INCREASING DIAMETER GROWTH CONTENT OF RED PINE (*PINUS RESINOSA*) THROUGH INTENSIVE MANAGEMEN

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INCREASING DIAMETER GROWTH CONTENT OF RED PINE (*PINUS RESINOSA*) THROUGH INTENSIVE MANAGEMENT

by

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ABSTRACT

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Intensive forest management can only be justified if it increases wood quality or yield sufficiently to compensate for the additional investment. Treatments such as thinning and/or pruning are typically only applied to high quality sites like those characteristically found at plantations. In Ontario there is an abundance of Red pine plantations across the province especially in southern regions. These plantations are the result of reforestation and afforestation efforts put into place to reduce soil erosion and to repurpose abandoned farm land. This study concentrates of the effect of an intensive pruning regime over a single growing season.

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ACKNOWLEDGEMENTS

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INTRODUCTION

Increasing and optimizing harvest yields is a constant challenge in Canada's forestry industry. One way of doing so is through the application of intensive forest management and tending techniques to a stand. Intensive forest management and tending techniques vary greatly but they all significantly increase operational costs. With a drastic increase in the operational cost, the application of an intensive forest management and tending technique must be sufficiently beneficial to offset the additional cost of its' application to be a viable practice. Due to the additional cost of intensive forest management and tending techniques they are exclusively applied to high quality sites such as plantations. This study will focus on the effects of an intensive pruning regime on the secondary growth response of immature red pine (*Pinus resinosa*).

The abundance of red pine plantations throughout the province of Ontario provide the ideal conditions for the application of intensive forest tending techniques. Many of the aforementioned plantations were previously utilized for agriculture and the soil remained rich with nutrients, which results in a higher level of productivity.

OBJECTIVES

The objective of this study is to determine the effects of subjecting *Pinus resinosa* to an intensive pruning regime at a young age. Understanding the secondary growth response of *Pinus resinosa* to intensive management will help further develop better management techniques and can potentially help increase wood quality and yield throughout the province. If immature *Pinus resinosa* responds well to being pruned it would directly correlate to an increase of clear wood and therefore wood quality and yield.

The experiment was conducted on the 44-hectare Hogarth Plantation which was donated to Lakehead University in 2003 (Lakehead University 2009). Within the Hogarth Plantation, experimental and control plots of juvenile *Pinus resinos*a were established and the encompassed trees were subsequently measured before and after the application of each plots randomly assigned tending treatment.

HYPOTHESIS

Regardless of applied tending treatment the growth of Red pine will not be altered in any way. If any difference of diameter growth is found, it is a result of the applied tending treatment

LITERATURE REVIEW

PHYSICAL DESCRIPTION AND BIOLOGICAL FEATURES OF *PINUS RESINOSA*

Pinus resinosa (Figure 1) has long been recognized as a high value merchantable species and is often planted and intensively managed in plantations (OMNR 1986). It is a medium sized conifer that is know for its' tendency to have a very straight bole (OMNR 1986). *Pinus resinosa* height typically measures between 20 to 35 meters and 1 m in trunk diameter (OMNR 1986). The tree's crown is initially conical in shape but develops into a narrow round dome with age (OMNR 1986). At the base of the tree the bark is thick and displays reddish brown colour but in the upper crown the bark becomes thinner and flakier. The needle like leaves are a dark yellow green and are found in fascicles of 2 with each leaf being approximately 12 to 18 cm in length. The long leaves are brittle and can be

Figure 1 Mature red pine (*Pinus resinosa*)

easily snapped when bent. The cones produced by *Pinus resinosa* are oval in shape and are typically 4 to 6 cm long and approximately 2.5 cm wide. *Pinus resinosa* is relatively long lived species averaging approximately 200 years but have been know to grow to well over 300 years in age (Ontario Ministry of Natural Resources 2000). They reach sexual maturity within 15 to 25 years if open grown but if grown in close stand conditions they only reach maturity between 50 and 60 years in age (OMNR 2000).

Figure 2 *Pinus resinosa* cones and seed (MSID 2017)

Pinus resinosa is a monoecious species that produces a very light seed and relies on the wind as a mechanism for pollination (OMNR 2000). Seed crops occur every 3 to 7 years, with seed production most prolific between the ages of 50 and 150 years old (OMNR 2000). A mature *Pinus resinosa* cone's (Figure 2) ripen in the spring and summer producing on average 18 liters of cones per tree (OMNR 2000). The seeds are subsequently dispersed on warm days throughout October and November (OMNR 2000). The primary seed dispersal method is wind, although squirrels play an important role by means of cone caches (OMNR 2000). Seed dispersal distances vary greatly, on average seed is distributed 12 meters from the tree of origin but can exceed 270 meters

(OMNR 2000). In the natural environment *Pinus resinosa* exhibits very little to no biochemical inhibition, which indicates that it might require a short period of stratification. In an artificial environment such as a nursery 14 to 21 days of stratification is required. The seeds that are produced have a relatively high germination rate, which typically ranges between 75% and 85% (OMNR 2000). *Pinus resinosa* is also able to reproduce through layering but this typically only occurs near tree lines and/or stand edges (OMNR 2000).

As *Pinus resinosa* develops they can encounter many pests that they must overcome (OMNR 2000). As seeds they encounter squirrels and songbirds, which consume them (OMNR 2000). Once *Pinus resinosa* develops to a seedling they are subjected to pine false webworm, Scleroderris canker, needle cast, needle rust, Diplodia tip blight, Sirococcus tip blight, Armillaria root disease, Annosus root rot and animal browsing (OMNR 2000). Mature trees are susceptible to pine shoot beetle, which is an invasive species that primarily targets Scots pine (*Pinus sylvestris*) (OMNR 2000).

ECOLOGICAL FEATURES OF *PINUS RESINOSA*

Pinus resinosa has a uniform morphology and expresses very little genetic variation (OMNR 2000). *Pinus resinosa* grows best on dry sandy sites that are well to moderately-well drained (OMNR 2000). It requires a moderate to low soil fertility, with an optimal pH range of 2.5 to 6.0 but does not perform well in calcareous soils (OMNR 2000). In Ontario *Pinus resinosa* is naturally found across the boreal forest region excluding zones 1E, 2E and 2W (OMNR 2000). It is also naturally prevalent in the Great Lakes St. Lawrence forest region except for the southwestern counties of Brant, Haldimand-Norfolk, Oxford, Middlesex, Elgin, Kent, Essex and the southern section of Lambtonabsent where it is exclusively found in plantations (OMNR 2000).

Pinus resinosa is a shade intolerant species that becomes more tolerant as it matures (OMNR 2000). Partial shade and a seedbed type of mineral soil, burned duff or pioneer mosses are essential for effective germination (OMNR 2000). Seedlings require a minimum of 35% light to survive but grow optimally between 65% and 100% (OMNR 2000). Mature *Pinus resinosa* responds strongly to being released regardless of the duration (200 years) of suppression and displays excellent self-pruning abilities (OMNR 2000).

MANAGEMENT OF *PINUS RESINOSA* PLANTATIONS IN ONTARIO

In Ontario the planting of *Pinus resinosa* dates back to the 1920's (OMNR 1986). Initially, reforestation was primarily driven by the province with the hope of re-establishing harvested areas with tree cover (OMNR 1986). In the 1800's most of the forest cover was removed by settlers clearing the land for agriculture (OMNR 1986). Some of the land cleared for agriculture was composed of nutrient deficient sandy soils that were unable to sustain agricultural practices and they were quickly abandoned (OMNR 1986). *Pinus resinosa* tree planting programs on public land were initiated to combat erosion of the sandy soils since that's the environment it naturally thrives in (OMNR 1986).

In the 1960's, the Woodlands Improvement Act (WIA) program was implemented (OMNR 1986). The WIA was instrumental in transferring the focus of reforestation from public to private land (OMNR 1986). As a result of the WIA and other government initiatives there are many thriving *Pinus resinosa* plantations throughout the province on public and private land (OMNR 1986). Numerous plantations have matured and are ready for harvest or to assist in the restoration of the forest to a more natural state (OMNR 1986).

To maximize the yield and wood quality of *Pinus resinosa* plantations intensive forest management practices are frequently applied. Intensive forest management practices such as pruning and thinning are effective because they emulate natural processes (OMNR 1986). Natural pruning is a process in which branches die and are shed by a tree as result of said branches being shaded out (BCMOE 1995). This process of shading out branches occurs throughout the life of a tree and is usually completed before it reaches mortality (OMNR 1986). The degree of and the frequency that the natural pruning process occurs is very species dependent and also heavily relies on the tree spacing (OMNR 1986). In plantations artificial pruning (the removal of branches by humans) is often used to expedite the process and is used to remove live and dead branches (OMNR 1986).

Artificial pruning at a young age helps increase the clear wood by restricting the resulting knots to the core of the bole (USDAF 2005). It is important that proper pruning techniques are applied to all trees to minimize damage and to maximize growth (USDAF 2005). Poor pruning techniques like bole damage and leaving large stubs will negatively impact tree growth and wood quality (USDAF 2005). If the damage caused by poor pruning practices is severe severe enough it can increase the risk of pathogens entering the tree and in some cases mortality (USDAF 2005). To minimize tree damage when artificial pruning the proper tool must be used (USDAF 2005). Hand saws, chainsaws and sheers are the most effective instruments and cause the least amount of damage. Tools like hatchets, machetes and axes typically cause more damage and frequently fracture the base of the branch inside the bole. The fracture often develops into decay, which in time reduces wood quality.

When artificially pruning *Pinus resinosa* it is crucial to select the right trees to prune because it is an expensive endeavor (USDAF 2005). When managing *Pinus resinosa* it is common to combine artificial pruning with stand thinning (USDAF 2005). Doing so maximizes the beneficial effects of each treatment (OMNR 1986). Mechanical stand thinning emulates and expedites the natural stand process of stem exclusion while simultaneously providing more resources for crop trees (PEIDAF 1997). Crop trees are the trees that compose the final harvest and they are the only ones that should be pruned (PEIDAF 1997). A good crop tree is a dominant or co-dominant tree, has a well developed leader, a full, round but finely branched crown, a straight bole and displays no evidence of bole injury (PEIDAF 1997). A total of 250 to 350 trees per hectare should be selected as crop trees to be pruned (OMNR 1986)

The first pruning should occur at a height of approximately 5 meters or a DBH (diameter breast height) of 10 to 15 cm to increase the quality of veneer and saw logs (USDAF 2005, PEIDAF 1997). To improve the quality of pole wood, the initial pruning should occur only when a tree has reached the height of 7.4 meters (USDAF 2005). Regardless of wood production objectives the first pruning should coincide with the first stand thinning (USDAF 2005). The second pruning treatment should be applied directly after the completion of the second stand thinning. In this instance the tree crown should be removed up to a height of 5.1 meters for saw logs and veneer or 7.4 meters for pole wood.

PRUNING TECHNIQUES AND APPLICATION

The practice of commercially pruning trees has been done for centuries (O'Hara 2007). They recognized that by doing so they would be able to positively impact tree form while simultaneously increasing wood quality (O'Hara 2007). The purposes for pruning varies, enhancing the quality of wood yielded has always been a primary objective (O'Hara 2007). Even though there has been centuries of experience pruning trees there are numerous contradictory recommendations for the proper application of the practice (Nicolescu 1986).

If a tree is pruned properly and once it has recovered from the pruning process it will most likely produce clear wood in the pruned area afterwards (O'Hara 2007). The process of trees developing clear wood and calluses over the wound is called occlusion (O'Hara 2007). When a branch is pruned from a trees stem it starts by developing callus over the exposed area (O'Hara 2007). Subsequently, once the callus has been formed it will begin to form new cambium over the callus. The newly developed cambium will be clear of any defects associated with the removed branch (O'Hara 2007). The knots created by the branch stub that remains are then contained in the core of the stem (O'Hara 2007). Increasing clear wood content is not the only achievable objective made possible through pruning (O'Hara 2007). Pruning forest trees also can help increase fuel wood production or harvest volume security by pruning out pathogens (O'Hara 2007).

Pruning is a common tree tending technique that can be successfully applied to a wide range of species (University of Maine 2016). There are two common categories of pruning cuts that each have a unique application (University of Maine 2016). The two types of pruning are thinning and heading (University of Maine 2016). Heading results in only a portion of the tree being removed at a point where a side branch and/or a healthy bud resides (USDAFS 1995). The removal cut should be done at a 45-degree angle just above the retained lateral

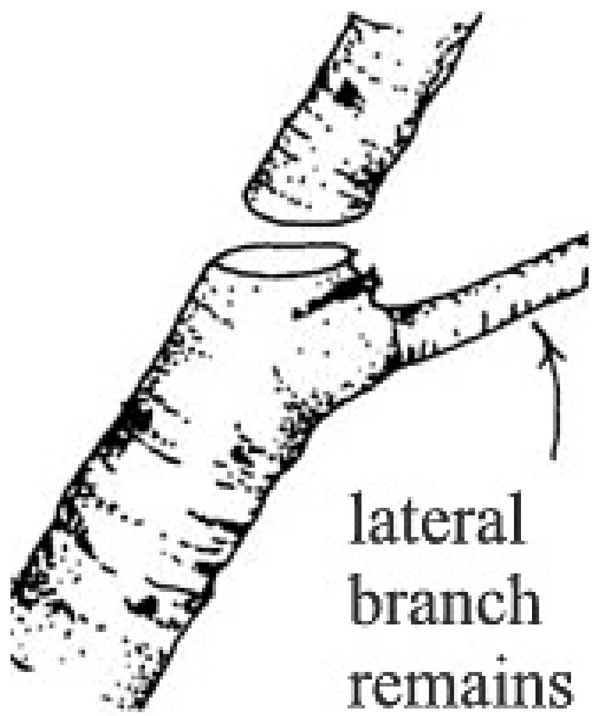

Figure 3 Proper heading cut (University of Florida 2015)

branch or bud (Figure 3). Heading is only applied when branches require redirection and shortening (USDAFS 1995). In contrast, thinning is the removal of a whole branch or limb at the branch collar and is applied when branch crowding occurs (USDAFS 1995).

Understanding how a tree responds to either of the previously mentioned pruning techniques is essential to ensure the most appropriate and effective pruning decisions are made (USDAFS 1995). A trees response to pruning is dictated by the age of the branch being pruned and the intensity of the applied pruning technique (University of Maine 2016). Juvenile or new growth is situated at the end of every branch with buds containing undifferentiated meristems (University of Maine 2016). In the subsequent growing season the buds with undifferentiated meristems will develop into spurs (short shoots that cease development rapidly after bloom) or shoots (small newly developed branches) (University of Maine 2016). If a heading cut is applied to new shoots it will incite the remaining buds with undifferentiated meristems to develop into longer leafy shoots instead of spurs (University of Maine 2016). If new growth is not pruned the buds will develop into spurs that in turn produce flowers instead of the more desirable long vigorous leaf bearing shoots (University of Maine 2016).

Thinning is a three step whole branch removing pruning process that minimizes the risk of bark tearing (Figure 4) (University of Maine 2016). Bark tearing can create a substantially sized wound that is not likely to fully compartmentalized or be healed by a tree (University of Maine 2016). The first cut, is a partial cut on the underside of the branch or limb approximately 30 cm from the branch collar (University of Maine 2016). The first cut should only go through approximately 30% of the branches diameter (University of Maine 2016). A branch collar is the ring of ridges that encompass the base of the branch where it attaches to the main bole of a tree (University of Maine 2016). The secondary cut is downward into the branch approximately 2.5 cm out from the first cut and completely goes through the branch limb (University of Maine 2016). If done correctly the weight of the branch and gravity will cause the limb to separate from the tree while the secondary cut is performed resulting in zero bark damage (University of Maine 2016). The remaining 30 cm stump of the branch is then removed at the branch collar to encourage recovery (University of Maine 2016). Cutting into the branch

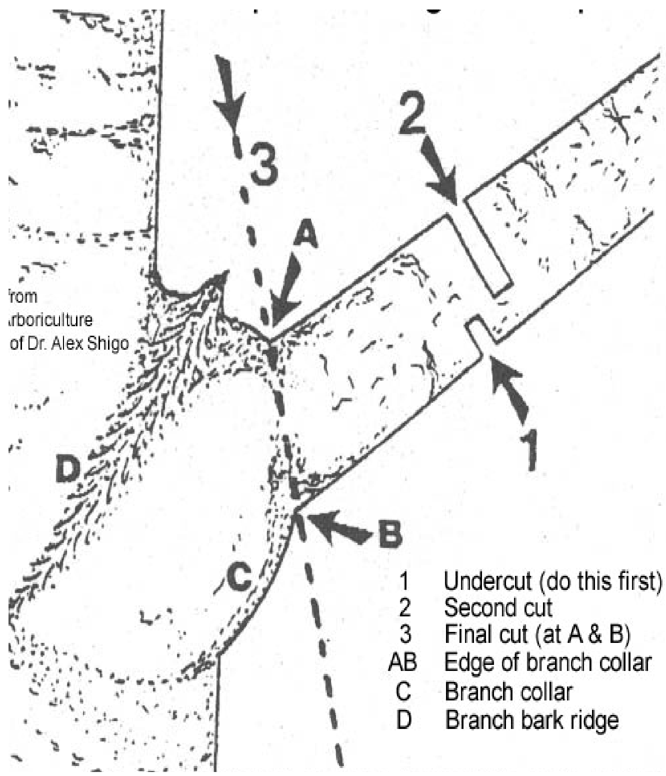

Figure 4 Proper pruning technique for thinning of branches (Active Tree Service 2017)

collar negatively impacts the healing of a tree wound and can result in pathogens entering the tree (University of Maine 2016). Leaving the 30 cm stump strongly encourages the development of watersprouts (University of Maine 2016). Watersprouts arise from latent buds in a wound and typically grow vertically, they develop slowly and are generally less vigorous (University of Maine 2016). To prevent the development of watersprouts pruning cuts should be clean and almost flush (University of Maine 2016).

Pruning can be incorporated into stand management plans and help facilitate the control of the overall branch size (O’hara 2007). The most optimal season to prune a tree is species dependent so it is crucial that is taken into account when intergrading pruning into a forest management plan (Uotila 1990). Stand density significantly impacts branch length, diameter and radial growth rates (O’hara 2007). As a result, a balance must be found between optimizing tree growth rates and minimizing branch size (O’hara 2007). Typically, if pruning is being implementing in a stand it occurs early in the forest harvesting rotation (O’hara 2007). Pruning early in the rotation helps reduce the amount of the defected wood and smaller living diameter branches can be removed (O’hara 2007). The smaller wound allows for quicker bark occlusion, less decay and thinner bark, which is easier to produce when compared to bark of more mature trees (O’hara 2007). Stem decay can be a limiting factor to pruning and in those cases numerous passes and/or light pruning regimes should be applied (Chou and MacKenzie 1988). Doing so allows smaller live branches to be removed and can result in a lower rate of infections in some species like

Radiata pine (*Pinus radiata*) (Chou and MacKenzie 1988).

EFFECTS OF PRUNING

As the world's population grows so does the demand for wood and wood products (FAOUN 2009). The augmented demand has driven the world's forestry industry to further increase the application of intensive silvicultural practices to meet said demand (Hevia et al. 2016). Pruning has the opportunity to play a major role in increasing the production of wood and bettering the quality of the wood that is produced because it limits the knots and other branch defects to the core of a tree (Hevia et al. 2016). The resulting clear wood is much more valuable but the pruning can also be detrimental to tree growth if not done properly (Hevia et al. 2016). In intensive pruning regimes it can negatively effect primary (vertical) and secondary (diameter) growth although this is typically a temporarily response (Hevia et al. 2016). Understanding how specific tree species respond to pruning is essential to ensure that the correct pruning regime is undertaken to maximize clear wood production and to optimize the efficiency of forestry operations (Hevia et al. 2016).

The removal of approximately 30% or less of live crown has been proven to have little to no influence on primary and secondary growth in trees (Cown 1972). Pruning if done incorrectly and/or too intensely can be detrimental to a trees' health and wood properties (Zobel 1992). If a tree is pruned improperly it is common for them to develop resin pockets and swirled grain (Zobel 1992). The primary source of wood degradation is resin pockets (Park and Parker 1982). The benefits of pruning are amplified when the trees are young and branches are small and alive but it does create openings for pathogens to enter a tree (Montagu et al. 2003). If a tree is too young pruning it may result in the production of epicormic shoots from the pruned area or from latent buds in the trunk or root system (Montagu et al. 2003). The ideal pruning age is species dependent and canopy closure can also be a factor (Montagu et al. 2003). If canopy closure is retained after pruning most species have a reduced risk of producing epicormic shoots of any kind (Montagu et al. 2003). It

The initial cost of pruning must be considered, even though if applied correctly the investment will be returned at harvest (Pinkard et al. 2004). To maximize the effectiveness of any pruning regime only trees that will not be thinned should be selected (Hevia et al. 2016). Trees should be examined for stem size and straightness to help minimize the size of the knotty core (Hevia et al. 2016). This being said, pruning in the forest settings is typically only applied to more economically valuable species (Zobel 1992). . It is best to pair a pruning regime with some degree of thinning. The combination of treatments assists with canopy manipulation and will increase the clear wood content (Forrester et al. 2010).

EFEECTS OF PRUNING ON NEW ZEALAND'S RADIATA PINE (*PINUS RADIATA*) PLANTATIONS

Roughly 90% of New Zealand's plantations are comprised solely of *Pinus radiata* (Cown 2005). New Zealand's attempt to improve wood quality and increase yield of Radiata pine (*Pinus radiata*) concentrates on tree health, growth rate and stem form (Carson 1987). An increased level of any one or combination of the three will result in increased profitability of forestry operations (Carson 1987). Intensive pruning regimes are commonly applied to New Zealand's *Pinus radiata* plantations (West 1998). The pruning of *Pinus radiata* plantation trees is done to produce more clear wood and when done successfully it increases the overall value of said plantation (Neilson and Pinkard 2003).

At 13 years of age *Pinus radiata* did not respond to 45% of it's tree height being pruned. Pruning to approximately 60% or 75% of tree height during a secondary application drastically reduced the diameter growth increment (Neilson and Pinkard 2003). As the pruning severity increased, the diameter growth increment decreased (Neilson and Pinkard 2003). Pruning had more effect on secondary growth than primary growth and a live crown ratio of approximately 55% helped mitigate the effects on diameter growth (Neilson and Pinkard 2003). *Pinus radiata* that developed from cuttings require less time to be pruned when compared to those of a seed origin (Tufuor and Libby n.d.). This was caused by the fact trees propagated vegetatively had significantly less and smaller branches, reduced taper, and the knotty core is a diminished size

(Tufuor and Libby n.d.). The impact of intensive pruning is more heavily felt by suppressed trees (Neilson and Pinkard 2003). The branches once removed if left in the stand can be an important source of nutrients for the recently pruned tree (Girisha et al. 2002). Once decomposed, the branches provide a significant amount of nutrients which can be converted by the trees into carbohydrates and used to heal the intentionally caused wounds that occur during the pruning process. Additionally, the branches impede competition from other vegetation and can help compensate for the lessened photosynthesizing ability of a pruned tree caused by the removal of a considerable amount of the crown.

WOOD QUALITY

Over the last century there has been evident trends of deceasing wood quality in naturally regenerated forests and plantations (Zobel and Raleigh 1984). Presently the forestry industry is harvesting smaller, younger and lower-quality timber that would have previously been classified as waste wood (Zobel and Raleigh 1984). The change in harvesting is the result of innovative new technology, increased demand and intensive management (Zobel and Raleigh 1984).

In most forest regions the cost of operating is steadily increasing but there is an unbalanced distribution of merchantable timber (Zobel and Raleigh 1984). Due to the increased cost and lower yield associated with an unequal distribution of timber, a shorter harvest rotation is often chosen to help mitigate this (Zobel and Raleigh 1984). The shortened rotation produces low quality, small-sized timber with an augmented amount of knots and juvenile wood (Zobel and Raleigh 1984). The use of plantations and exotic species is omnipresent and produces large volumes of wood but the wood being produced varies differently than what would have historically been produced on these sites (Zobel and Raleigh 1984). The chosen exotic species grow at an expedited rate and reach merchantable size earlier on, which means when harvested they have a higher percentage of juvenile wood and is not suitable for many applications (Zobel and Raleigh 1984).

Knots are caused by branches that are included in the stem of a tree (Jozsa and Middleton 1994, Bowyer et al. 2003). They are the most frequent cause for the downgrading of softwood structural lumber (Jozsa and Middleton 1994). There are two types of knots, which impact the quality of harvested timber in a unique way (Jozsa and Middleton 1994). Live knots are created by branches that are still alive at the time of harvest and remain continuously connected to the cambium (Jozsa and Middleton 1994). As a result of still being connected to the cambium live knots are far less detrimental to quality when compared to dead knots (Jozsa and Middleton 1994). The dead knots are a result of branches dying and their connection with a trees cambium no longer exists. The knot produced by a dead branch is loose and can significantly decrease the quality of lumber produced from a tree (Jozsa and Middleton 1994).

Even though live knots are generally accepted as the better of two knot types the ultimate goal for producing high quality lumber is to increase clear wood content (Montagu et al. 2003). Spacing between trees plays a fundamental role in quantity of live and dead knots in harvested timber (Montagu et al. 2003). Some species like *Pinus resinosa* are great natural pruners which can be capitalized on through tight spacing. By increasing the clear wood content, it significantly reduces the risk of downgrading lumber and results in an increase in the yield of quality lumber (Montagu et al. 2003).

Silvicultural practices and genetic manipulation have a pronounced impact on wood quality (Zobel and Raleigh 1984). Therefore, intensive forest management is a tool that can help counteract the decreasing levels of wood quality (Zobel and Raleigh 1984). The most efficient way to alter wood quality is through the manipulation of the duration of the harvest rotation (Zobel and Raleigh 1984). Newly developed manufacturing processes, like oriented strand-board facilitate the production of high-quality products from low-quality wood fiber (Zobel and Raleigh 1984). These manufacturing techniques result in products that differ greatly from those previously available but they are stable and of excellent quality (Zobel and Raleigh 1984).

Increased efficiency of forest operations results in less waste (Zobel and Raleigh 1984). Sawdust and bark are commonly used by mills and forest residue such as branches, limbs, stumps and leaves are more effectively utilized throughout harvesting operations (Zobel and Raleigh 1984). Thanks to technological advancement the diversification of harvested species has steadily been occurring (Zobel and Raleigh 1984). Previously undesirable and less valuable species have become viable to harvest due to newly developed applications (Zobel and Raleigh 1984). In addition, new and rapidly progressing industries that use wood as a source for energy and organic chemicals is increasing (Zobel and Raleigh 1984).

The current study examined the effect of thinning and pruning a young naturally seeded *Pinus resinosa* stand in the Thunder Bay District. Control and experimental plots were designed and implemented at Lakehead University's Hogarth Plantation. Understanding how a species responds to an intensive silviculture treatment or combination of treatments is imperative to determine whether or not the additional investment is warranted.

MATERIALS AND METHODS

STUDY AREA

On April 26th 2016, Dr. Mathew Leitch, Mr. Kevin Shorthouse and myself (David Boyle) went to the Hogarth plantation that is currently owned by Lakehead University. Three locations were assessed for use in the experiment. The two site requirements for the experiment were: large enough pure immature stands of *Pinus resinosa* to establish 4 experimental plots and tree height must not exceed 6 meters to facilitate pruning from the ground without ladders. The selected site is located at UTM coordinates 16U323027.92mE 5359284.45mN (Figure 5).

Once the best site was determined 4 experimental plots measuring 13 meters by 16 meters with and area of 208 m^2 were established. Each plot boundaries were then marked with wooden stakes. Subsequently, 2 plots were randomly selected to be treated (Plots 1 and 2). The remaining 2 were selected as control plots (Plots 3 and 4) (Figure 8). The treated plots were then pruned using motor-manual tools to the predetermined standard of retaining 4 branch whorls (Figure 6 and Figure 7). The pruned plots were also thinned to have approximately 1.5 to 2 meters between each tree. When the pruning was completed 25 trees in each of the 4 plots were randomly selected to be marked, numbered, and measured for diameter at breast height. Tress were only eligible for selection if they were two rows or further back from the perimeter of a plot to mitigate edge effect. On December 21, 2016 I returned to experimental location and re-measured and

Figure 5 Map of experimental area

recorded the DBH of all 100 previously sampled trees. At this time all flagging tape and wooden stakes were removed. All raw data can be seen in Appendix I

Figure 6 Treated plot

Figure 7 Treated plot showing that the limbs were left in the stand

Figure 8 Control plot

MATERIALS

The materials used in this experiment were: 2 chainsaws, 16 wooden stakes, 1 pole chainsaw, 1 pencil, 1 increment bore, 1 DBH tape, 4 sets of data sheets, gasoline, oil and 1 GPS receiver.

STATISTICAL ANALYSIS

Data analysis was performed to understand the effects of the applied treatment when compared to the control plots and the variation within treatments. Analysis of the increase in diameter at breast height measurements between the two treatments was performed. The measurements and treatment were analyzed. All data analysis was performed using Microsoft Excel. A one-way ANOVA at a 95% confidence interval was used to calculate variance in secondary growth (cm) between the treated and untreated experimental plots. Each individual plots (Appendix II) and treatments (Table 1) examined calculated diameter growth, initial and secondary measurements were also analyzed for mean, standard error, median, mode, standard deviation, sample variance, range, minimum and maximum. Additionally, the average age of each plot was determined.

RESULTS

Table 1 displays the condensed data results of the 2 pruned and control Red pine plots that contain 50 trees each, respectively. It should also be noted that the control plots had an average age of 9.5-years-old and the control plots had an average age of 9-years-old.

Table 1 Condensed data results for the two treated and two control plots

Summary of Combined Pruned Plots and Control Plots						
Type of Data Analysis	Pruned Plots			Control Plots		
	April	December	Growth (cm)	April	December	Growth (cm)
Average	8.45	9.39	0.94	7.57	8.83	1.26
Standard Error	0.31	0.31	0.07	0.31	0.35	0.08
Median	8.55	9.40	0.80	7.50	8.65	1.20
Mode	7.40	8.90	1.10	9.50	7.40	1.20
Standard Deviation	2.21	2.18	0.52	2.18	2.47	0.56
Sample Variance	4.87	4.77	0.27	4.74	6.09	0.31
Range	10.95	9.90	3.65	9.80	11.80	2.80
Minimum	2.65	4.80	0.10	2.60	3.10	0.50
Maximum	13.60	14.70	3.80	12.40	14.90	3.30
Total	422.45	469.40	47.0	378.70	441.50	62.80
Count	50.00	50.00	50.00	50.00	50.00	50.00

Table 2 depicts the variance between the diameter growth (cm). It is the results of a one-way ANOVA and it was performed at a 95% confidence level. The P-value and F-critical values were determined to be of 0.00423 and 3.938 respectively.

Table 2 One-way ANOVA results

ANOVA of Calculated Growth						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.512	1	2.512	8.578	0.00423	3.938
Within Groups	28.700	98	0.293			
Total	31.212	99				

Figure 9 depicts how many trees that were found to have developed epicormic shoots between the time of initial measurement in April 2016 and the secondary measurement which occurred in December 2016. A total of 31 trees out of the 50 pruned trees had epicormic shoots

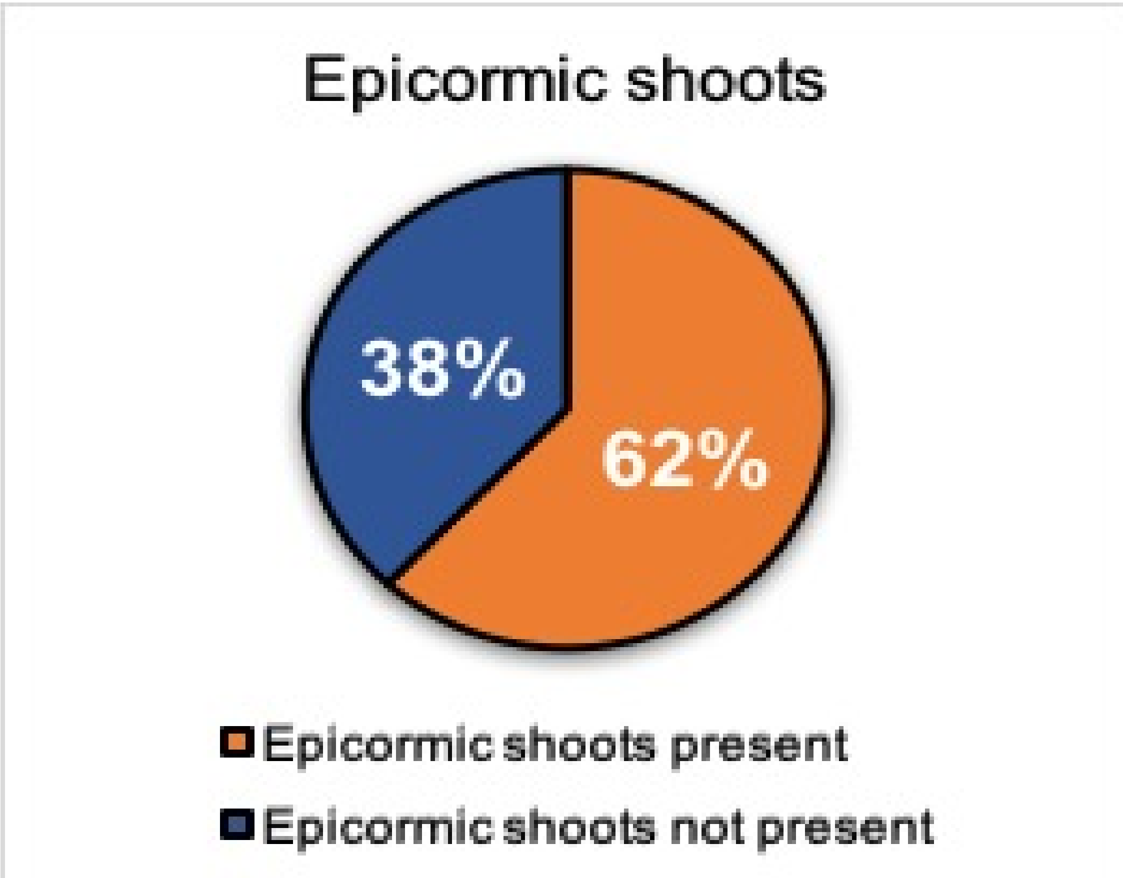

Figure 9 Amount of trees discovered with epicormic shoots

The following two figures (Figures 10 and 11) present the initial diameter measurements, secondary measurements and calculated growth of all 50 pruned trees and 50 control plots tress respectively.

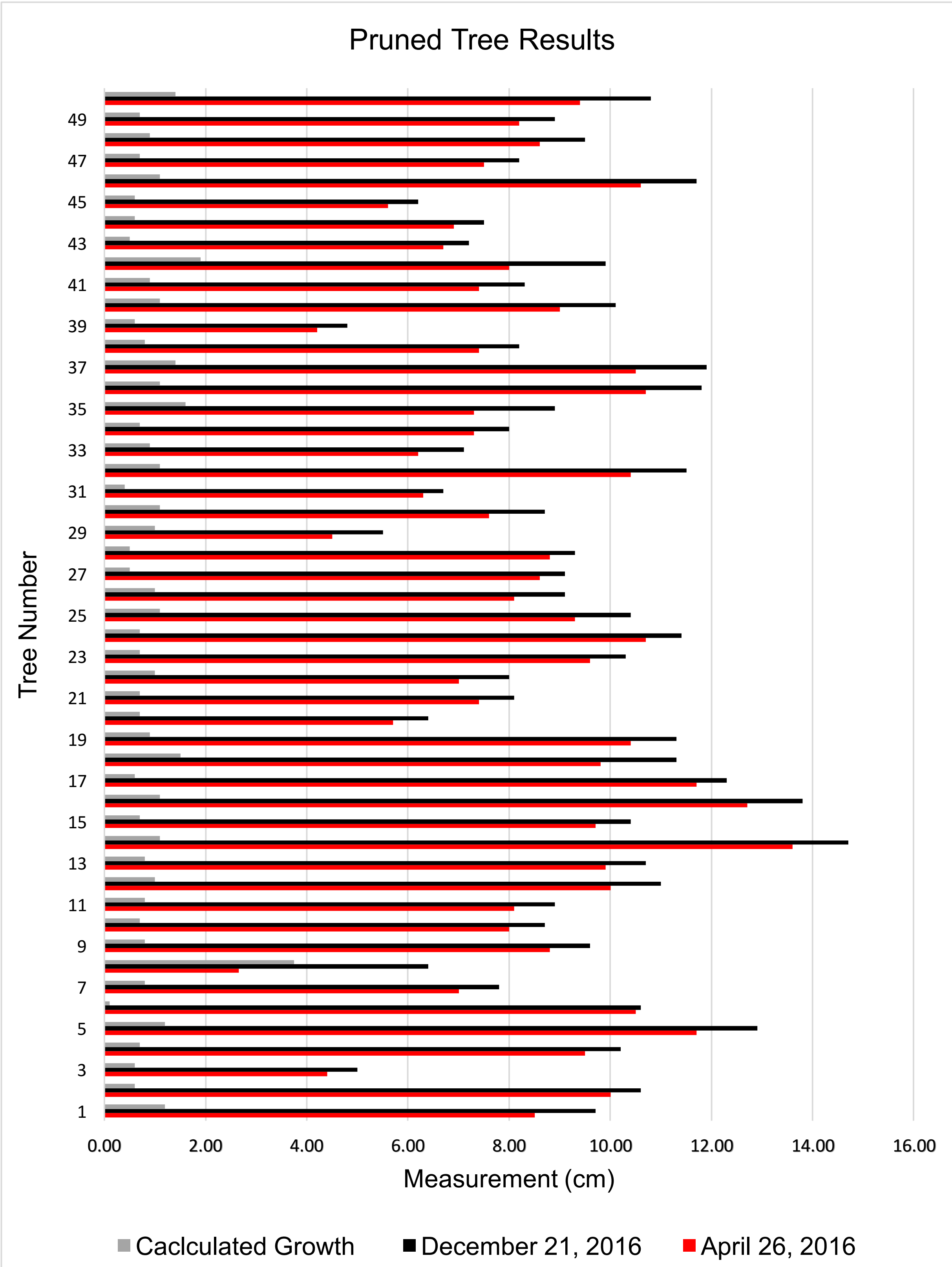

Figure 10 The initial measurements, secondary measurements and calculated growth of the pruned trees

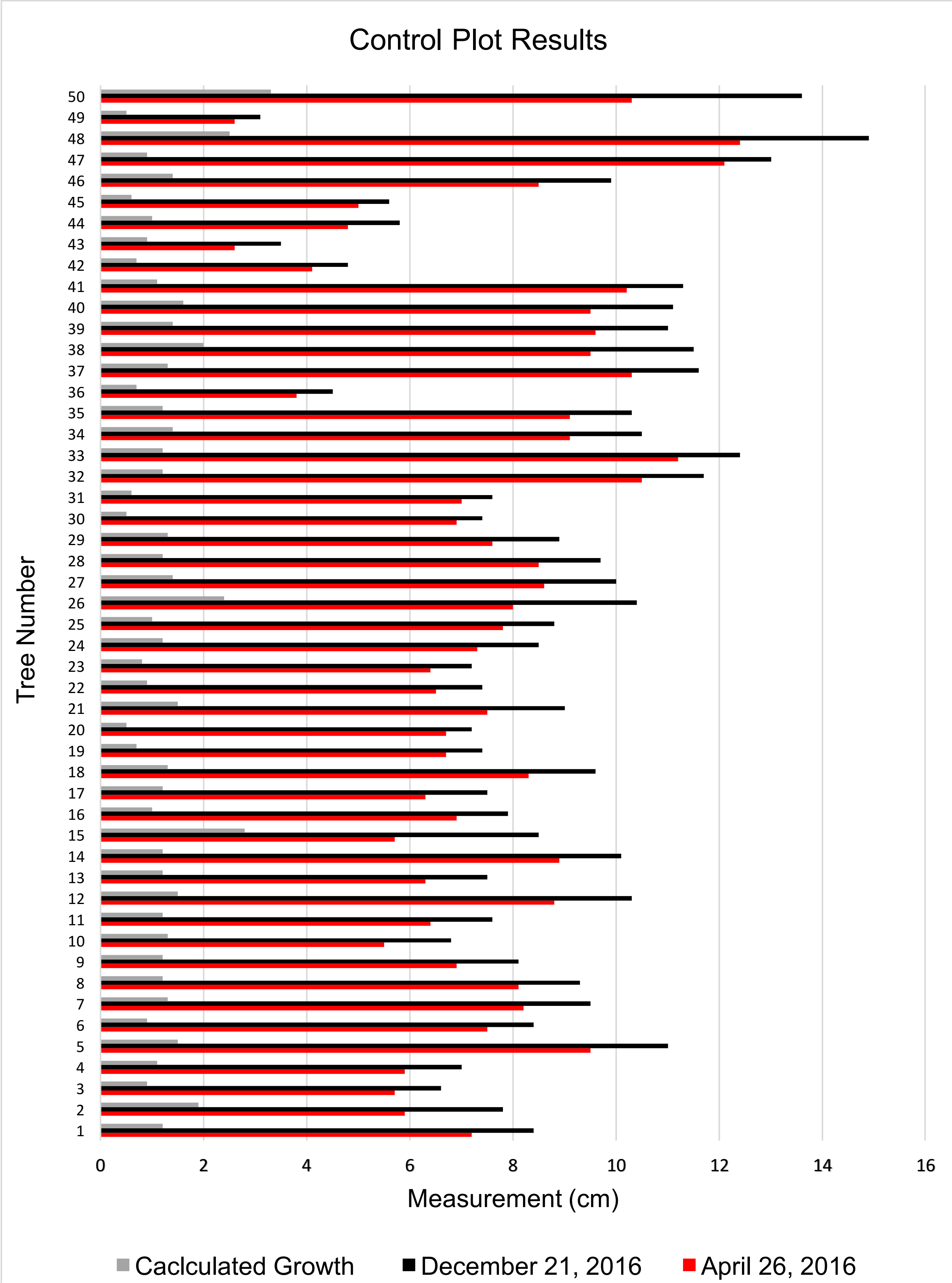

Figure 11 The initial measurements, secondary measurements and calculated growth of the control trees

Figure 12 shows the diameter growth of all 100 trees. The graph is divided into sections of 0.5 cm and the diameter growth is calculated by subtracting the initial DBH measurement that occurred in April 2016 from the final DBH measurement that occurred in December of the same year.

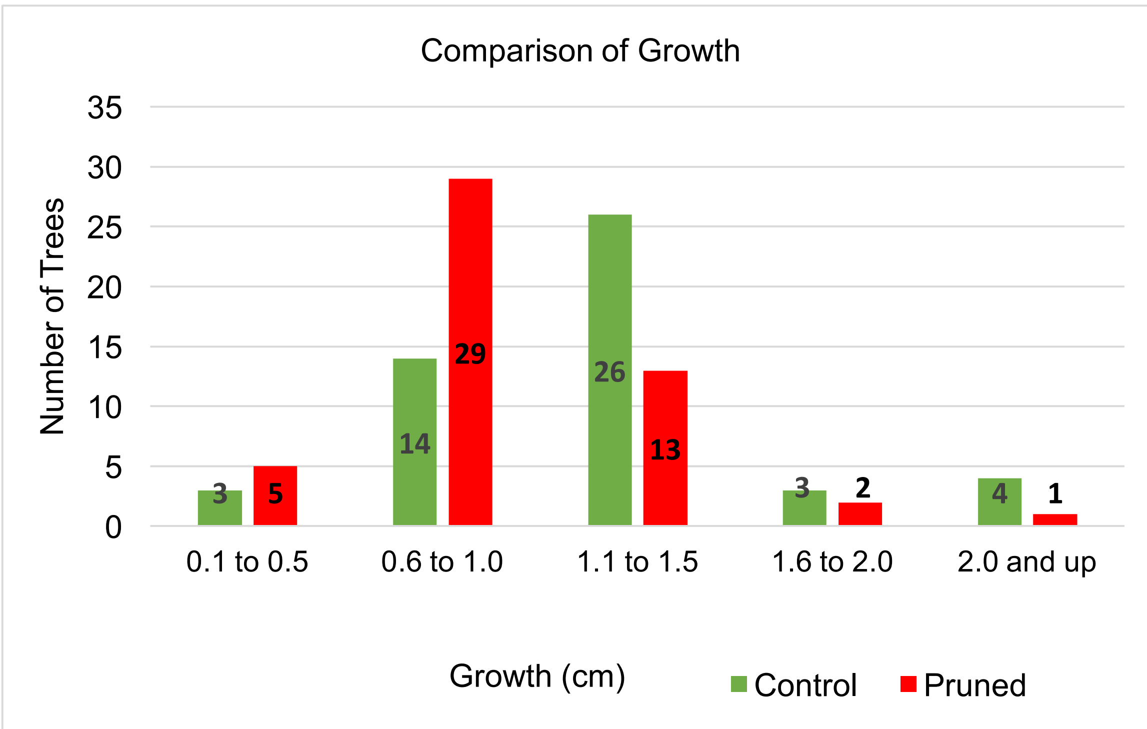

Figure 12 Distribution of growth (cm)

DISCUSSION

Initially the treated plots had the largest average DBH of 8.45 cm which is 0.88 cm larger than the average DBH of the pruned plots which was 7.57 cm. This difference decreased to 0.56 cm by December but the average DBH in the treated plots remained larger throughout the experiment. In respect to the smallest (minimum) measured DBH in both April and December the treated plot was once again determined to exceed that of the control plots.

The aforementioned differences can be explained by one primary factor, which is simply that nature is not uniform. As a result of this naturally the seeded experimental area has a wide initial range of DBH. This natural variance can easily explain the differences in all initial measurements and account for some of the differences between the later measurements such as the average DBH.

During the April measurements the largest measured DBH was found to be 13.6 cm and to be in the treated plots but by December the largest DBH was then found in the control plots and measured 14.9 cm. The range of the treated plots is 10.95 cm and 9.90 cm in April and December, respectively. The control plots originally had a smaller range of 9.8 cm, which then increased by 2.0 cm to 11.8 cm in December. When examining the growth of both the control and treated plots it must be noted that the treated plots only expressed a total of 47.0 cm of growth over all 50 trees while the control plots showed a total amount of growth of 62.8 cm. The total growth of the treated and control plots translated to an average growth per tree of 0.94 cm and 1.26 cm, respectively. The minimum amount of growth seen in the experimental plots was 0.1, which is 5 times less than the minimum growth of the control plot, which was 0.5 cm. In April the calculated sample variances were very similar and only had difference of 0.13 but by December the difference significantly increased by more 10 times to 1.32. When scrutinizing the treated and control plots maximum measured growth it was interesting to see that the treated plots had a tree that grew 3.75 cm while the controls plots only had a growth of 3.3 cm. This growth of 3.75 cm can be explained by the fact it occurred on the smallest pruned tree and that said tree had reduced competition. Additionally, the crown removal might not been felt as much by the smaller diameter tree.

The pruning of trees has many long-term benefits but they are not seen immediately (Hevia et al. 2016). It typically takes 2 to 4 years for trees to overcome the stress caused by a pruning regime and to see any of the benefits of pruning and the results of this study reinforce that statement (Hevia et al. 2016). The removal of any portion of the crown inhibits a trees ability to photosynthesize which in turns inhibits growth. Also, it is important to note pruning trees creates intentional wounds that a tree must compartmentalize and heal. The process of healing wounds means the allocation of carbohydrates that would typically be used for growth to heal said wounds. This diversions of carbohydrates once again inhibits a tree’s primary and secondary growth ability. These two factors combine to temporarily hinder diameter growth of pruned trees for a few years (Hevia et al. 2016). Even though a pruned trees diameter growth is initially restricted it limits the knots to the core of the tree, which in turn should increase clear wood content and overall value of the harvested timber (Hevia et al. 2016).

Increasing clear wood content is one of the greatest benefits that pruning tree provides (Hevia et al. 2016). Frequently when a pruning regime is applied to a stand it can result in the production of epicormic shoots like in this study

(Montagu et al. 2003). During the second set of measurements that occurred in December 31 out of the pruned produced epicormic shoots. These shoots have the potential to hinder the benefits of pruning if not naturally or artificially pruned (Montagu et al. 2003).

The distribution of growth expressed by all 100 samples trees is primarily concentrated between 0.6 cm to 1.5 cm, with a total of 82 trees showing growth in that 1 cm range. When observing the measured data for the pruned plots 34 out of the 50 trees showed growth of 1.0 cm or less. In comparison the diameter growth of the control plots were primarily concentrated above 1.1 cm to 2.0 cm, with 29 trees falling between the aforementioned 1 cm range. I also feel like it is important to note that only 3 of the control trees had growth of 0.5 cm or less while the pruned had 5 trees. Only a total of 5 trees expressed growth of 2.0 cm or more, 4 of which were control and the last one was from the treated plots. These differences reinforce the fact that the pruned trees growth is initially strongly inhibited by the stress caused by the implementation of an intensive pruning regime (Hevia et al 2016).

As earlier mentioned, a one-way ANOVA was performed at 95% confidence level to compare the calculated growth of the control. The calculated P-value was 0.00423, which is significantly lower than the established P-value of 0.05. This determines that the null hypothesis that states if any difference of diameter growth is found, it is a result of the applied tending treatment. The F-critical value was calculated to be 3.94 while the F value was established to be 8.58, which further reinforces the need to reject the null hypothesis. Since the null hypothesis has been rejected. As expected the application of the pruning regime has significantly impacted the growth of the pruned trees (Hevia et al. 2016). The impact of the pruning regime was not positive but that is projected to change overtime (Hevia et al. 2016).

RECOMMENDATIONS

This experiment went very well and produced results that are consistent with all reviewed literature. Even though the study produced the expected results there are several recommendations that could be used to improve this study or other future studies examining the effects of pruning. My first recommendation would be implement manual pruning instead of moto-manual. The use of large chainsaws caused some unwanted damage (Figure 13) which would increase tree stress levels and the time it would take to heal from the pruning regime. At the very least I would suggest the use of smaller chainsaws that are more manoeuvrable and size appropriate to the branches that were removed.

Figure 13 Damage cause in the motor-manual pruning process

I would also advise that in future studies larger experimental and control plots be established so that more trees can be studied. The studied trees would preferably be older, having and average age of 11 years or older. This age would allow for pruned trees to better respond to stress caused by a pruning regime. Furthermore, I would recommend that any future studies use artificially regenerated stands. An artificially regenerated stand would remove study variance and provide for more consistent DBHs within a single plot and among plots.

I strongly believe that a longer study period would be greatly beneficial. The longer study period would allow for the benefits of the pruning regime to actually be studied. It would also allow for an in depth examination of the impact of pruning on clear wood content. This study has the opportunity to be continued by future undergraduate students at Lakehead University in 3 to 4 years to ensure that enough time has passed to allow the treated trees to recover from the pruning regime.

Once a long-term study is performed it would also be paramount to examine whether intensive pruning is economically feasible. This means determining if the effects of pruning increases wood quality and/or yield sufficiently to compensate for the additional cost of the treatment.

CONCLUSION

This study produced the expected results in accordance with literature on this the topic of applying intensive pruning regimes to a high value species. With further study the intensive management of Red pine plantations, which are prevalently found across the province, could be justifiable. The plantations found in Ontario are typically very productive and as a result it is easy to justify the required additional economical investment. If an intensive pruning regime were to be implemented it could result in an increase of wood quality and yield.

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APPENDIX I

Plot 1 (Pruned)				
Tree	April DBH (cm)	December DBH (cm)	Growth (cm)	Epicormic shoots (Y/N)
1	8.50	9.7	1.20	Y
2	10.00	10.6	0.60	N
3	4.40	5	0.60	N
4	9.50	10.2	0.70	Y
5	11.70	12.9	1.20	N
6	10.50	10.6	0.10	Y
7	7.00	7.8	0.80	Y
8	2.65	6.4	3.75	N
9	8.80	9.6	0.80	Y
10	8.00	8.7	0.70	Y
11	8.10	8.9	0.80	Y
12	10.00	11	1.00	Y
13	9.90	10.7	0.80	N
14	13.60	14.7	1.10	N
15	9.70	10.4	0.70	Y
16	12.70	13.8	1.10	N
17	11.70	12.3	0.60	N
18	9.80	11.3	1.50	N
19	10.40	11.3	0.90	Y
20	5.70	6.4	0.70	Y
21	7.40	8.1	0.70	Y
22	7.00	8	1.00	Y
23	9.60	10.3	0.70	Y
24	10.70	11.4	0.70	N
25	9.30	10.4	1.10	Y
		Epicormic Shoots:		15

Plot 2 (Pruned)				
Tree	April DBH (cm)	December DBH (cm)	Growth (cm)	Epicormic shoots (Y/N)
26	8.1	9.1	1	N
27	8.6	9.1	0.5	Y
28	8.8	9.3	0.5	Y
29	4.5	5.5	1	Y
30	7.6	8.7	1.1	N
31	6.3	6.7	0.4	Y
32	10.4	11.5	1.1	N
33	6.2	7.1	0.9	Y
34	7.3	8	0.7	N
35	7.3	8.9	1.6	N
36	10.7	11.8	1.1	Y
37	10.5	11.9	1.4	N
38	7.4	8.2	0.8	N
39	4.2	4.8	0.6	Y
40	9	10.1	1.1	Y
41	7.4	8.3	0.9	N
42	8	9.9	1.9	Y
43	6.7	7.2	0.5	Y
44	6.9	7.5	0.6	Y
45	5.6	6.2	0.6	Y
46	10.6	11.7	1.1	N
47	7.5	8.2	0.7	Y
48	8.6	9.5	0.9	Y
49	8.2	8.9	0.7	Y
50	9.4	10.8	1.4	Y
		Epicormic Shoots:		16

Plot 3 (Control)			
Tree	April DBH (cm)	December DBH (cm)	Growth (cm)
1	7.2	8.4	1.2
2	5.9	7.8	1.9
3	5.7	6.6	0.9
4	5.9	7	1.1
5	9.5	11	1.5
6	7.5	8.4	0.9
7	8.2	9.5	1.3
8	8.1	9.3	1.2
9	6.9	8.1	1.2
10	5.5	6.8	1.3
11	6.4	7.6	1.2
12	8.8	10.3	1.5
13	6.3	7.5	1.2
14	8.9	10.1	1.2
15	5.7	8.5	2.8
16	6.9	7.9	1
17	6.3	7.5	1.2
18	8.3	9.6	1.3
19	6.7	7.4	0.7
20	6.7	7.2	0.5
21	7.5	9	1.5
22	6.5	7.4	0.9
23	6.4	7.2	0.8
24	7.3	8.5	1.2
25	7.8	8.8	1

Plot 4 (Control)			
Tree	April DBH (cm)	December DBH (cm)	Growth (cm)
26	8	10.4	2.4
27	8.6	10	1.4
28	8.5	9.7	1.2
29	7.6	8.9	1.3
30	6.9	7.4	0.5
31	7	7.6	0.6
32	10.5	11.7	1.2
33	11.2	12.4	1.2
34	9.1	10.5	1.4
35	9.1	10.3	1.2
36	3.8	4.5	0.7
37	10.3	11.6	1.3
38	9.5	11.5	2
39	9.6	11	1.4
40	9.5	11.1	1.6
41	10.2	11.3	1.1
42	4.1	4.8	0.7
43	2.6	3.5	0.9
44	4.8	5.8	1
45	5	5.6	0.6
46	8.5	9.9	1.4
47	12.1	13	0.9
48	12.4	14.9	2.5
49	2.6	3.1	0.5
50	10.3	13.6	3.3

APPENDIX II

PLOT 1

Plot 1 Summary Statistics			
Type of Data Analysis	April	December	Growth (cm)
Mean	9.066	10.02	0.954
Standard Error	0.493	0.456	0.129
Median	9.600	10.400	0.800
Mode	10.000	10.600	0.700
Standard Deviation	2.467	2.280	0.644
Sample Variance	6.087	5.197	0.415
Range	10.950	9.700	3.650
Minimum	2.650	5.000	0.100
Maximum	13.600	14.700	3.750
Confidence Level(95.0%)	1.018	0.941	0.266

PLOT 2

Plot 2 Summary Statistics			
Type of Data Analysis	April	December	Growth (cm)
Mean	7.832	8.756	0.924
Standard Error	0.350	0.385	0.074
Median	7.600	8.900	0.900
Mode	8.600	9.100	1.100
Standard Deviation	1.748	1.925	0.372
Sample Variance	3.055	3.705	0.139
Range	6.500	7.100	1.500
Minimum	4.200	4.800	0.400
Maximum	10.700	11.900	1.900
Confidence Level(95.0%)	0.721	0.795	0.154

PLOT 3

Plot 3 Summary Statistics			
Type of Data Analysis	April	December	Growth (cm)
Mean	7.076	8.296	1.220
Standard Error	0.219	0.233	0.088
Median	6.900	8.100	1.200
Mode	5.900	8.400	1.200
Standard Deviation	1.095	1.165	0.438
Sample Variance	1.199	1.358	0.192
Range	4.000	4.400	2.300
Minimum	5.500	6.600	0.500
Maximum	9.500	11.000	2.800
Confidence Level(95.0%)	0.452	0.481	0.181

PLOT 4

Plot 4 Summary Statistics			
Type of Data Analysis	April	December	Growth (cm)
Mean	8.072	9.364	1.292
Standard Error	0.564	0.648	0.134
Median	8.600	10.300	1.200
Mode	8.500	#N/A	1.400
Standard Deviation	2.822	3.238	0.669
Sample Variance	7.961	10.487	0.447
Range	9.800	11.800	2.800
Minimum	2.600	3.100	0.500
Maximum	12.40	14.900	3.300
Confidence Level(95.0%)	1.165	1.337	0.276