A Review and Evaluation of Growth Response, Stand Value and Profitability of Pre-Commercially Thinned Jack Pine Stands in Northwestern Ontario

by

William C. Lavaway

FACULTY OF NATURAL RESOURCES MANAGEMENT
LAKEHEAD UNIVERSITY
THUNDER BAY, ONTARIO

April 2021

A Review and Evaluation of Growth Response, Stand Value and Profitability of Pre-Commercially Thinned Jack Pine Stands in Northwestern Ontario

by

William C. Lavaway

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

Faculty of Natural Resources Management

Lakehead University

April 2021

---	----------------------------------
Dr. Kevin Crowe.	Dr. Mathew Leitch
Major Advisor	Second Reader

LIBRARY RIGHTS STATEMENT

In presenting this thesis in partial fulfillment of the requirements for the HBScF degree at Lakehead University in Thunder Bay, I agree that the University will make it freely available for inspection.

This thesis is made available by my authority solely for the purpose of private study and may not be copied or reproduces in whole or in part (except as permitted by the Copyright Laws) without my written authority.

Signature: ______________________________

Date: May 7, 2021 .

A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty, or of Lakehead University.

MAJOR ADVISOR COMMENTS

ABSTRACT

This thesis will be a literature review with the purpose of evaluating the impact pre-commercial thinning (PCT) has on the tree growth response and if it can meet the objective of profitability in Jack pine (*Pinus banksiana* Lamb.) stands in Northwestern Ontario. Timing and thinning intensity have been identified as two major factors which influence the success of PCT. A general conclusion that can be made from the literature reviewed is that there is no specific threshold for timing and thinning intensities. Both are dependent upon the management objective and success can only be attained when used properly. If the goal is to achieve high-quality logs, then applying PCT at a low intensity and later in the stand's development will help meet this goal. However, if the goal is to produce high volume with the shortest rotation age, then applying PCT at a high intensity at an early stage in the stand's development will yield positive results. Additionally, tree growth response is clearly impacted by PCT. Greater thinning intensities can cause rapid diameter growth at the cost of increasing the abundance of more severe defects and reduce the overall quality of wood. When applied appropriately, PCT was found to decrease the total stand volume however, it can increase the total merchantable volume. Furthermore, it was estimated that in some cases, PCT can produce approximately $2,880 more average lumber recovery per hectare when compared to control stands. From the literature reviewed, it appears that PCT can meet the objective of profitability in Jack pine stands in Northwestern Ontario when used correctly.

Key Words: Pre-commercial thinning, tree growth response, profitability, lumber recovery, total stand volume, merchantable volume

CONTENTS

TABLES

FIGURES

ACKNOWLEDGEMENTS

Firstly, I would like to thank Dr. Kevin Crowe for aiding me in my decision regarding a thesis topic. Additionally, Dr. Crowe assisted me with the development of this thesis and ultimately the direction in which it is presented. I would also like to thank Dr. Mathew Leitch for taking the time to be a second reader on this thesis project. Without the contributions from these individuals, this thesis would not have been possible, and I am grateful for their guidance.

1.0 INTRODUCTION

Forestry in Northern Ontario is one of the regions' main industries. However, despite its economic importance, timber supply is a potential limiting factor for further economic growth of this industry (Tong *et al.* 2005, Moulinier *et al.* 2015, Pacé *et al.* 2017). Since the low productivity of Northern Ontario's forests and the high demand for lumber, pre-commercial thinning (PCT) has been thought to be an appropriate method to increase productivity by reducing the time it takes trees to reach maturity (Tong *et al.* 2005). There have been a variety of studies on the positive effects of PCT with regards to species such as Balsam fir (*Abies balsamea*), Norway spruce (*Picea abies*), and Scots pine (*Pinus sylvestris*), but few that examine the relationship between PCT and Jack pine (*Pinus banksiana* Lamb.) in Northern Ontario.

PCT is a well-established method for promoting the growth of diameter at breast height (DBH) as well as the overall quality and quantity of merchantable volume within the tree (Pacé *et al.* 2017). However, timing and thinning intensity are two main factors that can contribute to the success or failure when applying PCT (Tong *et al.* 2005, Zhang *et al.* 2006, Splawinski *et al.* 2014, Splawinski *et al.* 2017). Depending on how these factors are applied, the result for the stand's lumber quality may be quite different (Van Damme & McKee 1990, Morris *et al*. 1994, Zhang *et al.* 2006). The appropriate time and intensity to apply PCT are dictated by the goal(s) of the management plan (Van Damme & McKee 1990). By understanding how timing and thinning intensity affect the growth of Jack pine, the application of PCT can be used to potentially increase the productivity in Northern Ontario's Jack pine stands.

1.1. Objective:

The objective of this thesis is to determine if PCT can be an economically viable option that can be applied to Jack pine stands in Northwestern Ontario. To achieve this objective, a review and comparison of relevant literature will be done. The timing, thinning intensity, and how they affect the growth of Jack pine will be evaluated to determine a possible conclusion.

2.0. LITERATURE REVIEWED

2.1. Jack pine Silviculture:

Jack pine is a shade-intolerant conifer that is widespread across Canada and is found in ecoregions 1-5E (typically restricted to plantations in ecoregions 6 & 7E) in Ontario (See figure 2.2.1. below) (Rudolph and Laidly 1990, OMNRF 2000). Although they are able to tolerate a variety of sites, they perform best on dry, well-drained sandy loam with a pH range between 4.5-7.0 (Chrosciewicz 1990, OMNRF 2000.).

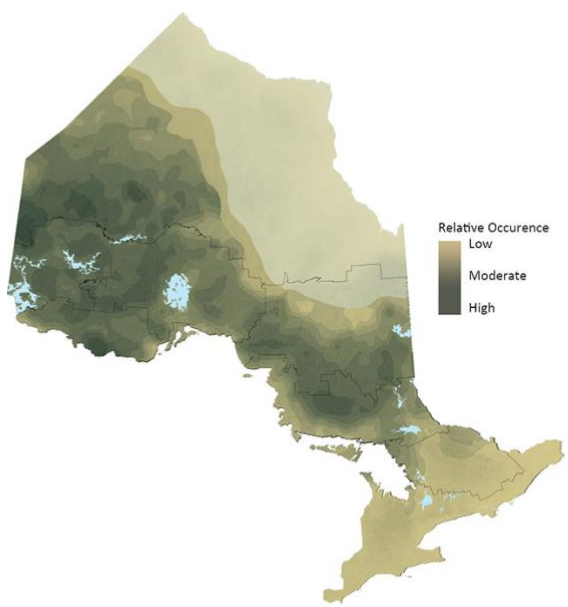

Figure 1. Density distribution of Jack pine in Ontario (Government of Ontario 2016)

Jack pine seeds require exposed mineral soil or burned duff for germination to occur as well as, slight shade and moisture to prevent desiccation (OMNRF 2000, OMNRF 2015). Jack pine seeds typically require 15 – 60 days to germinate, although some may take as long as 100 days (Rudolph and Laidly 1990). If conditions are not suitable for germination, seeds may remain dormant for between 5 – 10 years (OMNRF 2000, OMNRF 2015). In more northern areas of the tree's range, their serotinus cones require an approximate temperature of 50° C (122° F) to open (Rudolph and Laidly 1990). This kind of temperature is only achieved through wildfires, although, in Jack pine's southern range where cones are partially serotinous, the outside temperature required to open the cones is only 27° C (80° F) (Rudolph and Laidly 1990). If fire does not occur in a stand, Jack pine will often struggle to regenerate, and the stand will transition from Jack pine dominant to a more shade-tolerant species (Chrosciewicz 1990). In Ontario, Jack pine mixed stands typically consist of poplar (*Populus spp.)*, birch (*Betula spp*.), and spruce (*Picea spp*.) species (Rudolph and Laidly 1990, Longpré *et al.* 1994, Mann & MacDonald 2015). Unlike pure Jack pine stands, mixedwood stands create important habitat for a large variety of wildlife through improving soil quality (Longpré *et al.* 1994). Additionally, birch species have been found to increase the DBH of Jack pine when they are growing in the same stand (Longpré *et al.* 1994). However, too much competition in these stands (more than 4,950 trees/ha) will result in stunted growth for Jack pine (Rudolph and Laidly 1990).

Although Jack pine is shade intolerant, slight shade is required to achieve optimal form, especially at young ages (Rudolph and Laidly 1990, OMNRF 2000, OMNRF 2015). In the first 20 years of its development, Jack pine is one of the fastest-growing conifers and along with high initial stand densities, stem exclusion and self-thinning will result (Rudolph and Laidly 1990, Zhang et al. 2006, OMNRF 2015, Wisconsin Department of Natural Resources Division of Forestry 2016). Well stocked stands produce trees with a straight, slender stem profile and a crown cover percentage ranging between 30 to 45%, while trees in understocked stands are of poor stem form and display a higher crown cover percentage with branches typically reaching the ground (Wisconsin Department of Natural Resources Division of Forestry 2016). However, trees in overstocked stands do not receive enough sunlight and have thinner, weaker stems than those in understocked and well-stocked stands (Wisconsin Department of Natural Resources Division of Forestry 2016).

2.2. Aspects of PCT:

Pre-commercial thinning (PCT) is a method of thinning where trees in overstocked stands are released to stimulate growth and prevent the prolonged suppression of the target species (Fahlvik 2005, Williams and Harrington 2012, Uotila *et al.* 2020, Wotherspoon *et al.* 2020). PCT is implemented in overstocked stands where seedlings have not yet reached maturity and have no lumber value associated with them (Fahlvik 2005, Williams and Harrington 2012). This typically occurs at a mean stand height of approximately 1.3m (Fahlvik 2005, Williams and Harrington 2012). PCT reduces the overall competition within the stand and allows for trees to develop a larger mean diameter (Routa 2020, Wotherspoon *et al.* 2020). However, despite the decrease of all the stand's overall volume, the increase in average DBH and wood quality has the potential to increase the stand's value (Fahlvik 2005, Uotila *et al.* 2020, Wotherspoon *et al.* 2020). Removing trees of poor quality while retaining those of higher quality will ensure the best-growing stock is available at the final harvest and maximize profit (Fahlvik 2005, Williams and Harrington 2012). In addition to improving the quality and merchantable volume of trees within the stand, PCT also produces more vigorous stands with higher resistance to windfalls and insect outbreaks (Fahlvik 2005, Williams and Harrington 2012, Watson *et al.* 2013). In the long term, PCT will create more valuable stands by increasing the growth rate of the target species as well as increasing vigour and reduce the length of harvest rotations (Fahlvik 2005, Williams and Harrington 2012, Uotila *et al.* 2020, Wotherspoon *et al.* 2020).

When implementing PCT, the two methods that can be used are chemically and mechanically (Reukema 1975, Ligné 2005, Williams and Harrington 2012, Routa 2020). Using herbicides such as Glyphosate for PCT is typically done by manually spraying undesired seedlings, or, in conditions where seedlings are less than 1m in height, tractors can be used (Williams and Harrington 2012). Mechanical thinning is a much more common method and can be done either motor- manually or through mechanized tending methods (Ligné 2005, Williams and Harrington 2012, Routa 2020).

Mechanized tending is more costly than motor-manual tending and depending upon the size of the forest's stands may not be worth the investment (Ligné 2005, Routa

2020). In two separate studies done by Ligné (2005) and Routa (2020), it was found that over short periods, motor-manual tending is more productive than mechanized tending. However, it was hypothesized by Routa (2020) that as time spent tending increases, the efficiency of mechanized tending increases.

2.2.1. PCT effects on wood quality:

While PCT increases the general growth rate and increases tree volume, there are other indicators of wood quality that can be used to assess the effectiveness of PCT (Routa 2020, Wotherspoon *et al.* 2020). Modulus of rupture (MOR), modulus of elasticity (MOE), and wood density are all important measurements of lumber quality (Green *et al.* 1999, Zhang *et al*. 2006, Fernandes *et al.* 2017). MOR measures the maximum load a piece of wood can tolerate before it ruptures (Green *et al.* 1999, Zhang *et al.* 2006, Babiak *et al.* 2018). This is a useful metric because it allows for an understanding of the maximum weight a specific species can tolerate before breaking (Green *et al.* 1999). MOE measures the wood's stiffness and its ability to recover from the stress placed on it (Green *et al.* 1999, Zhang *et al.* 2006, Babiak *et al.* 2018). Unlike MOR, a MOE test does not take the wood to its breaking point but rather measures the maximum weight it can endure while being able to return to its original shape (Green *et al.* 1999). Wood density is simply the amount of wood fiber (mass) present in a given volume and is expressed as kg/m^3 (Green *et al.* 1999, Zhang *et al.* 2006). PCT does, however, produce a higher percentage of juvenile wood in trees at the time of maturity (Zobel & Van Buijtenen 1989). Juvenile wood in trees is not as structurally sound as mature wood and produces structurally inferior lumber (Zobel & Van Buijtenen 1989, Zhang *et al.* 2006, Kretschmann & Cramer 2007, Barrios *et al.* 2017). Although an increased growth rate may lead to higher juvenile wood content, less intensive PCT has been found to have little to no effect on the juvenile wood content in mature trees (Zobel & Van Buijtenen 1989, Kretschmann & Cramer 2007, Barrios *et al.* 2017).

2.3. How Jack pine Stands Respond to PCT:

PCT is used in overstocked stands where trees have a positive response to release. Jack pine's shade-intolerance means PCT has the potential to increase the productivity of Jack pine stands (Tong *et al.* 2005, Zhang *et al*. 2006, Splawinski *et al.* 2014). When applied to Jack pine stands, PCT has shown to provide a consistent increase in the average diameter of the stand (Tong *et al.* 2005, Tong & Zhang 2005, Zhang et al. 2006, Schneider *et al.* 2008, Splawinski *et al.* 2014, Moulinier *et al.* 2015, Splawinski *et al.* 2017). However, when exposed to excess sunlight, and thinned too early, trees of poorer form tend to arise (Rudolph & Laidly 1990, Splawinski *et al.* 2014). Conversely, too little sunlight and the seedlings may not respond to release when thinned in the future (Morris *et al.* 1994). DBH growth rate starts to decrease within 6-12 years after establishment and it is at this time that PCT is normally applied (Splawinski *et al.* 2014).

3.0. METHODS

Outlined in the methods are three sections that will be reviewed, and later evaluated. These sections provide a means to measure and evaluate the effectiveness of PCT. All three of these sections will be based on a comprehensive review of literature.

i. The effect of different thinning intensities
ii. The effects timing has on PCT success
iii. How PCT affects the growth characteristics of Jack pine

The first examines the effects different thinning intensities may provide. A series of different studies will be analyzed to determine the effects different intensities have on Jack pine. However, studies strictly pertaining to how varying PCT intensities may affect Jack pine were relatively uncommon. To provide more insight on the topic, studies of Scots pine from different regions in Finland were used as a comparison. Both species share similar silvics and were both grown in similar conditions.

The second section is a review of how the timing of PCT affects Jack pine stands. Here, literature will be compared to explore how Jack pine react to PCT at different ages. Studies in this section are from northwest Ontario, north-central Ontario, northwest Quebec, and northern Michigan.

The final section analyzes how both timing and thinning intensities affect the growth of Jack pine. Numerous studies will be used to examine the effects that PCT may have on DBH, height, modulus of rupture (MOR), modulus of elasticity (MOE), and a number of notable defects (knots, crook and sweeps, and forks). Studies in this section are from northwest Ontario, Manitoba, northwest Quebec, eastern New Brunswick, and northern Michigan.

4.0. RESULTS:

4.1. The Effects of Different Thinning Intensities:

In summary Table 1 below, the effects of different thinning intensities from multiple authors are compared.

Table 1. Studies comparing the effects of different thinning intensities of PCT.

Species	**Study**	**Area**	**Thinning Intensity Results**
Jack Pine	Tong *et al*. (2005)	Northwest Ontario	• PCT stands had a higher average DBH than control stands, • Increased thinning intensity showed a significant increase in DBH between control and PCT stands • Most intensively thinned stand (1,360 stems/ha) had the greatest difference when compared to control stand
Jack Pine	Zhang *et al.* (2006)	New Brunswick	• Most intensively thinned stand (spacing of 2.13m with a density of 2,212 stems/ha after thinning and 1,250 stems/ha after 34 years) had the largest average DBH. • Most intensively thinned stand had the greatest amount of merchantable volume (m3/ha)
Jack Pine	Morris *et al.* (1994)	Northwest Ontario	•Increased thinning intensities stands showed an increase in average DBH as well as an increased growth rate •Stands thinned to 3X3m had the greatest growth increase

Scots Pine	Huuskonen & Hynynen (2006)	Southern and Central Finland.	•Stands thinned at 3m to 3000 stems/ha allow for the largest merchantable volume during the first commercial thinnings •Stands thinned at 3m to a density of 2000 stems/ha have a 30% decrease in volume by the time of the first commercial thinning
Scots Pine	Ruha & Varmola (1997)	Lapland, Finland	• Late PCT when the dominant tree height is above 7m and reducing the stand density to 1600 stems/ha could postpone the first commercial thinning by 5-10 years when compared to 2500 stems/ha. • Of all thinning intensities analyzed in this study, 2500 stems/ha produced the best wood quality and volume yield.
Scots Pine	Makinen & Isomäki (2004)	Southern and Central Finland.	•Stands thinned to 42% of the basal area of control stands showed a significant increase in DBH growth, but not in height • Merchantable volume of the stand decreased significantly when thinned to 75-80% of the basal area of control stands

There are few studies exclusively comparing the effects of thinning intensities on Jack pine and therefore, the effects of thinning intensities on Scots pine are included in the table. Both species have similar silviculture and are easily comparable (Egnell 2000, Øyen *et al*. 2006). In the studies focused on Jack pine, all three studies found that stands receiving PCT displayed an increase in DBH growth. The results from these studies concluded that the most intensively thinned stand produced the most significant DBH growth. However, there is no specific spacing where the three studies agree PCT is most effective. Instead, the most intense spacing in each study was different but displayed the same overall trend. When compared with the studies on Scots pine, Ruha & Varmola (1997) found that after reducing a stand to 2500 stems/ha, both wood quality and merchantable volume were maximized. Stands thinned to a density of 1600 stems/ha had an increased chance of delaying the first thinning by up to 10 years. Similarly, Huuskonen & Hynynen (2006) found that stands thinned at 3m to 3000 stems/ha yielded the largest merchantable volume during the first commercial thinnings. As thinning intensity increased to a density of 2000 stems/ha, there may be a 30% decrease in volume by the time of the first commercial thinning. Additionally, Makinen & Isomäki (2004) reported merchantable stem volume decreased as thinning intensities increased Stands where thinning intensities exceeding 75–80% of the control stands basal area led to reduced merchantable volume production.

4.2. The Effects Timing Has on PCT Success:

Summary Table 2 below shows the findings from several studies with regards to how timing affects jack pine stands.

Table 2. Studies comparing the effects timing of PCT has on Jack pine stands.

Species	**Study**	**Area**	**Thinning Age Results**

Jack Pine	Tong *et al.* (2005)	Northwest Ontario	• Stands around the age of 30 displayed a less significant change in DBH than those below the age of 30 • Thinning at 11-12 years of age yielded the more significant increases in average DBH
Jack Pine	Tong & Zhang (2005)	Northern Michigan	• Stand thinned at 14 years of age had a significant increased growth period of 5 years
Jack Pine	Riley (1973)	Northern Ontario	•Stands thinned at ages 9 and 22 had an increased growth period of approximately 20 years • Stand thinned at age 33 only had an increased growth period of no greater than 5 years
Jack Pine	Splawinski *et al.* (2014)	Northwest Quebec	• PCT should be done 7-10 years after establishment to maximize growth and reduce treatment expenses
Jack Pine	Splawinski *et al.* (2017)	Northwest Quebec	•Thinning applied to Individuals between 4 and 9 years of age after establishment, had a significantly greater growth response than individuals thinned 10+ years after establishment

From Table 2, it can be seen that all studies display a similar trend where an increase in age shows a decrease in significant growth. In studies by Tong *et al.* (2005) and Splawinski *et al*. (2014) and (2017), it was observed that when PCT was applied to stands established at 10-12 years old there was a decrease in responsiveness to the treatment. Tong & Zhang (2005) had similar findings and determined that a stand thinned at 14 years of age or later, will only have a significant growth period of 5 years. However, despite this overall trend, there is no specific age where PCT immediately becomes ineffective. Riley (1973) found that stands thinned up to age 22 may still have an increased growth response of up to 20 years (the same as stands thinned at the age of 9).

4.3. How Timing and Thinning Intensities Affect Growth Characteristics of Jack pine

Summary Table 3 below shows the findings from several studies with regards to how timing and thinning intensity affect Jack pine stands.

Table 3. Studies comparing the effects thinning and thinning intensities of PCT have on the growth of Jack pine stands

Species	**Study**	**Area**	**Growth Results**

Jack Pine	Tong *et al.* (2005)	Northwest Ontario	• A positive increase in DBH and height for trees in PCT stands •Tree height in PCT stands did not show as significant of an increase at DBH
Jack Pine	Zhang *et al.* (2006)	New Brunswick	• MOE and MOR values decrease as PCT intensity increases • Knots present in the wood increased with increased thinning intensity • Trees of the most intensively thinned stand (2.13 m) had larger branches overall than moderately thinned trees (1.22 and 1.52 m) and those in the control stand
Jack Pine	Morris *et al.* (1994)	Northwest Ontario	•PCT stands showed an increase in average DBH • There was no clear relationship between thinning and height • Increased thinning intensity does however lead, to a more severe taper which may negatively affect wood quality
Jack Pine	Bella & deFranceschi (1974)	Manitoba	•PCT stands showed an increase in average DBH • There was no clear relationship between thinning and height

Jack Pine	Tong & Zhang (2005)	Northern Michigan	• PCT applied to Jack pine showed an increase in DBH and height compared to denser stand • Forks on the stems are reduced in PCT stands when compared to stands using increased spacing • Increased spacing leads to increased knot sizes in the lumber • Sweep and crook was reduced in PCT stand
Jack Pine	Splawinski *et al.* (2014)	Northwest Quebec	• As the height at which stems were cut increased, so to do the number of whorls
Jack Pine	Splawinski *et al.* (2017)	Northwest Quebec	• Approximately 75% of Jack pine receiving PCT showed a positive growth response

In Table 3 above, there are multiple different effects PCT has been shown to have on Jack pine growth. Splawinski (2017) reported that approximately 75% of Jack pine receiving PCT showed a positive growth response. The most obvious and consistent trend is the increase in average DBH. All studies documenting PCT's effect on DBH growth reported an increase in DBH when compared to control stands or stands with denser spacing. Tong *et al.* (2005), Morris *et al.* (1994), and Bella & deFranceschi (1974) all concluded that there is no consistent trend linking PCT to increased height growth. However, Tong & Zhang (2005) found that there was an increase in average height with PCT. Although PCT increases DBH, wood quality was not as positively affected. Zhang *et al.* (2006) found that both modulus of rupture (MOR) and modulus of elasticity (MOE) are lower in PCT stands than control stands. Tong and Zhang (2005) and Zhang (2006) both found that PCT also affects knot size and abundance. PCT stands tend to produce trees with more and larger knots than denser stands. PCT stands also produced trees with a more severe taper as reported by Morris *et al.* (1994). However, Tong & Zhang (2005) and Splawinski (2014) found sweep, crooks, and forks were reduced in PCT stands.

5.0. DISCUSSION:

5.1. The Effects of Different Thinning Intensities:

Different thinning intensities have a clear impact on PCT stands when compared to control stands. As seen in the results section, all three of the studies focused on Jack pine reported that stands with the greatest thinning intensities produced trees with significantly greater DBH growth than control stands. However, the densities for the most intensively thinned stands were different across all studies. Tong *et al*. (2005) and Zhang *et al.* (2005) had relatively similar densities of 1,360 stems/ha and 1,250 stems/ha respectively. The study by Morris *et al.* (1994) had a spacing larger than the previous two studies (at 3x3m) and still reported a significant increase in growth between the control stand and each thinning intensity. Results from the scots pine studies indicate that although greater intensities increase tree growth, volume yield decreases. This can be attributed to the fact that as thinning intensities increase, more volume is removed from the forest (Huuskonen & Hynynen 2006). A study from Varmola & Salminen (2004) found that there may be a significant loss in production when a stand is thinned to 1000 stems/ha. Huuskonen & Hynynen (2006) observed that when stands were thinned density of 2000 stems/ha, there was a 30% decrease in volume by the time of the first commercial thinning. Although, stands thinned to a density of 3000 stems/ha produced the largest amount of merchantable volume by the time of the first commercial thinnings. Tong *et al*. (2005) corroborated these findings and determined that PCT may reduce total tree volume per hectare, although total merchantable stem volume per hectare was increased when compared to control stands. While the specific densities between studies may differ, a report by Van Damme & McKee (1990) suggested that a suitable density may be chosen based upon the management objectives. For instance, in pulpwood operation, tree form is less important than in a sawlog operation, and therefore, it may be more beneficial to use a higher thinning intensity to increase growth. While a sawlog operation may want to use a less intense thinning to focus more on reducing defects and producing a clear stem. Morris and Parker (1992) also advised that an optimal density for Jack pine may not exist. As an alternative, they recommend that a series of thinnings may be more practical to achieve higher quality lumber. Additionally, Kojola *et al.* (2005) and Nilsson *et al.* (2010) both confirm that in the management of Scots pine, as many as three thinning phases may be implemented before the first commercial harvest.

5.2. The Effects Timing Has on PCT Success:

Similar to thinning intensity, all of the studies examining the effects timing has on PCT in the results section (Table 2) display a clear trend; with an increase in age comes a decrease in significant growth. Across all five studies, the age at which significant growth starts to decrease varies. All studies are within similar latitudinal coordinates to one another, and site conditions are all relatively similar. However, because studies were conducted in slightly different manners there is room for variation in results. The general conclusion that can be made from the results is that when PCT is applied to a stand past the age of 14, there is a significant reduction in relative growth. The lone exception to this conclusion is the study from Riley (1973), which found stands up to the age of 22 may still experience the same increased growth period as stands receiving PCT at age 9. As seen with thinning intensity, the report by Van Damme & McKee (1990) recommends that timing should be determined based upon the management objectives. An example from Morris *et al.* (1994) compares how in a pulpwood operation, Jack pine stands may be thinned at 10 years of age while a stand aimed at producing sawlogs may receive a thinning at age 25. By applying PCT at an appropriate time based on management objectives, there is the potential to decrease treatment costs and increase yield (Riley 1973, Morris *et al.* 1994, Tong *et al.* 2005). When compared to studies examining the effects of PCT on scots pine in Scandinavia, Varmola & Salminen (2004) found that stands receiving early PCT (where the average stand height is 3m) produce the highest standing volume and merchantable wood. However, they also acknowledge that the timing of PCT should be based on the management objectives set in place. Early PCT is more beneficial to high volume growth objectives while late thinnings favour merchantable removal and higher quality lumber objectives. They also acknowledge that a trade-off scenario (thinning at the dominant height of 5-6 m) is not an alternative solution for trying to achieve both high volume production and high wood quality.

5.3. How Timing and Thinning Intensities Affect Growth Characteristics of Jack pine:

While PCT has proven to be an effective method for increasing the DBH in Jack pine stands, there is no consistent evidence that shows an increase in height. Tong *et al.* (2005) and Tong and Zhang *et al.* (2005) found a correlation between height and PCT while the other studies did not. As such, PCT should not be relied upon with the sole focus of improving tree height. Wood characteristics are also an important aspect that must be considered when discussing the effects of PCT. MOR and MOE are excellent indicators of wood strength and are often affected by an increased growth rate (Green *et al*. 1999, Zhang *et al.* 2006, Fernandes *et al.* 2017). Zhang *et al.* (2006) found that increasing PCT intensity will lead to lower MOE and MOR values. A longer rotation period, although effective for increasing stand volume, produces a higher portion of juvenile wood within trees. Lower MOE and MOR values in PCT stands can be attributed to a higher juvenile wood content in trees which produces structurally inferior wood compared to mature wood (Zobel & Van Buijtenen 1989, Zhang *et al*. 2006, Kretschmann & Cramer 2007, Barrios *et al.* 2017). Although PCT may create a higher juvenile wood proportion, Ulvcrona & Ulvcrona (2011) found that thinning has little to no effect on the MOE within the juvenile wood of Scots pine. However, this is on the assumption that the width of the growth rings within the juvenile wood does not change. To avoid a higher juvenile wood content, and theoretically achieve higher MOE and MOR values, an older rotation age should be considered in stands receiving PCT (Zhang *et al.* 2006). Tong and Zhang (2005) found that forks in the stems were reduced in stands receiving PCT. However, this may be because the trees with forks were removed during thinning therefore decreasing their abundance. In stands with different spacing, that did not receive PCT, the number of forked trees did not increase or decrease with increasing spacing (Tong & Zhang 2005). Tong and Zhang (2005) as well as Zhang *et al.* (2006) also observed that increased intensity can lead to a larger number of knots present in the wood. The size of the knots was also observed to increase with PCT. PCT has also been found to increase other defects like taper, crook and sweep, and whorls. To avoid an increase in serious defects, thinning should be carried out at a later stage rather than earlier (Morris *et al.* 1994, Varmola & Salminen 2004, Zhang *et al.* 2006, Splawinski *et al.* 2014). Overall, there is not a specific time, nor intensity, at which PCT can be applied. Rather, with increased thinning intensities comes accelerated growth, but at the sacrifice of wood quality. While early thinnings lead to accelerated growth with decreased wood quality.

5.4. Potential Profitability of PCT in Jack pine Stands:

For PCT to be an economically viable option in northwest Ontario, timing and thinning intensities must be used in accordance with the management objective. Tong *et al.* (2005) determined that PCT in Jack pine stands in northwest Ontario is an economically viable option. They estimate that stands receiving PCT produced approximately $2,880 (in the dimension mill) and $1,700 (in the stud mill) more average lumber recovery per hectare when compared to control stands. They also determined that PCT stands produced higher economic returns than control stands. The benefit/cost ratio increased along with DBH in PCT stands when compared to control stands. Findings from Riley (1973) and Smith (1984) also suggested that PCT may be an economically viable option. However, they cautioned that treatment cost may be significantly increased the older the stand. The lowest age class had an estimated reduction of $4.29 at harvest while the oldest age class only had a potential reduction cost of $0.97 at harvest (in 1970 United States dollar value). They also estimated the cost/acre (in 1970 United States dollar value) for treatment of the youngest stand varied from $15.92 - $18.38 and $39.64 – $94.99 in stands aged 22 to 33 years old. Within the youngest stand, brushsaws proved to be the more cost-effective treatment option when compared to the chainsaws. Splawinski *et al.* (2014) corroborated these findings and suggested that thinning 7-10 years after establishment may reduce treatment costs while maximizing growth. However, if PCT is applied too early, conifer re-growth may occur which would lead to an additional treatment cost.

PCT has also been found to have financial benefits indirectly related to tree growth. A study done by Samariks *et al.* (2020) found that by reducing the number of trees lost due to windthrow, PCT creates higher stand volumes and increases net present value (NPV). Furthermore, Watson *et al.* (2013) determined that the risk of insect outbreaks can be greatly reduced by using PCT. Bark beetles (*Scolytidae*) outbreaks are particularly affected by PCT. Mountain pine beetles (*Dendroctonus ponderosae*) have been known to cause significant damage to lodgepole pine stands (*Pinus contorta*), a close relative to Jack pine, in British Columbia, and although not currently in Ontario, they have been identified as having the potential to move eastward into the boreal forest

(Bleiker *et al.* 2019). Using PCT can help to reduce a potential bark beetle outbreak risk and increased the commercial value of the forest (Watson *et al.* 2013, Stewart & Salvail 2017).

6.0. CONCLUSION:

From the results and discussion sections above, some conclusions that can be drawn from the results of this study:

First, PCT must be appropriately applied to meet the management objective. If the goal is to achieve high-quality logs (usually associated with sawlog operations) then applying PCT at a low intensity and later in the stand's development will help attain this goal. However, if the goal is to produce high volume with the shortest rotation age (usually associated with pulpwood operations), then applying PCT at a high intensity at an early stage in the stand's development will yield positive results.

Secondly, PCT has the potential to be an economically viable treatment option for Jack pine stands in northwest Ontario. Treatment costs have been found to be significantly less in early stands and may result in increased profit at the time of harvest. As well, PCT stands can produce a higher average lumber recovery per hectare when compared to control stands. As mentioned above, only through proper application can PCT meet the objective of profitability.

Overall, to say PCT can be an economically viable option that can be applied to Jack pine stands in Northwestern Ontario is too broad a statement. Instead, PCT can be an economically viable option for Jack pine stands in Northwestern Ontario when applied in accordance with the management objective.

7.0 LITERATURE CITED

Babiak, M., Gaff, M., Sikora, A., & Hysek, S. 2018. Modulus of elasticity in three- and four-point bending of wood. Composite Structures, 204, 454-465. Retrieved from https://www.sciencedirect.com/science/article/pii/S0263822317342538

Barrios, A., Trincado, G., & Watt, M. S. 2017. Wood Properties of Juvenile and Mature Wood of Pinus radiata D. Don Trees Growing on Contrasting Sites in Chile. Forest Science, 63(2), 184–191. https://doi.org/10.5849/forsci.2016-060

Bella, I.E. and deFranceschi, J.P. 1980. Spacing effects 15 years after planting three conifers in Manitoba. Can. For. Serv. North. For. Res. Cent. Inf. Rep. NOR-X223. Retrieved from https://d1ied5g1xfgpx8.cloudfront.net/pdfs/11593.pdf

Bleiker, K. P., Boisvenue, C., Campbell, E., Cooke, B. J., Erbilgin, N., Friberg, R. F., Whitehouse, C. M. 2019. Risk assessment of the threat of mountain pine beetle to Canada's boreal and eastern pine forests. Ottawa, ON: Canadian Council of Forest Ministers. Retrieved from https://cfs.nrcan.gc.ca/publications?id=39805

Chrosciewicz, Z. 1990. Site Conditions for Jack Pine Seeding. The Forestry Chronicle, 66(6), 579-584. Retrieved from https://pubs.cif-ifc.org/doi/pdf/10.5558/tfc66579-6

Egnell, G. 2000. SILVICULTURE AND MANAGEMENT OF SCOTS PINE IN SWEDEN. Swedish University of Agricultural Sciences, 165-174. Retrieved from http://www.inia.es/iaspf/2000/fueraserie/egnel.pdf

Fahlvik, N. 2005. Aspects of Precommercial Thinning in Heterogeneous Forests in Southern Sweden (Doctoral thesis, Swedish University of Agricultural Sciences, 2005) (pp. 1-38). Alnarp. Retrieved from https://pub.epsilon.slu.se/862/1/NilsFahlvik.pdf

Fernandes, C., Gaspar, M. J., Pires, J., Silva, M. E., Carvalho, A., Lima-Brito, J., & Louzada, J. 2017. Within and between-tree variation of wood density components in Pinus sylvestris at five sites in Portugal. European Journal of Wood and Wood Products. 75. 511-526. Retrieved from https://www.researchgate.net/publication/310765412_Within_and_between-tree_variation_of_wood_density_components_in_Pinus_sylvestris_at_five_sites_in_Portugal

Government of Ontario. 2016. Jack Pine – Pinus banksiana. Retrieved from https://www.ontario.ca/document/forest-resources-ontario-2016/jack-pine-pinus-banksiana

Green, D. W., Winandy, J. E., Kretschmann, D. E. 1999. Mechanical properties of wood. Wood handbook: wood as an engineering material. Madison, WI: USDA Forest Service, Forest Products Laboratory, 1999. General technical report FPL; GTR-113: Pages 4.1-4.45 Retrieved from https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr113/ch04.pdf

Huuskonen, S. & Hynynen, J. 2006. Timing and intensity of precommercial thinning and their effects on the first commercial thinning in Scots pine stands. Silva Fennica 40(4): 645–662. Retrieved from https://silvafennica.fi/pdf/article320.pdf

Kojola, S., Penttilä T. and Laiho, R. 2005. First Commercial Thinnings in Peatland Pine Stands: Effect of Timing on Fellings and Removals. Baltic Forestry, 11 (2): 51–58.

Kretschmann, D., Cramer, S. 2007. The role of earlywood and latewood properties on dimensional stability of loblolly pine. Proceedings of the Compromised Wood Workshop, 2007 January 29-30. Christchurch, NZ: Wood Technology Research Centre, School of Forestry, University of Canterbury, 2007: pages 215-236. Retrieved from https://www.fpl.fs.fed.us/documnts/pdf2007/fpl_2007_kretschmann002.pdf

Ligné, D., Nordfjell, T. & Karlsson, A. 2005 New Techniques For Pre-Commercial Thinning – Time Consumption and Tree Damage Parameters, International Journal of Forest Engineering, 16:2, 89-99, DOI: 10.1080/14942119.2005.10702518

Longpré, M.H., Bergeron, Y., Paré, D., and Béland, M. 1994. Effect of companion species on the growth of jack pine (Pinus banksiana). Canadian Journal of Forest Research. 24(9): 1846-1853. Retrieved from https://cdnsciencepub.com/doi/pdf/10.1139/x94-238

Mäkinen, H & Isomäki, A. 2004. Thinning intensity and long-term changes in increment and stem form of Scots pine trees. Forest Ecology and Management - FOREST ECOL MANAGE. 203. 21-34. 10.1016/j.foreco.2004.07.028.

Mann, R. & MacDonald, B.G. 2015. Growth of planted jack pine (Pinus banksiana) and natural regeneration ten years after pre- and post-harvest spraying and partial cutting in an Ontario boreal mixedwood forest. The Forestry Chronicle. 91(01): 52-59. https://doi.org/10.5558/tfc2015-010

Morris, D. M., Hills, S. C. and Bowling, C. 1994. Growth and form responses to pre commercial thinning regimes in aerially seeded jack pine stands: 5th year results. The Forestry Chronicle. 70(6): 780-787. https://doi.org/10.5558/tfc70780-6

Morris, D.M. and W.H. Parker. 1992. Variable quality form in mature jack pine stands: quantification and relationship with environmental factors. Can. J. For. Res. 22: 279-289.

Moulinier, J., Brais, S., Harvey, B. D., & Koubaa, A. 2015. Response of Boreal Jack Pine (Pinus banksiana Lamb.) Stands to a Gradient of Commercial Thinning Intensities, with and without N Fertilization. Forests, 6, 2678-2702. doi:10.3390/f6082678

Nilsson, U., Agestam, E., Ekö, P-M., Elfving, B., Fahlvik, N., Johansson, U., Karlsson, K., Lundmark, T. and Wallentin, C., 2010. Thinning of Scots pine and Norway spruce monocultures in Sweden – Effects of different thinning programmes on stand level gross- and net stem volume production. *Studia Forestalia Suecia* 219. 46 pp. ISSN 0039-3150, ISBN 978-91-86197-76-6.

OMNRF. 2000. A silvicultural guide to managing southern Ontario forests. Toronto: Ministry of Natural Resources. 654 pp.

OMNRF. 2015. Forest Management Guide to Silviculture in the Great Lakes-St. Lawrence and Boreal Forest of Ontario. Toronto: Queen's Printer for Ontario. 394 pp.

Øyen, B.H., Blom, H.H., Gjerde, I., Myking, T., Sætersdal, M., Thunes, K.H. 2006. Ecology, history and silviculture of Scots pine (Pinus sylvestris L.) in western Norway – a literature review, Forestry: An International Journal of Forest Research. 79(3). pp 319-329, https://doi.org/10.1093/forestry/cpl019

Pacé, M., Barrette, M., Fenton, N. J., Paré, D., & Bergeron, Y. 2017. Ground-Layer Composition May Limit the Positive Impact of Precommercial Thinning on Boreal Stand Productivity. Forest Science, 63(6), 559–568. https://doi.org/10.5849/FS-2017-062R2

Riley, L.F. 1973. Operational trials of techniques to improve jack pine spacing. Dep. Environ., Can For. Serv., Sault Ste. Marie, ON. Inf. Rep. 0-X-180. 26p. Retrieved from https://dlied5g1xfgpx8.cloudfront.net/pdfs/8860.pdf

Reukema, D. L. 1975. Guidelines for Precommercial Thinning of Douglas-Fir. Portland, OR: Pacific Northwest Research Station, U.S. Department of Agriculture, Forest Service. Retrieved from https://books.google.ca/books?hl=en&lr=&id=XvqhGJTRs9UC&oi=fnd&pg=PA1&dq=how+is+pre+commercial+thinning+done&ots=45_jv79pi6&sig=r7MLSTAmW4DX4pE57iXlyFEnMeg&redir_esc=y#v=onepage&q=how%20is%20pre%20commercial%20thinning%20done&f=false

Routa, J., Nuutinen, Y., & Asikainen, A. 2020. Productivity in Mechanizing Early Tending in Spruce Seedling Stands. Croatian Journal of Forest Engineering, 41(1), 1-11. Retrieved from http://www.crojfe.com/archive/volume-41-no-1/productivity-in-mechanizing-early-tending-in-spruce-seedling-stands/

Rudolph, T.D. and P.R. Laidly. 1990. Pinus banksiana (Lamb.), Jack Pine, pp. 280-293. In R.M. Burns and B.H. Honkala (eds.), Silvics of North America, Vol. 1, Conifers, U.S.D.A. For. Serv. Agric. Handbook. 654, Washington, D.C. From; https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_1/pinus/banksiana.htm

Ruha, T., & Varmola, M. 1997. Precommercial Thinning in Naturally Regenerated Scots Pine Stands in Northern Finland. Silva Fennica, 31(4), 401-415. Retrieved from https://helda.helsinki.fi/bitstream/handle/1975/8537/silva_1997_31_4_%283%29_ruha.t.pdf?sequence=3&isAllowed=y

Samariks, V., Krisans, O., Donis, J., Silamikele, I., Katrevics, J., & Jansons, A. 2020. Cost–Benefit Analysis of Measures to Reduce Windstorm Impact in Pure Norway Spruce (Picea abies L. Karst.) Stands in Latvia. Forests, 11(5), 576–. https://doi.org/10.3390/f11050576

Schneider, R., Zhang, S. Y., Swift, D. E., Bégin, J., & Lussier, J. 2008. Canadian Journal of Forestry Research, 38, 2030-2043. Retrieved from https://cdnsciencepub.com/doi/pdf/10.1139/X08-038

Smith, C.R. 1984. Precommercial thinning in jack pine with particular reference to experiments in Northeastern Ontario. In C.R. Smith and G. Brown (eds.). Jack Pine Symposium. pp. 122–130. Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, ON. and Ont. Min. Natur. Resour., Toronto, ON. COJFRC Symposium Proc. O-P-12. 195 p.

Splawinski, T. B., Drobyshev, I., Gauthier, S., Bergeron, Y., Greene, D. F., & Thiffault, N. 2017. Precommercial Thinning of Picea mariana and Pinus banksiana: Impact of Treatment Timing and Competitors on Growth Response. Forest Science, 63(1), 62–70. https://doi.org/10.5849/forsci.15-178

Splawinski, T. B., Gauthier, S., Bergeron, Y., & Greene, D. F. 2014. The impact of early precommercial thinning of dense jack pine (Pinus banksiana Lamb.) stands on the mortality of thinned stems. The Forestry Chronicle, 90, 371-377. Retrieved from https://pubs.cif-ifc.org/doi/pdf/10.5558/tfc2014-071

Stewart, J. D., & Salvail, J. C. 2017. Evaluation of precommercial thinning of lodgepole pine from long-term research installations in Alberta. Edmonton, AB: Natural Resources Canada, Canadian Forest Service, Canadian Wood Fiber Center. Retrieved from https://cfs.nrcan.gc.ca/publications?id=38085

Tong, Q. J., & Zhang, S. Y. 2005. Impact of initial spacing and precommercial thinning on jack pine tree growth and stem quality. The Forestry Chronicle, 81(3), 418-428. Retrieved from https://pubs.cif-ifc.org/doi/pdf/10.5558/tfc81418-3

Tong, Q. & Zhang, S. & Thompson, M. 2005. Evaluation of growth response stand value and financial return for pre-commercially thinned jack pine stands in Northwestern Ontario. Forest Ecology and Management - FOREST ECOL MANAGE. 209. 225-235. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0378112705000551?via%3Dihub

Uotila, K., Miina, J., Saksa, T., Store, R., Kärkkäinen, K., & Härkönen, M. 2020. Low cost prediction of time consumption for pre-commercial thinning in Finland. Silva Fennica, 54(1). Retrieved from https://www.silvafennica.fi/pdf/article10196.pdf

Ulvcrona, T., & Ulvcrona, K. A. 2011. The effects of pre-commercial thinning and fertilization on characteristics of juvenile clearwood of Scots pine (Pinus sylvestris L.). Forestry: An International Journal of Forest Research,84(3), 207-219. Retrieved from https://doi.org/10.1093/forestry/cpr007

Van Damme, L. and K. McKee. 1990. The extent and nature of seed- ed jack pine clumping following disturbance in northwestern Ontario. Ont. Min. of Nat. Resour., NWOFTDU Tech. Report # 58.

Varmola, M., & Salminen, H. 2004. Timing and intensity of precommercial thinning in Pinus sylvestris stands. Scandinavian Journal of Forest Research, 19(2), 142–151. https://doi.org/10.1080/02827580310019545

Watson, A. C., Sullivan, J., Amacher, G. S., & Asaro, C. 2013. Cost sharing for pre commercial thinning in southern pine plantations: Willingness to participate in Virginia's pine bark beetle prevention program. Forest Policy and Economics, 34, 65-72. Retrieved from https://www.sciencedirect.com/science/article/pii/S1389934113000968

Williams, R., & Harrington, S. 2012. Natural Resources Conservation Service Technical Forestry Note TX-FS-12-6: Pre-commercial thinning – Benefits/Costs? Retrieved from https://www.semanticscholar.org/paper/Natural-Resources-Conservation-Service-Technical-–/1a38d724a89f5a4258034091ecdb1aaf4418908a

Wisconsin Department of Natural Resources Division of Forestry. 2016. Chapter 33: Jack Pine Cover Type. In Silviculture Handbook (pp. 2-62). Madison, WI. Retrieved from https://dnr.wisconsin.gov/topic/forestmanagement/silviculture

Wotherspoon, A., Bradley, R., Houle, D., Tremblay, S., Barrette, M., & Reicis, K. 2020. Mechanisms by Which Pre-Commercial Thinning Increases Black Spruce Growth in Different Climates and Soil Types. Forests, 11(5), 599–. https://doi.org/10.3390/f11050599

Zhang, S. Y., Chauret, G., Swift, D. E., & Duchesne, I. 2006. Effects of precommercial thinning on tree growth and lumber quality in a jack pine stand in New Brunswick, Canada. Canadian Journal of Forestry Research, 36(4), 945-952. Retrieved from https://cdnsciencepub.com/doi/pdf/10.1139/x05-307

Zobel, B. J., & Van Buijtenen, J. P. 1989. Wood Variation - Its Causes and Control. Berlin: Springer-Verlag. Retrieved from https://link.springer.com/content/pdf/bfm%3A978-3-642-74069-5%2F1.pdf