-based herbicides are systemic, meaning that they are absorbed and transported through the plant's vascular system, killing the entire plant (Knight 2009). They alter the normal biological function of the plant by interfering with certain biochemical reactions (Au, 2003). Glyphosate-based herbicides are also non-residual and degrade readily from soil, with estimated half-lives ranging from 7 to 60 days (Accinelli 2004).

Glyphosate-based herbicides are commonly used in New Brunswick (NB) plantations (Burgess et al. 2010), however, not everyone in society agrees with the use of this product. There are public concerns about glyphosate entering drinking water, remaining within the soil, and causing disease in animal organs (Fraser 2017). The use of glyphosate, diluted with water, is approved by Health Canada (Pest Management Regulatory Agency 2017). However, the World Health Organization's (WHO) International Agency for Research on Cancer (IARC) has declared the product "probably carcinogenic to humans" (Sturgeon 2017).

IARC has received many criticisms after publishing their study since "it has been safe for more than four decades, and more than 800 scientific studies showed that it does not cause cancer" (Partridge 2015). Reuters questions IARC on their conclusion because their draft submission did not lead to the same conclusion (Kelland 2017). The credibility of IARC is now in question as the Agricultural Health Study (AHS), US Environmental Protection Agency (EPA), European Food Safety Authority (Efsa), and European chemicals agency have found that glyphosate does not have a harmful effect on humans (Case 2017)

Health Canada has reevaluated the product, but that has not appeased some NB residents because the product is continuing to be used throughout NB forests. Public perception often focuses on the possible negative consequences of herbicide use without understanding the potential ecological and economic benefits. Studies such as the one used in this report may be useful for explaining the role of herbicides in forest management to the public.

The goal of this study is to conduct a follow-up analysis on a planted spruce and pine herbicide/scarification trial in southeastern New Brunswick, Canada (Burgess et al. 2010). Earlier results found by Burgess et al. (2010) were that only jack pine survival was increased after intensive herbicide and drum chopping treatments, when compared to two treatments of herbicide. For all other planted species, intensifying the treatments with greater than two applications did not create significant differences in their growth. Specific objectives for this study include the quantification of survival, DBH growth, and height growth over a long period following scarification and herbicide applications. This assessment will demonstrate the potential benefits of using herbicide in forest management.

Methods

Study Design

Two experimental blocks were planted in 1994 in southern New Brunswick with jack pine (*Pinus banksiana*), white spruce (*Picea glauca*), Norway spruce (*Picea abies*), and black spruce (*Picea mariana*). The blocks were located in the Fundy Model Forest (45.87°N,65.06°W) in the Acadian Forest Region (Rowe 1972). The site resided in a rolling lowland with well to moderately well drained podsol soil. Podsol soils develop in temperate to cold moist climates and are suitable for coniferous species (Nova Scotia Museum 1996). Each of the two blocks were split into 72 different sub-plots and treated. Treatments include scarification, fertilization, and herbicide application. Two levels of scarification were used: no scarification and scarification using two passes of a Marden drum chopper. Three levels of fertilization were applied: none, one application at the first year of planting, and five applications at years 0 through 4. Three levels of herbicide were applied via helicopter using 3.7L/ha of active ingredient in Vision®. The intensity levels were two applications of herbicide at years 1 and 2 following planting, three applications at years 1, 2, and 4 following planting, and a control (no herbicide). Two applications of herbicide were applied because of the poor product performance in year 1 due to weather conditions in year one.

Due to operational constraints on the scarification and herbicide treatments, the factor levels were not fully randomized (Figure 1) resulting in a partial cross-nested design. Herbicide was applied in blocks across scarification and species treatments, and, likewise, scarification was applied in blocks perpendicular to herbicide treatment in blocks across herbicide and species. Fertilization effects are generally short-term effects and were found to not be significantly different in 2010 (Burgess et al. 2010) and are, therefore, ignored in this study.

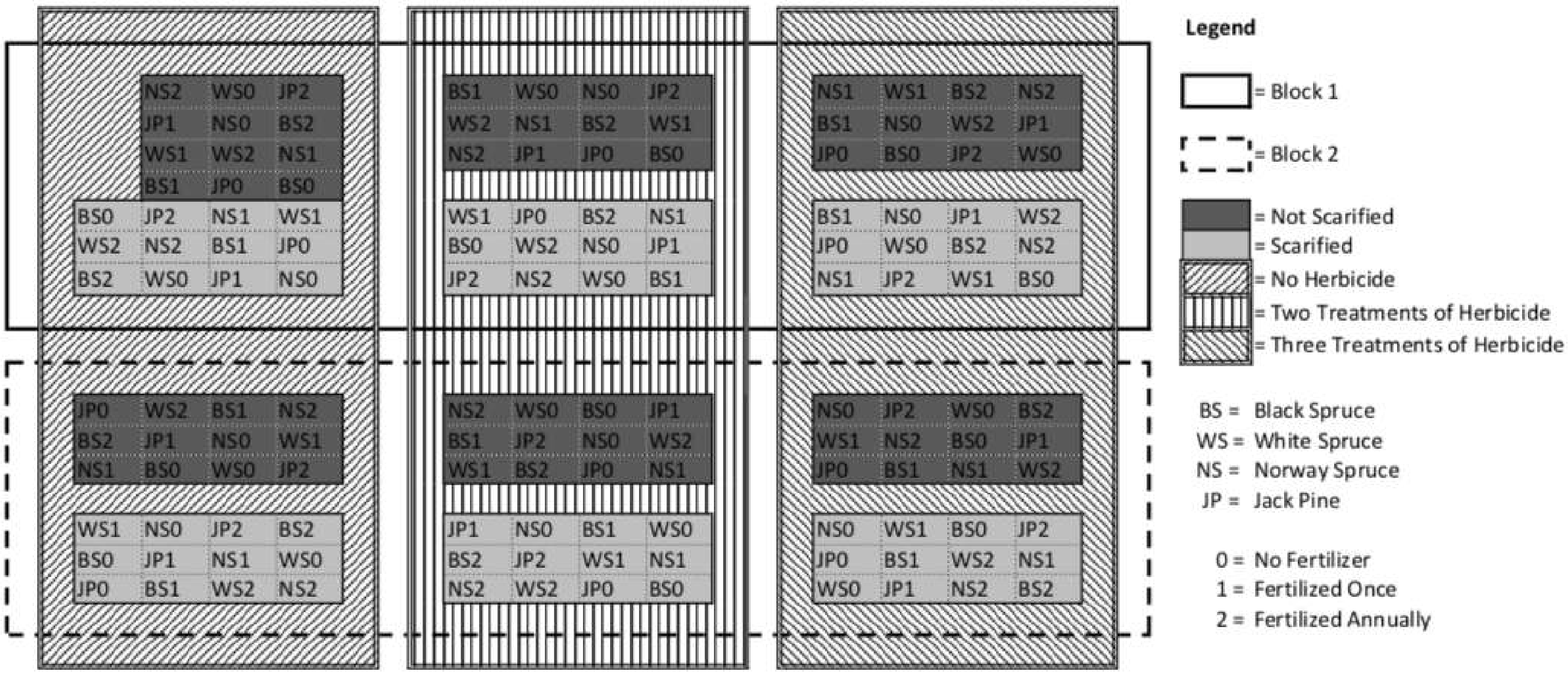

Figure 1. Sample design by Burgess et al. (2010) showing 72 different sub-plots for various treatments within each block.

Data Collection

Within each sub-plot, 100 trees were planted, but only the innermost 36 trees were assessed for survival (Figure 2). This created a buffer around the internal trees to decrease the probability of contamination from different treatments on adjacent sub-plots.

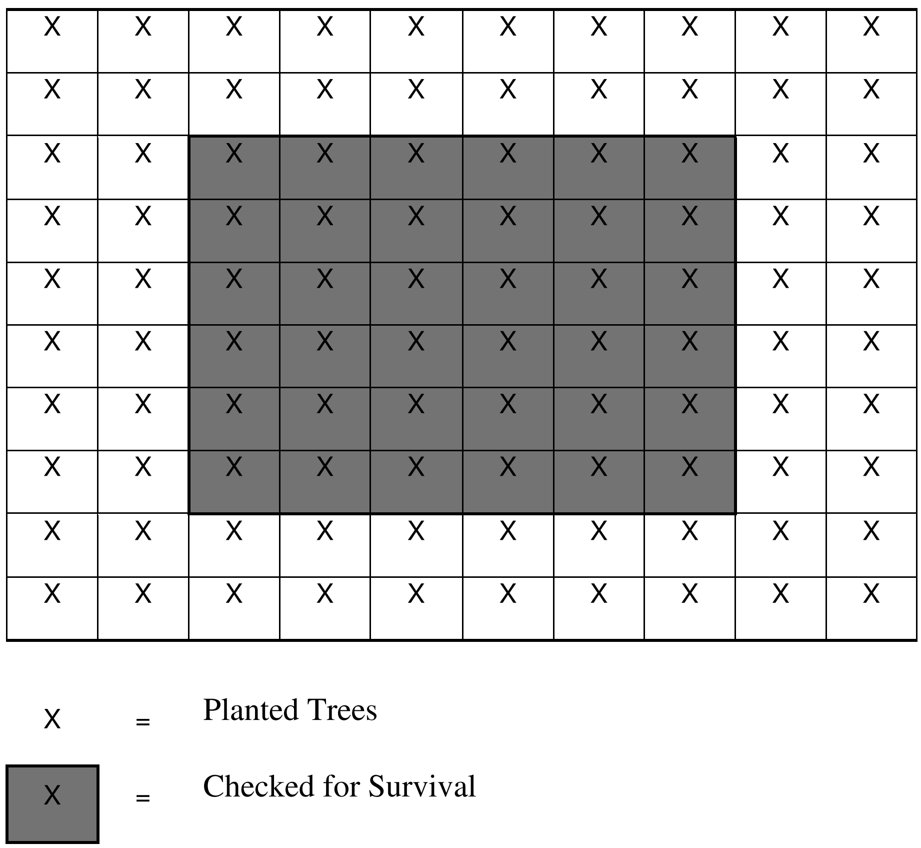

Figure 2. Sub-plot structure showing the innermost 36 trees that were verified for survival.

Within the 36 trees that were assessed for survival, every other tree, when possible, was measured. On each measured tree, diameter, (nearest mm) and height (nearest cm) were measured. For the trees measured in 1998 and 2003, the root collar diameter (RCD) was measured, and for 2011 and 2015 the diameter at breast height (DBH) was measured. The diameters were measured using a diameter tape, and the heights were measured using a hypsometer.

Data Analysis

Due to the cross-nesting, the analyses used mixed effects modeling with herbicide, and scarification as both fixed and random effects. Survival, mean DBH, and mean height measurements were used. A randomized block design was used at the sub-block level with species (F) × herbicide (F) × scarification (F) × block (R) as the fixed effects model with herbicide and scarification as independent random effects. The full model used:

$$M = B + S + H + C + B(S) + B(H) + B(C) + B(S*H) + B(S*C) + B(H*C) + B(S*H*C) + \sigma(H) + \sigma(C) + \sigma$$

Where B = sub-block, S = species, H = herbicide, C = scarification, ( ) denotes nesting, σ( ) = random effects, and σ = random error (residual error). In addition to the statistical model, beanplots, generalized boosted regression models (GBM) and histograms were used to illustrate the resulting differences.

Results

Height

As expected, jack pine had the largest mean height of 1117.6cm, after 21 years of growth, black spruce averaged 946.6cm in height, Norway spruce averaged 1054.0cm, and white spruce averaged 882.8cm (dead trees were excluded from the mean height calculation). Beanplots were created (Figure 3 & 5) to show the distribution of all measurements (including dead trees) around the mean value. Elongated beanplots indicate a large distribution of measurements and less certainty around the calculated mean. Compressed beanplots indicate a small distribution of measurements and increased certainty around the calculated mean. Mortality is one of the major factors contributing to the elongation observed in the beanplots.

Figure 3 shows that in 2011 and 2015, where no herbicide and no drum chopping were performed, jack pine did not have the largest mean height due to the high mortality (mortality trees were given values of 0 in Figure 3). By 2015, the planted jack pine either had very good growth, or they had died, having only 17% survival when no treatments were administered. Within the 3 spruce species, black spruce had the largest mean height early on at ages 4 and 9 (Appendix A); however, by ages 17 and 21 Norway spruce was able to surpass the mean height of the black spruce by 107.3cm. The height of white spruce was shorter than that of black spruce (63.8cm less).

Drum chopping had a very small effect on the mean height of each species (Figure 3). Examining the left and right sides of each beanplot, it can be seen that the mean height values were very similar. The average difference in mean height for plots that were drum chopped compared to plots that were not was 21.6cm. The large difference in the mean height of jack pine that resulted from drum chopping was due to mortality (600.0cm difference in Figure 3 compared to the actual difference of 275.1cm when only survival trees were used in the mean height calculation). Drum chopping had more of an influence on the survival of jack pine compared to mean height.

Herbicide had very little effect on tree height at age 4, however effects of herbicide on tree height became more apparent as the trees aged. By age 9 there were large differences in tree heights between trees that were treated with herbicide and those that were not. The differences were even greater for trees at age 17 and 21, increasing the average tree height by ≥ 525.9cm. There were no significant differences in the mean height when comparing two applications of herbicide versus three applications; variance from the mean was no larger than 68.3cm. From Figure 3 it was seen that the effects of herbicide on jack pine were significantly less than those for the spruce species.

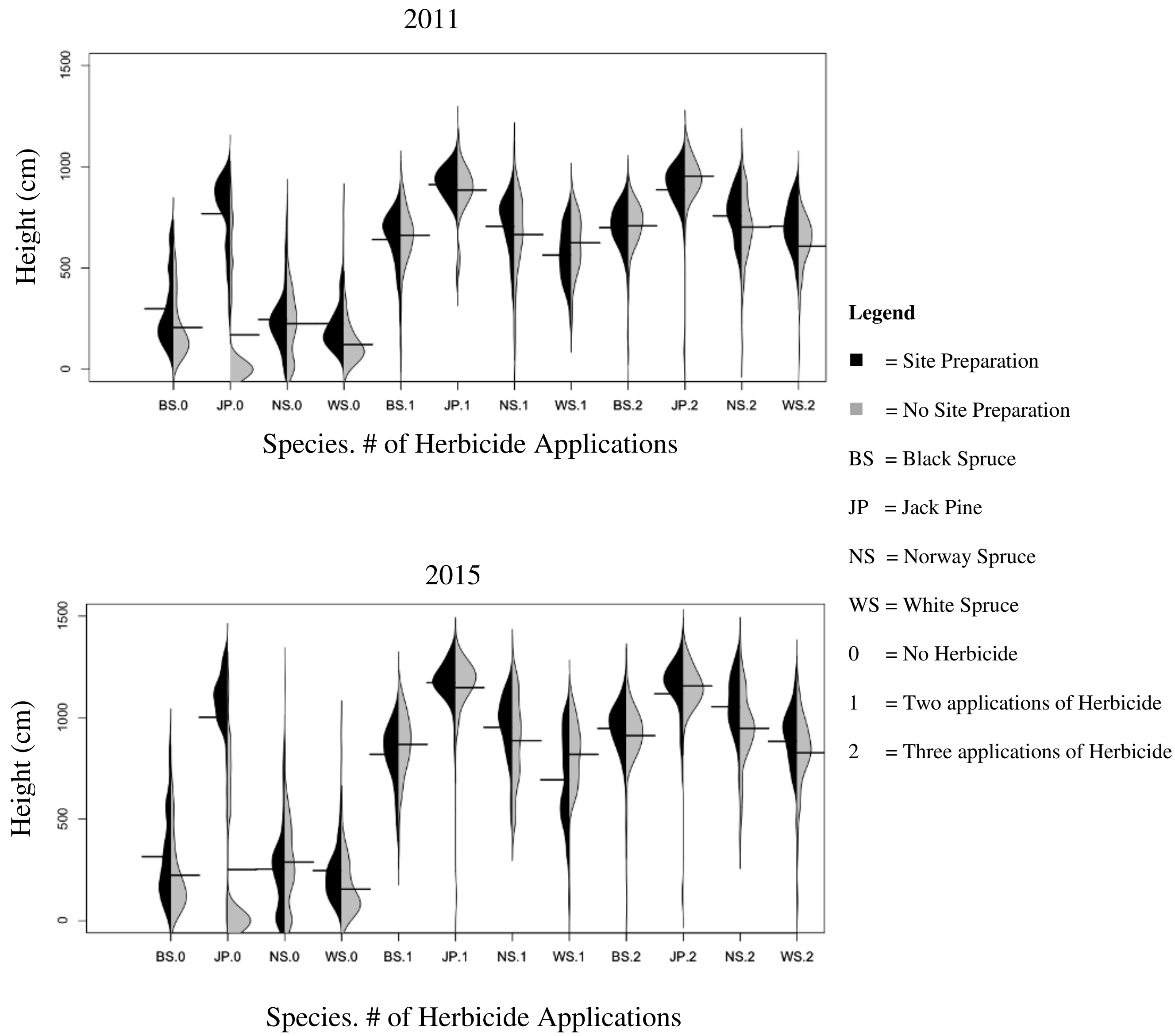

Figure 3. Beanplots of the height (cm) of different planted species at ages 17 and 21, after they've been treated with various applications of herbicide and site preparation; showing the height to be the greatest in jack pine, and greater for every species after herbicide application.

Using the linear mixed-effects model and examining the variation (standard deviation) in tree heights that resulted from random effects, Table 1 shows that there were no significant levels of variability in tree height associated with all drum chopping treatments over time. Similarly there was no variation in tree height associated with herbicide treatments in 1998, and the variation was smaller than that for species in 2003. However, in 2011 and 2015 random effects due to herbicide treatment were larger than those for species and accounted for the majority of the variability in height.

Table 1. Random effects associated with treatments over time and residual standard errors (cm) for height. Data excluded all dead trees.

Year	Treatment Effects			
	Site Preparation	Herbicide	Species	Residual
1998	0	0	34	30
2003	0	54	83	66
2011	0	252	71	148
2015	0	346	79	185

The GBM relative influences of species, site preparation, and herbicide on height are shown in Figure 4. The relative influence agrees with the results obtained from the mixed effects models (Table 1). Site preparation had zero influence on tree height throughout all ages, at age 4 and 9 species had 100% relative influence, and at ages 17 and 21 herbicide had 100% relative influence.

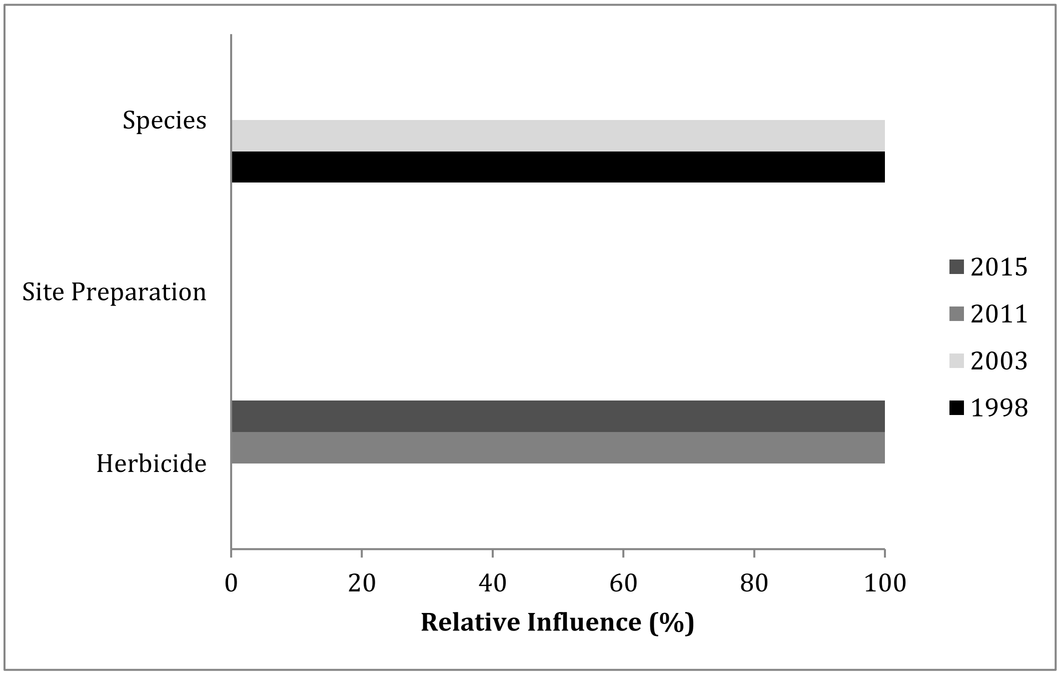

Figure 4. Relative influence (%) of species, site preparation, and herbicide on tree height at different ages, showing species having the most influence in 1998 and 2003, and herbicide having the most influence in 2011 and 2015.

Diameter

As with tree heights, jack pine also had the largest diameters reaching a mean of 13.647cm DBH after 21 years of growth (Figure 5). The mean diameters of the spruce species were very similar across all ages with black spruce being slightly larger in the earlier years (Appendix A). At ages 17 and 21 the diameter of Norway spruce and black spruce were similar with a mean of 12.568cm and 12.775cm DBH in 2015, respectively, and white spruce being only slightly smaller at 10.781cm DBH.

As can be seen in Figure 5, drum chopping had little to no effect on the mean diameters of each species. The mean diameter values were very close when looking at the left and right side of each beanplot. The mean diameter varied by an average of 0.432cm DBH as a result of drum chopping. There was a large difference in the mean diameter of jack pine that was associated with no herbicide because of poor survival (17%). This is not an indication of significant drum chopping effects on growth; the beanplots had zero values where trees were dead. In most cases, the mean diameter was slightly smaller when no drum chopping was performed.

Herbicide had a large effect on the diameters of the planted species. As the trees aged, the differences in diameters of the sprayed versus the non-sprayed species increased. The differences in diameters were ≥ 4.817cm by age 21. The differences in diameters between the trees that were sprayed with two applications of herbicide versus three were significant in the spruce species (≥ 1.482cm DBH by age 21).

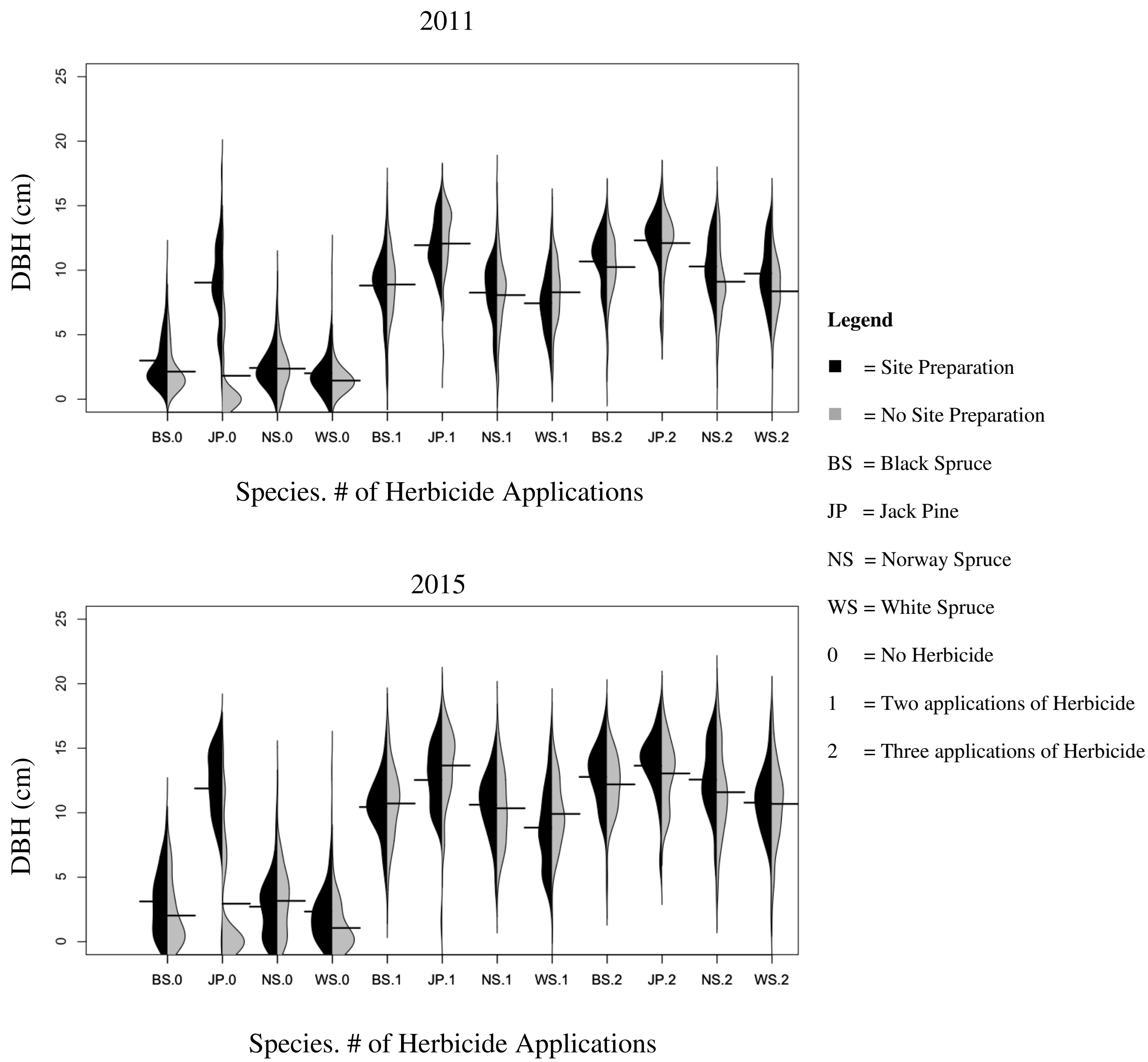

Figure 5. Beanplots of the diameter (cm) of different planted species at ages 17 and 21, after they've been treated with various applications of herbicide and site preparation; showing the diameter to be the greatest in Jack Pine, and greater for every species after herbicide application.

Similar to tree height, the random effects for site preparation was zero (Table 2). Random effects associated with herbicide increased with increasing time, emphasizing both the continued and increasing effects of herbicide treatment on both DBH and height. Early on, species accounted for most of the variance in tree diameter, but its effect declined more rapidly than what was observed for height (Table 1).

Table 2. Random effects associated with treatments over time and residual standard errors (cm) for diameter. Data excluded all dead trees.

Year	Treatment Effects			
	Site Preparation	Herbicide	Species	Residual
1998	0.0	0.3	0.8	0.8
2003	0.0	1.9	1.2	1.6
2011	0.0	3.9	0.0	2.3
2015	0.0	4.5	0.0	2.8

Likewise, the GBM relative influences (Figure 6) agreed with the results from the mixed effects models (Table 2). Site preparation had zero influence on diameter. Species had 100% of the relative influence in 1998, and a small amount of influence in 2003. Herbicide had the majority of the influence on diameter in 2003, and 100% in 2011 and 2015.

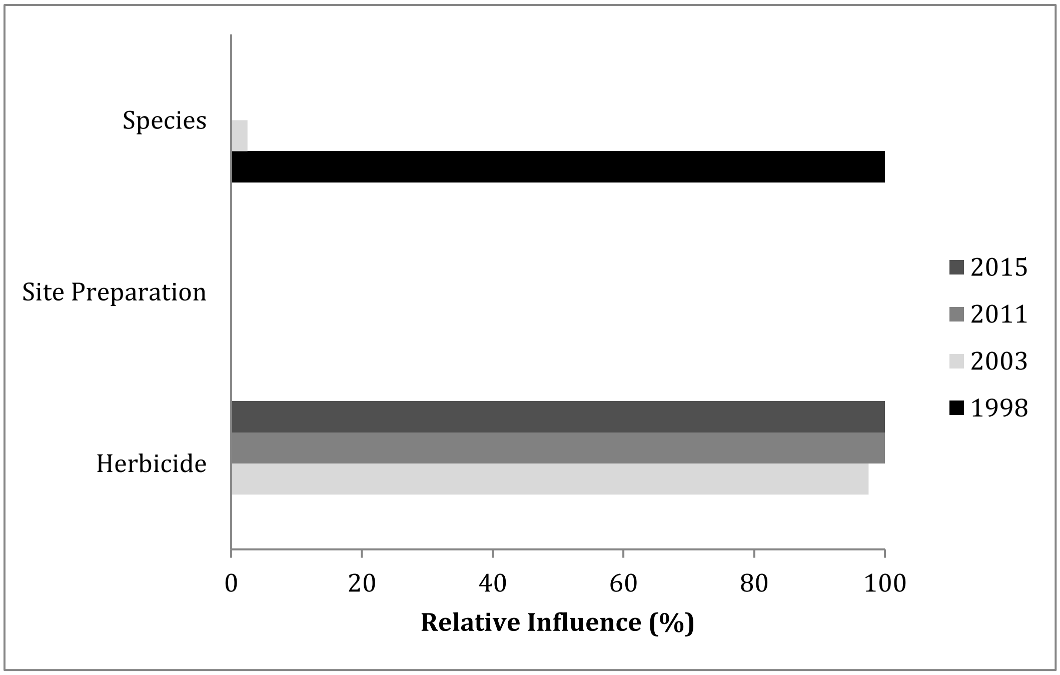

Figure 6. Relative influence (%) of species, site preparation, and herbicide on tree diameter at different ages, showing species having the most influence in 1998, and herbicide having the most influence in 2003 and beyond.

Three applications of herbicide, combined with site preparation, yielded the largest diameters of black spruce at 12.775cm mean DBH (Figure 7). Very close behind was three levels of herbicide combined with no site preparation at 12.196cm mean DBH. A trend could be seen showing little differences associated with site preparation when compared within individual levels of herbicide (Figure 7). However, there is a significant increase in mean diameter by ≥ 1.482cm DBH when comparing three applications of herbicide versus two applications.

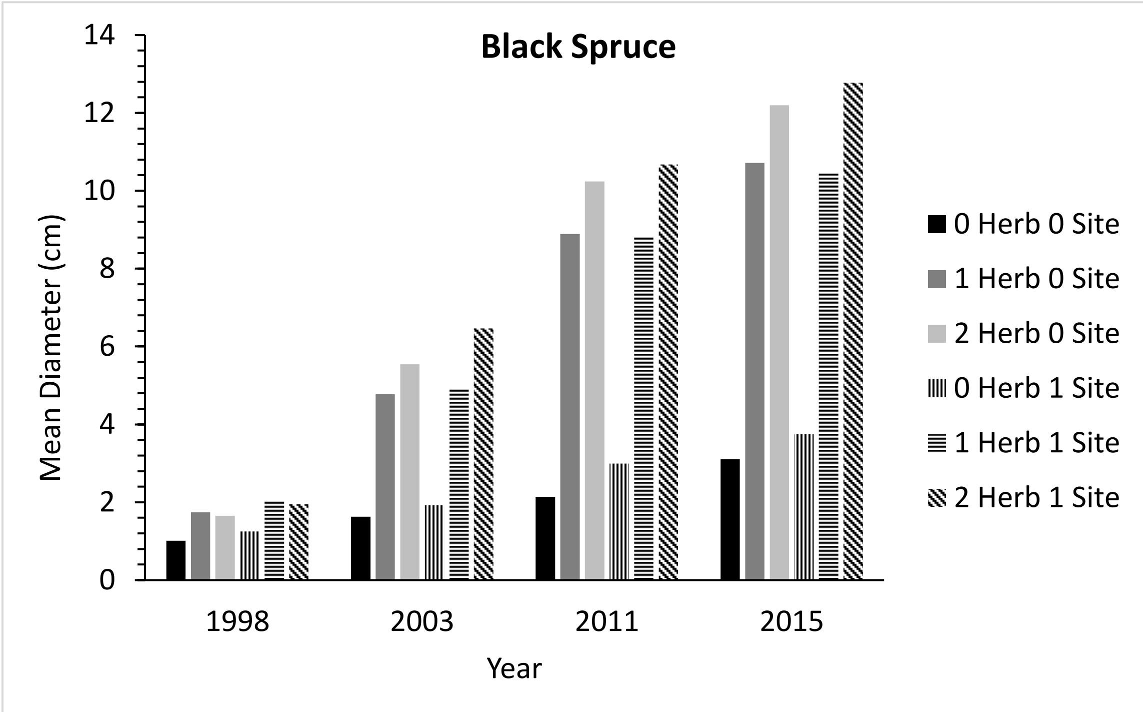

Figure 7. Mean diameter of black spruce over 21 years after various levels of silviculture treatments, showing three applications of herbicide combined with site preparation yielding the largest diameter of black spruce. Survivor trees only.

The mean diameter of jack pine was equal across most silviculture treatments (~12.0cm DBH) in 2011 (Figure 8). There were very little differences between the levels of herbicide. In 2015 the mean diameter of jack pine was lower after three applications of herbicide compared to two applications. The control (no site preparation and no herbicide), yielded the smallest average diameter of jack pine at 8.842cm DBH in 2015. Drum chopping resulted in a larger mean diameter when no herbicide was applied, (12.220cm versus 8.842cm). However, this difference was minor compared to the increases in mean diameters when jack pine were sprayed (Figure 8).

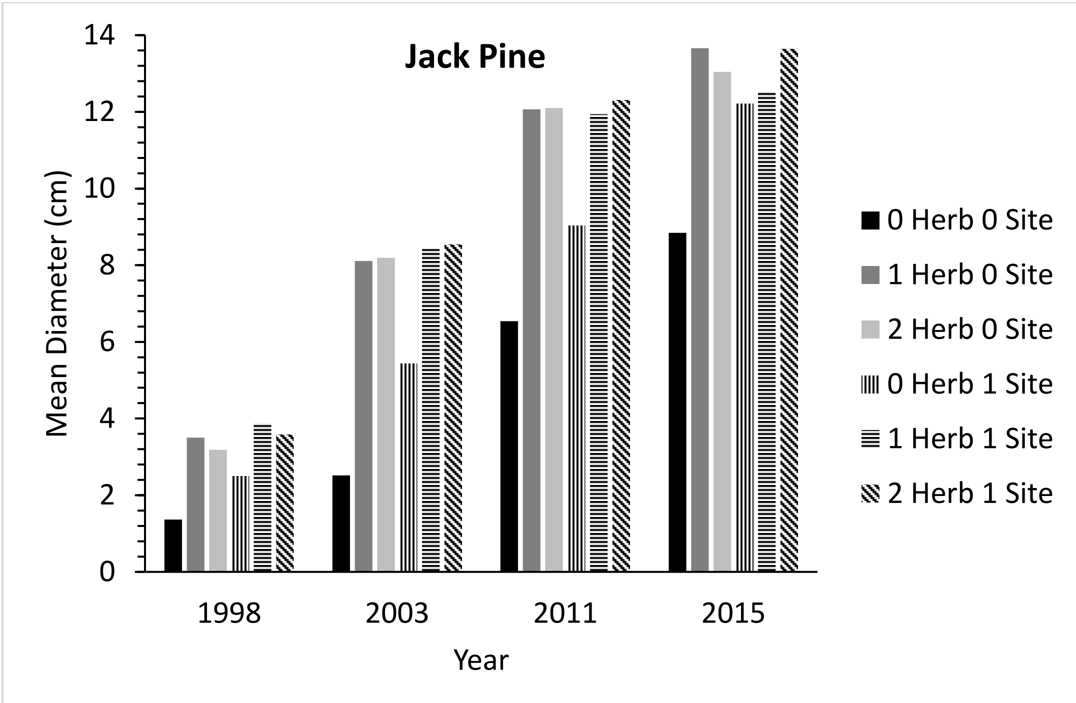

Figure 8. Mean diameter of jack pine over 21 years after various levels of silviculture treatments, showing very little difference in mean diameter size between two and three applications of herbicide, or levels of site preparation. Survivor trees only.

The mean diameter of Norway spruce and white spruce (Appendix B) followed a similar trend to that of black spruce. Three applications of herbicide, along with drum chopping, resulted in the largest diameter trees. However, there were less differences between silviculture treatments involving various levels of herbicide in white spruce compared to both black and Norway spruce.

Survival

Average survival rates for black spruce were 80% across all treatments. The lowest survival was 65% in 2015 for the control trees, and the greatest survival was 90% when drum chopping and three applications of herbicide were used (Figure 9).

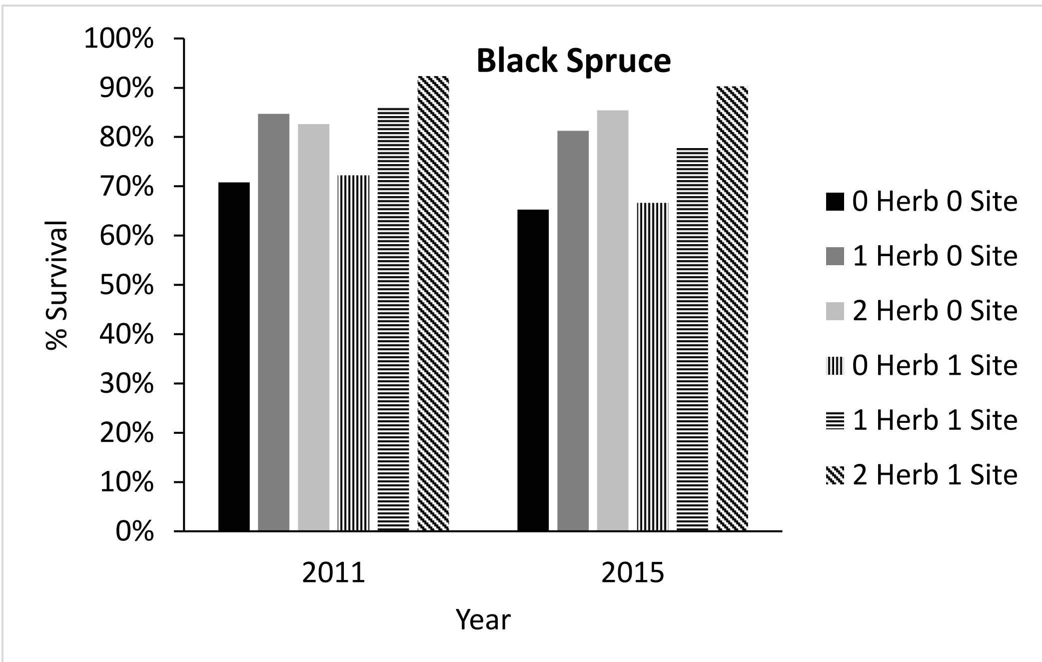

Figure 9. Survival of black spruce in 2011 and 2015 after various levels of silviculture treatments, showing the least survival where no herbicide was applied.

Jack pine had the second lowest survival rates of all the planted species (Figure 10). Average survival was 69% across all treatments in years 2011 and 2015. Survival was the least for the control trees (17%), and greatest for intensive silviculture applications (81%) in 2015.

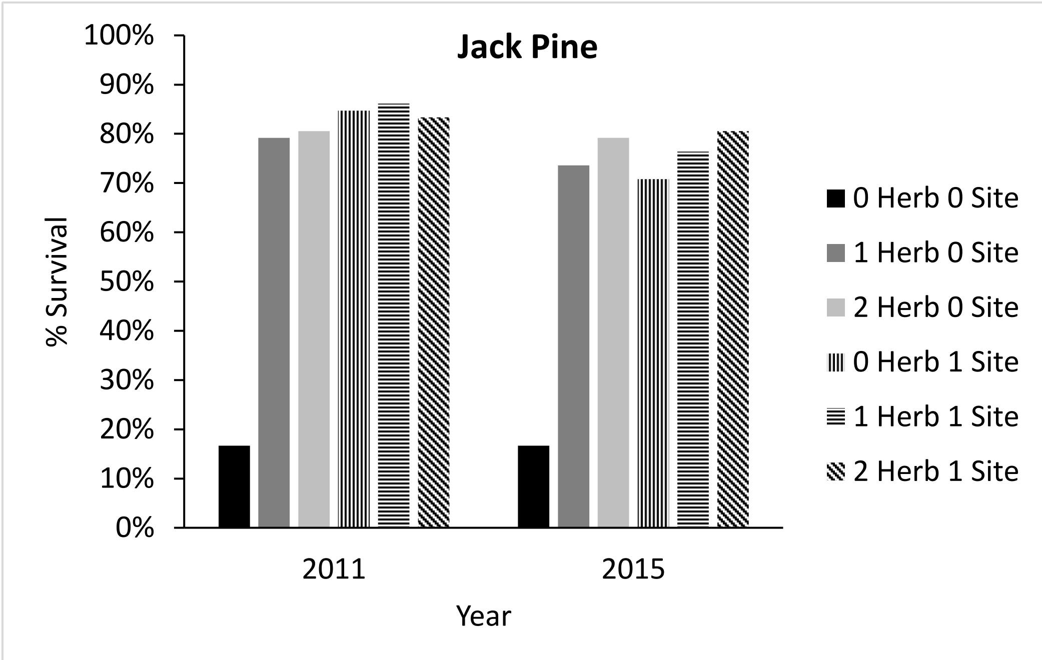

Figure 10. Survival of jack pine in years 2011 and 2015 after various levels of silviculture treatments, showing the least survival where no herbicide and no site preparation were applied.

The survival of Norway spruce was the poorest of all the planted species. Although the control trees did not have as low a survival rate as jack pine, the average survival rate for Norway spruce was 66% across all treatments in 2011 and 2015 (Figure 11).

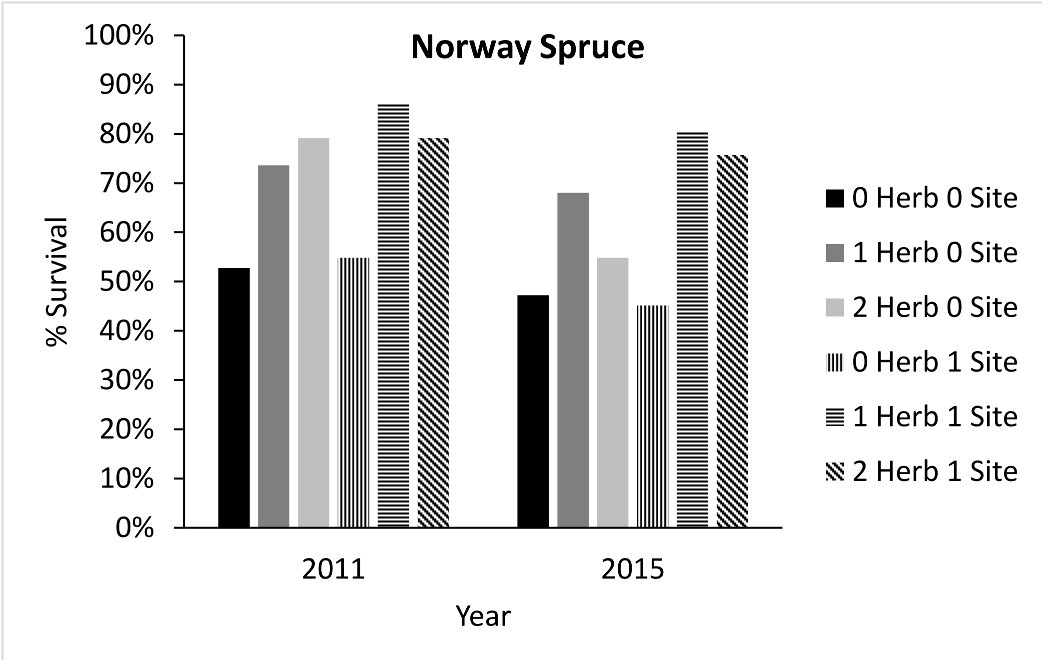

Figure 11. Survival of Norway spruce in years 2011 and 2015 after various silviculture treatments, showing the least survival where no site preparation was applied.

White spruce followed a very similar trend to black spruce (Appendix C). Survival was 61% in 2015 when no treatments were applied, and 92% with intensive silviculture treatments.

Discussion

Species

Differences in species had the greatest influence on tree height in the early development of the planted trees. As seedlings became established and began interacting with competing vegetation (or benefiting from the lack of competing vegetation), species differences became less obvious and silvicultural treatment effects became more obvious. This result emphasizes the need for long-term silvicultural studies because of the long periods required by trees to establish and adapt to the growing conditions around them.

Jack pine is one of the fastest growing conifers in its native range (Carey 1993). It was, therefore, no surprise that jack pine exceeded the mean heights of the spruce species. The study design favored jack pine growth as jack pine is shade intolerant and therefore grew well at an early age when established in an open site such as a clear cut (Martin 1996). Black spruce grew slower than jack pine, but survives longer, and becomes co-dominant after 90 years, eventually succeeding jack pine. (Fryer 2014). Even though black spruce is a shade tolerant species, it grows the fastest in open sites. Black spruce tends to grow on wet lowlands, which is opposite to jack pine that grows on dry uplands (Lamhamedi 1994).

White spruce is found on soils derived from calcareous parent material (Department of Natural Resources 2007). This shade tolerant species is similar to black spruce, in that it grows best in open sites, however, white spruce often grows very slowly in less favorable conditions, and accelerates in growth as it matures. The early growth of Norway spruce is slow and increases to maximum growth rates between 20 to 60 years of age (Bigler 2009). This was observed in the results for tree height and diameter where Norway spruce surpassed the dimensions of black spruce at age 17. It grows best in well-drained, sandy loams and is also a shade tolerant species (Gilman 1994).

Site Preparation

The results demonstrated that drum chopping had little or no influence on tree growth for both height and diameter in this study. The Marden drum chopper did not mix the mineral soil and the duff layer; it simply broke up the course woody debris. Drum chopping is designed to help tree planters maneuver through the block while they are planting, but does not expose the mineral soil to create optimal microsites (Murphy 2006). The most common site preparation method currently used in New Brunswick is disk trenching (Errson 2017), which provides soil exposure and tilling. Disk trenching increases the temperature of the soil, which increases the seedling nutrient uptake (Boateng 2006), and creates mounds that help to prevent root saturation on wet sites (Natural Resources Canada 2017).

Boateng et al. (2006) found that after 20 years, spruce height and diameter were larger in all mounding treatments than in the control in a mechanical site preparation and early chemical release study in the boreal region of northeastern British Columbia. However spruce planted on hinge positions in the Bräcke patch and blade scarification treatments did not grow well. This demonstrated that growth response is dependent on the type of site preparation treatments performed on different sites (Boateng 2006).

There are many factors that affect the rate of survival, including site suitability of the planted species, insects and disease, as well as environmental factors. Survival was

84% overall in 2003 and by 2015 survival decreased to 71% overall. Norway spruce had the least percent survival overall at 62%, which is not always the case in the Maritimes region of Canada. Fowler et al. (1980) showed that average survival of Norway spruce and black spruce were the same (86%) in 13 tests located in Eastern Canada. Norway spruce however is more susceptible to damage by white pine weevil than any of the three native spruces (Foweler 1980). Fill planting was irrelevant in this study, as it would have created bias in the data.

Drum chopping aided in the survival of jack pine, as those that were only treated with drum chopping had a higher percent survival than the trees that did not. This agrees with a study by Sutton (1991) that showed ≥ 85% survival in jack pine after various scarification treatments, and only 73% survival at age 5 when no site preparation was performed.

Herbicide

The diameters of jack pine showed large differences between the sprayed and non-sprayed, and jack pine height did not because diameter was more sensitive to competition than was tree height. Stand density has a greater effect on diameter, which is why herbicide had such a great effect on the growth of tree diameter. Herbicide reduced stand density by minimizing the competition, and gave the planted trees more space for growth by minimizing competition for water, nutrients, and sunlight (Balandier 2006). This was evident in the beanplots (Figures 3 & 5) that showed a significant difference in diameter in between the trees that had been sprayed with herbicide and the trees that had not.

Although herbicide resulted in a greater increase in diameter for the spruce species than height, the difference in height was still significant for the spruce species compared to the control trees. A study by Wang et al. (2000) showed that competition for light is important to the establishment and success of spruce plantations. They observed that there is a relatively strong relationship between black spruce seedling height growth and competition measures of light interception or direct measures of light transmission. Since herbicide reduced competition, it allowed more light exposure for the planted seedlings, which increased their growth in height.

The effect three applications of herbicide had, compared to two applications, was not significant on height growth for all species, and it was not significant on diameter growth for jack pine, in this study. The mean growth measurements decreased in various treatments after three applications of herbicide compared to two. However, it did increase the diameter of the spruce species. Each treatment site was sprayed twice at years 1, and 2, and the intensive sites were sprayed again at age 4. This gave a 2-year competitive advantage to the intensive sites where incoming competition was eliminated. The insignificant increase in height growth following 3 applications of herbicide compared to 2 applications demonstrated that the planted species were already dominating the competition for light exposure at age 4 and did not need further assistance.

The results showed that herbicide not only aided in increasing diameter growth, but in jack pine survival as well. Jack pine had the least percent survival when no treatments were performed, which are a result of it being a pioneer species that does not grow well in intensive competition. Jack pine is one of the most shade-intolerant trees in its native range (Department of Natural Resources 2016).

Clear-cutting of mature stands in the Acadian forest typically regenerates deciduous hardwoods and shrubs rapidly. Softwood development regenerates much more slowly (Olson et al. 2012). However, herbicide treatments have been effective at changing species composition to softwood dominance. The most effective vegetation management method is herbicide use due to its low cost, high efficacy, and associated improvements in seedling growth and survival (Flamanco 2018). Similar to this report, a study by Olsen et al. (2012) found an increase in merchantable volume of softwood by 60 m^3/ha at stand age 40 years when glyphosate was used as an herbicide treatment in central Maine, USA. This increase in wood volume has a positive impact for social, environmental, and economic forest sustainability.

With the use of herbicide, wood volume is increased, which allows harvesting to occur more frequently as the trees grow to merchantable size more quickly than stands that have not been sprayed with herbicide. The average cost of an aerial application of glyphosate in a spruce and pine plantation in Ontario was $210.50/ha in a study by Homagain et al. (2011). This resulted in an average merchantable volume of 188m^3/ha in the planted species compared to the control trees that averaged 140 m^3/ha after 70 years. The aerial herbicide treatments had the highest average value of fibre (timber, pulpwood, and hog fuel) production at $25,492/ha compared to the control that had an average value of $17,745/ha. This is economically beneficial as aerial herbicide treatments are cost-effective and result in higher gross total volume and gross merchantable volume, higher average value of fiber production, and higher net present value, benefit-cost ratio, and internal rate of return compared to other vegetation management treatments (Homagain, 2011).

The use of herbicide can also create a positive environmental impact, as less forest area needs to be harvested in order to produce the same amount of lumber than would be available if herbicide was not used. Herbicide increases the merchantable volume of timber, which shortens the rotation age of plantations (Wagner 2006). This allows plantations to be harvested more frequently, and permits less harvesting in the long-term of the total forest area. With less area harvested, more forest can be reserved in protected natural areas, providing more habitats for species that rely on mature forest. This would satisfy environmental objectives rather than using the increased volume to increase the annual allowable cut, which would satisfy more economic objectives (Bouchard 2013).

The social impact of herbicide use may be positive as well, as fewer roads need to be created with less area being harvested. This creates a positive impact to recreational forest users, as fewer roads will be used more frequently, requiring road maintenance to be performed more often. Therefore recreational users will be able to access the forest more easily in addition to having more mature forest to enjoy activities such as hunting, trapping, and bird watching. A study performed by Eriksson et al. (2012) found that forest scenes that exhibit higher visibility and physical accessibility tend to have higher preference ratings.

The positive impacts of using herbicide exceed the concerns around intensive pesticide use as herbicide is only sprayed once or twice over a small area every 40-60 years (Malik 1986). In NB, only 0.3% of the forests are treated with herbicides, such as glyphosate, annually (ForestInfo 2018). Compared to the long-term positive effects herbicide has on economic, environmental, and social forest sustainability, the public's concern around the short-term use of herbicide is not necessarily grounded in science. Herbicide may only be applied at a distance greater than 1km of a surface water supply intake, and between 30 and 75m from the banks of a watercourse. The typical maximum wind speed for aerial herbicide application is 10-12kph in NB and drift has become minimal with low-drift spray nozzles (Thompson 2012). Advanced aerial application technologies, including GIS-based mapping and electronic guidance systems are used for application accuracy (ForestInfo 2018). Glyphosate studies have shown that it degrades completely in soil and water microbiologically and through chemical breakdown processes in twelve weeks (Malik 1986). Finally, glyphosate is relatively non-toxic to mammals, birds, fish, insects, and most bacteria (Bell 1989). It is less toxic following ingestion than aspirin, table salt, or caffeine (McKean 1991).

Conclusion

This study demonstrated the positive long-term impacts herbicide could have on economic, social, and environmental forest sustainability. The results showed that after 21 years, herbicide had the greatest impact on height and diameter growth. Increasing the intensity level of herbicide yielded a greater mean diameter and height across various spruce and pine species. Drum chopping also increased the mean diameter and height, but it was not nearly as affective as herbicide.

At an earlier age species predominated the influence on tree diameter and height growth, however after 17 years of growth, herbicide gained 100% of the influence. Jack pine had a larger diameter than black, Norway, and white spruce at an early age, however the spruce species caught up after 21 years of growth to be almost the same diameter.

Survival was greatest for trees that were treated with herbicide and site preparation compared to those that were not. The level of herbicide made no difference on tree survival, and where no herbicide was applied, drum chopping helped to increase jack pine survival. These results demonstrate the long-term benefits of herbicide use to reduce competition.

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Appendix A

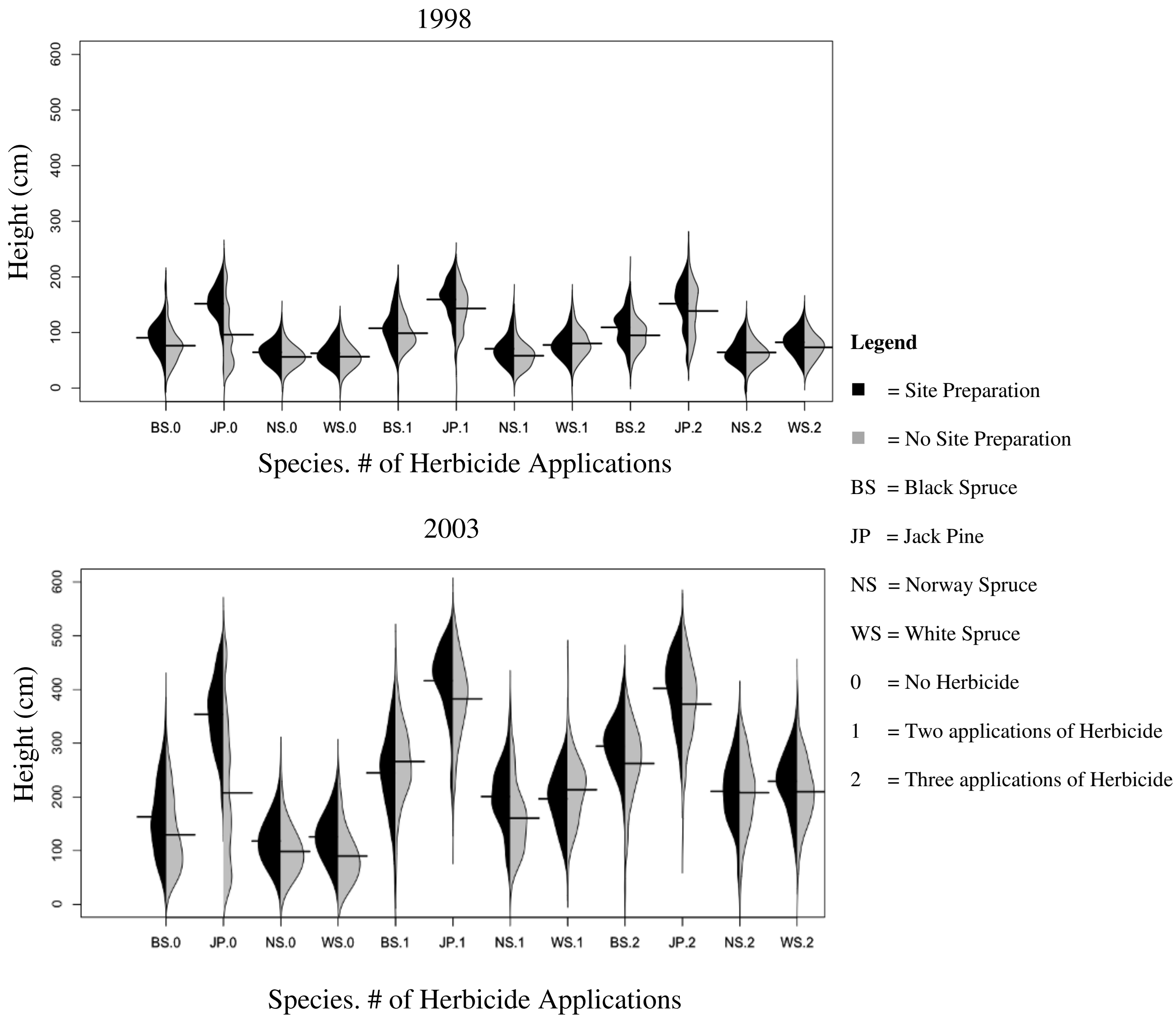

Figure 12. Beanplots of the height (cm) of different planted species at ages 4 and 9, after they've been treated with various applications of herbicide and site preparation; showing the height to be the greatest in jack pine, and greater for every species after herbicide application.

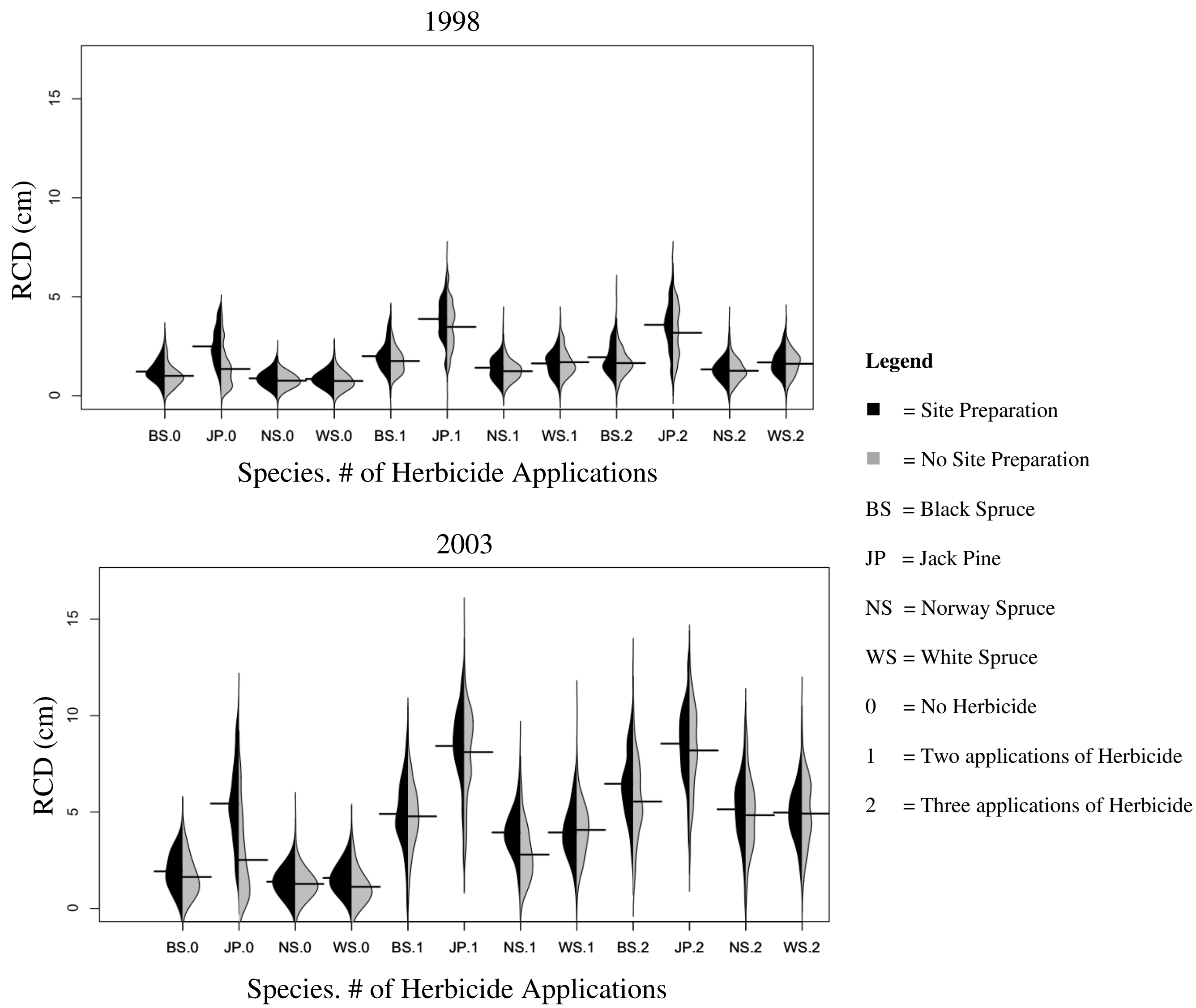

Figure 13. Beanplots of the diameter (cm) of different planted species at ages 4 and 9, after they've been treated with various applications of herbicide and site preparation; showing the diameter to be the greatest in Jack Pine, and greater for every species after herbicide application.

Appendix B

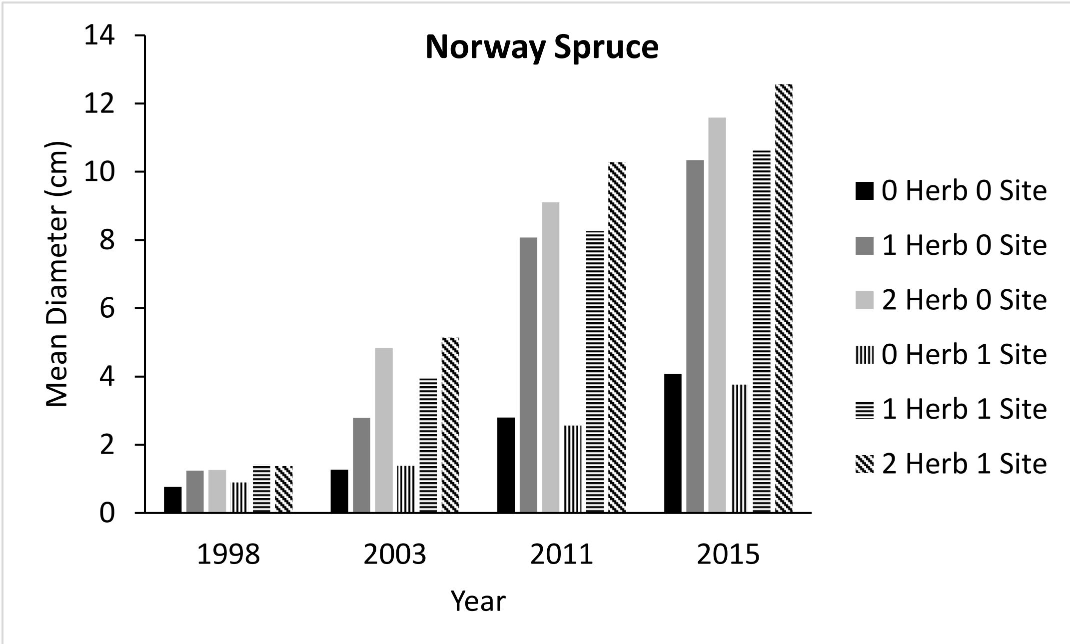

Figure 14. Mean diameter of Norway spruce over 21 years after various levels of silviculture treatment, showing three applications of herbicide combined with site preparation yielding the largest diameter of Norway spruce.

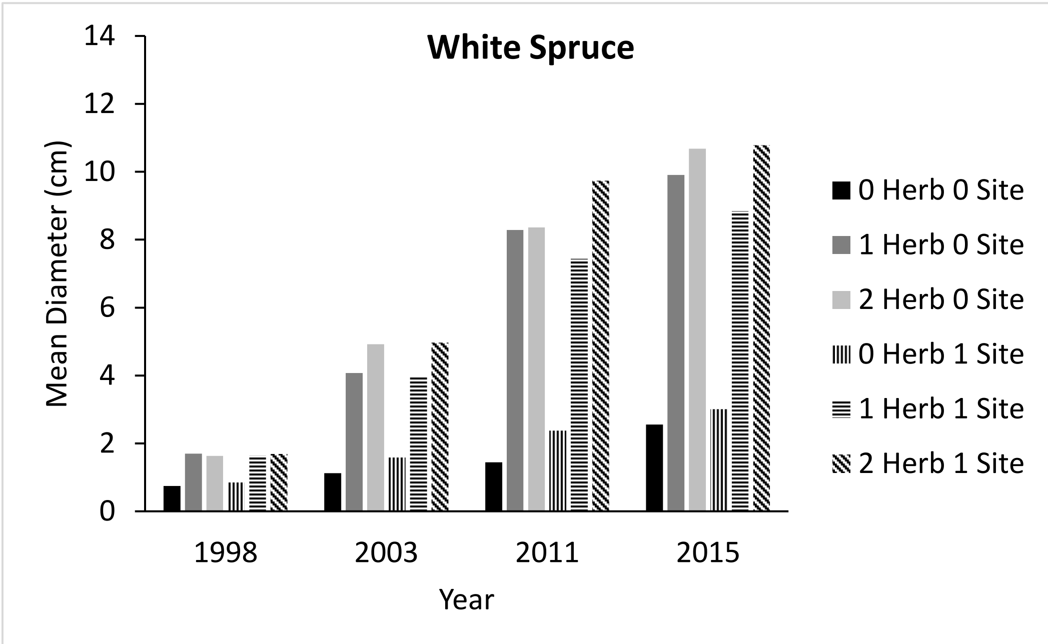

Figure 15. Mean diameter of white spruce over 21 years after various levels of silviculture treatments, showing very little difference in mean diameter between two and three applications of herbicide, and level of site preparation.

Appendix C

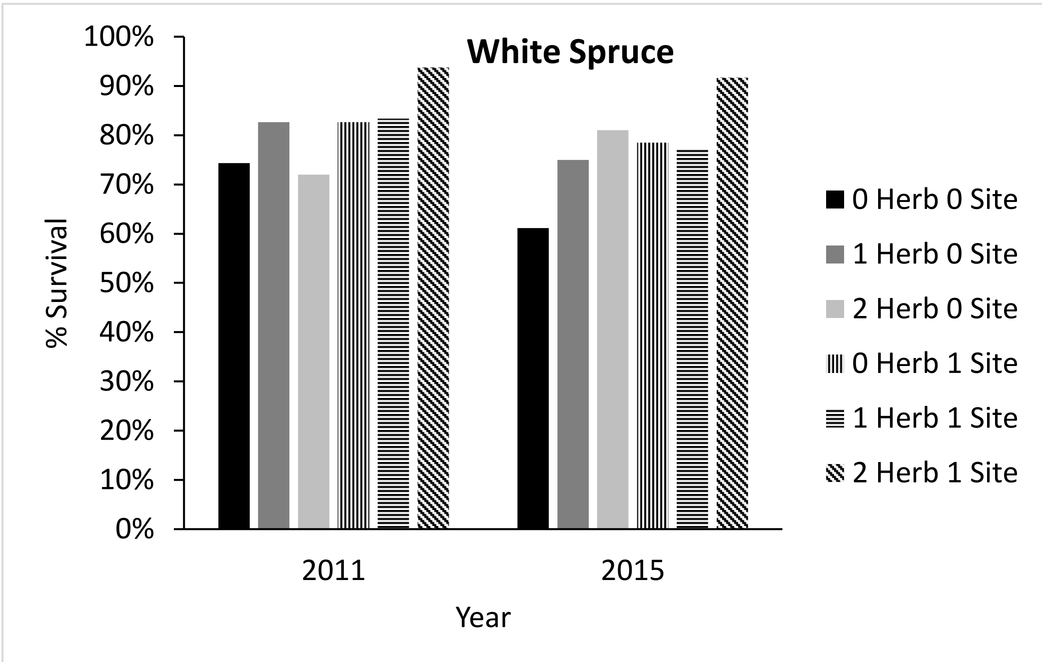

Figure 16. Survival of white spruce over 21 years after various levels of silviculture treatments, showing a decrease in survival after 2011 where no herbicide was applied, and a decrease in 2015 where no herbicide and no site preparation were applied.

Curriculum Vitae

Megan McKinley

University of New Brunswick

Bachelor of Science Honours (Medicinal Chemistry) May 2016

Publications: None

Conference Presentations: None