Outplanting Performance of *Pinus strobus, Pinus resinosa, Pinus banksiana*, and *Picea glauca* From Different Nurseries, and With Different Container Types Within Algonquin Park

by

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ABSTRACT

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Understanding planting performance of seedlings is integral to the forest industry of Canada. Many factors are involved in the performance of the seedlings once planted in the field. Factors include site conditions, planter competency, environmental conditions, nursery practices, container types and species characteristics. Information on the general location and environment of the site is included as well as information on species characteristics and studies involving past research with regards to container type comparisons, nursery comparisons and variations in site conditions and site preparation techniques. Four different species were examined by means of measuring tree heights, tallying number of dead and affected trees and performing prism swings to measure the mature residual basal area around homogenous plots. The seedlings were planted on similar sites in spring 2010. Each plot consisted of a specific container type, species and nursery origin. Differences between average mean height, percent defect and percent mortality were compared for container type, originating nursery, species characteristics and mature residual basal area. The results yielded stronger correlations between species characteristics than did nursery background and mature residual basal area with regards to mean height, and percent mortality. Percent defect with regards to mature residual basal area did have a correlation for *P. banksiana.* Container type had conflicting results, however~~,~~ significant correlations between container type and the variables assessed were present. Trees from one container type were much taller in mean height than the remaining container types, therefore yielding a significant result, however~~,~~ the remaining 6 container types proved to be insignificantly different from each other.

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ACKNOWLEDGEMENTS

Many people have been kind to help and motivate me to write this thesis over the last 9 months. I would like to thank the Algonquin Forestry Authority [AFA] for giving me the opportunity to work as a Tree Marker while allowing me to work on my thesis and provide funding for it. I would like to thank Tom Dolan from the AFA for hiring me, giving me the opportunity at the AFA, providing me with tools, support and information for the study and for being my second reader. I would like to thank Steve Bursey for setting up the study, explaining it to me and providing me with tools and information to assist with study completion. I would like to thank Dr. Jian Wang for being my first reader, and for providing positive feedback and assistance throughout this thesis process. I would like to thank my parents for assisting me when they could with the field work involved with this thesis. Lastly, I would like to thank my peers for discussing topics and sharing their knowledge with me throughout the last eight months.

1.0. INTRODUCTION

Resources on this planet are becoming harder to find as they are depleting relatively quickly (Spijkers 2018). Sustainability is a word commonly thrown around among people addressing this issue (Spijkers 2018). Sustainability is defined as the ability to maintain as much or more resources for future generations than currently present (Spijkers 2018). Forestry in Canada, at least in the beginning (1800's) was thought to be "inexhaustible", therefore the forests were heavily logged and quickly depleted (AFA 2019b). Algonquin Park has rich history with regards to the exhaustion of the mighty white pine (*Pinus strobus*) and many other species (AFA 2019b). Forest sustainability became very important when the integrity of the land was threatened by the timber barons (AFA 2019b). Algonquin Provincial Park was created to preserve headwaters of multiple watersheds, preserve native forest (that was quickly becoming depleted), protect wildlife, provide an area for forestry experimentation, and provide an area where the peoples of Ontario and the world could enjoy the outdoors (AFA 2019a). The Algonquin Forestry Authority was formed in 1974 and continues to this day as the Crown Agency responsible for Sustainable Forest Management in Algonquin Park (AFA 2019b).

Sustainable forest practices have been developing in Algonquin Park since 1893 when it was realized a change was necessary (AFA 2019a). Experimentation is necessary in order to determine the most sustainable forest practices (AFA 2019b). One form of experimentation to promote sustainability, improve tree quality and growth, and ultimately to save money, is to determine the best possible growing conditions and yield when planting seedlings.

An article by Flanagan et al. (2002) studied the difference in tree quality of *Pinus contorta* seedlings that were grown in three different container types. These container types included styroblocks, copperblocks, and airblocks (Flanagan et al. (2002). It was determined that none of the three different container stock seedlings yielded significantly slower growth over the two-year period than either of the other container types (Flanagan et al. (2002). This thesis will look at three different Jiffy pellet sizes and four different container sizes within styroblocks.

A Jiffy pellet is essentially a small organic disk with a seed in it. Once water is added, the Jiffy pellet expands into the organic mesh that surrounds the seed, making it the container in which it grows. The roots cannot grow very far outside the mesh if they make it that far and as a result, undergo root pruning. The size of the plug depends on the diameter of the disk and the fully extended length of the mesh (Fraser et al. 2014; Palvis 2017). Styroblocks on the other hand are styrofoam blocks of a given volume, generally 60mls to 120mls. These styroblocks are created by the company Beaver Plastics. These styrofoam blocks are filled with soil and nutrients and seeded. The roots on these seedlings have no way of expanding past the walls of the styrofoam therefore no root pruning occurs unless the nursery calls for it (Cobos et al. 2012; Dumroese et al. 2019; Chapman and Colombo 2006).

An article by Harrington and Howell (2004), studied the effects of different nursery practices on the infield development of the seedlings grown. This study determined that different nursery practices did alter the performance of the seedlings in the field and that it also depended on the seedling container types used in the nursery (Harrington and Howell (2004). Johnson and Walker (1980) determined that the choice of container size/type played a key role in the development of planted seedlings and had a significant effect on the ability for those seedlings to grow in the field.

Similar studies have been conducted in Algonquin Park by the AFA. This thesis will focus on a 9-year-old seedling trial (trial being 9 years old, seedlings being 10) planted by the AFA in North-Central (White Township) Algonquin Park as seen in Figure 1. The map in Figure 1 includes a red circle in the North-Central area of the Park. This is the location of the Seedling Trials studied in this paper. The Seedling Trials are located within White Township. The tree species in this study include~~s~~ *Picea glauca*, *Pinus resinosa*, *Pinus strobus*, and *Pinus banksiana* seedlings from two different nurseries using seven different container types between the two different nurseries.

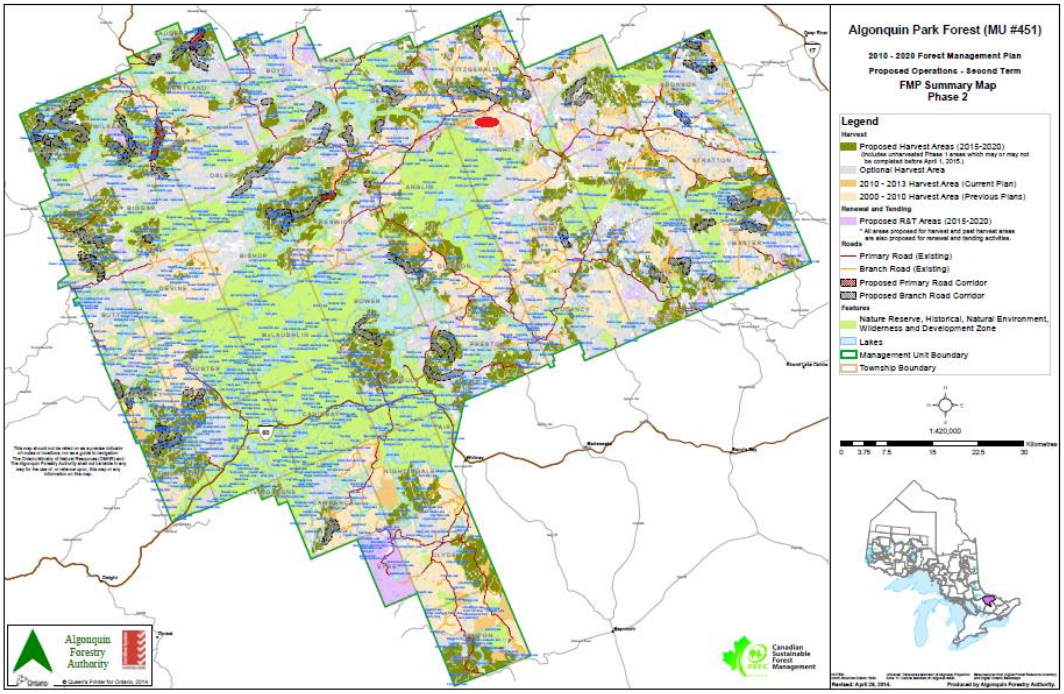

Figure 1. Map created by the AFA as a 2014 Forest Management Plan Summary Plan of their forest operations. As seen in the bottom right corner, the location of Algonquin Provincial Park within Ontario. The map includes a red circle in the North-Central area of the Park. This is the location of the Seedling Trials studied in this paper. The Seedling Trials are located within White Township. Source: AFA 2009.

1.1 Objective

The objective of this study is to determine if there is a significant difference in outplanting performance of seedlings with regards to nursery and container stock, or if mature residual basal area and other site condition and species characteristics have a greater effect on the seedling performance. than nursery or container type. This study will also discuss the implications of these results for sustainable practices within the park.

1.2 Hypothesis

The nursery and container type will not have a significant effect on the outplanting performance of the seedlings but instead site conditions and species characteristics will create significant effects on seedling performance.

2.0. LITERATURE REVIEW

2.1.Species Characteristics for Outplanting

This paper examined four tree species that were planted. These species include *P.* strobus, *P. resinosa*, *P. banksiana*, and *P. mariana*. The article "Optimum Vegetation Conditions for Successful Establishment of Planted Eastern White Pine (*Pinus strobus* L.)" by Farrell et al. (2016) studies the impacts of vegetation conditions on the ability of *P. strobus* to establish properly after being planted. Specific conditions were examined to determine what had the most effect on the seedlings' abilities to establish. These included competition from woody and non-woody vegetation (Farrell et al. 2016). This study also looked at the difference between ~~a~~ shelterwood and clearcut silviculture systems and how the white pine performed under both systems with regards to performance against competition and effects from the white pine weevil (Farrell et al. 2016). This study showed that the shelterwood systems with increased shade in comparison with clearcut systems creates favourable shade conditions and microclimate for *P. strobus*, as it lessens the ability for more shade intolerant species to grow and outcompete the slower growing *P. strobus* (Farrell et al. 2016; Smith and Wendel 1990). The paper by Farrell et el. (2016) is useful in that it looks at how the exposure to light in various silviculture systems affects the overall performance of *P. strobus*. This thesis includes a focus on the outplanting performance of *P. strobus* including its ability to tolerate different light levels based on environmental factors such as shade from mature residual trees. It also looks at how well the seedlings did under various mature residual basal areas.

An article by Palick et al. (2012), studies the microclimate and growth of planted red pine under varying densities of mature residual *P. resinosa* in Minnesota. The stands consisted of heterogenous stands previously thinned (Palick et al. 2012). The stands consisted of at least 80% or greater *P. resinosa* with small gaps being created with a radius of 36m and larger gap sizes at 45m radius (Palick et al. 2012). *P. banksiana* and *P.* glauca were also measured (Palick et al. 2012). The study looks at how well *P. resinosa* does under gap sizes rather than the standard silviculture systems which include clearcut and shelterwood systems (Palick et al. 2012; Rudolph 1990; Rudolph and Laidly 1990). The article by Palick et al. (2012), determined that for *P. banksiana* and *P. glauca*, height growth in all sizes of treatments improved over their height growth performance in uncut, control stands. *P. resinosa* only seemed to improve in stands with greater gap sizes (Palick et al. 2012; Rudolph 1990). This information is helpful since this thesis studies mature residual basal area effects on *P. resinosa* seedlings, and Palick et al. (2012) provides insight into how well *P. resinosa* specifically, but also *P. banksiana* and *P.* strobus do under varying degrees of light allowance based on the gap sizes created.

Baker et al. (2009), studies the effects of density and ontogeny on the ability for *P. mariana, P. strobus* and *Larix laricina* to grow. This article looks at aspects of interspecies competition and intraspecies competition for nutrients, light, and general space within Minnesota (Baker et al. 2009). Factors such as tolerance to shade, growth rate, and whether these species grow better in monocultures or in mixed stands are all examined (Baker et al. 2009). It was found that *P. strobus* had higher growth rates in monocultures (Baker et al. 2009). It was also found that *P. strobus* maintains the highest growth rate of the three species compared. It is known that *P. strobus* is a mid tolerant species compared to the tolerant *L. laricina* and *P. mariana* (Baker et al. 2009; Farrell et al. 2016; Smith and Wendell 1990). The article by Baker et al. (2009) will be useful to this thesis in that it creates an understanding of how *P. strobus* interacts within a monoculture compared to a mixed-wood system and under a clearcut system. It also shows how *P. strobus* grows under increased light conditions compared to more tolerant species. This will help determine if this thesis' hypothesis is rejected in that it will show if the growth and success of *P. strobus* depends more on container type or nursery practices or if it is more dependent on the environmental conditions.

Bradley et al. (2006) describes the differences in performance of *P. glauca* seedlings under partial and clear cuts of aspen dominated stands. When light and soil conditions were measured and compared to the varying height growth in the *P. glauca* understory, it was found that clearcut and planting of *P. glauca* creates too much competition for the seedlings from shade intolerant species (Bradley et al. 2006). It was found that maintaining 25% of the overstory canopy can also inhibit the seedlings' ability to grow properly (Bradley et al. 2006). This is important to the thesis in that it provides insight regarding the ability of *P. glauca* to withstand the light levels of a clearcut and thus be able to provide support for the rejection or acceptance of the hypothesis. Bradley et al. (2006) provides key information supporting this thesis' hypothesis that in fact environmental conditions play a more important role in seedling development than stock type or individual nursery practices.

The Silvics of North America manual developed by the USDA (1990) provides information about the characteristics of each species of tree in North America and the typical silviculture techniques used to deal with each species (Nienstaadt and Zaada 1990; Rudolph 1990; Rudolph and Laidly 1990; Smith and Wendell 1990). This manual covers native range, climate, soils and topography, associated forest cover, life history, growth and yield, special uses, and genetics of each species (Nienstaadt and Zaada 1990; Rudolph 1990; Rudolph and Laidly 1990; Smith and Wendell 1990). This manual is useful to this thesis because it provides background information for each tree species present in this thesis. It explains the shade tolerance differences of the four species examined. *P. banksiana* and *P. resinosa* are both shade intolerant species while *P. strobus* and *P. glauca* more shade mid-tolerant species (Nienstaadt and Zaada 1990; Rudolph 1990; Rudolph and Laidly 1990; Smith and Wendell 1990). It is important to understand the characteristics of each species studied in order to determine whether the hypothesis is rejected. Less specifically so, it is important to have this information to help determine whether it is the container type or nursery type or if the microclimatic and environmental effects play more of a key role.

2.2.Nursery Quality Comparisons

A study done by Harrington and Howell (2004) looked at how different nursery practices influenced outplanting performance of the seedlings including a comparison of cost and efficiency. The researchers did multiple different container sizes and fertilization regimes (Harrington and Howell 2004). The study determined that both larger container size and presence of fertilizer created faster growth than smaller container sizes and no fertilizer (Harrington and Howell 2004). This article supports the hypothesis that seedling success depends on the nursery and its practices. This article shows that if a nursery were to add fertilizer for example (a nursery practice), there will be an improvement in the seedlings' chances of success (Harrington and Howell 2004).

Bakker and Kooistra (2005) performed a study examining the difference in outplanting performance of frozen-stored un-thawed seedlings compared to seedlings thawed out before their plant. *L. laricina* did much better when thawed than un-thawed, while *Pinus* and *Picea* did not show significantly different results between the two treatments (Bakker and Kooistra 2005). The article by Bakker and Kooistra (2005), is relevant to the hypothesis of this thesis in that it shows how nursery practices can determine the ability of a seedling to succeed or not, therefore supporting the hypothesis that nursery practices and different nurseries do determine the ability of a seedling to succeed.

A study done by Guaita et al. (2018) looked at the properties of wood found in nursery seedlings and the resulting performance. This study found that by conducting genetic selection of trees from a seedling age to get maximum growth in the field would make a difference for multiple different species. The researchers found that by looking at strength and density characteristics in the nursery, they could predict the ability for those seedlings' success in the field (Guaita et al. 2018). This study was done to determine the best genes to use for nursery stock, to ensure the best chance of success in the field (Guaita et al. 2018). This is relevant to the thesis topic in that it can show how nursery effort and practices can be a determinant of overall success in the field, therefore supporting the hypothesis that nurseries and nursery practices can have varying effects on the success of the out-planted seedlings.

Van der Driessche (1984) performed a study relating to how the seedling spacing in the nursery affects the seedlings' abilities to grow. This study used *P. glauca*, *P. menziesii, P. sitchensis, P. contorta,* and *T. plicata* with multiple different seedling densities (van der Driessche 1984). It was found that for the most part, more space created larger trees and higher survival percentages (van der Driessche 1984). This information is relevant to this thesis' hypothesis in that nurseries and nursery practices do play a role in the ability of out-planted seedlings to grow and survive as it shows that different densities when sowed in nurseries create different outcomes in terms of success of the seedlings (van der Driessche 1984).

Dedefo et al. (2017), developed a study to determine if tree nurseries and seed procurement affects the quality of the seedlings when out planted in Ethiopia. The study set out to determine which seedlings performed the best under the seed procurement

(Dedefo et al. 2017). This study determined that the seedlings performed much better with hard coated seeds than soft coated seeds (Dedefo et al. 2017). It was found that many nurseries in Ethiopia do not pay attention to their seed quality, therefore, resulting in a lower quality of seedlings (Dedefo et al. 2017). This is relevant to this thesis' hypothesis that nurseries can have an impact on seedling quality and success once in the field because it shows that if nurseries are not careful with their seed procurements, the quality of the seedlings once out planted is also low, with less likelihood of survival (Dedefo et al. 2017).

2.3. Container Type Comparisons

2.3.1. Container Stock Differences

A study by Cobos et al. (2012), looks at the photosynthetic response, carbon isotopic composition, survival, and growth of three different container types under water stress and increased competition. This study determined that the seedlings grown in the largest of the three container sizes grew the best and withstood competition and water stress the best as well (Cobos et al. 2012). This can be related to the hypothesis stating that outplanted seedling success can be directly related to the container type they are grown and planted in. It was determined that a larger container size results in improved growing area for the seedlings, therefore giving them an advantage in the field when planted, thereby supporting the hypothesis (Cobos et al. 2012).

A similar study done by Dumroese et al. (2019), examined the persistence of container treatments on the field performance of Longleaf pine seedlings. This study looked at how using different volumes of plug and treating individuals with increased nutrients (nitrogen), affected which seedlings had the greatest field success (Dumroese et al. 2019). It was found that those seedlings with the greatest amount of added nutrients and the largest plug volumes performed the best with regards to root collar diameter and biomass in the field (Dumroese et al. 2019). This supports the hypothesis that container types have a direct effect on the success and quality of the seedlings and may assist the rejection of the null hypothesis as it was found that the seedlings have different success rates depending on container types. This article also supports the hypothesis that outplanted seedling success depends on the nursery practices that are involved. This study looked at the addition of nutrients while the seedlings were growing within the nursery and it was found that those with more added nutrients performed the best when planted (Dumroese et al. 2019).

Chapman and Colombo (2006), performed a study that looked at the difference in root and shoot growth of *P. banksiana* seedlings in the nursery that were grown in different types of containers. The containers included; multiplots, copperblocks, starpots, and Jiffy pellets (Chapman and Colombo 2006). It was found that there was no significant difference in the growth between the different container types with regards to root morphology. This is important information pertaining to accepting the null hypothesis that there will be no difference in seedling growth no matter what container type is used to because as this article showed, all container types studied created seedling characteristics that were enough for growth in the field (Chapman and Colombo 2006).

Another study by Nicholson (2008), looked at the difference in seedling growth in Nova Scotia with regards to their container size. The study took place in 10 different stands and looked at the competition levels in each site as well (Nicholson 2008). It was found that in all sites, the larger container stocks grew taller and had lower mortality rates than those of regular sized stock (Nicholson 2008). This is important to the null hypothesis that there will be no difference in seedling performance from different container types since it was found that larger stock types will have higher success rates when compared with the smaller ones. This article would support a rejection of the null hypothesis (Nicholson 2008).

Johnson and Walker (1980), studied the containerized conifer seedling performance in Northwestern Canada. This study set out to determine which container stocks performed the best once planted (Johnson and Walker 1980). The species studied were *P. contorta*, *P. glauca* and *P. Engelmanni* and the container types were styroblocks, sausage containers, and conventional containers (Johnson and Walker 1980). It was found that those seedlings that were from larger, heavier containers performed better once planted in terms of shoot/root ratio and height growth than those smaller (Johnson and Walker 1980). This is relevant to the null hypothesis that container types do not affect the success of seedlings. This article would reject the null hypothesis and provide important findings for this thesis in that different container types were studied (Johnson and Walker 1980).

2.3.2. Jiffy Pellets

Escobar et al. (1999) studied Jiffy pellets to see if they were a viable option for outplanting seedlings. This study took place using pine and eucalypt seedlings and compared them to standardized container stock (Escobar et al. 1999). Root collar diameter and height were recorded over the course of one year in the nursery and over the course of a year after planting (Escobar et al. 1999). It was found that as Jiffy pellets performed as well or better depending on conditions as compared to containerized stocks, however the Jiffy pellets cost significantly less than the containerized stock types (Escobar et al. 1999). This is relevant to the null hypothesis that states that there will be no difference in seedling performance between the different container types as this study shows how they found that Jiffy pellets of all sizes performed better than that of container stocks, thus rejecting the hypothesis (Escobar et al. 1999).

A study by Fraser et al. (2014) looked at multiple options for the reclamation of the oil sands. Multiple different Jiffy pellets were looked at in order to determine the most cost-effective way to reclaim the oil sands (Fraser et al. 2014). This is relevant to the thesis in that it looks at the performance of Jiffy pellets and their ability to reclaim the oil sands and this thesis compares Jiffy pellet planted seedlings to container stocks.

3.0. MATERIALS AND METHODS

3.1. Study Location

The research for this thesis took place in the north-central area of Algonquin Provincial Park within White Township. Algonquin Provincial Park is in southeastern Ontario; west of Ottawa and south of North Bay (As displayed in Figure 1). The individual plot locations can be found in Figure 2. This study had 3 main study locations shown in Figure 2 as well. Location 1 lies at an elevation of about 300m and on relatively flat ground to slightly south facing slopes in certain areas. Location 2 sits at an elevation of about 340m and on relatively flat ground. Location 3 was at an elevation of about 300m and on relatively flat ground. Location 2 and 3 had exclusively *P. strobus* and *P. glauca* while Location 1 had all four species present.

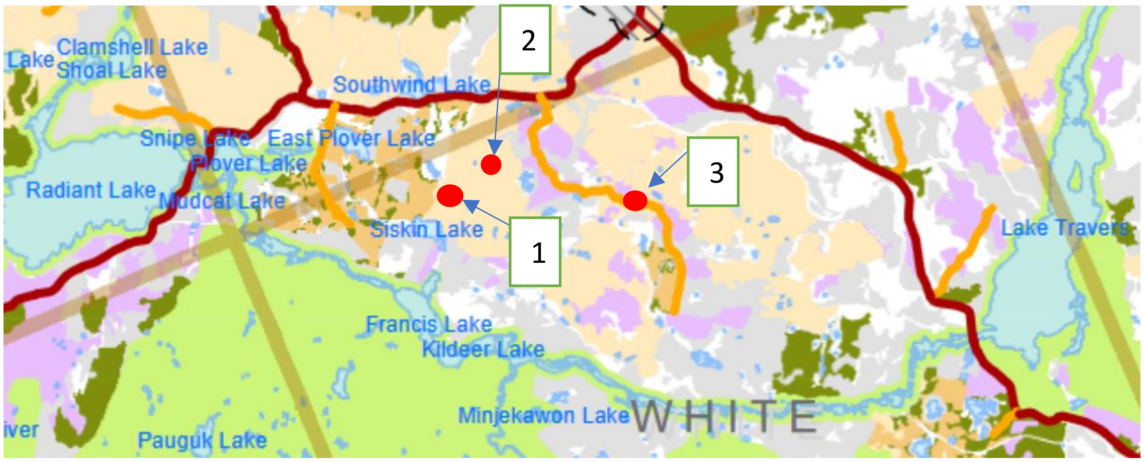

Figure 2. Map showing the exact locations of the three main study areas. The coordinates of these three study locations are; 1: 45.991°N, 78.195°W; 2: 45.997°N, 78.182°W; 3: 45.986°N, 78.147°W. Each study location has multiple different combinations of plot types. Source: AFA 2009.

3.2.Study Parameters

A total of 77 plots were measured, each with 25 seedlings per plot. Of the 77 plots, 5 plots were part of a fall plant and therefore were not used as part of this study. Therefore, a total of 72 plots was measured and used for this thesis, totalling 1800 individual seedlings. The seedlings were spring planted in 2010 and were planted at a 2m spacing. Figure 3 shows the pattern of the plant.

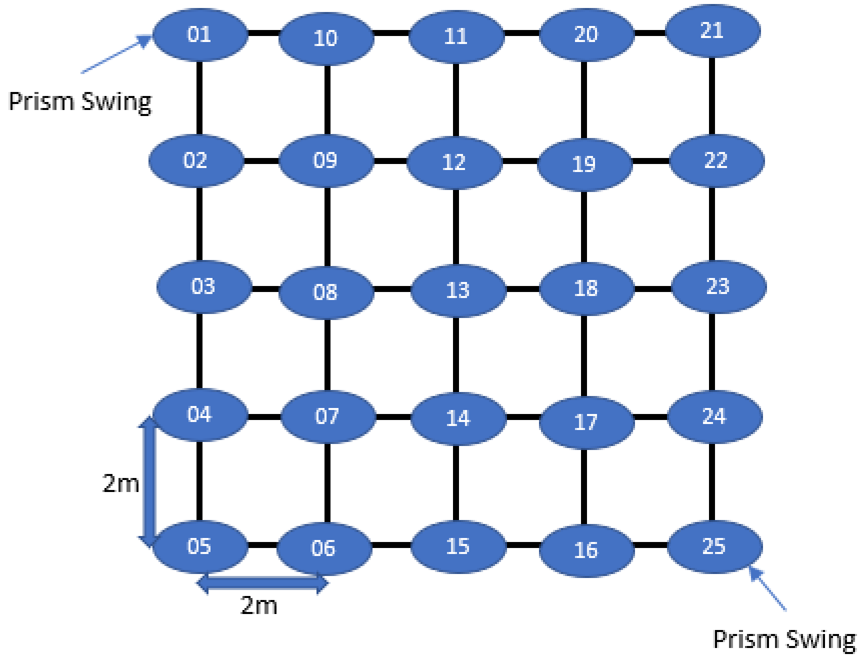

Figure 3. Pattern in which the trees were planted in and labelled as. This Figure represents the first plot as it has trees 1-25 present. For example; plot number 2 would have trees numbered 26-50 and so on. Each tree was spaced 2m apart as seen in this figure. A mature residual basal area prism swing was done at the first tree and the last tree in each plot (in this case, tree 1 and tree 25) and the average of the two numbers was taken and recorded.

Seedlings, along with their pigtails and labels, that could not be found were classified as “missing” and therefore, were not used for this study. Seedlings that could not be found or were clearly dead but still had their respective pigtail and label present were recorded and used in this study. They were labeled “dead.” Each plot of 25 seedlings consisted of a specific tree species with a specific container type from a specific nursery. The tree species studied were *P. glauca* (white spruce), *P. strobus* (eastern white pine), *P. resinosa* (red pine) and *P. banksiana* (Jack pine). Two nurseries were involved in this study. For the purpose of this paper they will be called “Nursery A” and “Nursery B.” Table 1 displays every possible species – container type – nursery combination that was planted. For each of these combinations, four identical plots were planted throughout the study area totalling 100 individual trees per combination.

Specifications for each stock type can be found in Appendix II. Volumes for each container type is shown in Table 2 and expanded diameter of each JIF stock type can be seen in Table 3.

Table 1. Contents of every possible species type – stock type - nursery combination planted. The "**X**" represents if a plot has been planted with that given combination.

Species	Container Type	*P. strobus*	*P. resinosa*	*P. banksiana*	*P. glauca*
Nursery A	PSB 309	**X**	**X**	**X**	**X**
	PSB 411	**X**	**X**	**X**	**X**
	JIF 30			**X**	**X**
	JIF 36/96	**X**	**X**		
Nursery B	PSB 310B			**X**	
	PSB 410A	**X**	**X**		
	JIF 30			**X**	
	JIF 36	**X**	**X**		

Table 2. Volume of each container type (SSI 2020a; PRTGSL 2020).

Container Type	Volume (ml)
PSB 309	60
PSB 310B	54
PSB 410A	80
PSB 411	90

Table 3. Expanded diameter of each JIF Stock type (SSI 2020b).

JIF Stock Type	Diameter (mm)
JIF 30	33
JIF 36	38
JIF 36/96	38

Each tree was given a pigtail with associated label including the following: container type, species, tree number, plot number, and nursery name. The pigtails were also wrapped in ribbon colour coordinated with each given stock type to make it easier to distinguish plot from plot when remeasuring.

3.3.Methods

All trees were measured for their height from the soil to the tip of the terminal bud. *P. strobus*, *P. glauca* and *P. resinosa* were measured using a metric measuring tape and the results were recorded to the nearest cm. *P. banksiana* was measured using an imperial measuring tape as it was more robust and was better able to measure the taller trees that *P. banksiana* tended to be. They were measured to the nearest quarter of an inch and were converted to cm in Excel. All dead and missing trees were recorded as well as any UGS (unacceptable growing stock) trees. UGS is defined as the likelihood that a tree will not live to the next cutting cycle based on its current condition (OMNRF 2004). These trees most commonly exhibited diseases such as white pine blister rust (*Cronartium ribicola*), western gall rust (*Endocronartium harknessii*), and *diplodia*. Severe white pine weevil (*Pissodes strobi*) was also classified as a defect as weevil in younger seedlings also create major deformities in the tree growth, often creating low quality timber (GOC 2013). They also exhibited physical deformities that made them UGS trees such as a lean >10°, a broken top and major crown die back >50% (OMNRF 2004). Every tree with a UGS defect was recorded with a "1" and every tree without a defect was recorded with a "0."

The mature residual basal area was recorded by taking a prism swing using a BAF 2 prism at tree 1 and tree 25 of each plot as displayed in Figure 3. These two numbers were then averaged to provide a mean mature residual basal area per plot. All data recorded on the tally sheets (as displayed in Appendix II) was then uploaded into the AFA's Plot Tally Master Sheet on Excel which consists of all the data collected each time the plots were remeasured dating back to 2010.

3.4.Statistical Analysis

The data collected was summarized for each species, stock types, and nurseries based on analysis of variance (ANOVA) with an alpha of 0.05. Each comparison examined mortality %, defect %, average height and mean mature residual basal area, however the significant of analysis could only be performed on the mean height. Mortality % was counted as some plots had missing trees which are not eligible to be used in this study. Defect % was defect count as some plots had missing trees which are not eligible to be used in this study as well therefore, a count would not be an accurate representation of the data. Graphs were created with specific parameters for specific variables such as height growth (cm) in 2019 compared among species. These graphs contain standard error bars based on 95% confidence intervals. For SPSS to determine the correct standard error bars, a standard error was calculated as in Equation 1 (Lane 2017). The standard error is an estimate of the variance of the distribution (Lane 2017).

$$Standard\ Error\ (SE) = \frac{\sigma}{\sqrt{n}} \qquad \text{Equation (1)}$$

where, n is equal to the total number of numbers such as the total number of trees in a plot and σ is the standard deviation.

In order to calculate the standard error, the standard deviation was calculated as seen in Equation 1. Equation 2 displays the calculation for standard deviation. Standard deviation is how much the data deviates from the mean (Lane 2017).

$$Standard\ Deviation\ (\sigma) = \sqrt{\frac{\sum(X - \mu)^2}{N}} \qquad \text{Equation (2)}$$

where, n is equal to the total number of numbers such as the total number of trees in a plot, μ is the mean of the population and X is a set of elements such as mean height for a specific container type.

Analysis of variance was done in order to determine if the null hypothesis is rejected or not rejected. A linear model was used in order to determine the difference in data developed. The multiple linear model followed Equation 3 depending on the number of variables that were being compared. The more variables compared, the larger the equation becomes. Multiple linear models were used to compare the difference in data between mean tree height (cm), species type and container type. Using Equation 3, V_1 was equal to the value of the species with relation to the mean height (cm) while V_2 was equal to the value of the container type with regards to mean tree height (cm).

$$Y = b_0 + b_1V_1 + b_2V_2 \ldots b_pV_p \qquad \text{Equation (3)}$$

where, Y is equal to dependent variable such as mean tree height, b is a constant and V is a variable such as container type.

Equation 1 was used to determine the outcome of the null hypothesis was a Type 3 sum of squares as displayed in Equation 4. This equation was used for every variable tested based on every other variable. Type 3 is commonly used in ANOVA's that are missing cells (Lane 2017).

$$Sum\ of\ Squares = \sum_{i=0}^{n} (X_i - X_{bar})^2 \qquad \text{Equation (4)}$$

where, n is equal to the total number of numbers such as the total number of trees in a plot, X_i is a set of elements such as mean height for a specific container type and X_{bar} is the total mean.

Based on the values determined from the linear model seen as Equation 5, an R^2 metric is to be calculated to determine the proportion of variability in the targeted value that the data comes. This equation is displayed as Equation 4 if the R^2 value is closer to 1, that means there is more of a 1:1 relationship based on the model displayed as Equation 5 and the target, thus becoming significant data. If the R^2 value was much less than 1, that means that the linear model equates a low chance of a significant relationship between the target and the data (Peixeiro 2018).

$$R^2 = \frac{TSS - RSS}{TSS} \qquad \text{Equation (5)}$$

where, R^2 is R^2 statistic, TSS is equal to the Total Sum of Squares and RSS is equal to the Residual Sum of Squares.

The second statistic used in the ANOVA analysis of variance was the degree of freedom. This equation calculates the ability for the population of variables that meet all constraints (Lane 2017). For example, there are 7 container types, therefore as the degree of freedom is equal to the number of variables minus one, the degree of freedom in this case is 6.

The third statistic used in the ANOVA is the mean square. The mean square was used to estimate variance across groups or variables. For mean square, there is both total mean square and mean square between groups. Two equations are used. Equation 6 represents the total mean square across all groups and Equation 7 represents the mean square between specific groups.

$$Mean\ Square\ Total\ (or\ Variance) = \sigma^2 \qquad \text{Equation (6)}$$

where, σ is equal to the variance.

$$Mean\ Square\ Between = n\sigma^2 \qquad \text{Equation (7)}$$

where, σ is equal to the standard error and n is equal to the total count.

The fourth statistic used in ANOVA's analysis of variance was the F distribution or "F-ratio). This statistic is the ratio between the variance of the total groups and the specific groups looked at. This determines if the group means are equal. If they are not, then there is a significant difference (Lane 2017). The equation is the ratio between the Mean Square total and the Mean Square between.

The F-ratio was used to determine the p-value or probability that something will occur. The p-value is a value computed as the final step to determine whether the statistics are significant or not and if the accept or reject the null hypothesis. The p-value or percentage value is based on an expected percent critical. This p-value is based on a 95% confidence interval therefore, equaling 0.05.

3.4.1. Container Type Comparisons

Each individual container type was compared using all data from all the species. The data used was mortality %, defect %, average height, and average basal area. The individual container types from each species was summarized and put in SPSS tables and graphs in order to create a comparison between each individual container type. Container types were also compared with species type and mature residual basal area with parameters including mean height, defect % and mortality %. Container type underwent significant of analysis comparisons and multiple linear regression relating to mean tree height (cm) and species.

3.4.2. Species Comparisons

Each individual species was compared using all data from all the species and combined. The data used was mortality %, defect %, average height, and average basal area. Each species was summarized by species and put into Excel and SPSS tables and graphs in order to create a comparison between each individual species. Species types were also compared with container type and mature residual basal area with parameters including mean height, defect % and mortality %. Species underwent significant of analysis comparisons and multiple linear regression relating to mean tree height (cm) and container type.

3.4.3. Nursery Comparisons

Each individual nursery was compared using all data from all the species and combined. The data used was mortality %, defect %, average height, and average basal area. Each species was summarized by nursery and put into SPSS tables and graphs in order to create a comparison between each individual nursery. Nursery types were also compared with species type with parameters including mean height, defect % and mortality %.

3.4.4. Mature Residual Basal Area Comparisons

Each species was compared based on mature residual basal area by taking the average basal area for each plot taken for each species and compared to each other within the specific species as each species has its own ability to grow under varying mature residual tree density. A simple single variable linear regression analysis was performed relating defect %, mortality % and mean height. Two categories were developed in order to improve the quality of statistics. These two were more shade tolerant species (*P. glauca* and *P. strobus*) and more shade intolerant species (*P. resinosa* and *P. banksiana*).

4.0. RESULTS

4.1.Container Type Comparison

The average height growth for each current year container stock was calculated using SPSS. As can be seen in Figure 4, the average height growth for STY 310B was significantly taller with an average height of 398cm compared to the other container stocks. The remaining container types grew insignificantly different from each other based on a 95% confidence interval between 215cm and 268cm in height.

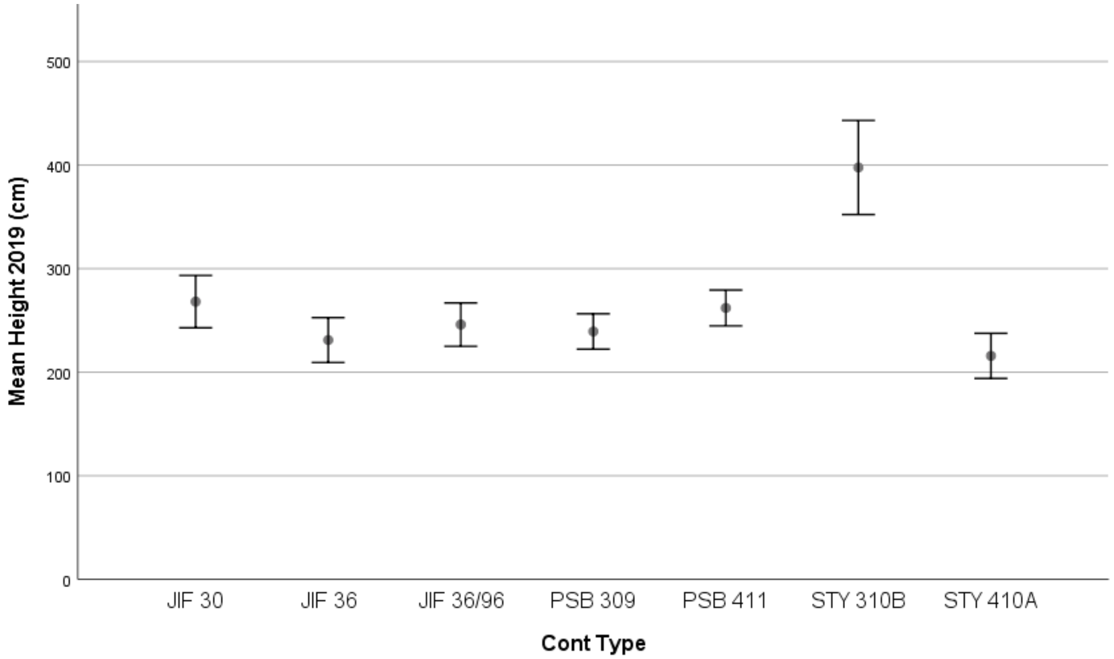

Figure 4. Scatter plot depicting the mean height in 2019 for each of the 7 different container types at a 95% confidence interval. As can be seen, all the different container types are insignificant in height difference except for STY 310B. Source: SPSS and AFA Plot Master Excel Sheet.

Percent mortality and percent defect calculated for container type comparisons can be seen in Figure 5 and Figure 6. As can be seen in Figure 5, container types ranged between 18% and 27% mortality with JIF 30 and STY 410A having the highest percent mortality while STY 310B had the lowest percent mortality. STY 310B however, can be seen in Figure 6 to have by far the highest percent defect with nearly 30% of the seedlings having a major defect. JIF 30 has the next highest defect percent at roughly 16%. The remaining container types were all below 5% defect.

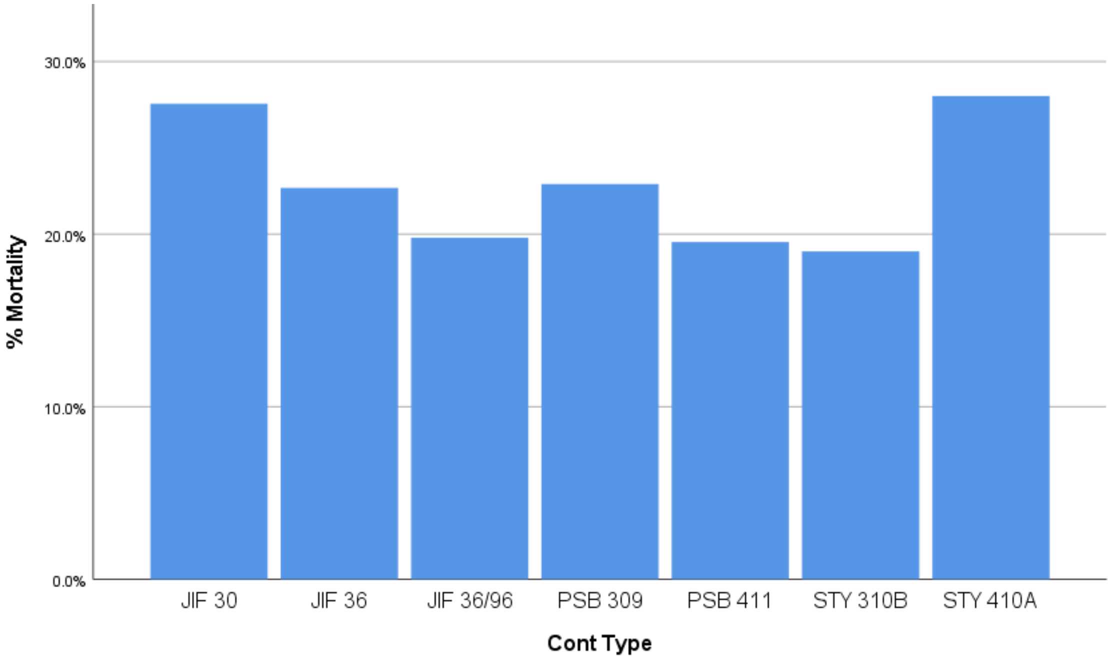

Figure 5. Bar chart depicting the percent mortality for each of the container types planted for this study. Source: SPSS, AFA Plot Master Excel Sheet.

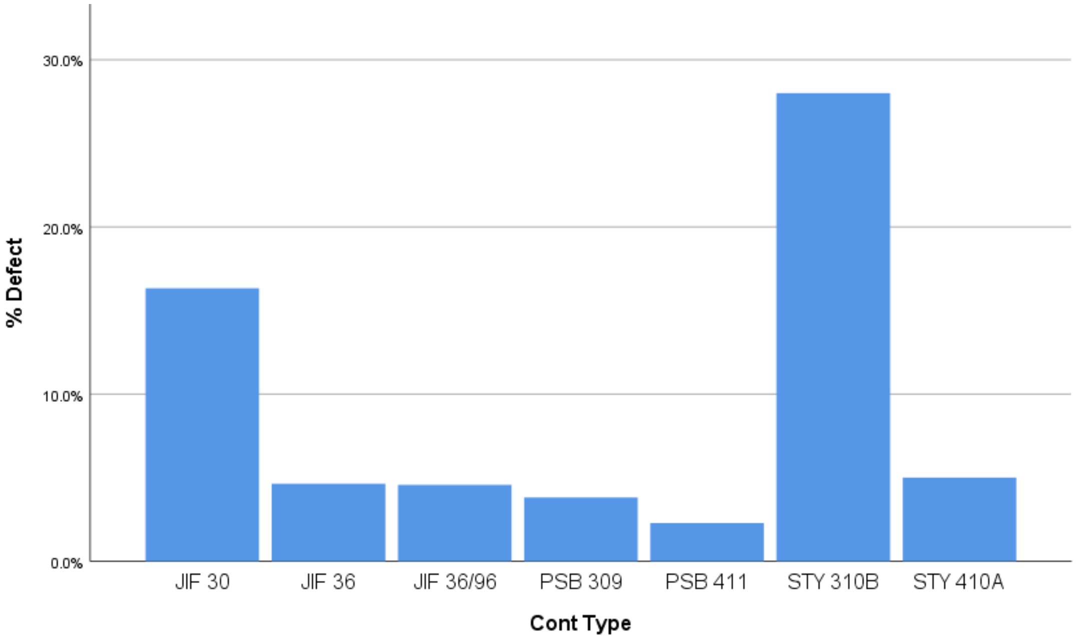

Figure 6. Bar chart depicting the percent defect for each of the container types planted for this study. Source: SPSS, AFA Plot Master Excel Sheet.

4.2. Nursery Type Comparison

As the comparison in Nursery Types only had two different nurseries, it is difficult to provide an accurate estimation of the impact different nurseries have on the seedlings. Since there are only two variables in this comparison a conclusion cannot be made. However, for the sake of this study and the employer, Figure 7 shows that there is in fact, no difference based on mean height in 2019 between Nursery A and Nursery B. Nursery B did yield a higher mean height but based on a 95% confidence interval, the standard error proved that the difference in mean height is not significant. As seen in Figure 8 and 9, Nursery B did have a higher percent mortality and a much higher percent with a defect.

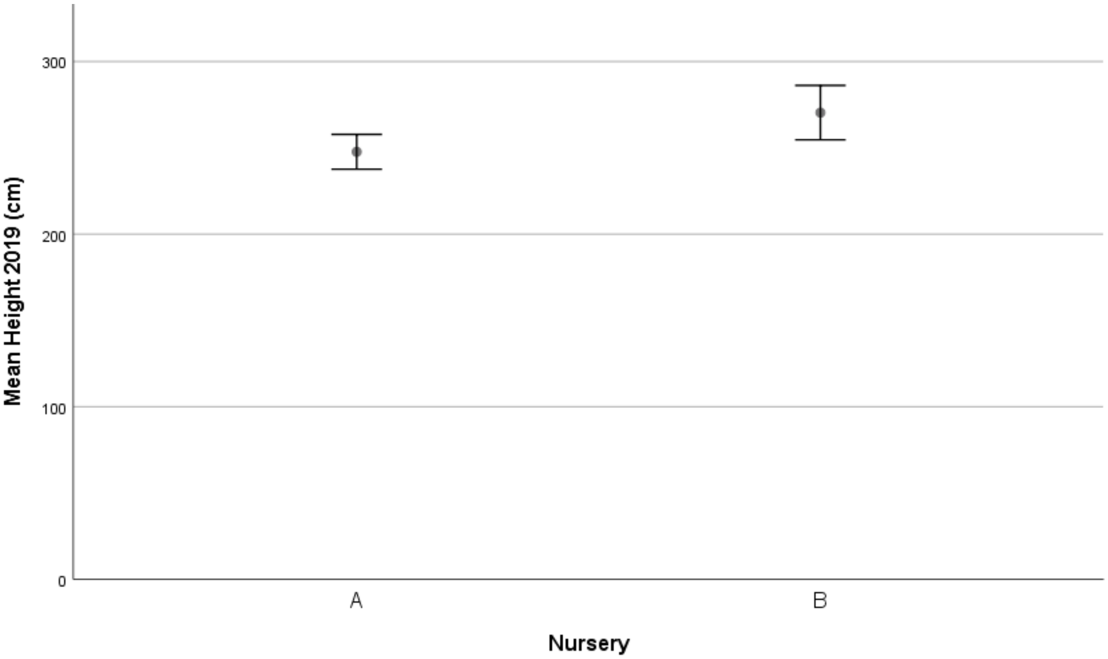

Figure 7. Scatter plot with 95% confidence intervals and standard error bars displaying the difference in mean height (cm) in 2019 between Nursery A and Nursery B. Source: SPSS, AFA Plot Master Excel Sheet.

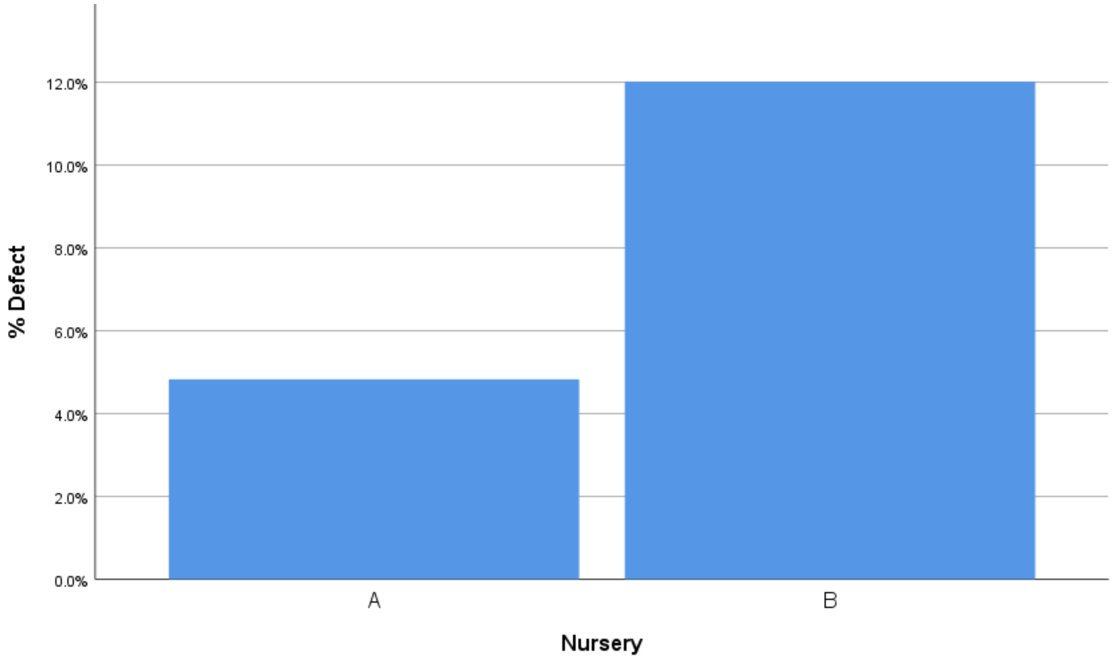

Figure 8. Bar chart depicting the percent defect for two different nurseries used in this study. Source: SPSS, AFA Plot Master Excel Sheet.

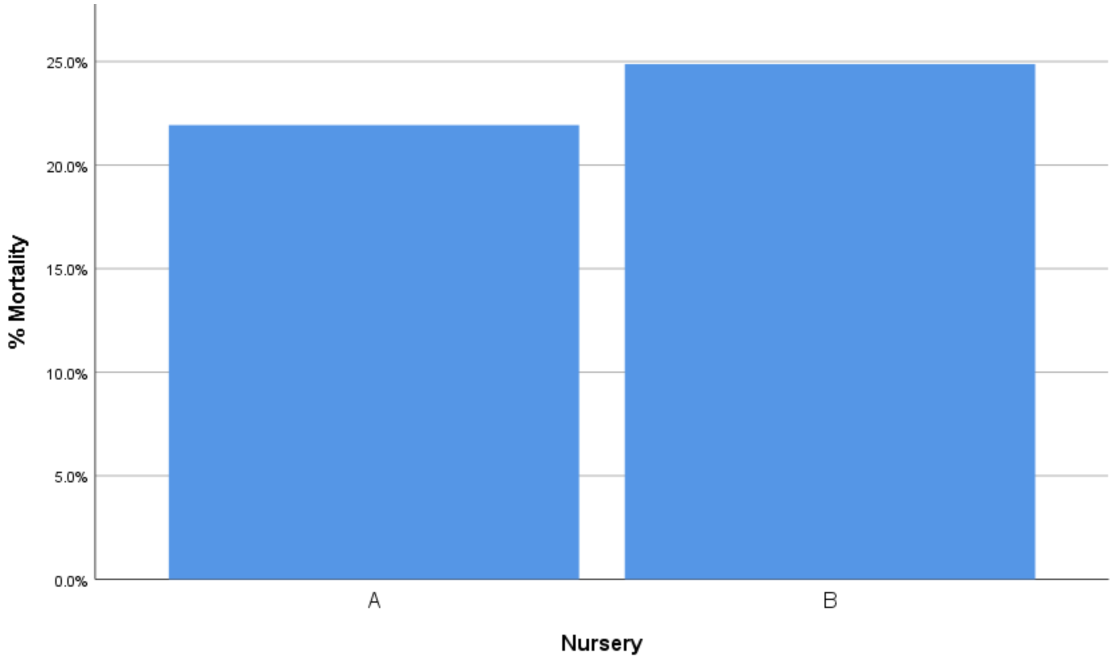

Figure 9. Bar chart depicting the percent mortality for two different nurseries used in this study. Source: SPSS, AFA Plot Master Excel Sheet.

4.3.Species Comparison

The mean height for the current year’s growth was calculated and compared using SPSS. As seen in Figure 10, *P. banksiana* had the highest mean height at 346cm while *P. glauca* had the lowest at 171cm. Both *P. strobus* and *P. resinosa* as seen in Figure 8 were insignificant in height between each other.

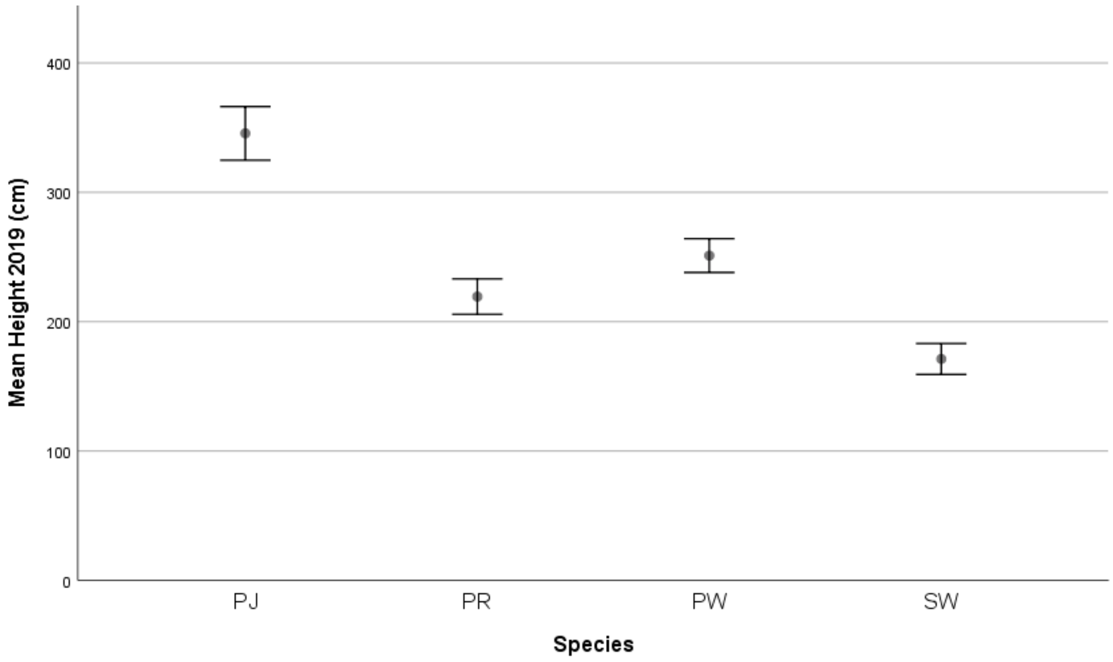

Figure 10. Scatter plot depicting the mean height in 2019 for each of the 4 different species at a 95% confidence interval. Source: SPSS and AFA Plot Master Excel Sheet.

As seen in Figure 11, the percent mortality was highest in *P. resinosa* with *P. banksiana* close at almost 30% mortality. Both *P. strobus* and *P. glauca* had a low percent mortality at around 15%. Figure 12 describes the percent defect that was found in each species. As can be seen, *P. banksiana* had the highest percent defect at over 15% while *P. strobus* has the second highest at about 8%. Both *P. resinosa* and *P. glauca* had less than 4% defect.

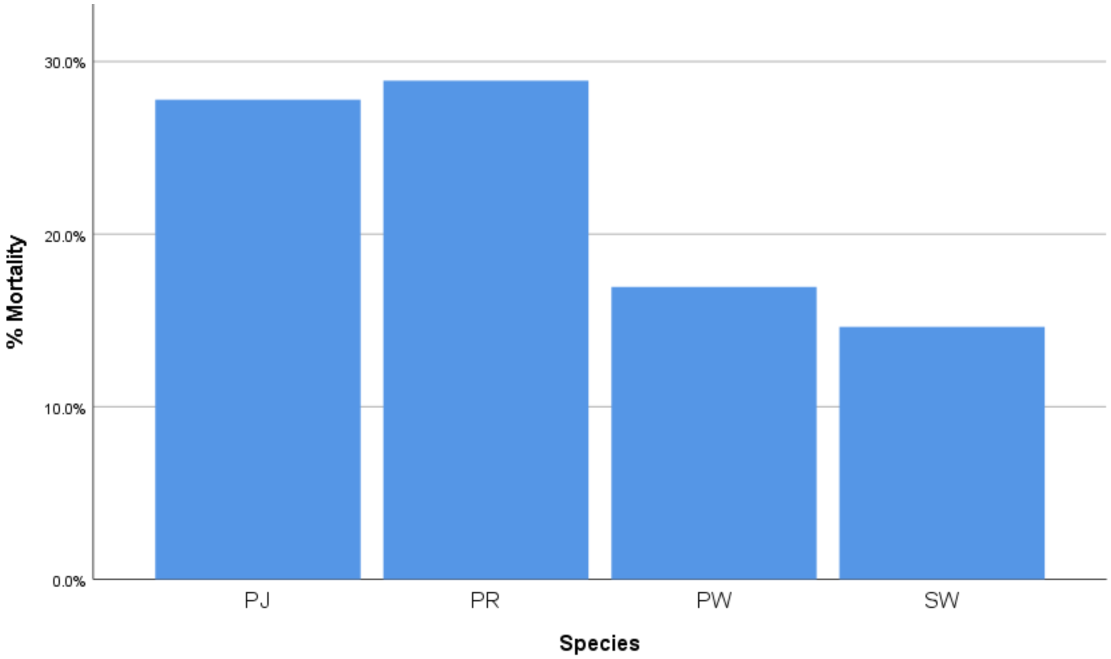

Figure 11. Bar chart depicting the percent mortality for each of the 4 species. *P. resinosa* had the highest percent mortality while *P. glauca* had the lowest. Source: SPSS and Excel Plot Master Sheet.

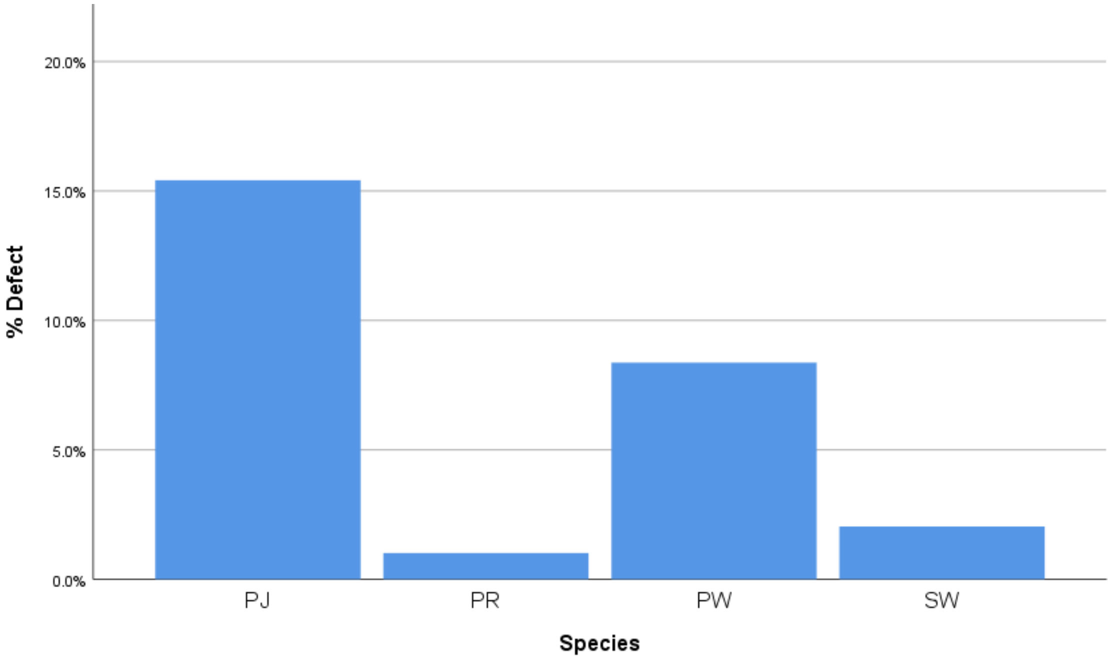

Figure 12. Bar chart depicting the percent defect for each of the different species planted for this study. Source: SPSS, AFA Plot Master Excel Sheet.

4.4.Container Type – Species Comparison

A combination between average height for the present year compared with species and container types can be seen in Figure 13. This graph depicts the relationship between the success of a plot based on species and container type. As can be seen, the correlation between *P. banksiana* and its respective container types yielded significantly taller present seedlings when compared with the other species and container types. This can also be seen in *P. glauca* being shorter, in certain cases significantly shorter, than all the remaining container type – species comparisons.

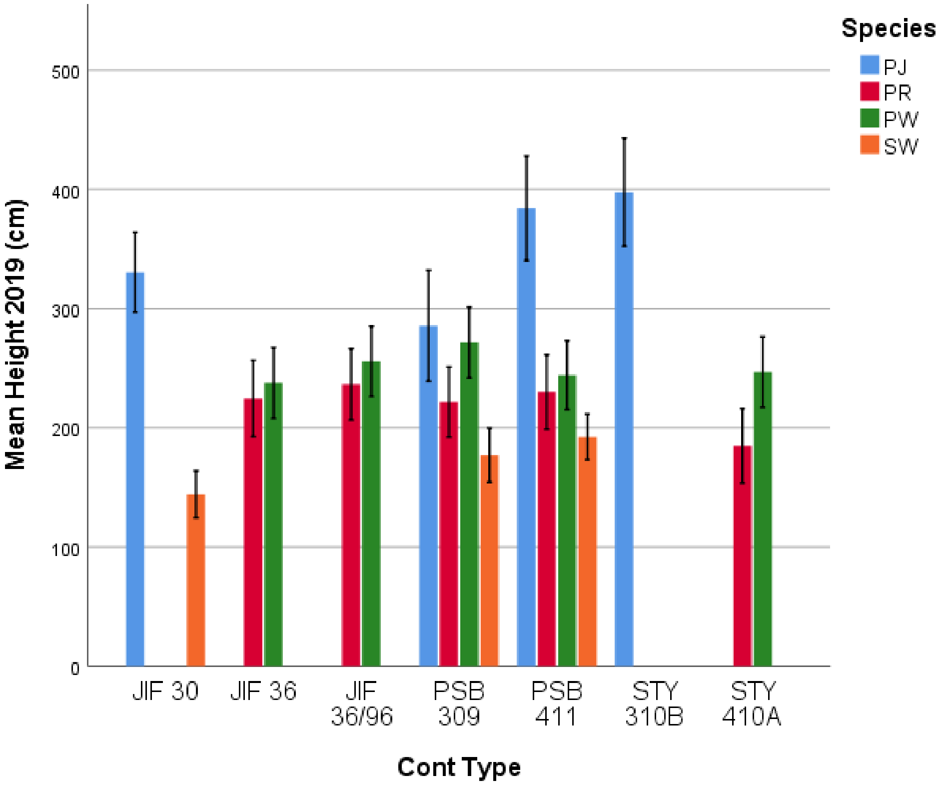

Figure 13. Scatter plot depicting the mean height in 2019 for each of the 4 different species and each of the 7 different container types at a 95% confidence interval. As can be seen, all the different stock types are insignificant in height difference except for *P. banksiana* with the PSB 411 and the STY 310B stock type (significantly taller) and *P. glauca* (significantly shorter) with the JIF 30 stock type. Source: SPSS and AFA Plot Master Excel Sheet.

The significance of analysis by means of a univariate calculation done in SPSS can be seen in Table 4. As seen in the final column, the significance of this analysis yielded 0.000 for species, 0.001 for container type and 0.010 for species and container type combined. As each value is less than the alpha of 0.05, this test has significantly different variables as also noticed in Figure 13 with the standard error bars.

Table 4. Univariate test of between container type combined with species and mean height 2019(cm). "df" displays the degrees of freedom, "F" displays the frequency and "Sig." displays the significance of analysis. Source: SPSS.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	7900543.577[a]	16	493783.974	16.861	.000
Intercept	96035616.182	1	96035616.182	3279.267	.000
Species	4534482.323	3	1511494.108	51.612	.000
ContType	665180.601	6	110863.434	3.786	.001
Species * ContType	540729.228	7	77247.033	2.638	.010
Error	51249975.116	1750	29285.700		
Total	174293603.000	1767			
Corrected Total	59150518.694	1766			

a. R Squared = .134 (Adjusted R Squared = .126)

4.5.Mature Residual Basal Area – Species Comparison

The mean mature residual basal area was calculated in the field and compared using SPSS. As seen in Figure 14, *P. banksiana* and *P. resinosa* maintained a mature residual basal area average of less than 3m^2/ha while *P. glauca* and *P. strobus* maintained an average residual basal area of over 5m^2/ha. This mature residual basal area was dependent on the forester. The forester chose, to an extent, the number of mature residual trees based on their respective ability to tolerate levels of shade. As stated in the methods, two categories were developed based on their ability to tolerate shade. As shown in Figure 14, the forester prescribed less mature residual basal area for *P. banksiana* and *P. resinosa* while *P. glauca* and *P. strobus* maintained a higher density of mature residual basal area.

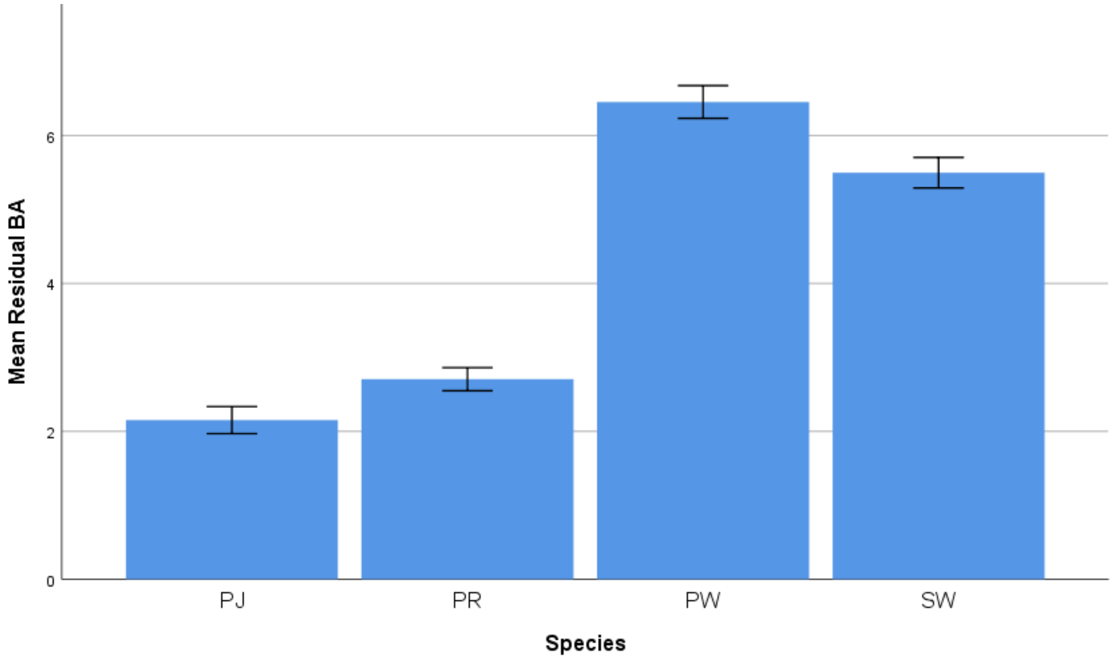

Figure 14. Bar chart depicting the mean mature residual basal area (m^2/ha) for each of the 4 different species at a 95% confidence interval. Source: SPSS and AFA Plot Master Excel Sheet.

4.5.1. Mature Residual Basal Area (Shade Intolerant Species)

As discussed in the Literature Cited, *P. resinsosa* and *P. banksiana* require higher levels of quality of light to properly grow. The simple single variable linear regression performed as depicted in Figure 15 for defect % yielded an R^2 value of 0.383 for *P. banksiana* while the R^2 value for *P. resinosa* is found to be 0. The R^2 was relating the two species to % mortality however, *P. banksiana* produced an R^2 value of 0.037 while *P. resinosa* produced an R^2 of 0.013, therefore yielding a very low relationship between the data and target produced in the linear model.

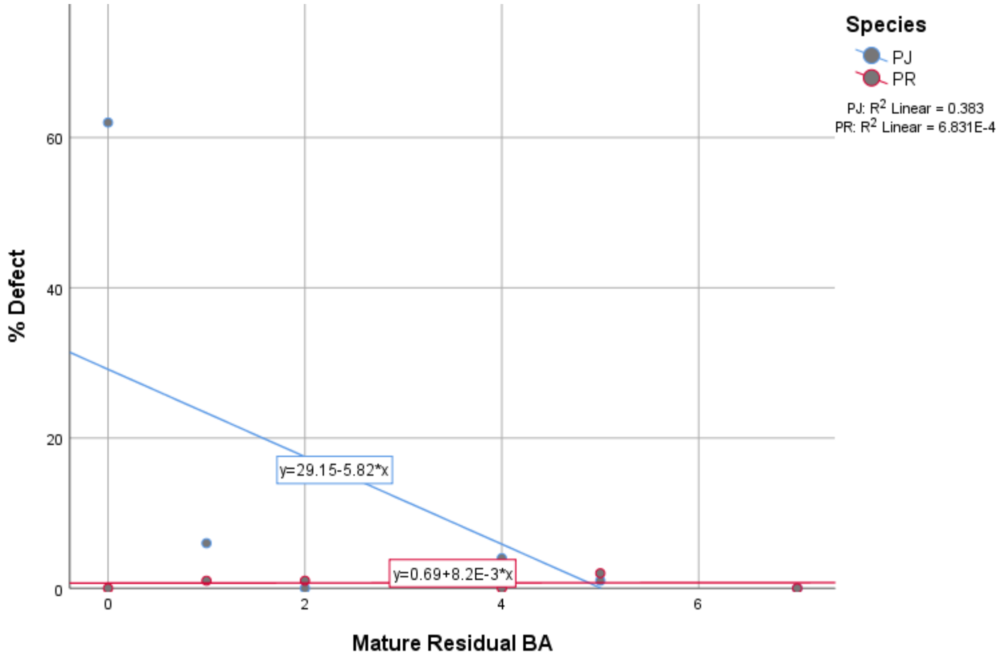

Figure 15. Depiction of the % Defect in relation to average mature basal area for two shade intolerant species (*P. banksiana* and *P. resinosa*). Source: SPSS, Excel Plot Master Sheet.

Mean Height for 2019 (cm) for the two shade intolerant species along with simple linear regression lines and R^2 values are displayed in Figure 16 including error bars. Neither species produced an R^2 value close to 1, however, a small correlation between the increasing in mature residual basal area producing smaller trees. This correlation as seen in Figure 16, is stronger in *P. resinosa* (R^2 value of 0.144), while the correlation for *P. banksiana* is essentially non-existent with an R^2 of 0.052.

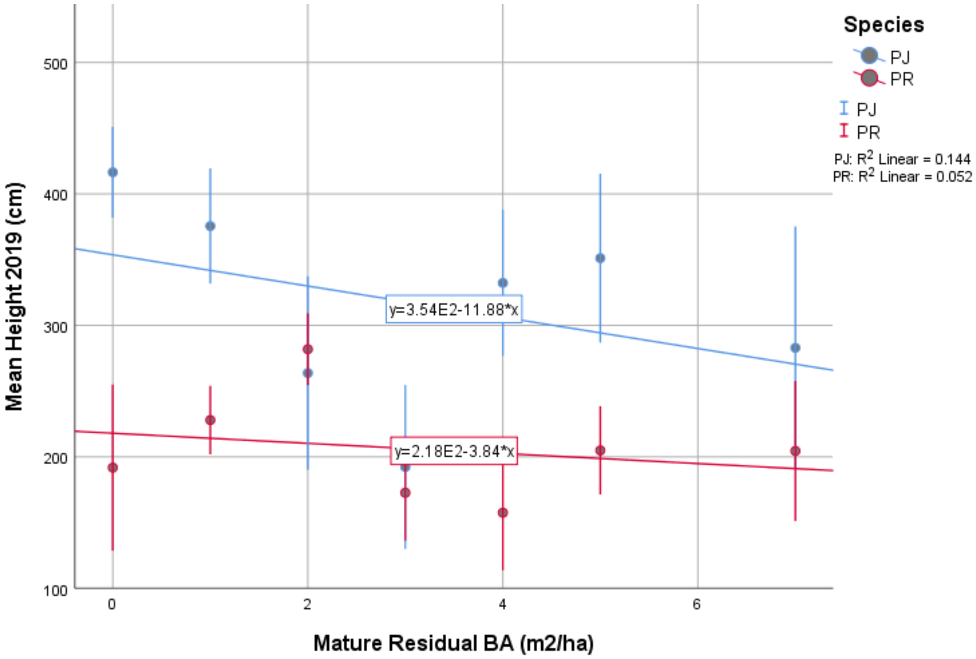

Figure 16. Depiction of the Mean Height for 2019 (cm) in relation to average mature basal area for two shade intolerant species (*P. banksiana* and *P. resinosa*). Source: SPSS, Excel Plot Master Sheet).

4.5.2. Mature Residual Basal Area (Shade Tolerant Species)

As discussed in the Literature Cited, *P. glauca* and *P. strobus* require lower quality of light to properly grow than *P. resinosa* and *P. banksiana*. The simple single variable linear regression performed as depicted in Figure 17 for defect % yielded an R^2 value of 0.398 for *P. strobus* while the R^2 value for *P. glauca* is found to be 0.026. This means that both species have a negative relationship in defect % with mature residual area (the lower the mature basal area, the higher the defect %).

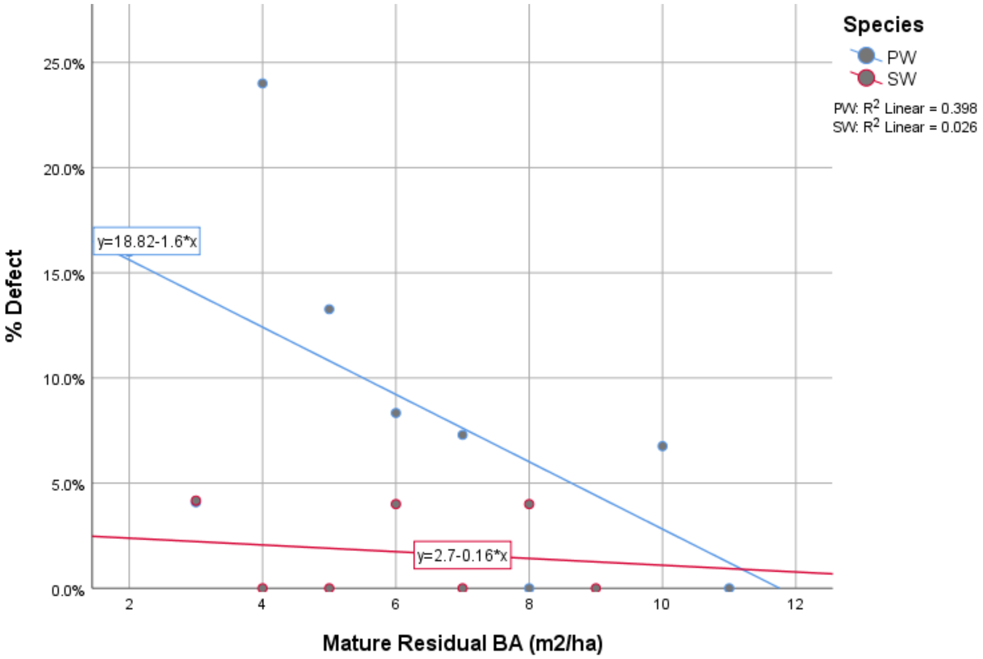

Figure 17. Depiction of the % Defect in relation to average mature basal area for two shade intolerant species (*P. glauca* and *P. strobus*). Source: SPSS, Excel Plot Master Sheet).

The R^2 was calculated relating the two species to % mortality. *P. glauca* produced an R^2 value of 0.248 while *P. glauca* produced an R^2 of 0.392, therefore yielding a relatively low relationship between the data and target produced in the linear model. A general trend in data is displayed in Figure 18 and that being with an increase in mature basal area comes a decrease in % Mortality.

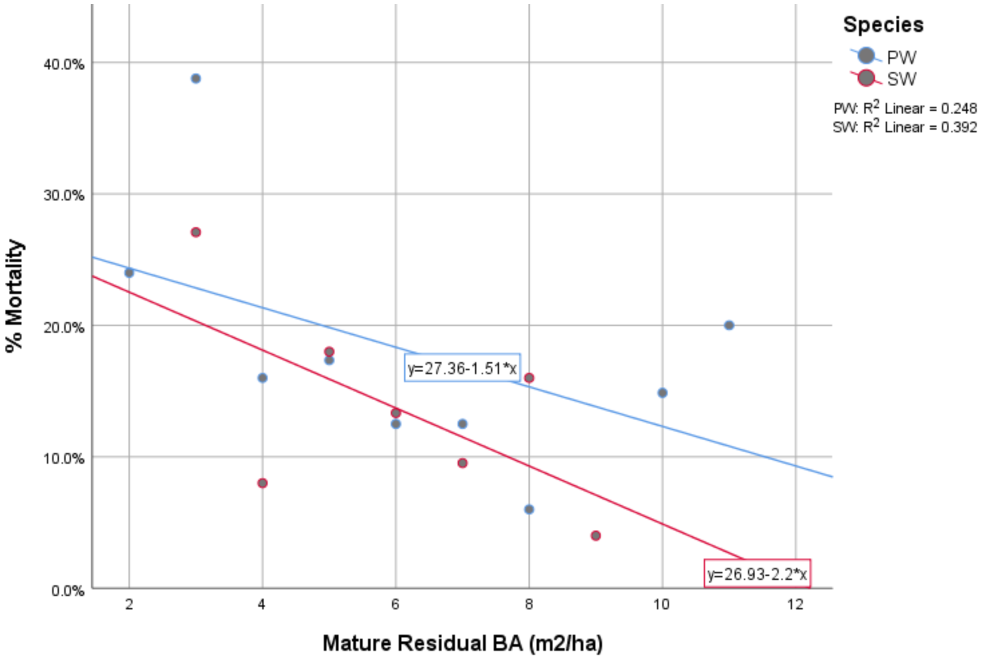

Figure 18. Depiction of the % Mortality in relation to average mature basal area for two shade intolerant species (*P. glauca* and *P. strobus*). Source: SPSS, Excel Plot Master Sheet).

The mean height for 2019 (cm) as displayed in Figure 19, yielded a low correlation between the model and the target. *P. strobus* produced an R^2 value of 0.132 while *P. glauca* with only 0.030, yielding no relation. A general trend however can be seen although not proven in Figure 19 in that with an increase in mature residual basal area comes a slight decrease in mean height.

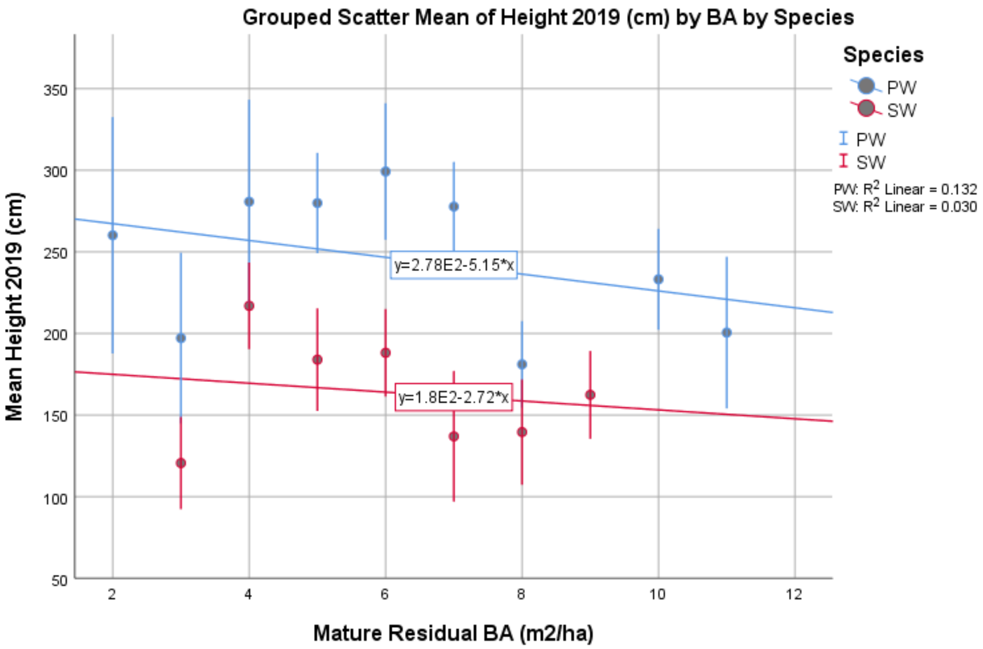

Figure 19. Depiction of the Mean Height for 2019 (cm) in relation to average mature basal area for two more shade tolerant species (*P. strobus* and *P. glauca*). Source: SPSS, Excel Plot Master Sheet).

5.0. DISCUSSION

5.1.Container Type Comparison

As the results show, within the significance of analysis table (Table 4), when comparing container type to mean height 2019, the *p* value is 0.01, which is less than 0.05, thus rejecting the null hypothesis. This means that there is a significant difference in mean seedling height among the 7 different types of containers. As discussed in the results, the container type with the highest mean height growth is the STY310B container type.

According to Figure 4, STY 310B is the only container type that is significantly different in mean height than the other 6 container types. This information does go against what has been found in multiple articles published in that these studies found there to be a significant correlation between the size of the container type and the ability for the respective seedlings to grow taller when they have a higher volume container type (Cobos et al. 2012; Dumroese et al. 2019; Nicholson 2008; John and Walker 1980; Harrington and Howell 2004). For example, a study by Cobos et al. (2012) compared three different container sizes; 60ml, 90ml and 120ml in volume. They found that the 60ml grew to a height of 20.0cm while the 120ml container stock grew to a height of 28.3cm, while the 90ml grew to a height of 25.0cm. The STY310B container type is not the largest (60ml). As shown in Appendix I, the largest container type based on volume is the PSB 411 at 90mls. The reason for seedlings generally growing larger when grown in larger container types is because it allows the roots to expand larger and become more robust. This allows them to persist in more soil conditions and environmental variables as well as being able to take up more water and nutrients during their nursery time and initially once out planted. This allows them to grow more quickly when planted as they can acquire the necessary water and nutrients and larger more robust roots to help the seedlings persist against more intense environmental elements (Cobos et al. 2012; Dumroese et al. 2019; Nicholson 2008; John and Walker 1980; Harrington and Howell 2004). Based on Figure 4, the data collected does not follow multiple studies on similar scenarios with regards to seedling growth variations from different container types. This then, accepts the null hypothesis generally as 6 of the 7 different container types grew insignificantly different from each other in terms of mean height growth.

STY 310B is entirely *P. banksiana*. *P. banksiana* is known to have the fastest growth rate of the four species studied, but no other container type is strictly *P. banksiana* to bring up the mean height. Therefore, the significantly taller STY 310B can be attributed in part to species characteristics as well as container type as a significant result was found as displayed in Table 4 (Rudolph and Laidly. 1990). A study by Dinger et al. (2019) determined that although it has been found that larger container types do have an increased outplanting performance, not a significant enough difference was found between the sizes of stock types and may not be worth the extra investment that these larger stock types require. This would follow the rejection of the null hypothesis in that not a significant difference in field performance between container sizes is present enough to invest in larger container types.

For percent defect and mortality (Figure's 5 and 6), the percent mortality maintains a relatively similar trend across all stock types ranging from 19% to 28% mortality. The percent defect however, ranged from 2% to 27% defect. In the article by Cobos et al. (2012), the percent mortality between three different container sizes was determined. It was found that the larger container type maintained nearly 20% to 40% less mortality than that of the other sizes of containers. The data collected in this thesis showed STY 310B and PSB 411 (60ml and 90ml respectively) having both about 19% mortality while STY 410A and JIF 30 both had mortality around 28%. Within this data, no correlation can be made between the container type with regards to mortality percent which differs from what Cobos et al. (2012) displayed in their study being that the percent mortality was found to be higher in the smaller volume container types.

Harrington and Howell (2004) concluded that there is no significant difference between medium and large container type volumes, however there is a significant difference with the small container type volumes. They concluded that based on cost estimates, although the smaller container types are much cheaper, the benefits of the larger container types 5 years after plant outweigh the cost savings from using the smaller container types. This correlation, although not significant within the results determined in this thesis, does provide insight into future planting regimes in that using mid to large size containers will help improve the return in the long term.

However, defect percent calculations showed that the JIF 30 and STY 310B both had over 15% defect (STY 310B with over 25%). STY 310B being 60ml in volume and the JIF 30 having a 30mm diameter, are both smaller in their respective categories. This is, as stated above, because with smaller cavities for root growth, they are not able to produce as much large root mass, and therefore not able to take up as much nutrients and water once out planted and which ultimately makes it more difficult for them to withstand weather elements as they are weaker. This makes them more susceptible to disease, rot and poor form as there is less structure and resource extraction available for the seedlings. It is also found that for Jiffy pellets, when cutting them from their nursery, they lose significant amounts of root mass and pulling occurs on their taproots, therefore leaving less roots to take up nutrients and provide support and stability within the soils (Chapman and Colombo 2006). Specifically, for STY 310B, there is a general trend across nearly all the plots that they all have western gall rust. It is not known if they had contracted it onsite, during transport or in the nursery however, the reason for the very high percentage of affected *P. banksiana* STY 310B is due to the gall rust.

5.2.Nursery Comparison

As per the results, the Nursery Comparison for this study cannot be used as a scientific one as there are only 2 different nurseries, therefore only one degree of freedom. However, for the purpose of this thesis, the data is organized and interpreted. As Figure 7 displays, there is no major difference between either nursery with regards to mean height as of 2019. This correlates with the article by Bakker (2005) where he examined different nursery practices with regards to how warming and thawing affects the seedling development once out planted. Bakker (2005) determined that 6 weeks after planting, there was no difference in seedling performance, therefore correlating with the findings seen in Figure 7. Bakker (2005) did however determine that seedlings that underwent a frozen plant did have a higher chance of becoming infected by disease, something similarly seen in Figure 8. Figure 8 shows a large difference in that Nursery B has a much higher percent defect than Nursery A. This may be due to differentiating nursery tactics between the two. Also as discussed in section 5.1., the STY 310B container type had a very high percent defect compared to the other container types. This was because it was exclusively *P. banksiana* and nearly half of the STY310B had contracted western gall rust. STY 310B is a container type from Nursery B, which as seen in Figure 8, has a much higher defect percentage. This would ultimately increase the defect percentage for Nursery B when compared with Nursery A.

5.3.Species Characteristic Comparison

As displayed in Figure 10, *P. banksiana* has significantly higher mean height as of 2019 compared to the other 3 species. *P. glauca* has a significantly lower mean height as of 2019 as discussed in the results. *P. strobus* and *P. resinosa* have a mean height insignificantly different from each other and between the mean heights of *P. glauca* and *P. banksiana*. Table 4 also displays that the species - mean height interaction yields a p value of 0.000, therefore rejecting the null hypothesis and yielding a significant result between the different species and mean height.

This agrees with Rudolph and Laidly (1990) in that they state that predominantly due to its intolerance to shade, *P. banksiana* has evolved over time to become the fastest growing conifer. This is especially true following a burn or clear cut in its respective region except for *L. laricina* (Rudolph and Laidly 1990). Therefore, as it is seen that *P. banksiana* is significantly taller in mean height as of 2019 compared to the other 3 species measured in this study (Figure 10), this correlates with the measured values in this thesis. Rudolph and Laidly (1990) also state that *P. banksiana*, being the fastest growing conifer next only to *L. laricina*, puts on an average of 1.4m every 5 to 8 years depending on site quality. As seen in Figure 10, this would be more than the expected mean height growth over the 9 years in that the *P. banksiana* planted in this thesis grew to over 300cm. This is possibly since the northern part of Algonquin park is part of in *P. banksiana*'s more southern range, therefore providing a longer growing season and allowing for increased height growth (Smith and Wendel 1990).

As explained by Rudolph and Laidly (1990), *P. banksiana* are very susceptible to many different damaging agents, especially when immature. As displayed in Figure 12, *P. banksiana* has the highest percent defect of any of the species by almost double (over 15%). This is mostly due in part to the STY 310B container type as discussed previously being 100% *P. banksiana* composition with nearly 30% having defects. These trees all have a gall rust on them, something explained by Rudolph and Laidly (1990) to be a disease that *P. banksiana* is particularly susceptible to. *P. banksiana* also had the second highest mortality percent (Figure 11). This can be attributed to the high susceptibility to disease as seen with the gall rust and the high shade intolerance and reaction to over topping competition. As Rudolph and Laidly (1990) explain, if *P.*

banksiana does not receive enough sunlight in earlier stages of development, it will not survive. Figure 11 which shows 27% mortality is consistent with this.

It is also found that both *P. resinosa* and *P. strobus* grow at moderate rates in the seedling stages in their respective growing regions (Smith and Wendel 1990; Rudolph 1990). This correlates with both *P. strobus* and *P. resinosa* having grown insignificantly different in height from one another. It was found by Smith and Wendel (1990) that *P. strobus* will grow significantly faster in more mature stages than it does in the less mature stages. The Tree Marking Guide for Ontario outlines that on similar stands, both *P. resinosa* and *P. strobus* grow at very similar rates (OMNR 2004). Rudolph (1990) explains how both naturally regenerated and planted *P. resinosa* grow at an average rate of 30cm per year in their first 50 years of height growth. This correlates with the findings in this thesis in that a mean height of 225cm to 250cm for both *P. resinosa* and *P. strobus* as displayed in Figure 10 occurred. As expected by Rudolph (1990), the mean height growth would be closer to 270cm over the 9 year span, however, as northern Algonquin Park is in the more northern range for both species, it is possible that they may not be achieving full height growth due to the shorter growing seasons in the cooler climate (Smith and Wendel 1990; Rudolph 1990).

With regards to percent defect and percent mortality in *P. strobus* and *P. resinosa*, neither species is very disease prone nor have high mortality relative to each other. However, *P. strobus* is susceptible to both White Pine Weevil and White Pine blister rust. As displayed in Figure 12 *P. strobus* does have the second highest percent defect in this study at about 8%. As the percent mortality for *P. strobus* is the second lowest at about 17%, this correlates to a high percentage of white pine weevil. Weevil often does not kill the tree but does however destroy much of the merchantability of the trees for saw logs. Blister rust is common in these plots as well, but may not have fully killed the seedlings (Smith and Wendel 1990). *P. resinosa* had the highest percent mortality at about 28% (Figure 11) but the lowest percent defect at about 2% as displayed in Figure 12. This may correlate to site conditions such as less acidic, finer textured and poorly drained soils to which *P. resinosa* is not adapted and which can expose them to some damaging agents and other factors that affect their survival rate. They do, however, have very little damaging agents that affect them which is why Figure 11 shows such a low defect percentage (Rudolph 1990). It is also discussed by Rudolph (1990) that *P. resinosa* does not respond very well to competition, which kills off many younger seedlings. This can be seen in Figure 11 with *P. resinosa* having the highest percent mortality compared to the other 3 species studied in this thesis.

Nienstaadt and Zasada (1990) describes how *P. glauca* develops no more than 30 to 50cm in average height for natural regeneration in the first 4 to 6 years of its life. *P. glauca* grows better in full light and the ones planted for this study are 10 years old. Nienstaadt and Zasada (1990) explain that open grown, full sunlight conditions allow for the highest increase in height growth per year. The seedlings planted for this study achieved a mean height growth of just under 200cm in 10 years (Figure 10), being significantly higher than the expected growth rate from Nienstaadt and Zasada (1990) (around 100cm in the first 10 years). However, Nienstaadt and Zasada (1990)'s study was done under natural regeneration light levels and not complete sunlight as the conditions present in this study location. This information correlates with Table 10 in that the mean height growth for *P. glauca* is significantly less so in seedling stages compared to the other three species studied.

5.4.Mature Residual Basal Area Effects

5.4.1. Shade Intolerant Species

P. resinosa and *P. banksiana* are generally seen as shade intolerant species (*P. resinosa* being mid-tolerant to intolerant) in seedling stages. As displayed in Figure 14, the average mature residual basal area for *P. resinosa* and *P. banksiana* are just about 3m^2/ha and 2m^2/ha respectively. As a BAF 2 prism was used to measure these values, this means that on average, 1 mature tree was left in and around each plot. This choice is subject to the forester who prescribed the mature residual basal area based on knowledge about each of the species.

For *P. banksiana*, being such an intolerant to shade species, it often requires full sunlight and cannot persist under anything less than 60% sunlight. Therefore, if a high number of mature residual trees are left, they may not be able sustain proper growth rates and become highly susceptible to disease and eventually die off (Rudolph and Laidly 1990). As Figure 15 depicts, a relationship between mature residual basal area, *P. banksiana* and percent defect is present with and R^2 value of 0.383 showing that with an increase in mature residual basal area comes an increase in percent defect is common. This correlates with Rudolph and Laidly (1990) in that as the residual mature basal area increases, therefore increasing shade, the higher percentage of *P. banksiana* seedlings are affected by disease and poor form. Mature residual basal area has less of an effect on *P. banksiana* in terms of mean height growth as the R^2 value is 0.144. As site condition and competition have greater effect on mean height rather than other factors, *P.*

banksiana has little correlation with the effect mature residual basal area has on their mean height growth (Dinger et al. 2019; Mohammed et al. 2001). Percent mortality has nearly no correlation to mature residual basal area in this study, however as percent defect is so high currently, it is likely that many of those trees will not survive until the next cutting cycle as they are present with UGS diseases (OMNR 2004). This information ultimately accepts the hypothesis that natural factors such as competition and mature residual basal area have more of an effect on seedling growth and survival than nurseries or container types/ sizes.

P. resinosa, is also a shade intolerant species, although more tolerant than *P. banksiana*. *P. resinosa* is a 2.4 out of 10 with regards to shade tolerance (*Tsuga canadensis* being a 10 and *Populus* being a 0.7) (Rudolph 1990). Seedlings are found to be more tolerant as seedlings but exhibit very low growth rates, supporting the hypothesis that states that mature residual basal area and other natural conditions have more of an effect on seedlings than container type and nursery practices (Rudolph 1990). Figure 15 shows very little correlation between percent defect and mature residual basal area with an R^2 value of 0.206, therefore going against this thesis' hypothesis. *P. resinosa* also exhibits no pattern with regards to mean height and mature residual basal area. Factors for this may be that although there are varying amounts of mature trees left, not enough were left to provide a significant difference for a tree that is less intolerant than *P. banksiana*. Also *P. resinosa* is a species very tolerant to damaging agents, therefore already has a low percent defect, thus no significant correlation would likely occur regardless of mature residual basal area (Rudolph 1990). A study by Palik et al. (2012) found that *P. resinosa* only responds well to large gap openings with regards to height growth and does not respond to small gap openings. Palik et al. (2012) shows similar results to those of this thesis in that since all the stands maintained relatively low amounts of mature residual basal area. They already are exposed to high light levels compared to highly shaded conditions, therefore growing at full potential is possible.

5.4.2. Shade Tolerant Species

P. strobus and *P. glauca* are generally seen as species mid-tolerant to tolerant to shade in seedling stages. As displayed in Figure 14, the average mature residual basal areas for *P. strobus* and *P. glauca* are just about $7m^2$/ha and $5m^2$/ha respectively. As a BAF 2 prism was used to measure these values, this means that on average, 3 mature trees were left in and around each plot. This choice is subject to the forester who prescribed the mature residual basal area based on knowledge about each of the species.

For *P. strobus* being a tolerant to mid-tolerant species to shade at the seedling stage and eventually becoming intolerant to shade as it matures, seedlings develop well under up to 80% shaded canopy conditions. Therefore as *P. strobus* is a slow growing species in general, not a large effect is expressed under varying light conditions. However, *P. strobus* reacts poorly to vegetative competition, and therefore, often performs poorly under clearcut conditions (Smith and Wendell 1990; Palik et al. 2012). If vegetation is under control, as it was for the most part in this study, then *P. strobus* can grow well in clearcut conditions. No major correlation is present between varying amounts of mature residual basal area. A general trend in percent mortality and percent defect is present among varying amounts of mature residual basal area. Both have slight correlations in that with a higher mature residual basal area, lower percentages of mortality and defects are present. As *P. strobus* is relatively susceptible to damaging agents such as the white pine weevil and blister rust, maintaining some canopy cover in early development can protect against these infectious diseases (Smith and Wendell 1990). As examined in the study by Farrell et al. (2016), height growth per year at age 10 is as high or higher under controlled stands versus clearcut stands. White pine weevil damage is almost non existent in shelterwood stands while in clearcut stands white pine weevil damage is up to 60%. This supports the hypothesis that natural factors such as mature residual basal area and vegetation influence *P. strobus* growth and survival. Although no major correlation is present in this thesis, a general pattern emerges that shows that an increase in shade helps mitigate the amount of damage that may incur these seedlings.

P. glauca being the most shade tolerant of the 4 species studied, is also the slowest growing, therefore it can persist in lower levels of light. *P. glauca* can persist in the understory for up to 70 years but responds well to release regardless of age of release. Therefore, they do well in clearcut conditions regardless of the mature residual basal area and vegetation competition (Nienstaadt and Zasada 1990). *P. glauca* displays little correlation between mean height growth and percent defect with regards to mature residual basal area differences. Previous studies have determined that increased light levels do allow for an increase in growth for *P. glauca* however, the studies performed examined stands with denser cover compared to clearcut while this study examines clear cuts with varying low densities of mature residual trees. It is possible *P. glauca* is receiving light to grow at a fast rate (Gradowski et al. 2008; Bradley et al. 2006). Although *P. glauca* has the lowest percent mortality in this study, it does exhibit a small correlation (R^2 of 0.392) between percent mortality and mature residual basal area. *P. glauca*, based on its morphology, is commonly affected by natural disturbances such as ice and snow (Nienstaadt and Zasada 1990). An increase in stronger residual trees can help protect the seedlings against the natural elements that may damage and kill them. Many pathogens and diseases can also affect *P. glauca*, however few were identified. Therefore, it is unlikely these seedlings were subject to disease and instead they incurred poor site quality characteristics and other natural disturbances.

6.0. CONCLUSIONS AND IMPLICATIONS

It is determined that the null hypothesis is accepted in that there is not a significant enough correlation between the container type and the growth and survival of the planted seedlings. The study by Dinger et al. (2019) determined that although there is some significance to the size of container type and the growth and survival of the seedlings, it is not significant enough to invest in these larger seedlings as after the first 10 years the seedlings do not exhibit enough difference to justify spending more on larger container types or more expensive container types.

More effort should be put into choosing the right site for the species to be planted, and there should be appropriate work done on site preparation and vegetation management techniques. As this thesis has shown with data and past research, the importance of site level management will reflect higher growth and survival of the chosen species to plant.

Factors affecting this study that were not examined but may be included in future studies of similar origin or for a return to the same sites include studying: how planting techniques may affect the performance of seedling growth; comparing identical container types across all species if possible; accessing more nurseries so as to validate that test; examining the number of natural desired seedlings within the plots; and, looking at vegetation competition as well as the mature residual basal area. Another study that may be essential for understanding the significance of species choice for outplanting and stand tending efforts would be to study the impacts of wildlife on the mortality of the seedlings. This would attempt to encompass all factors that may have affected the seedlings.

7.0. LITERATURE CITED

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APPENDICES

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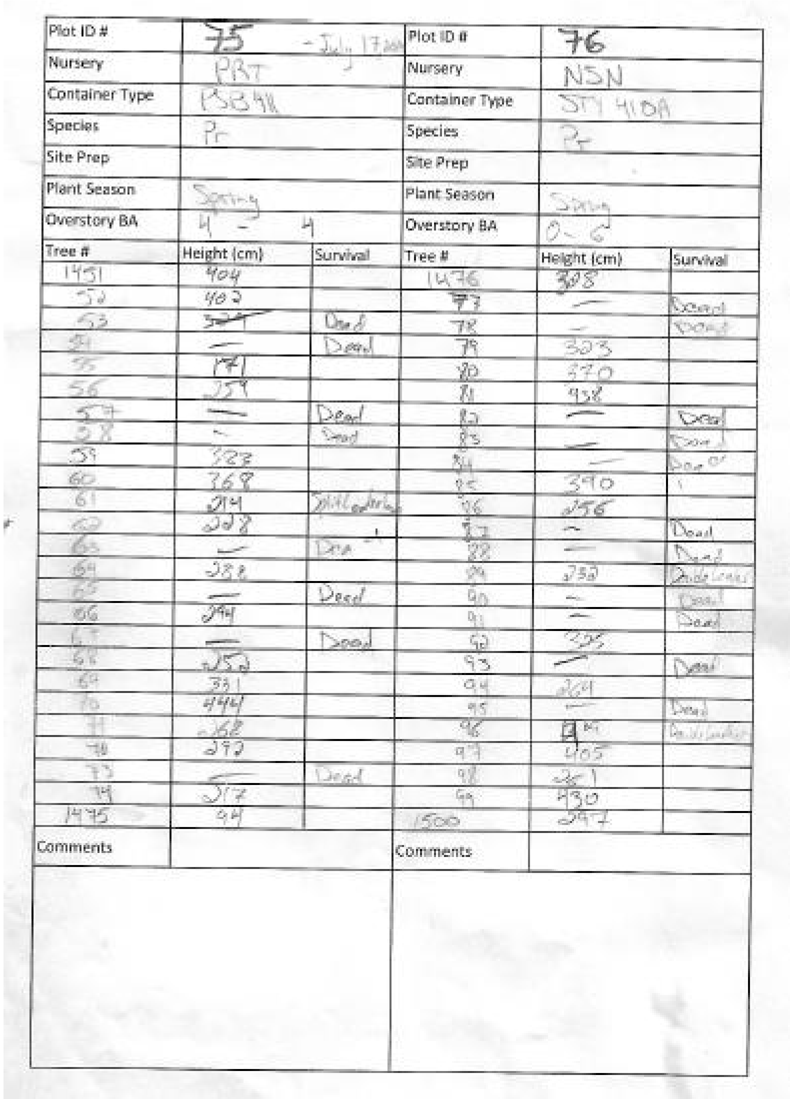

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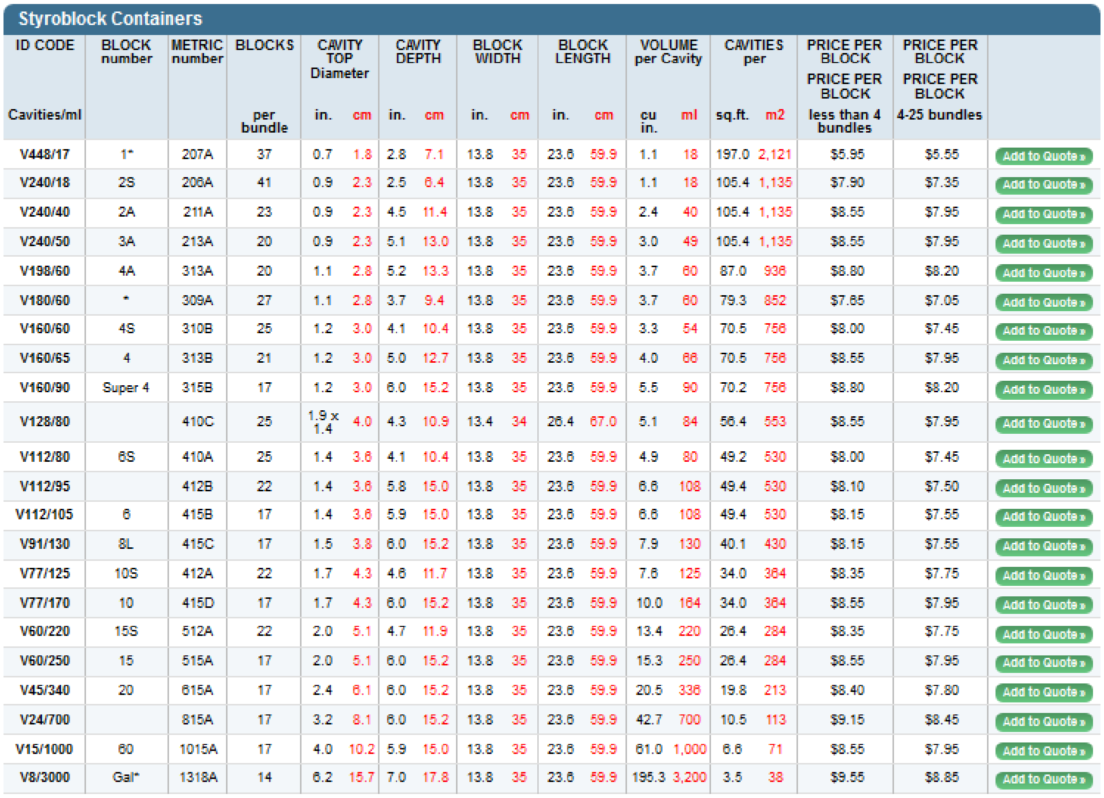
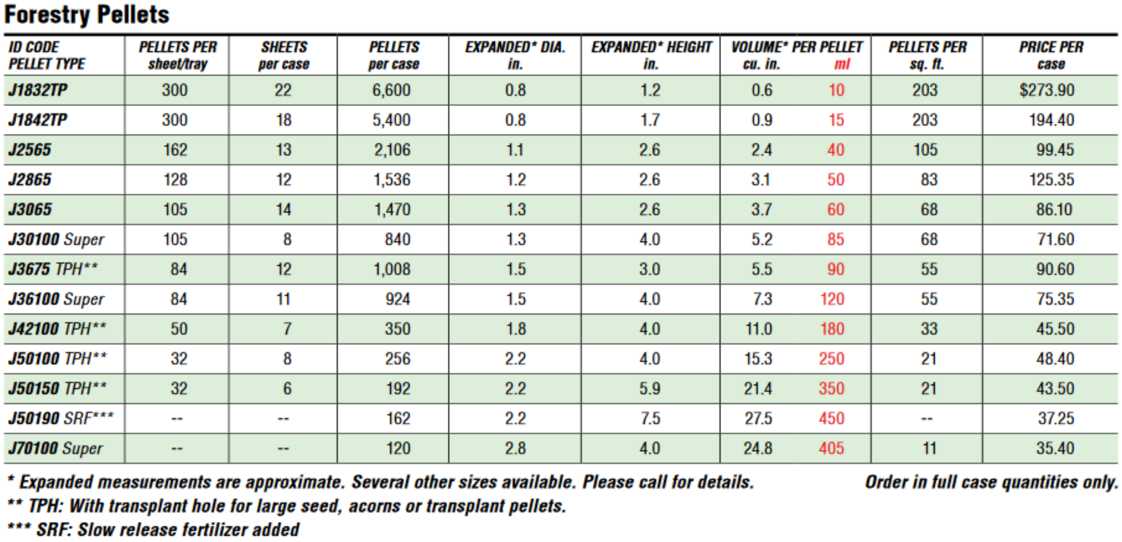
Nursery	PRT	
Container Type	PSB 4[illegible]	
Species	Pr	
Site Prep		
Plant Season	Spring	
Overstory BA	4 - 4	
Tree #	Height (cm)	Survival
1451	404	
52	402	
53	~~324~~	Dead
54	—	Dead
55	171	
56	257	
57	—	Dead
58	-	Dead
59	323	
60	368	
61	214	Split leader
62	228	
63	—	Dea
64	238	
65	—	Dead
66	294	
67	—	Dead
68	252	
69	331	
70	444	
71	268	
72	292	
73	—	Dead
74	317	
1475	94	
Comments		

Plot ID #	76	
Nursery	NSN	
Container Type	STY 410A	
Species	Pr	
Site Prep		
Plant Season	Spring	
Overstory BA	0 - 6	
Tree #	Height (cm)	Survival
1476	308	
77	—	Dead
78	—	Dead
79	323	
80	370	
81	438	
82	—	Dead
83	—	Dead
84	—	Dead
85	390	
86	256	
87	~	Dead
88	—	Dead
89	232	Double leader
90	—	Dead
91	—	Dead
92	325	
93	—	Dead
94	264	
95	—	Dead
96	[illegible]	Double leader
97	405	
98	261	
99	430	
1500	297	
Comments		



Styroblock Containers

ID CODE	BLOCK number	METRIC number	BLOCKS	CAVITY TOP Diameter		CAVITY DEPTH		BLOCK WIDTH		BLOCK LENGTH		VOLUME per Cavity		CAVITIES per		PRICE PER BLOCK PRICE PER BLOCK	PRICE PER BLOCK PRICE PER BLOCK	
Cavities/ml			per bundle	in.	cm	in.	cm	in.	cm	in.	cm	cu in.	ml	sq.ft.	m2	less than 4 bundles	4-25 bundles	
V448/17	1*	207A	37	0.7	1.8	2.8	7.1	13.8	35	23.6	59.9	1.1	18	197.0	2,121	$5.95	$5.55	Add to Quote »
V240/18	2S	206A	41	0.9	2.3	2.5	6.4	13.8	35	23.6	59.9	1.1	18	105.4	1,135	$7.90	$7.35	Add to Quote »
V240/40	2A	211A	23	0.9	2.3	4.5	11.4	13.8	35	23.6	59.9	2.4	40	105.4	1,135	$8.55	$7.95	Add to Quote »
V240/50	3A	213A	20	0.9	2.3	5.1	13.0	13.8	35	23.6	59.9	3.0	49	105.4	1,135	$8.55	$7.95	Add to Quote »
V198/60	4A	313A	20	1.1	2.8	5.2	13.3	13.8	35	23.6	59.9	3.7	60	87.0	936	$8.80	$8.20	Add to Quote »
V180/60	*	309A	27	1.1	2.8	3.7	9.4	13.8	35	23.6	59.9	3.7	60	79.3	852	$7.65	$7.05	Add to Quote »
V160/60	4S	310B	25	1.2	3.0	4.1	10.4	13.8	35	23.6	59.9	3.3	54	70.5	756	$8.00	$7.45	Add to Quote »
V160/65	4	313B	21	1.2	3.0	5.0	12.7	13.8	35	23.6	59.9	4.0	66	70.5	756	$8.55	$7.95	Add to Quote »
V160/90	Super 4	315B	17	1.2	3.0	6.0	15.2	13.8	35	23.6	59.9	5.5	90	70.2	756	$8.80	$8.20	Add to Quote »
V128/80		410C	25	1.9 x 1.4	4.0	4.3	10.9	13.4	34	26.4	67.0	5.1	84	56.4	553	$8.55	$7.95	Add to Quote »
V112/80	6S	410A	25	1.4	3.6	4.1	10.4	13.8	35	23.6	59.9	4.9	80	49.2	530	$8.00	$7.45	Add to Quote »
V112/95		412B	22	1.4	3.6	5.8	15.0	13.8	35	23.6	59.9	6.6	108	49.4	530	$8.10	$7.50	Add to Quote »
V112/105	6	415B	17	1.4	3.6	5.9	15.0	13.8	35	23.6	59.9	6.6	108	49.4	530	$8.15	$7.55	Add to Quote »
V91/130	8L	415C	17	1.5	3.8	6.0	15.2	13.8	35	23.6	59.9	7.9	130	40.1	430	$8.15	$7.55	Add to Quote »
V77/125	10S	412A	22	1.7	4.3	4.6	11.7	13.8	35	23.6	59.9	7.6	125	34.0	364	$8.35	$7.75	Add to Quote »
V77/170	10	415D	17	1.7	4.3	6.0	15.2	13.8	35	23.6	59.9	10.0	164	34.0	364	$8.55	$7.95	Add to Quote »
V60/220	15S	512A	22	2.0	5.1	4.7	11.9	13.8	35	23.6	59.9	13.4	220	26.4	284	$8.35	$7.75	Add to Quote »
V60/250	15	515A	17	2.0	5.1	6.0	15.2	13.8	35	23.6	59.9	15.3	250	26.4	284	$8.55	$7.95	Add to Quote »
V45/340	20	615A	17	2.4	6.1	6.0	15.2	13.8	35	23.6	59.9	20.5	336	19.8	213	$8.40	$7.80	Add to Quote »
V24/700		815A	17	3.2	8.1	6.0	15.2	13.8	35	23.6	59.9	42.7	700	10.5	113	$9.15	$8.45	Add to Quote »
V15/1000	60	1015A	17	4.0	10.2	5.9	15.0	13.8	35	23.6	59.9	61.0	1,000	6.6	71	$8.55	$7.95	Add to Quote »
V8/3000	Gal*	1318A	14	6.2	15.7	7.0	17.8	13.8	35	23.6	59.9	195.3	3,200	3.5	38	$9.55	$8.85	Add to Quote »



Forestry Pellets

ID CODE PELLET TYPE	PELLETS PER sheet/tray	SHEETS per case	PELLETS per case	EXPANDED* DIA. in.	EXPANDED* HEIGHT in.	VOLUME* PER PELLET cu. in.	ml	PELLETS PER sq. ft.	PRICE PER case
J1832TP	300	22	6,600	0.8	1.2	0.6	10	203	$273.90
J1842TP	300	18	5,400	0.8	1.7	0.9	15	203	194.40
J2565	162	13	2,106	1.1	2.6	2.4	40	105	99.45
J2865	128	12	1,536	1.2	2.6	3.1	50	83	125.35
J3065	105	14	1,470	1.3	2.6	3.7	60	68	86.10
J30100 *Super*	105	8	840	1.3	4.0	5.2	85	68	71.60
J3675 *TPH***	84	12	1,008	1.5	3.0	5.5	90	55	90.60
J36100 *Super*	84	11	924	1.5	4.0	7.3	120	55	75.35
J42100 *TPH***	50	7	350	1.8	4.0	11.0	180	33	45.50
J50100 *TPH***	32	8	256	2.2	4.0	15.3	250	21	48.40
J50150 *TPH***	32	6	192	2.2	5.9	21.4	350	21	43.50
J50190 *SRF****	--	--	162	2.2	7.5	27.5	450	--	37.25
J70100 *Super*	--	--	120	2.8	4.0	24.8	405	11	35.40

**** Expanded measurements are approximate. Several other sizes available. Please call for details.*** ***Order in full case quantities only.***

***** TPH: With transplant hole for large seed, acorns or transplant pellets.***

****** SRF: Slow release fertilizer added***