THE EFFECTS OF COMPETITION ON UNDERPLANTED JUVENILE WHITE SPRUCE IN FILL BLOCKS IN NORTHERN ALBERTA.

by

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An Undergraduate Thesis Submitted
in Partial Fulfillment of the Requirements
for the Degree of Honours Bachelor Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 2020

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ABSTRACT

Schumacher, M.A. 2020. The effects of competition on underplanted juvenile white spruce in fill blocks in northern Alberta. 40 pp.

This paper examined the effects of competition on juvenile white spruce growth planted in the understory of lodgepole pine on a mixedwood boreal site. Growth and success of planted white spruce seedlings were investigated under four young canopy densities. Seedlings showed no statistically significant differences in total height growth or total root collar diameter between any density. The mortality rate was found to be extremely low (3%). This finding supports the suggestion low mortality rates of underplanted species is in part the result of protection from the overstory canopy. The findings of this study can be applied to similar situations where white spruce is planted beneath an established or establishing canopy. A review of applicable literature regarding light availability and competition from shading is included.

Keywords: competition, density, fill plant, growth, height, light availability, mixedwood, root collar diameter, shading, white spruce.

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ACKNOWLEDGEMENTS

My sincere thanks go to the entire Lakehead Faculty of Natural Resources Management. I have gained a wealth of valuable knowledge throughout my years of study at this university that I have applied to the completion of this undergraduate thesis. My experience at Lakehead has prepared me well for a future in the forest.

I must thank Dave Flynn from Vanderwell Contractors Ltd. for providing the maps, block information and all other relevant information that I required regarding the study site.

I am tremendously grateful to Next Generation Reforestation for offering me the opportunity to plant with their crew and become a part of their bush family. My years as a planter have inspired me, cultivated my love for the bush and spurred the idea behind this thesis.

INTRODUCTION

White spruce (*Picea glauca* (Moench) Voss)) is an important tree species found in all forested regions across Canada excluding the far Pacific coast (Farrar 2010). It is a crucial component of boreal mixedwood forests. White spruce is a shade tolerant species but can grow under a range of sunlight conditions (Alberta Agriculture and Development 2003). As a mid-successional species, the slower growing white spruce can remain in the understory for many decades but will eventually grow through the canopy to dominate the stand (Chen and Popadiouk 2002).

Spruce trees (white spruce, black spruce, Sitka spruce and other species) are the dominant species found on Canada's landscape, accounting for 47% of Canada's total wood volume (National Forest Inventory 2018). White spruce is acknowledged as one of Alberta's most valuable commercial species. It accounts for 30% of the province's total forest inventory, and 48% of Alberta's merchantable volume of coniferous growing stock (Alberta Agriculture and Development 2003).

The wood of white spruce is highly valued for lumber, plywood and pulp production (Alberta Agriculture and Rural Development 2003). Accordingly, white spruce is a prominent species in Alberta's regeneration program. In 2010-2011, planted seedlings reforested 75% of harvested area on public land. This planted land totaled over 55 000 hectares (ha) in area and just less than 45% of that land was planted with spruce (mainly white and black spruce) (Alberta Government 2012). In 2013, over 420 000 ha were regenerated by planting in Canada (compared with only 11 197 ha seeded) (National Forestry Database 2018). The total area planted is directly correlated with the area harvested that year. All commercially harvested land must be regenerated within a few years of the original harvest.

Natural regeneration of white spruce is variably successful, so artificial regeneration is often prescribed (Lieffers and Beck 1994). Artificial regeneration through planting increases the likelihood of achieving regeneration to the desired future forest species composition (Natural Resources Canada 2014). It also allows for the maximum control of density and stocking. Another advantage of planting is the predictability of seedling establishment and future forest composition. Planting is increasingly used to ensure improved stocking of conifers, as conifers do not regenerate as easily as deciduous species such as aspen (Greene *et al.* 2002).

In Canada, planting occurs on such a large scale that in many cases, the best growing conditions are not always obtainable. Ideally, harvested sites would be assessed in terms of which species were harvested, what type of site it is, and which, if any, understory regeneration was naturally occurring. Individual species' growth requirements differ; certain species are better suited for certain growing conditions. The species that was harvested from a site may not be the same species that is eventually regenerated there. The robustness of white spruce makes it an ideal species for planting in both clearcut blocks and fill blocks across Canada.

Planting is primarily the responsibility of the forest licensees that harvest and manage the forest. However, in the case of this study site, the government of Alberta initiated a special project to plant white spruce seedlings in a previously planted, young lodgepole pine stand. This study is personally connected to my past silviculture experience. During my career as a planter, I planted trees across many regions in northern Alberta and British Columbia. The blocks from which the information for this study was collected were blocks that myself and my crew planted in the summer of 2010. It was interesting to return to previously planted blocks and observe the development of the seedlings. I questioned why certain blocks are planted if they do not necessarily possess the optimal growing conditions for that tree species. Of particular interest was whether or not increased levels of shading would hinder growth of the white spruce seedlings. Fill planting is an artificial regeneration technique used to further increase the density of a previously planted stand. New seedlings are planted in the understory of existing stands that do not meet the target density requirements of the stand.

The original stand located near Slave Lake, Alberta was planted with lodgepole pine in 2000. Naturally occurring seasonal fires burned in the area, assumingly negatively impacting tree growth in some areas. Large areas were assigned planting prescriptions based on estimates of damage as well as amounts of seedling surplus from the nursery. It was unknown to what stocking level individual stands remained at, at the time of the second (or fill) plant. The 2010 project required that white spruce seedlings be planted to fill presumed gaps left by fire. The planted spruce seedlings were added to residual standing lodgepole pine stand to achieve an overall, combined density of 1400 stems/ha.

Variables such as temperature, rainfall, soil nutrients, sunlight, and numerous other factors all can affect the establishment of conifer plantations (Brand and Janas 1987). Available sunlight and shading conditions differ greatly between fill plantations and clearcut plantations. The measures used in this study to evaluate white spruce seedling success are total height and total root collar diameter (RCD). Sampled plots were chosen semi-randomly in the field.

Objective

The objective of this study was fundamentally two-fold. The non-scientific objective of the study, borne of curiosity and personal connection, was to observe the initial success of the project and draw conclusions about fill planting projects in general. The scientific objective examined white spruce seedling growth under different lodgepole pine canopy densities, and thus different shading conditions. Statistical analysis was used to determine whether there were statistically significant differences in growth between plots of varying canopy densities. Analyses were helpful in identifying a potential threshold where increased planting or density will no longer result in increased growth.

Another goal of this report was to compare the study's results with peer-reviewed journals to determine the effects of competition and light exposure on the growth of juvenile white spruce seedlings. The results of this study were compared with prior research concerning white spruce growth under aspen and in other mixedwood scenarios.

Hypotheses

Null hypotheses (*Ho*): There will be no statistically significant difference in height and/or root collar diameter (RCD) growth of white spruce seedlings between plots with varying densities of residual lodgepole pine trees.

Alternative hypothesis (*Ha*): There will be a statistically significant difference in height and/or root collar diameter (RCD) growth of white spruce seedlings between plots with varying densities of residual lodgepole pine trees.

LITERATURE REVIEW

White spruce is a critical tree species in mixedwood boreal forest stands across Canada. Boreal mixedwood stands as defined by MacDonald (1995) are sites

> "with climatic, topographic, and edaphic conditions that favour the production of closed canopy stands dominated by trembling aspen (*Populus tremuloides*) or white birch (*Betula papyrifera*) in early successional stages, black spruce (*Picea mariana*) or white spruce (*Picea glauca*) in mid-successional stages, and balsam fir (*Abies balsamea*) in late successional stages."

MacDonald (1995) proposed, "a boreal mixedwood stand is a tree community on a boreal mixedwood site in which no single species comprises 80% or more of the total basal area." This wide, belt-shaped region that stretches across Canada, is characterized by a complex and dynamic mosaic of forest types that vary both structurally and in the composition of broadleaf and conifer tree species. It is a highly productive and diverse ecosystem influenced by a spectrum of climate, soil and disturbance factors (Bergeron *et al.* 2014). Canadian boreal mixedwood stands are found mainly on mesic sites reaching from the east to west coasts, and are composed of white spruce (*Picea glauca* (Moench) Voss)), balsam fir (*Abies balsamea* (L.) Mill.), trembling aspen (*Populus tremuloides* (Michx.)) and additional minor species (Lieffers *et al.* 1996). Throughout the boreal range, although major species abundances vary, white spruce maintains its presence in virtually all forested regions.

White spruce is a mid to late successional species that possesses the ability to tolerate shade during most stages of growth (Farrar 2010). It can withstand moderate brush and grows steadily in the understory, reaching the canopy after 50-90 years (Huang *et al.* 2013). Being suppressed for most of its early life, it recovers well once gaining an increased exposure to light. Its presence in the understory is especially common in stands with multiple cohorts. Aspen, a pioneer species, usually establish first, followed years later by the white spruce (Huang *et al.* 2013, Lieffers *et al.* 1996).

Many studies focus on spectrums of tolerance to different factors; however, less research is available on optimal growing conditions. Current research results are varied regarding optimal growing conditions for many species including white spruce. Optimal growth requirements are more specific and difficult to precisely demonstrate. Nature does not always provide ideal growing conditions, as there are many dynamic factors simultaneously in action, each influential to varying degrees.

Factors that Affect Growth

The term growth is defined as an increase in any of height, diameter, biomass, or crown dimensions. Juvenile seedling growth is affected by several internal and external factors including but not limited to, genetics, climate, water, temperature, light, seedbed substrate and soil nutrient availability. For the purposes of this study, total height and total diameter growth relative to light exposure will be the key focus.

Light Availability

The light in forests is constantly changing in both intensity and direction (Lieffers *et al.* 1999). Light availability changes as you move through the canopy layers. The amount of light transmitted to the ground level will be different than the amount of light available to the top reaches of the canopy. Logically, the higher the position in the canopy, the greater the light exposure.

The main factors affecting understory light environments are total leaf area, live crown height, spatial distribution of the trees, sun angle, sky conditions, and tree species (Messier 1996). Even in relatively uniform stands with a relatively dense overstory, there is significant spatial variation in light transmitted to the understory (Lieffers *et al.* 1999).

Variation in understory light quantity can be related to overstory canopy type, specifically the composition of deciduous and coniferous tree types. The presence of aspen or birch tends to increase understory light quantity when compared with conifer-dominated stands (Messier 1996). Lieffers and Stadt (1994) also proved a direct relationship between hardwood basal area and light, in that the greater the hardwood basal area the more light was transmitted by the canopy (aspen being the dominate species with some balsam poplar). Conversely, the greater basal area of softwood (mostly white spruce) the less light was transmitted to the understory (Lieffers and Stadt 1994). Mixedwood stands dominated by hardwood had 14 - 40% light transmittance. Stands with the lowest light transmittance were more densely populated by mature white spruce (Lieffers and Stadt 1994). In spruce-aspen mixedwoods, the higher percentage composition of spruce in the overstory, the less light is transmitted to the understory (Lieffers and Stadt 1994). Constabel and Lieffers (1996) found that in sampled Alberta mixedwood forests, light transmission to the ground level was as low as 6%. An immature overstory such as the lodgepole pine canopy in this study would presumably allow more light to reach to the understory than in a mature stand.

Light Levels and Growth Effects

The effects of light exposure on white spruce growth have been extensively researched. Generally, understory spruce growth seems to be more impeded by low light levels under conifer-dominated canopies than under aspen-dominated canopies. White spruce has been shown to endure light levels as low as 8% full sunlight (Lieffers and Stadt 1994). Their study found that in stands below 8% transmitted light, white spruce saplings were almost entirely absent. Comparably, Logan's study (1969) found that white spruce remained alive in their lowest light treatments of 11 and 13%. Kobe and Coates (1997) projected increased mortality of white spruce (likely to exceed 20% of the sample) when light levels are below 5% and 15%, respectively. Huang *et al.* (2013) showed poor conifer growth under dense hardwood stands was linked to exceptionally low light levels (under 20%). Herbaceous cover such as grasses and low shrubs will also affect light availability to the understory.

Chen (1997) found that planted spruce (Engelmann spruce, *Picea engelmannii* (Parry ex Engelm.)) displayed the highest survival figures (almost 100% survival) compared to non-spruce species over the first three growing seasons. These successful rates were observed consistently over all light conditions. Groot (1999) demonstrated high success in white spruce seedling growth when exposed to full (100%) sunlight in clearcuts. A clearcut regenerated (specifically planted) before any initial return of herbaceous vegetation, would experience full sunlight conditions. In all study sites and treatment combinations, the survival rates were quite high (averaging above 80%) (Groot 1999). These results all prove that white spruce can grow successfully under full light conditions.

The height growth of conifer seedlings or saplings generally increases with increases in light and may reach maximum levels at or close to full sunlight (Coates and Burton 1999; Comeau *et al*. 1993). Conversely, there is also evidence supporting a height growth plateau theory related to light exposure (Comeau *et al.* 1993; Lieffers and Stadt 1994; Logan 1969; Man and Lieffers 1997). Lieffers and Stadt (1994) have shown a growth plateau in height above 40% light levels. Their study showed that white spruce height growth at around 40% sunlight was approximately equal to height growth exhibited in open-grown sites. Logan (1969) also reported height growth in white spruce reached a maximum at 45% full sunlight in a controlled artificial shade experiment. Coates and Burton (1999) demonstrated a plateau in height growth at levels above 60% in interior British Columbia.

Effects on Height versus Diameter

Groot (1999) argues that poor growth performance in height and diameter is directly related to low light levels. He found that both height and diameter growth was poorest under fully intact canopies. However, height growth and diameter growth respond differently when exposed to equal light levels. Controlled experiments have shown that diameter increases with light levels up to 100% (Logan 1969). However as stated above, height growth continued but slowed between 45 and 100% light. These results indicate that diameter growth of conifers is more sensitive to competition than height growth (Lanner 1985).

Jobidon (2000) also found that white spruce diameter was more greatly affected by low levels of vegetation than by height growth. Height growth was more greatly affected by moderate or high levels of competing vegetation, rather than lower vegetation levels (Jobidon 2000).

Height to diameter ratio (HDR) has been proposed as an alternative competition index in determining the vigour of crop trees. HDR is an individual tree-based index, which is calculated by dividing the height of the crop tree either by the diameter at the root collar or diameter at breast height (DBH) of the tree (Opio *et al.* 2000). Increases in the HDR with increases in competition have been widely reported (Lieffers and Stadt 1994, Opio *et al.* 2000). A large height to diameter ratio generally indicates rapid height growth coinciding with a disproportionate diameter growth (Jobidon 2000). These trees expend more energy growing upwards than outwards, suggesting that they are less stable and likely more susceptible to damage and stress (Jobidon 2000).

The ratio of tree height to diameter for spruce increases with decreasing light intensity (Lieffers and Stadt 1994). They found that average leader length reached a maximum at about 40% light (similar results to open stands). Leader length of spruce saplings decreased with decreasing transmitted light (Lieffers and Stadt 1994). The reduction in height to diameter ratio in full sunlight and increase in leader diameter shows that height alone is not the only measure of success. Lieffers and Stadt (1994) found that white spruce will add more biomass at light intensities over 40%.

Competition

Competition plays an important role in growth, composition, structure, and succession of boreal mixedwood stands (Huang *et al.* 2013). Quantifying the effects of competition can help enhance a better understand of forest growth and dynamics, as well as improve forest management decisions (Huang *et al.* 2013).

Competition for light is asymmetric, where larger trees suppress smaller trees more greatly than smaller ones suppress larger ones (Lieffers and Titus 1989). Logically, it can be assumed that the underplanted species would be far more shaded by the overstory, than the reverse effect. Trees increasingly compete for resources such as light, soil moisture and nutrients as they develop in size, leading to decreases in stem density (Huang *et al.* 2013).

Huang *et al.* (2013) conducted a study that examined the effects of competition on white spruce. They found mixed results in their study of four different regions within Alberta. In two of the regions, deciduous competition was found to have a greater effect on spruce growth, while in the other two regions coniferous competition had the greater effect. This effect was a non-linear decrease in spruce growth with increased deciduous or coniferous competition (Huang *et al.* 2013). In a study of controlled mixtures of white spruce and aspen, it has been shown that white spruce grown without aspen had significantly higher rates of height and diameter growth (Kabzems *et al.* 2007).

It is generally accepted that when under competition from aspen, white spruce seedlings are shown to have reduced growth and survival (Filipescu and Comeau 2007). Neufeld *et al.* (2014) found that total competition negatively affected white spruce growth, however there was a negligible difference in the competitive effect based on species (aspen versus spruce). Kabzems *et al.* (2007) found that an increasing density of aspen between 1000 and 10 000 stems per hectare did not significantly affect the height and diameter growth of white spruce seedlings. Open grown white spruce were found to have significantly greater height and diameter growth that sites that retained aspen (13 - 17-year-old spruce). Therefore, that although competition has been proved to negatively affect white spruce growth, increased competition levels are not always linearly correlated. The witnessed negative growth may not exclusively be the result of available light, as there are other competitive mechanisms occurring.

In addition to aspen, competition from lower herbaceous vegetation including shade intolerant grasses has resulted in slow growth and mortality of white spruce. This was observed in many white spruce plantations across the three Prairie provinces (Alberta, Saskatchewan and Manitoba) (Lieffers and Beck 1994). It is well known that white spruce survival and growth during the stand establishment phase can be significantly affected by competing vegetation (Morris and MacDonald 1991). The optimal growth of conifers is commonly achieved by maintaining competition below critical levels from an early age (Jobidon 2000). However, later in succession when the plantation is entering the stem exclusion stage of stand development, lower vegetation has less of an effect (Neufeld *et al.* 2014).

Light gaps

Light gaps are found when there is an opening in the canopy to allow sunlight to filter through into the understory. These gaps can occur when a disturbance event occurs or during the natural succession of a forest. As the size of the opening increases, the amount of light reaching the centre of the gap also increases (Lieffers *et al.* 1999).

Conifers are often at an advantage in smaller openings because their needles have a high photosynthetic efficiency even under low sunlight without experiencing the heat, water, and light stress that occur in large gaps and openings (Chen and Klinka 1997). Coates and Burton (1999) found that both diameter and height growth rates of interior spruce planted in gaps under a conifer-dominated mixed stand increased continuously up to full sunlight. Site factors related to soil and moisture conditions affect gap dynamics, but their influence is less obvious compared to light availability (Chen 1997).

Gaps can be achieved through management by manually creating gaps. One way in which foresters attempt to influence the available light to the understory, is through shelterwood cutting.

Shelterwood Harvesting

Interest in partial cutting and mixedwood management has inspired research relating to establishment and growth of trees under shade conditions. Competition can offer positive effects on the early growth of planted seedlings. White spruce has been shown to benefit from shelter provided by an overstory or close competition (Man and Lieffers 1999*a*). Juvenile white spruce seedlings are susceptible to damage by late-spring frosts (Groot and Carlson 1996). High survival rates of white spruce seedlings may be due to reduced frost damage and protection from extreme weather exposure. Such weather exposure can include high temperatures, severe wind, and sun scorching from their positioning in the understory (Stewart *et al.* 2000). The beneficial effect of shelter on protecting against frost did not outweigh the essential requirement of sunlight. Groot (1999) found that white spruce height growth and diameter growth was generally poorest in their treatments with fully intact overstory. His study suggests that there may be an ideal combination of vegetation control and sheltering that could create optimal environmental conditions for height growth of white spruce (Groot 1999).

Shelterwood systems are created by gradually removing the old stand with incremental cuts, while simultaneously introducing the next stand under the older trees (Man and Lieffers 1999*a*). Partial canopy of shelterwoods can provide less extreme environmental conditions than clearcuts. Conditions of a shelterwood system relative to a clearcut include higher humidity and soil temperature, lower maximum air temperature and occurrence and severity of night frost and a light regime that was nearly optimal for height growth of juvenile white spruce (Man and Lieffers 1999*a*).

In favour of shelterwood cuts, it has been shown that grasses and low shrubs (*C. canadensis and E. angustifolium*) were suppressed to varying degrees with any amount of light cover (Lieffers and Stadt 1994). The edge effects of shelterwood cutting could provide enough shading to inhibit their growth, thus contributing to less initial competition for crop trees. Overstory can help inhibit growth of very shade intolerant shrubs, herbs, grasses with limited effect on the growth of the target understory crop trees (Lieffers and Stadt 1994).

Regeneration and Planting

There are two predominant methods of forest tree regeneration - natural and artificial. Natural regeneration occurs through seeding, sprouting and root suckering. White spruce is reliant mainly on seeding and seed dispersal for natural regeneration. There must be enough viable seed carried to and distributed on favourable growing sites in order to germinate.

Because natural regeneration is highly unpredictable, artificial regeneration is commonly used to establish the desired forest. Planting is an artificial regeneration technique with a high degree of certainty in terms of regeneration species and stocking. Residual stems or brush competition, site preparation, and fertilization are the main influences on naturally occurring, site-specific resources available to planted trees (Brand and Janas 1987).

Planted seedlings are typically grown from seed in nurseries until they are lifted. The seedling has had time to develop from seed, its roots established and its branching beginning. Planted seedlings begin growth in the ground at a later stage in life than naturally occurring seedlings, thus giving stems are more competitive advantage.

Mixedwood Management

In a mixedwood forest, species develop interdependence to maintain balance. Each species occupies its own niche and plays a unique role in the succession of the forest. Trembling aspen and white spruce are commonly found together in mixed stands in the boreal forest (Huang *et al.* 2013). Many studies have been conducted on the frequent coexistence of white spruce and hardwood species such as aspen (Kabzems *et al.* 2007; Man and Lieffers 1997). Many times, if stands remain undisturbed for long periods, they will likely become uneven-aged mixtures of spruce and balsam fir.

The reduction of pest attack and increase in wind stability are two benefits, among others, of mixedwood forests (Man and Lieffers 1999*b*). Additionally, Man and Lieffers (1999*b*) argue that certain species interactions could potentially produce even greater yield in a mixture scenario than individually. There is evidence that this relationship exists between aspen and white spruce, but no concrete proof has specifically linked lodgepole pine and white spruce.

White spruce wood has a high commercial value (Lieffers and Beck 1994). Regulations and silvicultural treatments have been largely aimed at promoting commercially valuable species like white spruce (Lieffers and Beck 1994). However, silvicultural operations in Alberta have focused on establishment and growth of relatively pure stands of white spruce. Even aged monocultures of white spruce in naturally mixedwood zones could sustain long term problems and overall growth decline (Jobidon 2000). In recent years, with the devastation of the mountain pine beetle and increasingly intense seasonal fires, ecologists are becoming increasingly interested in the effects of mixedwood forests. Continuing in the future, management systems will likely move away from single-species plantation and promote more mixed forests (Lieffers and Beck 1994).

METHODOLOGY

Study Site

The study area is in a boreal mixedwood region in central Alberta near the Town of Slave Lake. The study was carried out within Forest Management Area (FMA) S7, the smallest of all management units (FMU) in Alberta. Figure 1 is a map of the Forest Management Agreement boundaries in Alberta. FMA S7 is the circled red area. It is under the operation of Vanderwell Contractors (1971) Ltd.

The data was collected from fill plant blocks with fourteen-year-old established lodgepole pine trees (Fill planting occurs when the original stand does not meet the target stocking levels. Additional seedlings are planted in the "gaps" throughout the stand to increase density.). The young lodgepole pine on site had also been manually planted. The blocks are on an upland boreal mixedwood site that supports lodgepole pine, aspen, planted jack pine and planted white spruce. No site preparation had been done prior to planting of the white spruce seedlings, as there is a higher risk of disturbance to the established trees by machinery and equipment used in the process.

The blocks are located near roadside off Highway 2, approximately 45 km southeast of Slave Lake, Alberta (the nearest kilometer marker is km 48). Figure 2 is the map with latitudes and longitudes used to locate the blocks. Measurements were gathered from three separate blocks. Blocks numbered 104, 105 and 106 were all within a few kilometers of each other on similar latitudes and longitudes north of the highway. Block 104 was 27.8 ha; block 105 was 34.2 ha; block 107 was 118.1 ha. A total of 85 680 seedlings were prescribed for planting amongst the lodgepole pine in these three blocks.

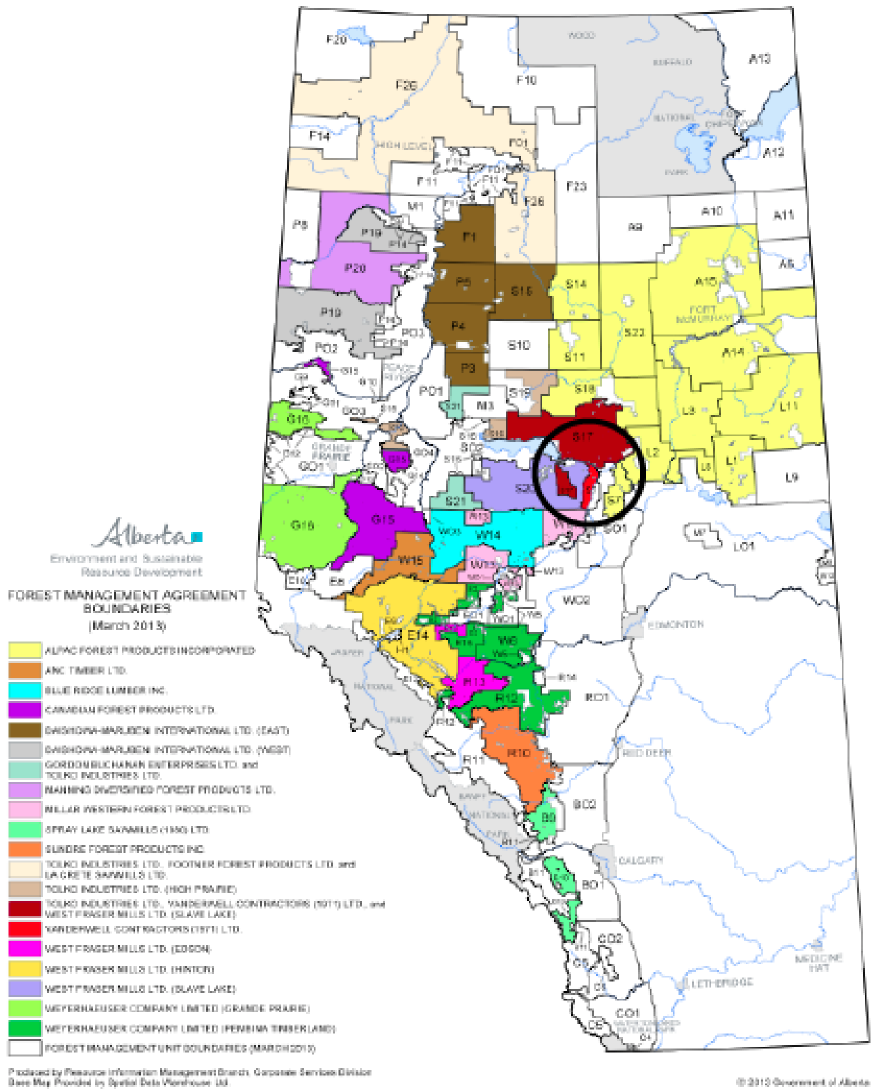

Figure 1. Alberta's Forest Management Areas.
Source: Government of Alberta 2013

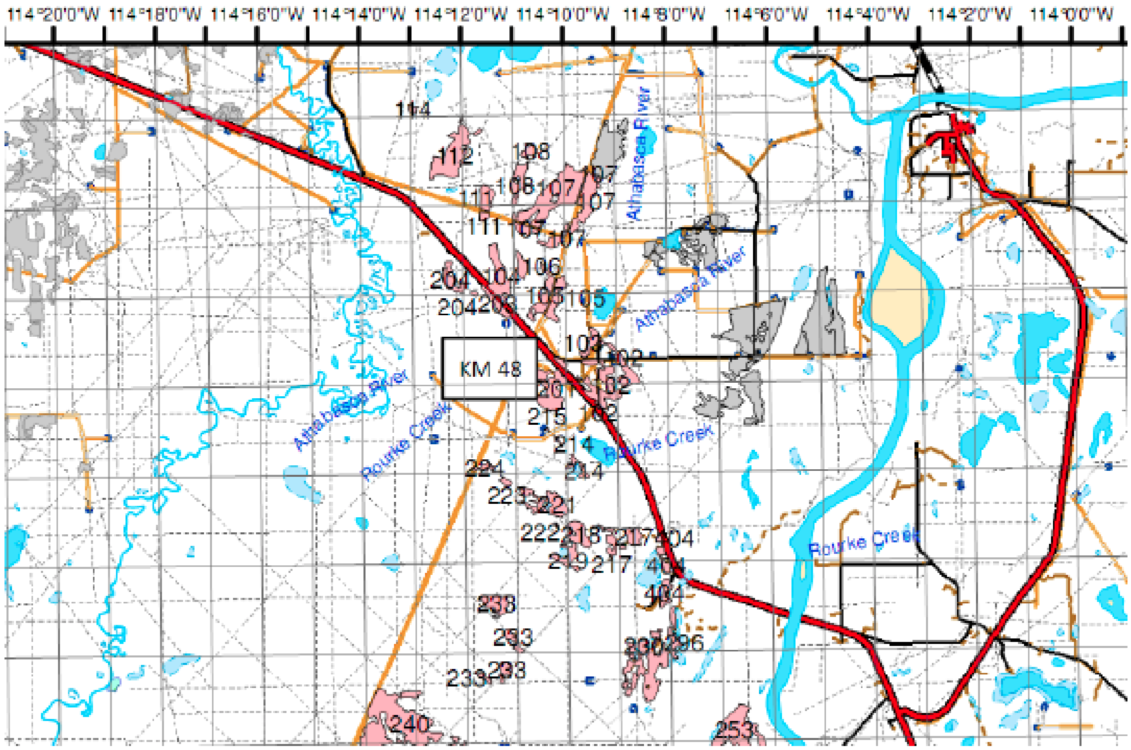

Figure 2. Vanderwell blocks and location map.

Source: Vanderwell Contractors 2010

Background

In 2001 the Chisholm Fire, ranked as a class 'E' fire devastated a vast area around Slave Lake. Vanderwell's FMU (S7) was the most severely affected of any of the FMUs. More than 11 000 hectares within FMA S7's net land base was lost, impacting over 69% of their conifer stock (Government of Alberta 2001).

The planting stock was a plugged white spruce stock supplied by Chinook Nursery Ltd. located in Medicine Hat, Alberta. Nursery stock are grown in a controlled greenhouse environment; exposure to light, watering levels, air and soil temperatures are strictly regulated and applied consistently to all growing stock. The stock was lifted the same day, meaning that all seedlings were boxed and maintained under same conditions for the same amount of time before being distributed for planting purposes.

The three stands from which data was collected, were of the same ages of pine trees and spruce trees. The three stands were alike ecosite types. The soils were sandy and competing vegetation was minimal. Grasses (genus's unidentified) were the most abundant type of understory competing vegetation.

The goal of the 2010 fill plant was to reach an overall density of 1400 stems per hectare. An overall density of 1400 stems per hectare equates to an average of seven trees per plot. Seedlings were to be planted at an optimal spacing of 2.1 m apart and no closer than one metre. Spacing off pine and spruce was to be the same. Figure 3 is a photo taken in block 104.

Figure 3. Vanderwell fill block 104, Slave Lake.
Source: Photo by Melissa Schumacher 2013

Experimental Design

Measured competition was exclusively conifer competition, more explicitly the residual pine trees that had been planted in 2000. Competition was assessed by the creation of four groups to categorize different densities. Categories were based on the number of residual pine trees in the plot. Category one: zero residual trees, category two: one to four residual trees, category three: five to seven residual trees, category four: eight or more residual trees. Fifteen plots from each category were sampled to total 60 plots. Twenty plots were taken from each of the three blocks. The plot locations were not fixedly predetermined from maps. Instead, plots were mostly chosen at random on the ground level by walking through the blocks. Certain plots had to be selected over others to fulfill the requirements of each density category. To control as many variables as possible, sites were selected with similar site qualities and flat slope. Aspen presence was also avoided in plot selection.

Measurement and Sampling

All data was collected between August 16th and October 12th, 2013. A total of 248 white spruce trees were measured in 60 plots.

Using a standard 3.99 metre plot cord, the number of juvenile spruce stems per plot was counted. A plot cord with a 3.99 m length is a plot area of 0.005 hectares or 50 square metres. The number of lodgepole pine trees within the plot was counted and assigned to one of the density categories. Once all counts were recorded, necessary measurements were then taken.

To find diameters of the spruce seedlings, an electronic diameter instrument was used. The small caliper arms were fitted around the base of the stem outside of the bark, at the level of soil. The reading was given in millimetres and accurate to two decimal places. Heights of the spruce trees were taken with a measuring tape and recorded in centimetres (to the nearest 0.01 cm). Height was measured from the base of the stem at the soil to the top point of the leader.

Next, a second measure of number of pines trees within proximity to each white spruce was taken. This approach still used the original 60 plots however, rather than grouping the number of pine trees into categories, the exact number was recorded. The number of pines within three metres (as opposed to 3.99 metres) of each of the 248 white spruce seedlings was counted. It is important to note that all pine trees within three metres but growing outside of the original plot were omitted from count. In some instances, there were no pine trees within three metres of a spruce seedling, whereas in other instances there were multiple pine trees counted within the three metres.

White spruce mortality was tallied by was determining if the sapling was alive or dead. The needles of dead saplings were either non-existent or brittle to the touch. The density category in which the dead seedling was found in was also recorded.

Analysis

Statistical testing was conducted in an IMB statistical analysis program called SPSS Statistics™. Descriptive statistics and a one-way analysis of variance (ANOVA) were analyzed. A one-way analysis of variance (ANOVA) is a helpful tool when analyzing the differences between group means and among multiple groups. It is used to determine whether there are any statistically significant differences between the means of multiple independent groups. In this study, independent groups were the four density categories. Analysis of variance used a p-value of 0.05 (95% confidence intervals).

Regression analysis was also conducted to determine the strength of the relationship between competition (number of adjacent pine trees) and height or diameter.

RESULTS

A total of 248 white spruce trees were measured in 60 plots. Although the same number of plots were measured from each density category, the total number of juvenile seedlings sampled was not equal between the four density categories. Plots with more pine trees in them should logically have fewer spruce seedlings planted to achieve the density goal was 1400 stems/ha (or seven stems per plot). Table 1 and Table 2 show the number of seedlings sampled from each category. The number of measured individuals does indeed follow this logic; the highest number of spruce seedlings was found in plots with zero pine, while the least number of spruces was found in plots with eight or more. Essentially, there should be zero spruce seedlings found in plots with eight or more pine trees if the planting was completed correctly to meet specifications. This was not the case, as there were 32 spruce seedlings found planted in category four.

Table 1 is a summary of the spruce height measurements. At the time of survey, the spruce were three years old. The greatest mean height (36.7 cm) was in plots with five to seven pine trees. The smallest mean height was in the plots with eight or more pine trees (32.7 cm). The maximum height in the eight and over category was also the lowest maximum height observed in any of the four categories.

Table 1. White spruce seedling height summary.

Density category	Number of trees sampled	Mean height (cm)	Minimum height (cm)	Maximum height (cm)
0	93	35.31	12.00	58.20
1-4	82	36.00	18.90	51.90
5-7	41	36.59	17.50	53.20
8+	32	32.71	13.10	51.00
Total	248	35.41	12.00	51.00

Source: SPSS AVONA output 2014

Table 2 is a summary of the root collar diameter measurements. The greatest mean RCD (6.6 mm) was also found in the plots with five to seven pine trees. The range of means was relatively small (0.45 mm). The lowest mean (6.1 mm) RCD was in the plots with zero pine trees. Minimum and maximum RCDs were not consistently correlated with competition from the pine.

Table 2. White spruce seedling RCD summary.

Density category	Number of trees sampled	Mean RCD (mm)	Minimum RCD (mm)	Maximum RCD (mm)
0	93	6.11	2.98	12.13
1-4	82	6.14	3.81	10.05
5-7	41	6.56	2.82	14.60
8+	32	6.12	3.31	9.06
Total	248	6.20	2.82	14.60

Source: SPSS AVONA output 2014

As stated, 248 seedlings were measured in sixty plots. Within those sixty plots, eight seedlings were dead. Measured trees plus dead trees among plots totaled 256. The calculated mortality is 3.1% (eight dead of potential 256).

Data Analysis

Table 3 shows the one-way analysis of variance (ANOVA) results of 1) height between and within density categories and 2) RCD between and within density categories. The level of statistical significance was set at ($p < 0.05$) with a confidence interval of 95%. The computed p-value for height ($p = 0.294$) was greater than 0.05, expressing no statistically significant difference was found between heights among density categories. The p-value for RCD ($p = 0.487$) was also greater than 0.05, similarly expressing no statistical significance among the density categories.

Table 3. One-way ANOVA results of height/diameter and density category at a 0.05 significance level ($p = 0.05$).

		Sum of Squares	df	Mean Square	F	Sig.
Height	Between Groups	318.426	3	106.142	1.244	.294
	Within Groups	20824.407	244	85.346		
	Total	21142.833	247			
RCD	Between Groups	6.484	3	2.161	.813	.487
	Within Groups	648.265	244	2.657		
	Total	654.749	247			

Source: SPSS ANOVA output 2014

Figure 4 generates a linear expression of the relationship between competition (number of pine trees) and height. The plotted points used all influential pine trees, rather than the density groupings. The r-squared (R^2) value for the relationship between height and competition is 0.0027. Root collar diameter showed an even weaker correlation than height. Figure 5 expresses a linear relationship between competition (number of pine trees) and RCD. The R^2 value for the relationship between RCD and competition is 0.0019. The calculated R^2 values for both correlations are extremely low, meaning that the data does not correlate well.

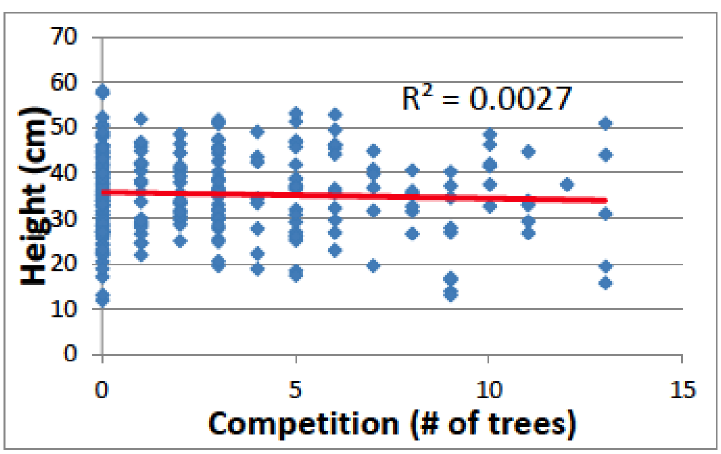

Figure 4. Competition regression versus height
Source: Graphical representation of data 2014

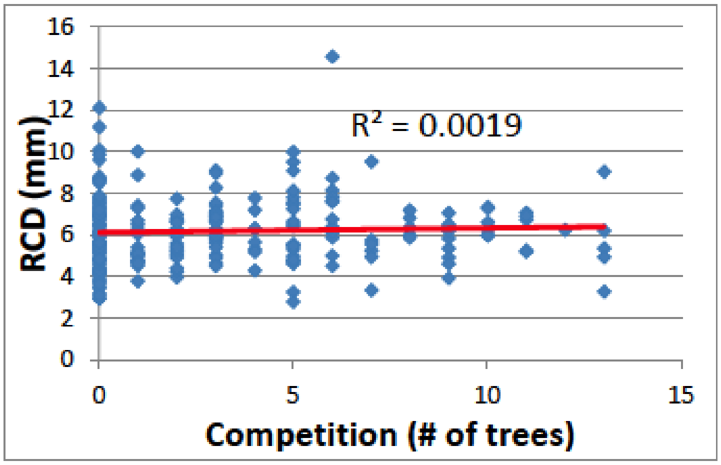

Figure 5. Competition regression versus RCD
Source: Graphical representation of data 2014

Table 4 shows the one-way analysis of variance (ANOVA) results of total height and the number of pine within three metres. Again, the level of statistical significance was set at ($p < 0.05$) with a confidence interval of 95%. The computed *p*-value for height ($p = 0.469$) was greater than 0.05, expressing no statistically significant difference was found between height number of pine trees within three metres. The *p*-value for RCD ($p = 0.973$) was also greater than 0.05, similarly expressing no statistical significance between RCD and number of pine trees with three metres. No graphical representation was created, as the data was too insignificant.

Table 4. One-way ANOVA of total height and number of pine within three metres at 95% confidence interval ($p = 0.05$).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	569.778	7	81.397	.950	.469
Within Groups	20573.056	240	85.721		
Total	21142.833	247			

Source: SPSS ANOVA output 2014

Table 5. One-way ANOVA of total RCD and number of pine within three metres at 95% confidence interval ($p = 0.05$).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.689	7	.670	.247	.973
Within Groups	650.060	240	2.709		
Total	654.749	247			

Source: SPSS ANOVA output 2014

DISCUSSION

The null hypothesis must be accepted, as no statistically significant differences were found between plots of varying pine densities. The anticipated relationship between 1) competition level (number of pine trees in a plot) and total height growth and, 2) competition level and total root collar diameter growth was found to be statistically insignificant. The alternative hypothesis stating there will be statistically significant differences must be rejected. Finding no statistical significance does not mean that the results of this study are in themselves insignificant. This discussion will compare the findings of this study to the results of past studies, drawing relevant conclusions.

The lowest mean height (32.7 cm; over two cm smaller than height in any of density category) was observed in the category with the most competition (eight or more residual pine trees). This is perhaps the most valuable numeric result of the study. Many studies support height growth reduction under shade conditions (Groot 1999; Lieffers and Stadt 1994; Stewart *et al.* 2000).

Although the mean RCD (6.12 mm) was not the smallest of means, the maximum RCD was considerably smaller than the maximums in any other density category. Independently, this figure is not enough to compare with other studies that prove conifer diameter growth is more sensitive to light exposure than height (Jobidon 2000, Lanner 1985). These results were inconsistent with other studies that did not find strong relationships between diameter and light levels (Coates and Burton 1999) or competition. The lowest mean RCD is contradictory to other findings, and contradictory to height to diameter ratio implications. Should grow equally tall and wide with less competition.

The mean height of white spruce seedlings in this study (35.4 cm) compared to Kabzems (2001), was 8.6 cm shorter. In Kabzems (2001), two different opening sizes were created in the canopy and growth responses of planted white spruce were observed. He found that over the same duration of time as this study (a three-year period or three growing seasons), artificially regenerated white spruce seedlings averaged 44.0 cm in height (20% greater total height). Although this study measured seedlings in a fill block, comparing Kabzems' seedling heights to the plots with no pine could show a closer comparison; the plots with no pine would more closely mimic canopy gaps. In comparing these two scenarios instead of the entire study, the seedlings were exposed to similar light conditions. However, the mean height of white spruce seedlings in plots with zero pine trees (35.3 cm) was still significantly lower than the findings from Kabzems (2001).

The lower overall growth rates suggest that the plot size used may not actually mimic canopy gaps, as the openings were relatively small in comparison to true canopy gaps, or gaps created in Kabzems (2001). Furthermore, it is possible that the difference in light transmission was negligible between plots of varying densities.

As previously referenced, Lieffers and Stadt (1994) argue that spruce may persist so successfully in the understory due to its ability to survive and grow slowly under aspen canopies at light levels as low as ten percent of full sunlight. If then, the light transmission was similar (and other variables remained the same) but the overstory was comprised of a different species such as lodgepole pine, it could be argued that understory white spruce would too, grow successfully regardless of overstory species type.

Mortality

Stewart *et al.* (2000) found 2 - 4% mortality rates of underplanted white spruce compared to seedlings planted in clearcuts in Alberta. Man and Lieffers (1999*a*) also found reduced seedling mortality in shelterwood systems. Jobidon (2000) reported no significant difference in spruce mortality among different treatments over the first four years of their study. Their mortality rates were between 1.7 and 5.0%, comparable to the 3.1% mortality observed in this study. He suggests that mortality occurring during the first few years after planting may be independent of competition effects. A likely cause of any mortality observed in this study, could be manual planting error and inconsistencies (discussed below).

Study Weaknesses

It is important to bring to the reader's attention any identified weaknesses of the study. The greater number of uncontrolled variables, the greater degree of uncertainty there will be. Factors other than competition such as soil moisture and nutrient availability may have a greater influence on white spruce growth at the juvenile stage. These topics were outside of the scope of this study but is worth noting as uncontrolled variables.

Planting quality and consistency is a factor that will certainly have affected seedling growth from its initial insertion in the ground. The planting was completed by numerous planters with different planting techniques. It is highly unlikely that the same planter planted all the trees sampled for this study, as the area sampled was relatively large. Although areas were assessed by a quality checker, it is impossible to check tree quality of every stem. Poorly planted trees would start at a disadvantage, having first to overcome obstacles like shallow plugs, leaning stems and bent roots before contributing energy to height and diameter growth. If underplanting of spruce was to be studied in the future, planting standards and consistency would have to be enforced.

All data used in this study was collected over a two-month period (August to October). Particularly in northern Alberta, the months of May to October generally exhibit good growing conditions regarding temperature and frost, making it a crucial time for sapling growth. The saplings measured in the last phase of data collection were given more time to grow in height and RCD. The study did not differentiate which seedlings were measured in which month. It is likely that there were unidentified differences in growth in the data.

This unaccounted-for shading likely came from any pine and/or aspen trees that fell outside of the individual plot, yet still within an influential distance to the spruce seedlings. The method neglected to count pine trees that were still within three metres of a measured spruce but grew outside of the plot radius. The actual number of pine trees within a three-metre distance from any given white spruce seedling is likely much greater than the recorded number. Shading due to adjacent trees could have account for the overall reduced growth.

Accounting for initial tree size has been recommended as a more effective technique when studying growth (Filipescu and Comeau 2007). Although planting stock experienced identical treatment conditions at the nursery, individual seedlings will exhibit different sizes in height and diameter. These differences were not considered and remained unaccounted for.

Improvements

Canopy closure was not quantified in this study however, it can be assumed that light levels were somewhere between 0% (full closed canopy scenario) and 100%

(clearcut scenario). It is likely that the thinner crowns of the young lodgepole pine allowed for greater light transmission. Quantifying light transmission could have proved beneficial in helping understand light transmission in younger understories, and therefore in fill plant scenarios (Filipescu and Comeau 2007; Messier 1996).

This study did not measure yearly incremental growth rather, only the total growth at present time was recorded. Measurements of the length and diameter of the current leader, number of lateral buds on the current leader, length of the previous year's leader, tree height, and diameter – all additional measures that could have helped determine success (Lieffers and Stadt 1994). Competition experienced in previous years affect the potential growth of spruce in subsequent years (both in terms of height and diameter) (Jobidon 2000).

The results cannot be solely attributed to pine shading since sedges and other minimal understory vegetation were present in some sampled plots (Figure 3). The white spruce seedlings were small enough for growth to be affected by not only overstory canopy, but lower vegetation as well. The effect of these lower competitors remained unaccounted for in this study. Understanding the impact of competing vegetation could determine which types of management strategies would be most beneficial. Managing interfering vegetation as a silvicultural option may promote increased growth of the target species (Lieffers and Stadt 1994).

In this fill plant, it is evident that there was sufficient light transmission to support healthy growth of white spruce saplings. This is shown in the low mortality, and acceptable total height and diameter growth. Lieffers and Stadt (1994) found that acceptable annual leader growth was attained at light levels between 15 and 40% (Lieffers and Stadt 1994).

CONCLUSION

This study utilized a fill plant site with white spruce underplanted beneath a young but established lodgepole pine stand. Three-year white spruce seedling total height and total RCD were not statistically significant between any of the four different density categories. Mortality was found to be low, which is consistent with other findings of underplanted white spruce. This suggests that fill planting can help reduce mortality in white spruce seedlings. Low mortality and sufficient white spruce total height and diameter prove the success of this fill plant project.

Fill planting has been and will continue to be used to in the management of Canada's mixedwood forests. When naturally occurring white spruce seedlings are found growing under a canopy, they rarely experience full sunlight conditions in the juvenile stage. Their shade tolerance makes white spruce a well-suited species in fill plant projects. Nevertheless, management techniques could help determine an optimal balance of residual canopy that could deliver sufficient light to allow greater success of desired trees but avoid competitors.

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APPENDICES

APPENDIX I

Raw SPSS Descriptive Statistics Outputs

Table 1. Descriptive statistics of height and RCD in density categories* at 95% confidence interval (0.05).

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Height	1.00	93	35.3097	9.39373	.97408	33.3751	37.2443	12.00	58.20
	2.00	82	35.9976	8.34640	.92171	34.1637	37.8315	18.90	51.90
	3.00	41	36.5878	9.74641	1.52213	33.5115	39.6642	17.50	53.20
	4.00	32	32.7156	10.26073	1.81386	29.0162	36.4150	13.10	51.00
	Total	248	35.4137	9.25195	.58750	34.2566	36.5709	12.00	58.20
RCD	1.00	93	6.1135	1.82161	.18889	5.7384	6.4887	2.98	12.13
	2.00	82	6.1427	1.21182	.13382	5.8764	6.4089	3.81	10.05
	3.00	41	6.5605	2.16070	.33745	5.8785	7.2425	2.82	14.60
	4.00	32	6.1225	1.09676	.19388	5.7271	6.5179	3.31	9.06
	Total	248	6.1982	1.62813	.10339	5.9946	6.4019	2.82	14.60

Source: SPSS ANOVA output 2014

(*Density categories: 1.00 = 0 pine trees in a plot; 2.00 = 1 - 4 pines trees in a plot; 3.00 = 5 -7 pine trees in a plot; 4.00 = 8 pines in a plot

Table 2. Descriptive statistics of total height and number of pine trees within three metres at 95% confidence interval (0.05).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
.00	110	35.6127	9.43626	.89971	33.8295	37.3959	12.00	58.20
1.00	36	36.6778	8.25449	1.37575	33.8849	39.4707	15.90	51.90
2.00	42	36.4762	9.61013	1.48287	33.4815	39.4709	14.00	51.40
3.00	32	33.7375	9.51731	1.68244	30.3061	37.1689	16.50	53.20
4.00	16	32.6000	6.38947	1.59737	29.1953	36.0047	22.30	47.40
5.00	8	33.4500	12.73118	4.50115	22.8065	44.0935	13.10	51.00
6.00	3	31.8000	8.40060	4.85009	10.9318	52.6682	26.90	41.50
9.00	1	48.6000					48.60	48.60
Total	248	35.4137	9.25195	.58750	34.2566	36.5709	12.00	58.20

Source: SPSS ANOVA output 2014

Table 3. Descriptive statistics of RCD and number of pine trees within three metres at 95% confidence interval (0.05).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		

.00	110	6.0831	1.74564	.16644	5.7532	6.4130	2.98	12.13
1.00	36	6.2267	1.47782	.24630	5.7266	6.7267	3.31	10.05
2.00	42	6.4171	1.43267	.22107	5.9707	6.8636	2.82	9.56
3.00	32	6.3322	2.06607	.36523	5.5873	7.0771	3.28	14.60
4.00	16	6.0556	.71302	.17826	5.6757	6.4356	4.81	7.11
5.00	8	6.1400	1.47206	.52045	4.9093	7.3707	4.64	9.06
6.00	3	6.3567	1.04749	.60477	3.7546	8.9588	5.27	7.36
9.00	1	6.6300					6.63	6.63
Total	248	6.1982	1.62813	.10339	5.9946	6.4019	2.82	14.60

Source: SPSS ANOVA output 2014

APPENDIX II

Post Hoc Tests

Table 4. Multiple comparisons for height and density categories*.

Dependent Variable				Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Height	LSD	1.00	2.00	-.68788	1.39946	.623	-3.4445	2.0687
			3.00	-1.27813	1.73185	.461	-4.6894	2.1332
			4.00	2.59405	1.89335	.172	-1.1353	6.3234
		2.00	1.00	.68788	1.39946	.623	-2.0687	3.4445
			3.00	-.59024	1.76703	.739	-4.0708	2.8903
			4.00	3.28194	1.92558	.090	-.5109	7.0748
		3.00	1.00	1.27813	1.73185	.461	-2.1332	4.6894
			2.00	.59024	1.76703	.739	-2.8903	4.0708
			4.00	3.87218	2.17914	.077	-.4202	8.1645
		4.00	1.00	-2.59405	1.89335	.172	-6.3234	1.1353
			2.00	-3.28194	1.92558	.090	-7.0748	.5109
			3.00	-3.87218	2.17914	.077	-8.1645	.4202
	Bonferroni	1.00	2.00	-.68788	1.39946	1.000	-4.4104	3.0346
			3.00	-1.27813	1.73185	1.000	-5.8847	3.3285
			4.00	2.59405	1.89335	1.000	-2.4421	7.6302
		2.00	1.00	.68788	1.39946	1.000	-3.0346	4.4104
			3.00	-.59024	1.76703	1.000	-5.2905	4.1100
			4.00	3.28194	1.92558	.537	-1.8400	8.4039
		3.00	1.00	1.27813	1.73185	1.000	-3.3285	5.8847
			2.00	.59024	1.76703	1.000	-4.1100	5.2905
			4.00	3.87218	2.17914	.461	-1.9242	9.6686
		4.00	1.00	-2.59405	1.89335	1.000	-7.6302	2.4421
			2.00	-3.28194	1.92558	.537	-8.4039	1.8400
			3.00	-3.87218	2.17914	.461	-9.6686	1.9242

Source: SPSS ANOVA output 2014

(*Density categories: 1.00 = 0 pine trees in a plot; 2.00 = 1 - 4 pines trees in a plot; 3.00 = 5 -7 pine trees in a plot; 4.00 = 8 pines in a plot

Table 5. Multiple comparisons for RCD and density categories*.

Dependent Variable				Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
RCD	LSD	1.00	2.00	-.02913	.24692	.906	-.5155	.4572

		3.00	-.44694	.30556	.145	-1.0488	.1549
		4.00	-.00895	.33406	.979	-.6670	.6491
	2.00	1.00	.02913	.24692	.906	-.4572	.5155
		3.00	-.41780	.31177	.181	-1.0319	.1963
		4.00	.02018	.33974	.953	-.6490	.6894
	3.00	1.00	.44694	.30556	.145	-.1549	1.0488
		2.00	.41780	.31177	.181	-.1963	1.0319
		4.00	.43799	.38448	.256	-.3193	1.1953
	4.00	1.00	.00895	.33406	.979	-.6491	.6670
		2.00	-.02018	.33974	.953	-.6894	.6490
		3.00	-.43799	.38448	.256	-1.1953	.3193
Bonferroni	1.00	2.00	-.02913	.24692	1.000	-.6859	.6277
		3.00	-.44694	.30556	.869	-1.2597	.3658
		4.00	-.00895	.33406	1.000	-.8975	.8796
	2.00	1.00	.02913	.24692	1.000	-.6277	.6859
		3.00	-.41780	.31177	1.000	-1.2471	.4115
		4.00	.02018	.33974	1.000	-.8835	.9239
	3.00	1.00	.44694	.30556	.869	-.3658	1.2597
		2.00	.41780	.31177	1.000	-.4115	1.2471
		4.00	.43799	.38448	1.000	-.5847	1.4607
	4.00	1.00	.00895	.33406	1.000	-.8796	.8975
		2.00	-.02018	.33974	1.000	-.9239	.8835
		3.00	-.43799	.38448	1.000	-1.4607	.5847

Source: SPSS ANOVA output 2014

(*Density categories: 1.00 = 0 pine trees in a plot; 2.00 = 1 - 4 pines trees in a plot; 3.00 = 5 -7 pine trees in a plot; 4.00 = 8 pines in a plot