CHALLENGES WITH REGENERATING CHIPPER DEBRIS PADS: EVALUATING SEEDLING PERFORMANCE NINE YEARS AFTER PLANTING

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ABSTRACT

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Keywords: Chipper debris pads, silviculture, wood chips, productive land, portable chain flail chipper.

Debris from in-bush portable chain flail chippers can alter the abiotic environment factors within the mineral soil. Thus, chipper debris can create an unsuitable seedbed for seedling growth and survival. In this thesis, jack pine and white spruce will be planted on fresh chip pads (age=2) and chip pads that had time to decompose (age=9). Previous research has shown that chipper debris can insulate the soil, repel or maintain moisture based on the age of debris, and leach toxic material based on the age of debris. Ensuring that chipper debris pads are regenerating with merchantable species is important for forest managers to maintain productivity on crown land.

CONTENTS

TABLES

FIGURES

ACKNOWLEDGEMENTS

I would like to thank Dr. Doug Reid from the Centre for Northern Forest Ecosystem Research (CNFER) for guiding me on my thesis for the past year. I would also like to thank Dr. Dave Morris at CNFER for providing the data and helping with the analysis for this thesis. I would also like to thank my second reader Shayne Elliott for helping me with my thesis.

INTRODUCTION AND OBJECTIVES

Forest managers have been practicing sustainable forest management since the early 1990's, in regard to having a more ecological and social considerations. Part of keeping the forest sustainable is to ensure that what was considered productive land before harvest is kept as productive (i.e., regenerating with the desired tree species).

Over the last two decades, the use of portable chain flail delimber-debarker-chippers (DDC) has increased in northwestern Ontario. DDC became popular in the forest industry as it improves production, provides better chip quality and is more cost effective (Pulp and Paper Canada 2004; Thompson and Sturos 1991). Chipper debris management from roadside chipping has some forest managers concerned as the chipping debris accumulates and thus possibly loosing productive land. One concern about chipper debris piles is that it may not be a suitable growing condition for softwood seedlings to grow in, thus losing productive land in the future. Areas with chipper debris must be able to be reclaimed and regenerated as productive land to achieve sustainable forest management.

This study is designed to examine how the fresh (2 year old) and legacy (8 year old) debris from a in-bush chipper affects seedling growth and health. As the chipper debris decomposes the soil conditions may change, which will be discussed as previous theses reviewed and examined this from the same sites. The experiment was situated on the Lundstrom road and the Shabaqua area which is northwest of Thunder Bay, ON. The data that will be collected is the tree's height, root collar diameter, dbh (if present) and a health assessment for both white spruce and jack pine.

<u>Objective and hypothesis</u>

This thesis examines how jack pine and white spruce seedling growth differs on a fresh chip pad (2 years) vs an older, more decomposed chip pad (9 years). Seedling health and growth (height and diameter) were recorded in and outside of the chipper pads. The hypothesis for this thesis include:

1. Planted jack pine (*Pinus banksiana)* will be more likely to have better growth (RCD, height, and basal area) in chipper debris compared to white spruce (*Picea glauca*).
2. The age (fresh vs legacy) of the chipper debris pad will have an positive affect seedling survival and growth.

It is hypothesised that the seedling planted on older chip pads will have better growth and health compared to the fresh piles as the older piles will be more decomposed have more nutrients readily available.

LITERATURE REVIEW

Chipper debris from in-bush DDC is viewed negatively as it impedes regenerative efforts. Debris from the chipper has been shown to impede seedling growth and survival. Currently, research is examing the effects chipper debris has on the soil and how those effects impact seedling growth and survival. This effort is to ensure there is no lost productive land and meets silvicultural goals (i.e., meets free-to-grow requirements). Chipper debris alters seedling growth as it alters soil temperature, soil moisture, creates frost pockets, and leads to the leaching of allelochemical agents, which also impede seedling growth. The literature review will discuss how chipper debris affects seedling growth.

Chipper Debris

Chipper debris consists of branches, foliage, and bark that has been stripped away from the merchantable wood. After a pulp wood harvest with a DDC, the amount of biomass material left on site can be significant. As an example, in British Colombia, the "average" productive (250m3/ha) aspen stand (*Populus tremuloides* Michx.) can produce 42 tonnes per hectare (Conlin et al. 2004). In northwestern Ontario, chipper debris pads can occupy >3% of the harvested block area (Buda et al. 2015). Chipper-debris pads have become smaller in area compared to historical ones, as skidder operators have implemented a carry-back system to minimize the area of the chipper debris pads (Buda et al. 2015). To minimize the chip pad's total thickness and surface area, the in-bush DDC is moved around the block to where it has a shorter distance for the skidder to haul trees from the buncher.

Chipper debris can be variable as it may consist of different species composition (i.e., tree composition from cut block), size/material source (flail vs sliver chute), the season of harvest, and time since the harvest (Buda et al. 2015). The DDC produces two types of debris; most of the debris that comes from the main debris chute consists of bark, branches and foliage materials (Buda et al. 2015). The second chute (i.e., sliver chute) produces long slivers from the unmerchantable material of the log; this material accounts for 10% or less of the total debris left on site (Buda et al. 2015).

Chipper debris size may also be dependent on the season of harvest. Harvesting in the summer produces more bark strands and material from limbs and tops within the chipper debris (Buda et al. 2015). The increase in chipper debris is due to the warmer temperatures and increased moisture content leaving the tree more flexible and more likely to be chipped as debris (Buda et al. 2015). Chipper debris produced in the winter results in smaller flakes and has overall less debris left on site. A tree’s tops and limbs are much more brittle during the winter and are more likely to be broken off during skidding (Buda et al. 2015). The less material going into the DDC will result in less chipper debris left on site (Buda et al. 2015).

Soil Temperature

Soil temperature is crucial for seedling growth as it can influence seedlings' total mass, which includes root biomass, foliage biomass, and stem biomass (Peng and Dang 2002). Seedling growth will differ amongst species as they have different growing requirements and tolerances to soil temperatures (Bulmer et al. 2007). Soil temperature will also influence a seedling's physiological activity as it can impact the absorption of water and nutrients (Peng and Dang 2002). The decomposition of organic matter also depends on soil temperature, which in turn will impact seedlings' nutrient availability, thus affecting their growth (Peng and Dang 2002). Thus, the soil temperature is essential to seedling growth and physiology as it influences many biotic and abiotic factors.

Root growth usually begins in the spring when soil temperatures reach a certain degree. Each seedling has a preferred soil temperature where root growth begins and when it becomes dormant (Peng and Dang 2002). Jack pine will begin root growth when temperatures reach 4°C in 15cm of soil; shoot growth occurs within a week after it’s root growth (Rudolph and Laidly 1990). Root growth in jack pine will stop once soil temperature drops to 7°C for six consecutive days or more (Rudolph and Laidly 1990).

The optimum soil temperature during the growing season differs amongst species as they grow in different environments (i.e., upland vs lowland, etc.). Jack pine tends to grow in areas that have been burned by forest fires, the area would be open and have lots of sunlight, thus the soil temperature is typically warm. A study by Peng and Dang (2002) found that jack pine seedlings have optimal growth in total biomass when soil temperatures are at 27°C, whereas white spruce seedlings was found to have optimal growth at 19°C. The difference in optimal soil temperatures supports field observations that pioneer species (i.e., jack pine) are more suitable for higher soil temperatures than for mid-succession species (i.e., spruces) (Peng and Dang 2002).

Grossnickle and Blake (1985) found root development in jack pine was more significant in the soil at 22°C compared to the soil at 10°C. White spruce was found to have no significant increase of root development at 22°C but more root development than jack pine at 10°C. The study has also found that seedlings planted at lower soil temperatures showed high levels of water stress compared to seedlings planted in higher soil temperatures. The result of the seedlings having higher water stress levels in lower soil temperatures is due to the increased viscosity of water in the soil and roots and the decrease of the permeability of the roots (Kaufmann 1975; Grossnickle and Blake 1985).

Chipper debris has been found to act as an insulator to the soil; this insulating effect can affect the seedling growing season. A study by Blanchette and Shaw (1978) found that the soil temperature under chipper debris was warmer than the ambient temperature during winter. This insulating effect influences the seedling's growth season as the soil tends to stay warm during the end of the growing season, causing the seedling to continue to grow (Bulmer et al. 2007). However, during the spring, the soil stays cooler due to the insulating effect causing a delay in growth in new growth for a seedling (Bulmer et al. 2007). Although the seedling's growth may be delayed in the spring, the insulating effect makes up for it during the fall.

Soil Moisture

Soil moisture is essential for plant growth as it influences the soil temperature, aeration, nutrient availability, and microbiological activity (Wilde 1958). Previous studies have shown that chipper debris or CWD (Coarse Woody Debris) tend to have a higher soil moisture content than exposed mineral soil (Bulmer et al. 2007; Conlin 2004; Dhar et al. 2022). The soil moisture content is higher under CWD as the woody material acts as a barrier that reduces the evaporation of the water from the mineral soil. Older chipper debris has been found to have higher soil moisture content than fresh piles and areas with no debris (Purves 2013). The higher soil moisture content in the aged debris is due to the decomposed debris able to retain more precipitation inputs (Purves 2013). Increasing soil moisture during the growing season can also benefit seedlings when precipitation can be minimal during the summer.

A fresh chipper debris pad (2-year-old) will have hydrophobic properties that repel water from the soil. In contrast, an older chipper pad (9-years-old) is shown to have hydrophilic properties and thus prevent water from reaching the soil (Purves 2013). Purves (2013) found no significant difference in moisture content between a 2-year-old chipper debris pad and an 8-year-old chip pad. The study showed that the chipper pad's overall soil moisture content was greater than the soil outside of the chip pad.

Planting Site

Factors to consider when deciding on a site to plant seedlings is the site itself (e.g., exposure to frost, upland vs lowland, etc.), soil (e.g., soil texture and structure, moisture content, aeration, leaving air pockets, etc.) and biotic factors (e.g., competition of herbaceous or woody vegetation, browsing, insects, etc.) (Wilde 1958).

Chipper debris pads are known to have air pockets if the seedlings are not planted correctly; tree planters are expected to screef through the chipper debris to reach mineral soil to avoid the potential of air pockets. This can depend on how deep the chipper debris is or if the chipper debris pad had site preparation before planting (i.e., if the chipper debris is thicker, it may be harder to reach that mineral soil for the tree planter). Air pockets are detrimental to seedlings' health as they trap cold air near the seedling's roots, thus creating a "frost pocket" (Buda et al. 2015).

Leachate

The debris from an in-bush chipper contains soluble compounds from the decaying bark, wood, and foliage. The compounds from the decomposing bark, wood and foliage, the debris will contain remnants of the dissolved sugars from the phloem, phenols, resin acids and terpenes (Taylor and Carmichael 2009). These compounds protect the living tree from insects and infections and, thus, are toxic to some organisms (Taylor and Carmichael 2009). The decomposition of the lignin can also release toxic phenolic compounds (Taylor and Carmichael 2009). Leachate occurs when water passes through the chipper debris collecting the allelochemical agents and is released into the soil, thus impeding seedling growth and survival (Taylor and Carmichael 2009).

A study by Taylor and Carmichael (2009) found that the toxicity of the aspen leachate declined after two years. The researchers stated that this finding was likely due to increased rainfall, diluting the leachate over time. However, the total mass of toxic leachate did not decline over time, suggesting that even with higher moisture levels, the amount of toxic leachate is still significant. Another possibility for the leachate to decline with time is that CWD becomes hydrophilic; thus, water does not flow through the material as much (Pichler et al. 2011). A similar study by Conlin (2001) also used aspen chipper debris to produce leachate to determine its effects on white spruce, lodgepole pine, paper birch, and aspen seedlings. The results from the study found that the treatment with the aspen leachate decreased height growth and root/shoot ratio for all species relative to the control.

Competition

Herbaceous vegetation competition has been shown to directly compete with planted seedlings for resources such as light, water and nutrients. Increase of competition will result in lower survival and reduced growth. The tolerance of interspecific competition differs amongst each conifer seedling species. The tolerance of a seedling is determined by the ability of a planted seedling to survive and grow (i.e., growth in height and volume) in the presence of interspecific competition (Noland et al.

2001). Knowing a seedling's tolerance of interspecific competition will help forest managers decide which species to plant based on the level of herbaceous competition.

White spruce can grow on sites dominated by conifer or on sites mixed with hardwood species (Groot 1999). White spruce is known to be a climax species that can grow with limited sunlight (i.e., shade-tolerant species); therefore, its competition tolerance on moderate brush sites is considered high (Groot 1999). White spruce seedlings are known to have frequent damage from late-spring frost; the understory herbaceous species (i.e., shrubs and herbs) can benefit white spruce seedlings as it creates shelter from low temperatures and low humidity (Groot 1999). Although understory competition does protect the seedlings from the elements, too much interspecific competition can reduce height and volume (Groot 1999). Eis 1980 studied the effect herbaceous vegetation has on white spruce establishment. The study found that white spruce had a negligible mortality rate and no reduction of height growth when occupied with the high interspecific competition.

Jack pine is well known to regenerate after a forest disturbance such as forest fires, which results in the landscape being bare and exposed to sunlight. Therefore, jack pine requirements/characteristic for regeneration is shade-intolerance, serotinous cones and an adequate seedbed (Bèland et al. 2003). Since jack pine is a primary successional species and is shade-intolerant, the understory competition after a harvest/disturbance may impede the survival and growth of a jack pine seedling (Bèland et al. 2003).

A study by Bèland et al. 2003 examined how interspecific competition affects jack pine establishment on a site that had competition control (i.e., scarification) and a site without competition control. The study found that jack pine seedling mortality was significantly ($P<0.012$) higher on the site with competition (i.e., uncut) compared to the scarified site. It was also found that scarification positively affected the height and diameter of jack pine seedlings. However, a similar study by Longprè et al. 1994 found no significant effect of vegetative competition affecting jack pine's height growth. The Longprè et al. 1994 study also found that jack pine's DBH was significantly greater on sites that contained paper birch (Betula papyrifera), and sites occupied with aspen (Populus tremuloides) also did not have a negative effect on the volume growth of jack pine seedlings.

MATERIALS AND METHODS

The trial is located at two locations, Lundstrom road (48°27’N, 89°36’W) and Shabaqua (48°33’N, 89°52’W); both locations are nearby of each other and are about ~27-39km northwest of Thunder Bay, Ontario. The chipper debris at the Lundstrom block has the fresh chipper debris pile (2 years old), whereas the Shabaqua has the older (9 years old) chipper debris piles. Each location had two chipper pads that were selected for planting seedlings. The methods are a continuation of the Scheliga (2015) thesis with updated data.

The chipper debris depth varied within each location, with the Lundstrom (fresh piles) block having an approximate 50-60cm and the Shabaqua averaging 30cm in depth. The chipper debris pile area for the Lundstrom site is approximately 0.75ha to 1ha; the Shabaqua piles had a similar pile size of 0.75-1.25ha. There was no mechanical site preparation on the chipper pads. Chipper debris is a mixture of foliage and bark from the harvested site; the debris is dependent on the species composition from the site. Both locations have different species compositions but are mixed-wood stands, which is displayed in Table 1.

Table 1. Species composition in the Lundstrom and Shabaqua locations.

Species	Trembling aspen (*Populus tremuloides*)	Balsam fir (*Abies balsamea*)	White birch (*Betula papyrifera*)	Black spruce (*Picea mariana*)	Jack pine (*Pinus banksiana*)
Lundstrom	50%	20%	20%	10%	0%
Shabaqua	30%	0%	10%	50%	10%

Each location had three plots for both species planted on the chipper pad. Two plots were placed in the general harvested site near the pad to act as the control. White spruce and jack pine were planted in plots adjacent to each other (refer to figures 1 and 2). The size of each plot was 15m by 15m. The plots contained 49 trees, with a 2m spacing. Seedlings were planted during the spring of 2013. Figures 1 and 2 illustrate the experiments' plots and how each tree was counted/measured (i.e., in a zig-zag pattern). Figure 1 shows the Shabaqua chipper pads; Figure 2 shows the Lundstrom chipper pads.

Figure 1. Shabaqua chipper pads and plots.

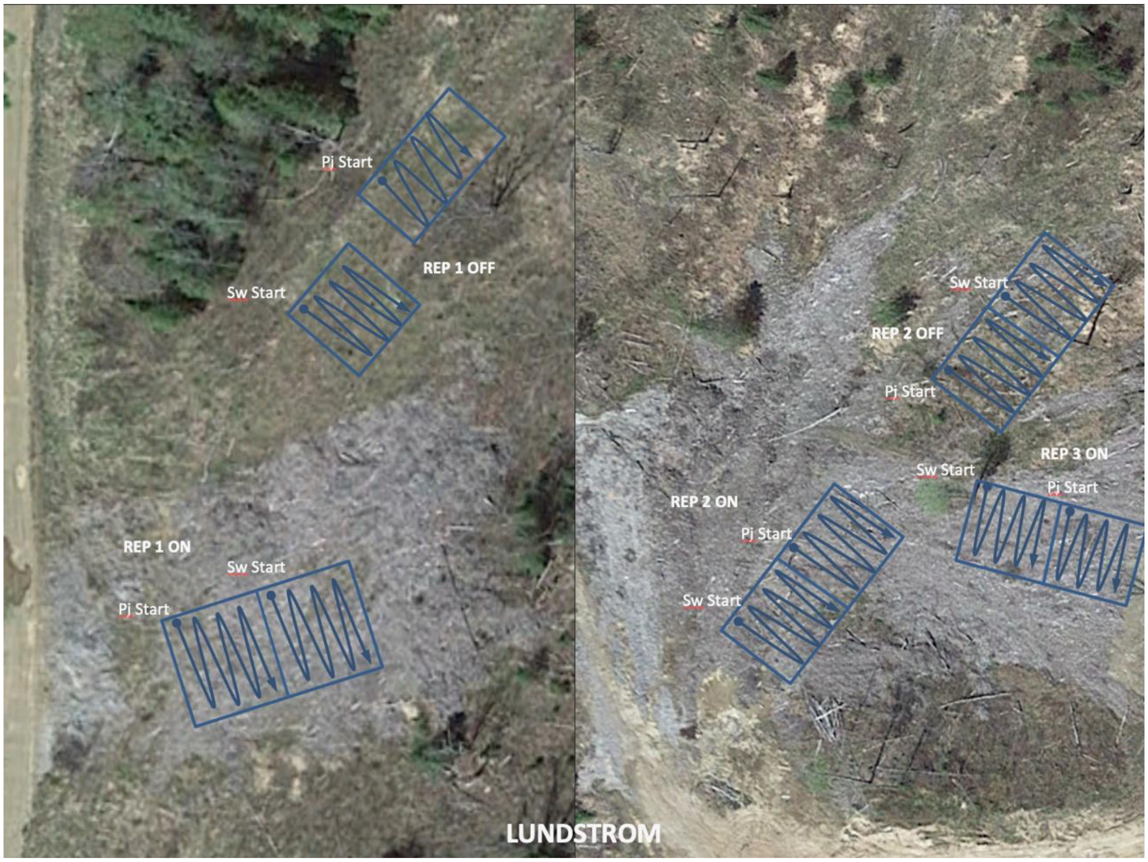

Figure 2. Lundstrom chipper pads and plots.

Measurements

Seedlings were measured for their health (i.e., alive, dead, browsed or chronic), height, root collar diameter, and dbh (if present). Basal area (m^2/ha) will be calculated based on the root collar diameter (RCD), it should be noted that in 2014 and 2016 the basal area will be low as the seedlings would have been very small and not yet reached the traditional DBH requirement. Each seedling had a designated number allowing for an individual assessment (i.e., can see each tree's growth). The trees are measured in a zig-zag pattern seen in Figures 1 and 2. The measurements were recorded during the fall of 2013 (one growing season after planting, only measuring health to see if they survived), 2014, 2016, 2021 and in the spring of 2017. During the fall of 2021, the number of competing stems was also recorded. For this thesis only 2014 spring (only recorded the health assessment), 2014 fall, 2016 and 2021 measurement periods will be analyzed.

Statistical approach

Microsoft Excel and R Statistical Analysis are used to analyze the data in a three-way ANOVA and with box plots. The repeated measures (2014-2021) will be analyzed graphically to show how the means in each group changed over each successive measurement period. The ANOVA is produced by having a randomized design with three dependent response variables (health (i.e., dead or alive)), height and root collar diameter (RCD). Individual seedlings are used as the sampling unit, and the plots means are treated as the experimental units. Where treatment effects were detected ($p<0.05$), group means were compared using the Turkey's least significant difference test. The model for this experiment is a continuation of the Scheliga (2015) thesis. The model for the experiment is:

$$Y_{ijkl} = \mu + A_i + S_j + L_k + A_i * S_j + A_i * L_k + S_j * L_k + A_i * S_j * L_k + \varepsilon_{(ijk)l}$$

where:

μ = mean

A_i = fixed factor of pile age (i= 1-2)

S_j = fixed factor for species (j=1-2)

L_k = fixed factor of planting location (k=1-2)

$A_i * S_j$ = interaction effect of the ith pile age by jth species

$A_i * L_k$ = interaction effect on the ith pile age by the kth planting location

S_j*L_k= interaction effect of the jth species by kth planting location

$A_i*S_j*L_k$ = interaction effect on the ith pile age by the jth species by the kth planting location

RESULTS

The repeated measure analysis of variance shows that there was a significant time by species interaction for survival ($p=0.0046$; Figure 3). The post hoc test indicated a significant difference between species ($p<0.05$) in 2014 and 2021, but not in 2016.

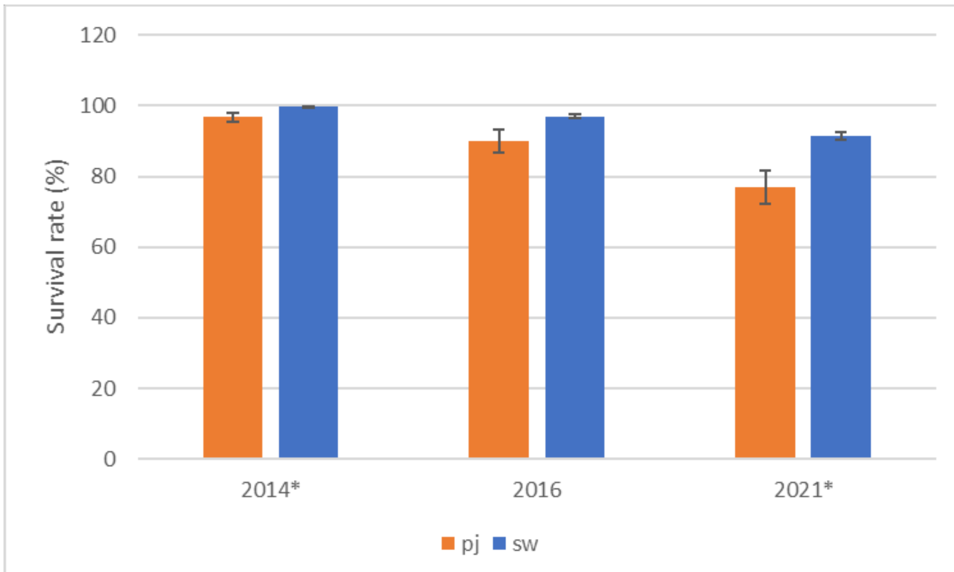

Figure 3. Survival rate (%) of jack pine (Pj) and white spruce (Sw) at each of the three measurement periods. An asterisk (*) for a group indicates a significant difference ($p<0.05$) between the species means.

There is also a significant three-way time by species by location interaction for survival ($p=0.042$). Based on the post hoc comparisons there was no difference between species planted on the chipper pad at all three measurement periods. Survival of trees that were planted off the chipper pad did differ however, in 2021 white spruce had higher survival rate than jack pine (Figure 4). There was no difference in survival for trees off the chipper pad in 2014 or 2016 (data not shown).

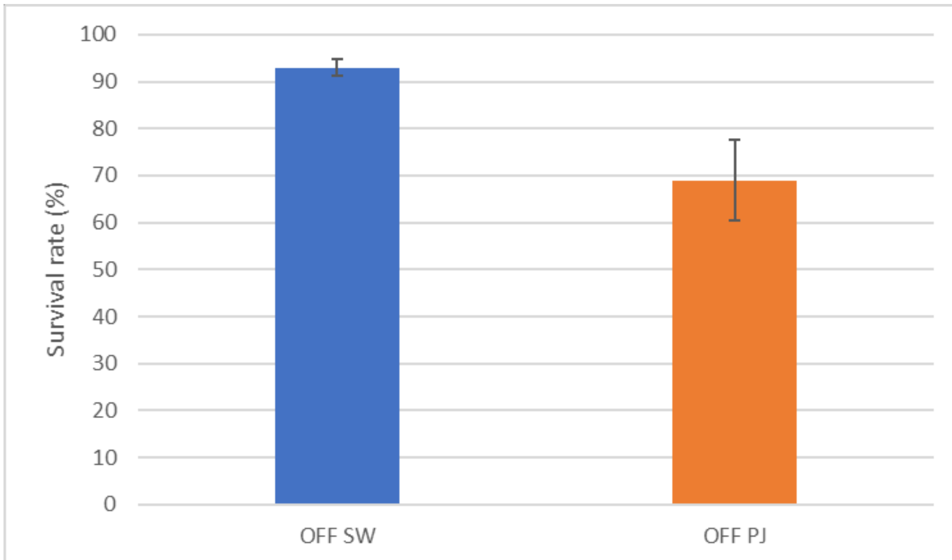

Figure 4. Survival rate (%) of white spruce (Sw) and jack pine (Pj) off the chipper pad in 2021.

For height, there was a significant time by species interaction (p=0.0048; Figure 5) as differences between the two species were observed at some time periods but not others. There was no difference in height between species in 2014, but in 2016 and 2021 jack pine was significantly taller than white spruce based on post hoc comparison of means (p>0.05, Figure 5).

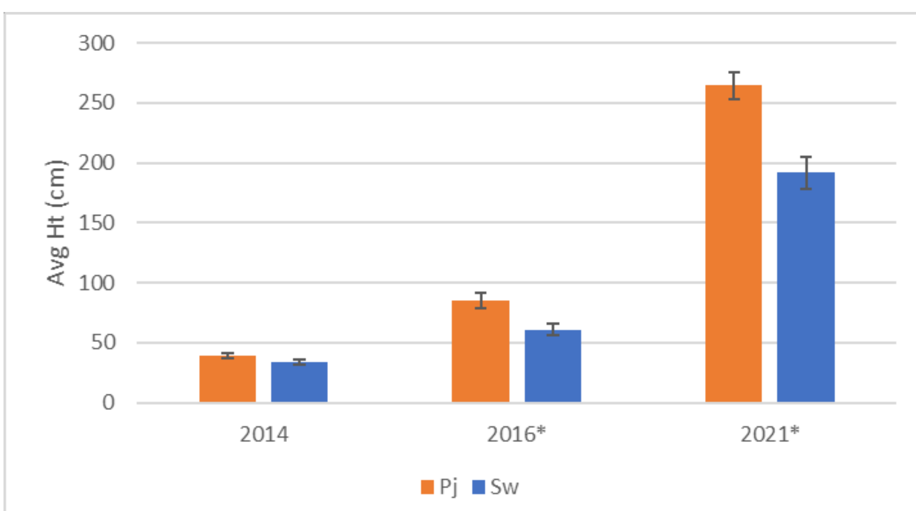

Figure 5. Height of jack pine (Pj) and white spruce (Sw) trees at each of the three measurement periods.

There was also a moderately significant three-way interaction of time by species by age associated with tree height (p=0.0887). The younger chip pads (age=2; Lundstrom) did not have different heights between the two species at any time period based on the post hoc comparisons of means. However, on the older site (age=9; Shabaqua) heights did differ between the species in 2016 and 2021, with jack pine being taller (Figure 6). The older chipper pad in 2014 did not have height differences between the species.

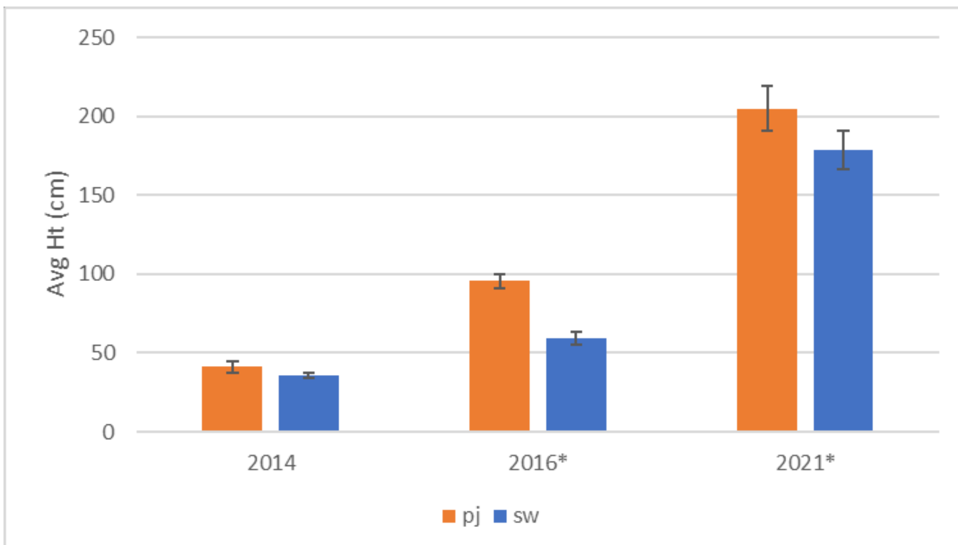

Figure 6. Height of planted jack pine (Pj) and white spruce (Sw) at each time period, located on the older Shabaqua site (age=9).

For root collar diameter (RCD) there was a significant time by species interaction (p=0.0002) found in the repeated measure analysis of variance. Root collar diameter did not differ in 2014, but jack pine were found to have larger RCDs in both 2016 and 2021 than white spruce based on the post hoc comparison of means ($p<0.05$; Figure 7).

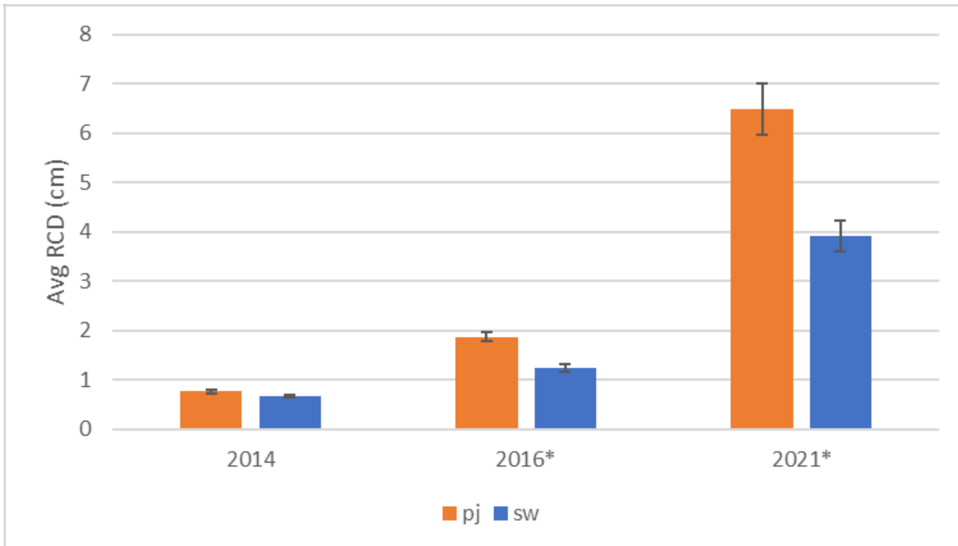

Figure 7. RCD of planted jack pine (Pj) and white spruce (Sw) trees at each of the three measurement periods.

There also a significant time by location interaction (p=0.0009) for root collar diameter (RCD). Root collar diameter did not differ between locations (on or off the pads) in 2014 or 2016, but in 2021 the trees planted on the chipper pad had a higher RCD than trees planted off the chip pad (p=≤0.05; Figure 8).

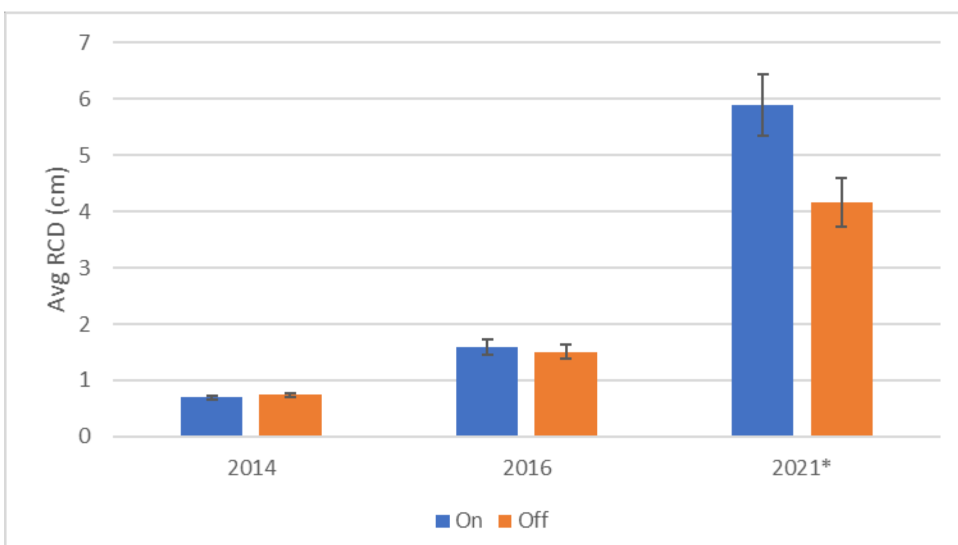

Figure 8. RCD of trees planted on and off the chip pads at each of the three measure periods.

There was also a significant three-way time by species by location interaction for root collar diameter (RCD; p=0.0212) detected by the repeated measure analysis of variance. Based on the post hoc comparison of means there was no difference in RCD between species during all the time periods for trees planted off the chipper pad. For trees that were planted on the chipper pad, RCD differed between species (p>≤0.05) in 2016 and 2021, but there was no difference in RCD during the 2014 time period (Figure 9). Jack pine had a larger RCD compared to white spruce in 2016 and 2021.

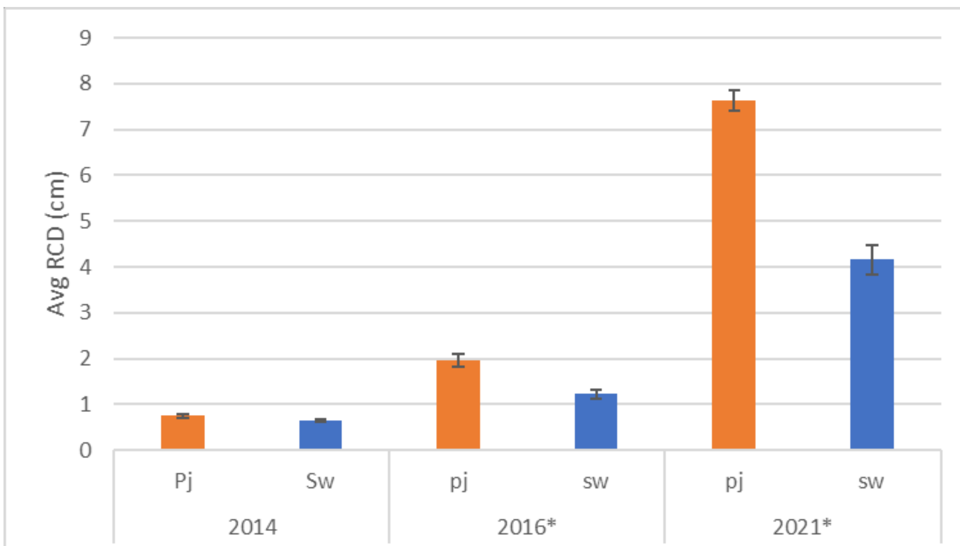

Figure 9. Mean root collar diameter (RCD) of jack pine (Pj) and white spruce (Sw) planted on chipper pads during the three measurement periods.

For basal area, there was a significant time by species interaction (p=0.0004) Basal area (m^2/ha) did not differ between species during the 2014 time period, but in 2016 and 2021 jack pine had a larger basal area than white spruce based on the post hoc comparison of means (p>0.05; Figure 10).

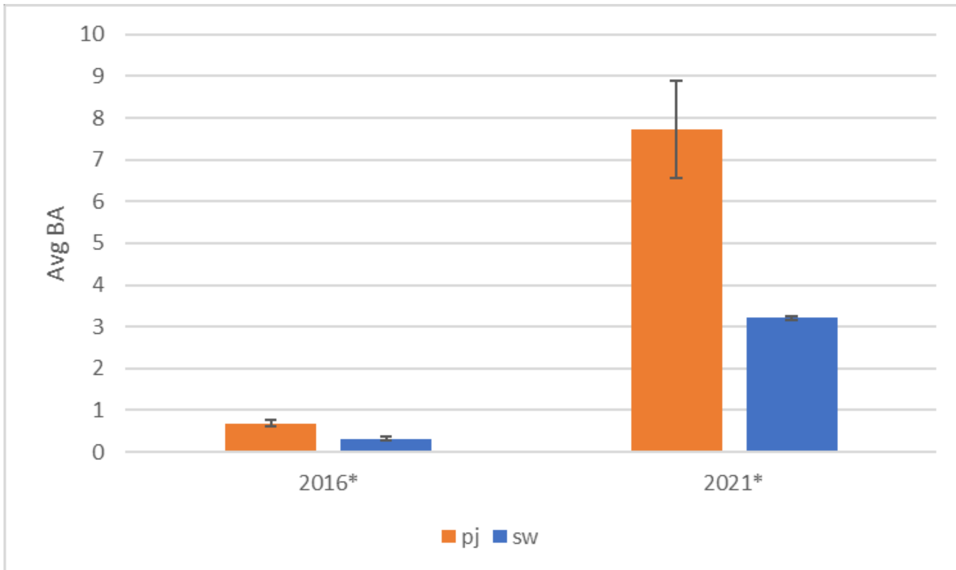

Figure 10. Basal area (m^2/ha) of planted jack pine (Pj) and white spruce (Sw) during 2016 and 2021.

There was a significant interaction between time and location (on vs off) for basal area (p=0.0008). Post hoc comparisons revealed that basal area did not differ between planting locations (p<0.05) in either 2014 or 2016. In 2021, however, basal area of trees planted on the chipper pads was higher than for trees planted off the chipper pads (p<0.05; Figure 11).

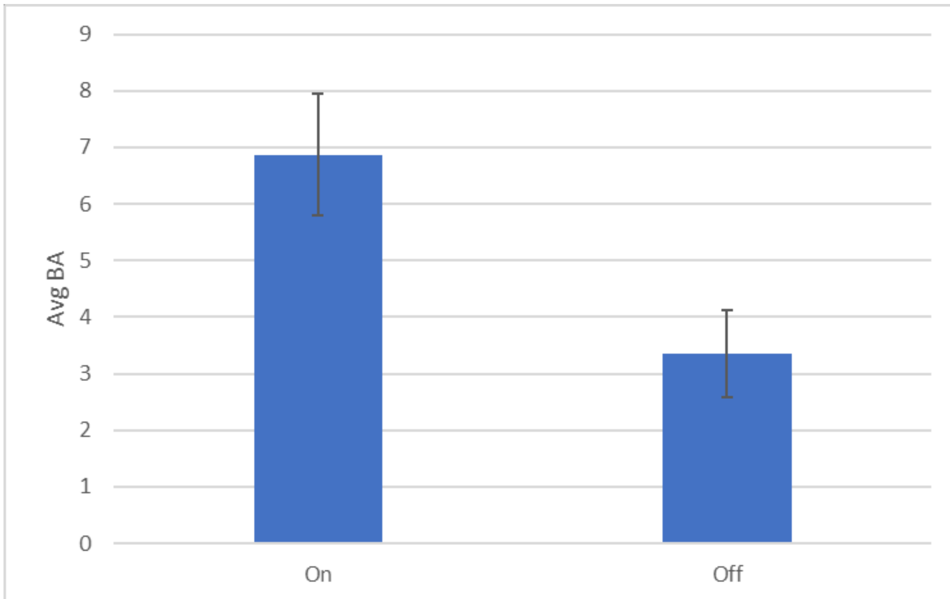

Figure 11. Basal area comparing time by location interaction in 2021.

There was also a significant (p=0.0063) three-way time by species (jack pine vs. white spruce) by location (on vs. off) interaction for basal area (m^2/ha). There was no difference in basal area between species at any of time periods for trees planted off the chip pad. On the chipper pads, however, jack pine had the higher basal area compared to white spruce in 2016 and 2021, there was no difference in 2014 ($p<0.05$; Figure 12).

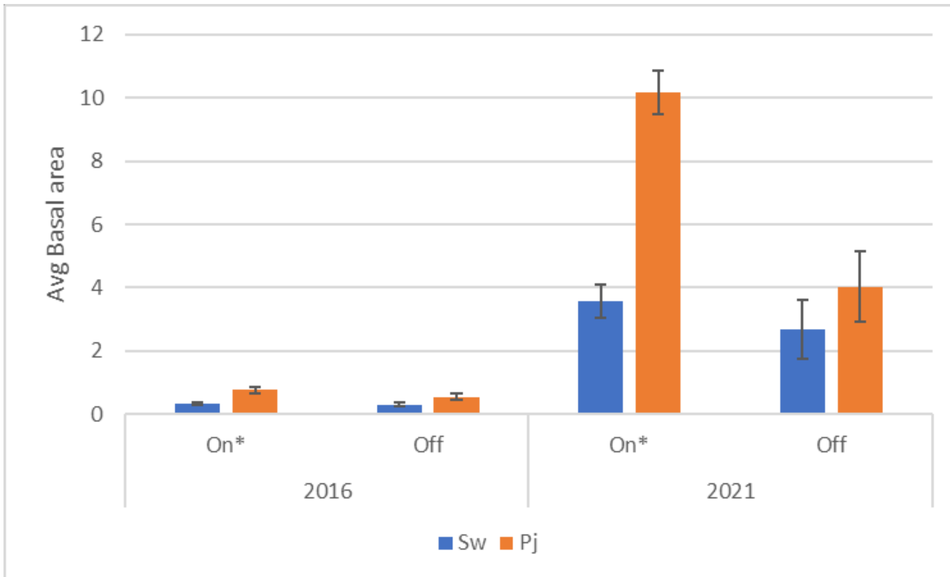

Figure 12. Three-way interaction (time by species by location) of basal area of jack pine (Pj) and white spruce (Sw), 2014 data not shown.

The repeated measures analysis of variance model results for survival, height, root collar diameter and basal area for all variables can be viewed in the appendices.

DISCUSSION

Planting trees on the chipper pad was shown to have an overall high survival rate throughout the years. There was no indication of difference in survival rate between on and off the chipper pad based on the post hoc comparison of means. The significant differences that were found ($p>0.05$) to have a survival rate difference is between species; where white spruce had a higher survival rate (91%) compared to jack pine (77%). It was also found white spruce planted off the chipper pad also had higher survival rates after 7 years of establishment (2021) compared to jack pine. Thus, planting seedlings on the chipper pads showed no huge loss in survival and they can withstand its environment.

The survival rate between both species can be related to the increased interspecific competition as the findings are similar to other studies that have shown the same results. Bèland et al. (2003) showed a decline in survival for jack pine in areas that had high interspecific competition. Eis (1980) found that white spruce seedlings showed no decline in survival on sites that had high competition. Therefore, the loss of survival of jack pine is likely due to high amounts of competition as jack pine is primary successional species and is shade-intolerant. White spruce can tolerate higher competition levels as it is more shade tolerant and the increased density of vegetation provides protection from frost (Groot 1999).

The growth of the trees planted on the chipper pad resulted in significantly larger mean root collar diameter (cm) and plot basal area (m^2/ha) in 2021. There was no indication that planting trees on chipper pads slowed the growth of the planted trees. The trees planted on the chipper pad had significantly better growth compared to the trees planted off the chipper pad because in 2021 as they had a higher mean RCD regardless of species (Figure 8), basal area was higher on the pads (Figure 11), and the highest basal after 7 years of growth (10.17m^2/ha) was from jack pine on the pads (Figure 12). The chipper pads created an environment with added moisture, insulation and more nutrients available which likely caused the increased of growth for both species (Blanchette and Shaw 1978; Bulmer et al 2007). The higher height and RCD growth in jack pine is likely due to the chipper pad providing a suitable habitat for jack pine. The chipper debris likely created an insulating effect which can increase the soil's temperature. Jack pine is a serotinous species and thrives on higher soil temperatures (Peng and Dang 2002; Blanchette and Shaw 1978).

The increased growth of both species on the chipper pad could also be due to lack of competition. The chipper pads may have created an environment that is undesirable for vegetative competition and therefore having an increased growth (RCD and basal area) for both white spruce and jack pine. These findings are similar to those of Longprè et al. (1994), which found jack pine having an increased volume and height growth in areas that had less interspecific competition. Jack pine also likely had a higher basal area and height growth compared to white spruce as jack pine is a primary successional species which tends to grow faster at younger ages naturally.

Between the two species it is shown that white spruce (91%) had a significantly higher survival rate than jack pine (71%) 7 years after establishment (2021), however, jack pine were larger (i.e., RCD and height) and higher basal area. As jack pine is a pioneer species this result makes sense as to why it has better growth compared to white spruce which is a climax species that takes longer to reach establishment.

When examining the effect of the ages of the chipper pads (Shabaqua age=9 vs Lundstrom age=2) the two species responded differently to this factor as there a significant interaction between age and species. Jack pine that was planted at older site Shabaqua was found to have a greater height compared to white spruce (figure 6). Overall, jack pine seedlings that were planted on the older chip pad grew taller than the seedlings planted on the younger chipper pad (appendix V). For white spruce, the trees on the younger chip pad grew taller compared to the older site, however this interaction was found to be not significant by the post hoc comparison of means (appendix V). The advancement in jack pine's growth on the older chipper pad is likely due to there being more nutrients available, more moisture available (fresh chip pads have been shown to be hydrophobic) and less leachate in the old chipper pad compared to the fresh pad (Pichler et al. 2011; Bulmer et al. 2007).

CONCLUSION/RECOMMENDATION

It is concluded that planted white spruce and jack pine seedlings can survive in chipper pads. Jack pine is shown to thrive on chipper pads more than it does outside of the chipper pad. Even though jack pine had a lower survival rate than white spruce, it is recommended to plant jack pine in chipper pads with a higher density to account for the lower survival rate. White spruce is shown to have good success and should be planted in sites where white spruce would be more beneficial (i.e., plant white spruce in areas where it is wet/winter blocks).

Planting seedlings on older vs fresh sites does not significantly affect the seedlings as was initially thought. The age of the chip pad should not be a deciding factor on whether or not to plant either species based on the results presented here. Although older chip pads were shown to have a significant height difference after eight years of planting, the mean height of trees planted on younger chip pads was comparable to trees planted off the pads, indicating satisfying growth for that age of seedling.

When deciding if you should wait nine years to plant a chip pad can also be costly as you may have to reopen an old in-block road. Furthermore, delaying planting chipper pads does not make logical economic sense to plant a handful of chip pads (i.e., chipper pads can occupy >3% of a cut block's total area) when/if the rest of the block is already planted. If it is decided to delay the entire cut block for nine years so that the chip pads will not be the only area missed, the greater the risk of having a high competition of hardwood species in the block. Therefore, it is recommended to plant the chipper pads as soon as possible to minimize cost and to reduce competition.

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APPENDICIES

APPENDIX I

Repeated Measures Analysis of Variance for Survival
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Adj Pr > F G - G	Adj Pr > F H - F
time	2	2043.801194	1021.900597	34.06	<.0001	<.0001	<.0001
time*SPP	2	420.125873	210.062937	7.00	0.0040	**0.0046**	0.0040
time*Age	2	32.555879	16.277940	0.54	0.5882	0.5817	0.5882
time*LOC	2	111.273081	55.636540	1.85	0.1783	0.1801	0.1783
time*SPP*Age	2	3.216252	1.608126	0.05	0.9479	0.9430	0.9479
time*SPP*LOC	2	221.875145	110.937572	3.70	0.0398	**0.0420**	0.0398
time*Age*LOC	2	104.192697	52.096349	1.74	0.1976	0.1991	0.1976
time*SPP*Age*LOC	2	118.723680	59.361840	1.98	0.1602	0.1623	0.1602
Error(time)	24	720.070341	30.002931				

Greenhouse-Geisser Epsilon 0.9617
Huynh-Feldt Epsilon 1.8095

APPENDIX II

Repeated Measures Analysis of Variance for height
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Adj Pr > F G - G	Adj Pr > F H - F
time	2	398668.0655	199334.0327	374.46	<.0001	<.0001	<.0001
time*SPP	2	11660.9318	5830.4659	10.95	0.0004	**0.0048**	0.0007
time*Age	2	53.7887	26.8943	0.05	0.9508	0.8467	0.9392
time*LOC	2	342.6697	171.3348	0.32	0.7279	0.6001	0.7086
time*SPP*Age	2	3536.5367	1768.2683	3.32	0.0533	**0.0887**	0.0588
time*SPP*LOC	2	10.3527	5.1763	0.01	0.9903	0.9373	0.9862
time*Age*LOC	2	417.9465	208.9732	0.39	0.6796	0.5603	0.6613
time*SPP*Age*LOC	2	675.4791	337.7395	0.63	0.5389	0.4538	0.5257
Error(time)	24	12775.9316	532.3305				

Greenhouse-Geisser Epsilon 0.5474
Huynh-Feldt Epsilon 0.9121

APPENDIX III

Repeated Measures Analysis of Variance for root collar diameter
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Adj Pr > F G - G	Adj Pr > F H - F
time	2	200.7604317	100.3802159	353.37	<.0001	<.0001	<.0001
time*SPP	2	13.3248442	6.6624221	23.45	<.0001	**0.0002**	<.0001
time*Age	2	0.0662454	0.0331227	0.12	0.8904	0.7709	0.8827
time*LOC	2	9.3569151	4.6784575	16.47	<.0001	**0.0009**	<.0001
time*SPP*Age	2	0.5741010	0.2870505	1.01	0.3790	0.3439	0.3766
time*SPP*LOC	2	3.6477709	1.8238855	6.42	0.0058	**0.0212**	0.0066
time*Age*LOC	2	0.1433621	0.0716811	0.25	0.7790	0.6544	0.7699
time*SPP*Age*LOC	2	0.3117055	0.1558528	0.55	0.5848	0.4939	0.5778
Error(time)	24	6.8174992	0.2840625				

Greenhouse-Geisser Epsilon 0.5703
Huynh-Feldt Epsilon 0.9582

APPENDIX IV

Repeated Measures Analysis of Variance for basal area
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	Pr > F	Adj Pr > F G - G	Adj Pr > F H - F
time	2	298.4444111	149.2222056	150.29	<.0001	<.0001	<.0001
time*SPP	2	46.4702908	23.2351454	23.40	<.0001	**0.0004**	<.0001
time*Age	2	1.4785948	0.7392974	0.74	0.4856	0.4073	0.4650
time*LOC	2	38.0651241	19.0325621	19.17	<.0001	**0.0008**	<.0001
time*SPP*Age	2	0.3680697	0.1840348	0.19	0.8320	0.6790	0.7943
time*SPP*LOC	2	21.3489108	10.6744554	10.75	0.0005	**0.0063**	0.0011
time*Age*LOC	2	2.5745762	1.2872881	1.30	0.2920	0.2778	0.2902
time*SPP*Age*LOC	2	5.4409688	2.7204844	2.74	0.0848	0.1230	0.0962
Error(time)	24	23.8301350	0.9929223				

Greenhouse-Geisser Epsilon 0.5096
Huynh-Feldt Epsilon 0.8370

APPENDIX V

Time*Spp*Age comparison of height (cm)

age = 2 SPP=Pj

year	mean	error
2014	36.68	2.5
2016	74.88	9.29
2021	242.11	9.57

age=2 SPP=Sw

year	mean	error
2014	32.56	3.2
2016	62.46	9.2
2021	205.12	24.66

age = 9 SPP=Pj

year	mean	error
2014	41.05	3.83
2016	95.49	4.64
2021	286.73	14.2

age=9 SPP= Sw

year	mean	error
2014	35.45	1.63
2016	59.14	3.96
2021	178.54	12.03