EFFECTS OF SILVICULTURAL INTENSITY ON JACK PINE DENSITY AND QUALITY 20 YEARS POST HARVEST

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Dr. Jian Wang Major Advisor	Dr. F. Wayne Bell Second Reader

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ABSTRACT

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Keywords: density management, intensive silviculture, jack pine, timber quality, thinning,

Rising global timber demand necessitates exploring intensive silvicultural practices in Canada. This thesis investigated how different silvicultural intensities affect jack pine stand density and quality at the Sioux Lookout site of the NEBIE network. 20 year post-treatment growth and yield data were analyzed to assess the impact of five silvicultural treatments (Natural, Extensive, Basic, Intensive, and Elite) on stand density and timber quality. While statistically significant differences in stand density weren't observed, a general trend emerged in the data where stand density decreased while silvicultural intensity increased. Conversely, timber quality generally improved with increasing intensity. These findings suggest potential benefits of intensive silviculture for future timber production, particularly as stands mature and treatments to improve stand quality and production are applied. However, further research in 20 years may reveal a more pronounced effect of intensity as stands approach harvest age. Overall, this study highlights the need for continued investigation into intensive silviculture to optimize Canadian forest management practices for both timber production and ecological sustainability.

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1.0 INTRODUCTION

Recently the rising demand for timber products has increased the global production of wood by 70% in the end of last century (Campinhos 1999). With the global population increasing raising the demand for lumber and the uncertain effects of climate change forest managers are considering implementing a more intensive approach to silviculture on productive sites in Canada (Lautenschlager 2000). Intensive forest management has been of interest as an attempt to avoid timber shortages by creating continuous flow of timber while also increasing the quality of wood fiber being produced through investing in intensive silviculture closer to milling and processing infrastructure (Lautenschlager 2000). This approach allows for shorter rotation times resulting in more frequent harvesting of young trees in intensely managed forests (Lautenschlager 2000). This leaves more forest area on the landscape to be managed extensively or unmanaged allowing forest ecosystem services such as wildlife habitat and biodiversity to be less affected by forestry activities such as silviculture (Tittler et al 2015).

Managing select forests with the appropriate intensity of silvicultural, depending on factors such as management goals, site quality, proximity to mills and timber markets, can be an effective and efficient way to increase timber and value to meet Canada’s demand (Lautenschlager 2000) (McKenney 2000). Arguments have been made for Canada’s vast amounts of forested land to remain extensively managed (Benson 1988), but this system may not suit the future lumber demands with unknown climatic changes that may alter future forest conditions that require adaptive management. The present issues facing timber production have highlighted the need for new silvicultural approaches that are designed to adapt to future forest conditions and timber demand (Achim et al 2022).

The NEBIE plot network is a stand-scale silvicultural and ecological research project established in 2001(Bell et al 2017). The project was designed to test the effects of various intensities of silvicultural treatments at 8 sites across Ontario, each located in the Canadian boreal or northern temperate forest (Bell et al 2017). The project name NEBIE is an acronym in which each letter represents a silvicultural treatment (Bell et al 2017). The 5 treatments included in the project are Natural (disturbance), Extensive, Basic, Intensive and Elite (Bell et al 2017). Each treatment is more intensive than the previous for the purpose of testing the effects of increasingly intensive silviculture practices on different forests across Ontario. In this thesis, 20-year-old growth and yield data from the Sioux Lookout site were analyzed to determine how each silviculture treatment will affect stand density and wood quality of jack pine (*Pinus* banksiana Lamb.). The Sioux Lookout site is a jack pine dominated forest with some black spruce (*Picea* mariana [Mill.]) B.S.P) and balsam fir (*Abies* balsamea L.) present.

The data analysis included a randomized complete block design ANOVA on metrics that indicate stand density which will determine if there is a significant difference in the density of jack pine between the 5 silvicultural treatments tested at the Sioux Lookout site. Plots from each or the 5 silvicultural treatments will be presented on a density management diagram (DMD) for jack pine. The objective of this thesis is to evaluate how different silvicultural intensities affect jack pine density which can alter timber production and quality. By determining how stand density is affected by silvicultural intensity, the use of intensive silviculture can be considered for use to increase timber production and quality while harvesting less forest area.

2.0 LITERATURE REVIEW

2.1 Density management diagrams

Density management diagrams sometimes referred to as stand density management diagrams (SDMD) (Sharma and Zhang 2007, Newton 1997), are tools that aid in the planning process for forest stand management (Newton 1997). Stand density management as a concept uses management objectives for a forest stand to direct resource competition control through operational actions such as initial spacing, and planned thinning (Newton 1997). DMDs provide a mode for management schedules based on the management objectives for the stand and determine what activities need to take place and when to meet the objectives (Newton 1997, Sharma and Zhang 2007). These diagrams present the relationship between the average volume, height, diameter and density of a stand (Archibald and Bowling 1995, Newton 1997). Many DMDs are created using the law of self-thinning (Yoda et al 1963) to model when stands at various densities will start to self-thin.

The self-thinning theory, which has been named Yoda's power law or the -3/2 power rule is a theory that describes how total biomass is affected by density (Yoda et al 1963). This theory originated when Yoda et al analyzed plants in cultivated and natural conditions to test if density drives natural self-thinning due to the increase in competition between individuals. An equation was formulated to graphically illustrate this law and the slope of the resulting relative density line was -3/2 (Yoda et al 1963). This law can be applied to many plant species including many commercially used tree species in Canada. This law was tested using soils of varying fertility levels and a significant number of results followed the predicted curve (Yoda et al 1963). This rule has been re-tested in an interspecific relationship situation with slope results of -1/2 (Weller 1987) which differs from the -3/2 presented by Yoda et al. This was due to Weller using a liberal definition of the originally proposed conservative definition of the self-thinning line (Osawa and Sugita 1989) which was targeted at an intraspecific competition relationship (Yoda et al 1963).

The first major line found on a DMD is the relative density (RD) line which is the biological carrying capacity which is the maximum volume of biomass that can be obtained while the stand is stocked with a certain density (Archibald and Bowling 1995, Yoda et al 1963). This line follows the self-thinning rule presented by Yoda et al (1963) and has a slope of -3/2. For the trees in the stand to increase in size and increase the total volume of the stand, thinning must occur to release the dominant trees which would decrease the overall density of the stand due to mortality (Archibald and Bowling 1995). The next major line seen on DMDs is the Zone of Imminent Competition Mortality (ZICM). This line is the lower limit of stand volume and density where the thinning of the stand will begin (Archibald and Bowling 1995). The maximum growth rate for a stand will occur before this line is reached (Archibald and Bowling 1995). The relative density of 0.50 for this line has been defined by Drew and Flewelling (1979) for use on Douglas-fir plantations and Newton and Weetman (1993) for use in black spruce management. The third main line on DMDs is the crown closure line. This line is the stage of stand development when the density and volume of the stand are high enough that the crown is fully closed and light penetration to the forest floor becomes limited (Archibald and Bowling 1995).

The first attempt at a jack pine density management diagram made for the northern Ontario application was by Archibald and Bowling in 1995 which involved calibrating each line using data collected from over 800 data points. The diagram includes the main three lines that follow the relative density index (RDI) as defined by Drew and Flewelling (1979). The first relative density (RD) line with a slope of -1.512 at RD 1.0 is the self-thinning line, zone of imminent competition mortality at RD 0.55 and canopy closure situated at RD 0.15 graphed on the X-axis of density (stems per hectare) and the Y-axis of mean total tree volume (m^3) (Archibald and Bowling 1995). The slope of the relative density line was derived from data analysis and is very similar to the self-thinning theory slope of -3/2 while the RD values for the ZICM and canopy closure were figured out using other diagrams and were not yet proven to be the best values (Archibald and Bowling 1995). The other lines included on the main graph represent the average dominant tree height (curved lines with heights on the y axis) and quadratic mean diameter (qDBH) (straight lines with measurements on the RD 1.0 line) for the stand (Archibald and Bowling 1995). The diagram includes a site index graph in the top right-hand corner of the DMD which allows for age to be estimated based on height which can improve management objective timeline estimates (Archibald and Bowling 1995).

A more modern jack pine stand density management diagram was developed by Sharma and Zhang (2007) (Figure 1) using more efficient modelling components and data collected from Ontario and Quebec with the objective of application across all eastern Canada. This diagram is situated on density displayed in trees per hectare on the X-axis and the mean total tree volume in m^3/tree on the Y-axis. The 4 main vertical lines are stand development stages at any given density. The black line at RD 1.0 stands for space where self-thinning within a stand occurs, the red line at RD 0.55 is the zone of imminent competition mortality, the blue line at RD 0.40 is the limit of the productive zone and finally the crown closure line is in green and is at RD 0.15 (Sharma and Zhang 2007). The isolines present in the area below the black relative density line are the quadratic mean diameter at breast height and the isolines along the Y-axis represent dominant tree heights (Sharma and Zhang 2007).

The relative density indices used in this diagram were determined using Drew and Flewelling’s (1979) interpretations that a stand that reaches an RD less than 0.15 will show a growth per unit area in proportion to the density in that stand. Stands between RD 0.15 and 0.40 show an increase in growth per area unit with density while growth per individual tree decreases, relative densities between 0.40 and 0.55 show growth per unit area that is unaffected by the density of the stand and relatives densities larger than 0.55 show a lower net growth if significant mortality has occurred in the stand.

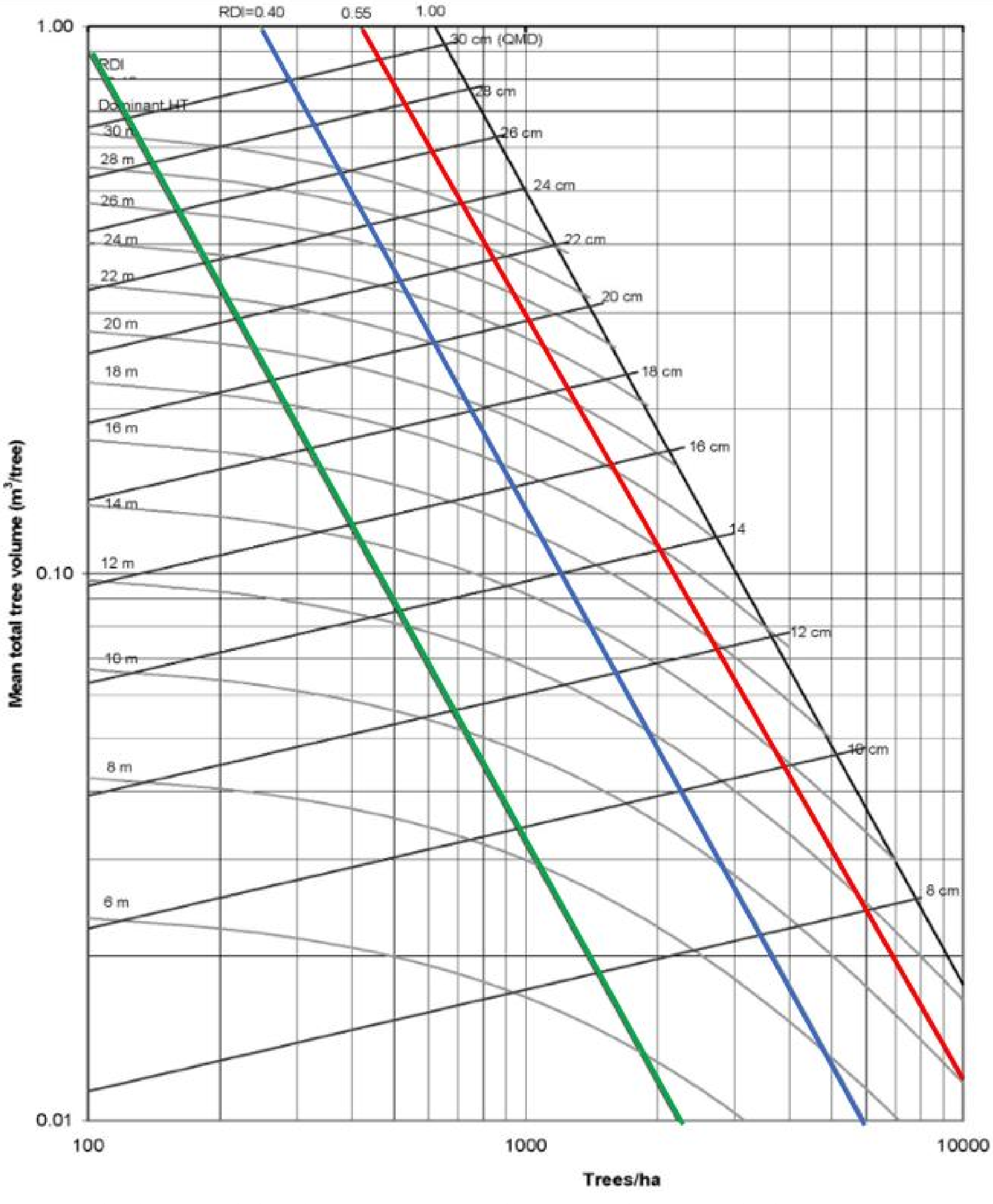


Figure 1. Jack pine stand density management diagram (Sharma and Zhang 2007). Green line = crown closure, blue line = limit of the productive zone, red line = zone of imminent competition mortality, black line = self-thinning line.

2.2 Jack pine silvics

Jack pine is known to be a shade intolerant species especially after the seedling stage of growth as a pioneer species where trees can establish with full access to light and create an overstory (Rudolph and Laidly 1990). Jack pine is often associated with other shade-intolerant species such as trembling aspen (*Populus tremuloides* Michx.) but the most competition for jack pine in a site is interspecific competition from species more tolerant to shade (Longpre and Morris 2012). The species is prone to high initial sapling density after naturally regenerating recently burned or disturbed sites (Rudolph and Laidly 1990) with exposed mineral soil which are advantageous conditions for the fire-adapted serotinous cones (Carmean and Lenthall 1989). Jack pine is often found growing on dry poor sites where other trees would not grow as well as a wide range of high-quality soils (Rudolph and Laidly 1990, Sterrett 1920). The species is slow growing during the first 3 years post-establishment but rapidly increases in growth rate after 4 years of age (Rudolph and Laidly 1990, Sterrett 1920, Rudolph 1958). Growth rates within the first 20 years of age allow for jack pine to be the second fastest growing conifer after the tamarack (*Larix larancina* (Du Roi) K. Koch) (Rudolph 1958). Growth rates for the species are maintained at a consistent rate of approximately 30 cm per year until 60 years of age on a poor-quality site and 80 years on a good site when growth declines significantly to only 6 cm of growth each decade (Rudolph 1958).

2.3 The effect of intensive silviculture on timber

Intensive silviculture as a management approach in forestry includes management invested into the stand from planting until final harvest. This ensures that forests grow to meet the future management goals of a stand (Lautenschlager 2000). A general trend seen in initial stand density effects on growth involves understanding the trade-off between increased stand density and wood production per stand area (Gabria et al 2023). A benefit of intensive silviculture is the ability to control stand density from the initial management activities such as seeding or planting. This contrasts with natural regeneration, which relies on natural reproductive efforts from each species and brings uncertainty with stand density and species composition (Greene et al 1999). Even after natural or artificial seeding occurs in a stand intensive management practices such as fill in planting are methods to meet stocking requirements to ensure the success of silvicultural investment in the stand (Greene et al 1999).

Jack pine timber is processed to produce many different commercial products such as dimensional lumber which is used for construction materials such as doors, window frames and shelving, composite timber products such as trusses and rafters, and pulp and paper products (Zhang and Koubaa 2008). Both the internal wood quality (measured by features such as wood density and fibre coarseness) and external characteristics (includes features such as branches retained on stem, taper, diameter and height) determine what wood products can be derived from each log based on timber quality (Newton 2019). Stand timber quality is affected by initial stand density of stems as increased spacing between trees can lead to the development of undesirable stem characteristics which in turn will reduce stem quality (McKinnon and Kayahara 2006). Example of stem characterises that reduce stem quality are stem taper, persistent branches or delayed self-pruning, high juvenile wood production near live crown and low wood density (McKinnon and Kayahara 2006).

Acceptable growing stock (AGS) and Unacceptable growing stock (UGS) are terms used to define the potential of a particular tree in relation to vigor and future growing abilities (Nyland 1996, McGrath 2018). Trees that are considered AGS must exhibit healthy form with the potential to increase in size and quality by the next cutting activity (thinning or harvest) to produce timber that aligns with the management goals of the stand (McGrath 2018). AGS trees must be able to continue to grow and thrive in the stand after release from thinning until the time of harvest, general thought to be 15- 20 years (McGrath 2018). UGS trees are of lower quality due to poor form, health or damage and will not have the potential to thrive in the stand after thinning until harvest (Nyland 1996, McGrath 2018). AGS and UGS are a simple visual method or evaluating the quality potential of individual trees within a stand and can aid in tree selection for thinning treatments within the stand.

3.0 MATERIALS AND METHODS

3.1 The site

The data used in this thesis were collected from the Sioux Lookout site located in the boreal forest on crown land near Sioux Lookout, Ontario (50° 01’ N, 91° 28’ W)

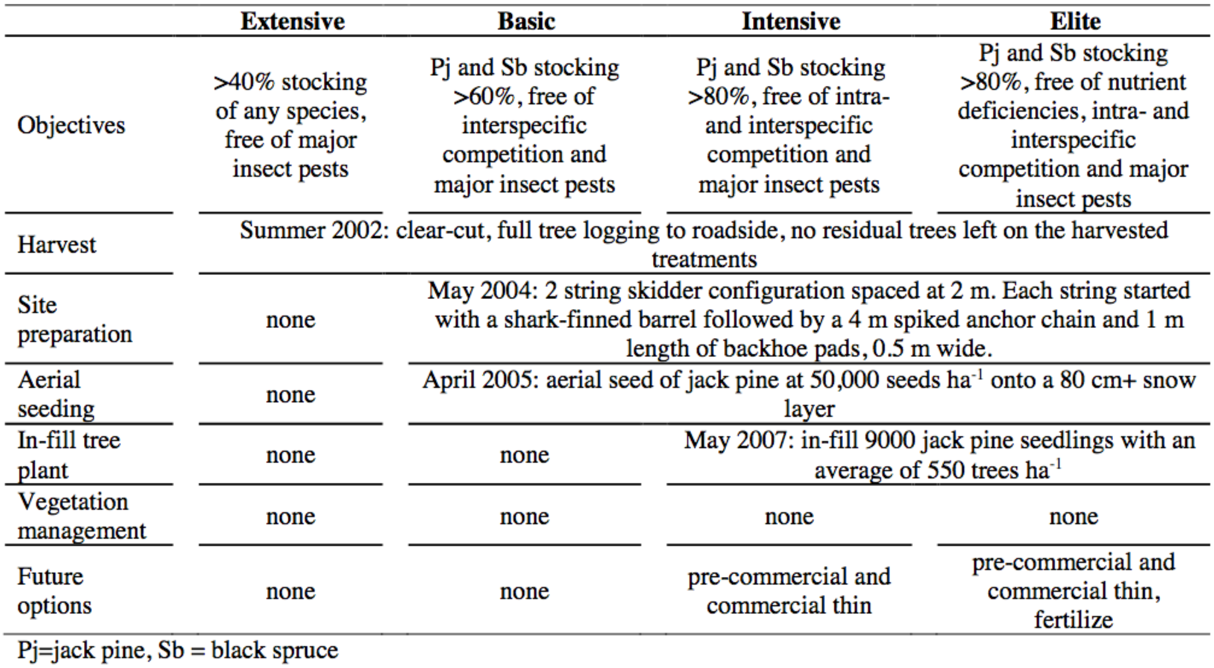
(Figure 2) (Bell et al 2017). The site is classified as site class two and was comprised of an even-aged 90-year-old jack pine stand of fire origin in 2002 before harvesting (Bell et al 2017). Most of the soil at the site has a medium sandy texture with loamy coarse, silty fine and fine sand as well (Bell et al 2017). The drainage class for the site is rapid with less common areas being very rapid and well drained and a moisture regime of moderately dry in most of the site with areas of moderately fresh soil (Bell et al 2017).

Figure 2. NEBIE plot network site locations in Ontario, Canada (Bell et al 2017)

3.2 The NEBIE network design

At each site for the NEBIE plot network the experimental design involves the application of all 5 silvicultural intensities on 100m x 200m (2ha) plots with a 20m buffer zone along the outer edge and 4 replications (Bell et al 2017). The objectives and silvicultural activities associated with each silvicultural treatment are explained in Table 1 by Bell et al 2017. 20m x 20m subplots within each experimental unit were randomly assigned a monitoring plot for data collection (soils, biodiversity, and growth and yield) (Figure 3) and the plots with destructive and non-destructive sampling were separated in the plot (Bell et al 2017).

Table 1. Silvicultural activities and objectives for each silvicultural treatment at the Sioux Lookout site of the NEBIE network (Bell et al 2017).



	Extensive	**Basic**	**Intensive**	**Elite**
Objectives	>40% stocking of any species, free of major insect pests	Pj and Sb stocking >60%, free of interspecific competition and major insect pests	Pj and Sb stocking >80%, free of intra- and interspecific competition and major insect pests	Pj and Sb stocking >80%, free of nutrient deficiencies, intra- and interspecific competition and major insect pests
Harvest	Summer 2002: clear-cut, full tree logging to roadside, no residual trees left on the harvested treatments			
Site preparation	none	May 2004: 2 string skidder configuration spaced at 2 m. Each string started with a shark-finned barrel followed by a 4 m spiked anchor chain and 1 m length of backhoe pads, 0.5 m wide.		
Aerial seeding	none	April 2005: aerial seed of jack pine at 50,000 seeds ha^{-1} onto a 80 cm+ snow layer		
In-fill tree plant	none	none	May 2007: in-fill 9000 jack pine seedlings with an average of 550 trees ha^{-1}	
Vegetation management	none	none	none	none
Future options	none	none	pre-commercial and commercial thin	pre-commercial and commercial thin, fertilize

Pj=jack pine, Sb = black spruce

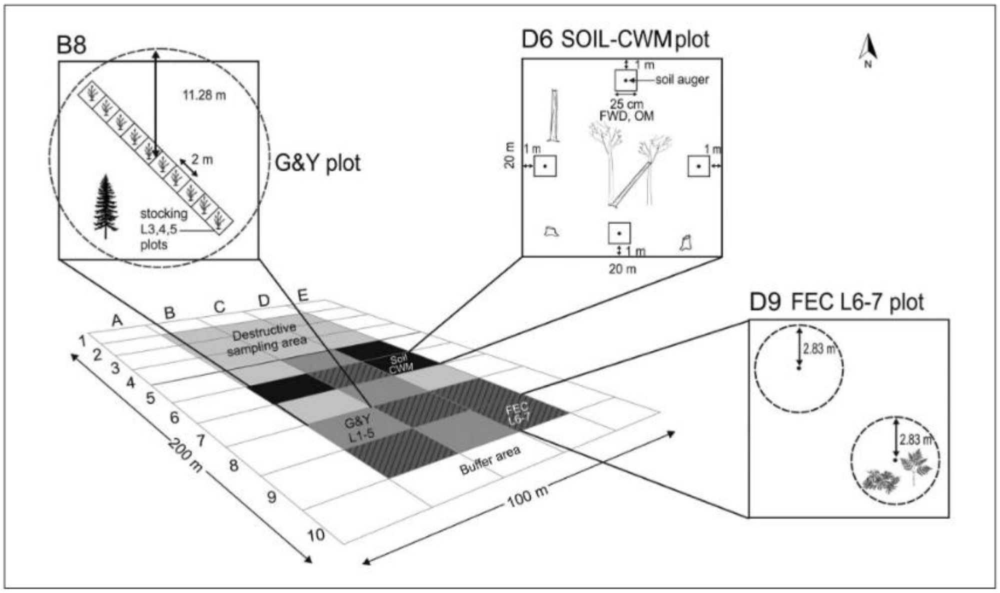


Figure 3. 2 ha experimental plot design used at each site in the NEBIE plot network. Contains 20m x 20m subplots with a random layout of sub-plots and monitoring types (Bell et al 2017).

3.3 Data collection

The NEBIE network plots have been measured before harvest, and 2, 5, 10 year and 20 years after harvest (Searle et al. 2021). Before the treatment application, site data including plot location, soil type, and elevation was collected (Searle et al. 2021). Sample plots within blocks were circular and had areas of $400m^2$, and within them, trees with a DBH greater than 2.5cm were tagged (Searle et al. 2021), and data such as DBH, species, and crown class was recorded for each tree. Other data such as height and quality in the form of acceptable growing stock (AGS) vs unacceptable growing stock (UGS) was recorded only for some trees.

3.4 Data analysis

A few key stand metrics were calculated for each experimental unit. These metrics were stand density, basal area, and quadratic mean diameter. These metrics were used to plot each experimental unit on the jack pine density management diagram created by Sharma and Zhang (2007). To complete the density management diagrams with the experimental units in Sioux Lookout, the jack pine site index curves in northern Ontario (Carmean 1996) was added to the diagram.

To determine if significant variance is present in the stand density of jack pine between the 5 different silvicultural treatment areas a one-way analysis of variance (ANOVA) was conducted using RStudio. The null hypothesis for this ANOVA is that the stand density of jack pine would not significantly differ among the stands within the 5 different silvicultural treatment areas. The Anderson-Darling normality test was run on the full data set to discover if the distribution of the data was normal and suitable to run the ANOVA. The Anderson-Daring test showed that the entire data set was not normally distributed due to an outlier in the stand density of block 2 in the extensive treatment. Due to the significance of this outlier, it was removed from the data set to correct the distribution normality. When the data was re-tested for normality, it showed a normal distribution of the data. When the ANOVA was re-tested for normality, it showed a normal distribution of the data, and the ANOVA was run on the stand densities of all 4 blocks within the 5 treatment types as well as a separate ANOVA for all 4 block of only the extensive, basic, intensive and elite treatment types. The natural treatment was excluded from the second ANOVA in order test the plots where silvicultural treatments were applied. Finally, a Tukey test was run on the treatment groups excluding the natural treatment to examine the amount of variance between the densities in each treatment.

The timber quality of jack pine trees in each treatment was calculated by using the counts of AGS and UGS trees in each 4 blocks of the treatments. To understand the ratio of AGS to UGS trees for each treatment the average count of AGS and UGS trees from each block was calculated for each treatment. This average will show the general trends in AGS to UGS ratios between treatment types. A direct comparison between treatment types cannot be made as not ever tree was assessed and labelled as either AGS or UGS.

4.0 RESULTS

The main question this thesis addresses is how silvicultural intensity affects the stand density and stand quality of jack pine. The 20 year growth and yield data was analysed for key stand metrics including stand density, quadratic mean diameter, avarage basal area, dominant (max) height and timber quality. Each key stand metric was calculated and presenting in a bar chart as and averaged for all four blocks within each treatmnet. To display these result a series of bar charts compares the avearges of these key stand metircs between treatments.

Figure 4 illustrates the average maximum height for each treatment. The natural treatment stands out with the highest average maximum tree height of 22 m. All four other treatments have similar average maximum tree heights, reaching around 8 m tall.

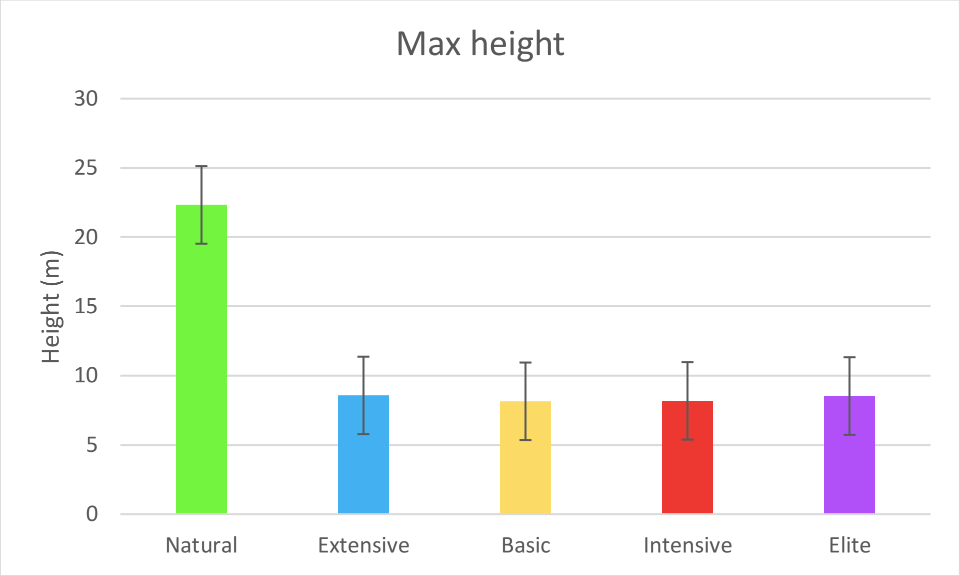


Figure 4. Average maximium (dominant) tree height from all silvicultural treatments.

Figure 5 displays the average quadratic mean diameter for each silvicultural treatment. Once again, the natural treatment has the highest average QDBH of all treatments, at 15.66 cm. The other treatments average near 7 cm.

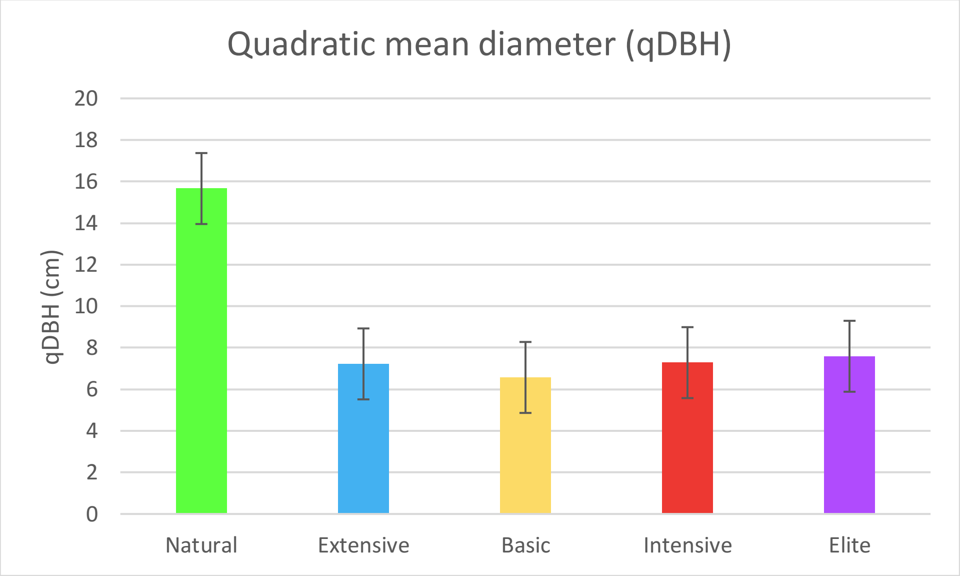


Figure 5. Average quadratic mean diameter from all silvicultural treatments.

Figure 6 shows the average stand density in stems per hectare for each treatment. The natural treatment has the lowest average stand density, at 944 sph. The average stand densities of the other four treatments show a trend of lower densities occurring with increasing silvicultural intensity. The extensive treatment, which was naturally regenerated, has an average of 5716 sph, while the elite treatment has an average of 2583 sph.

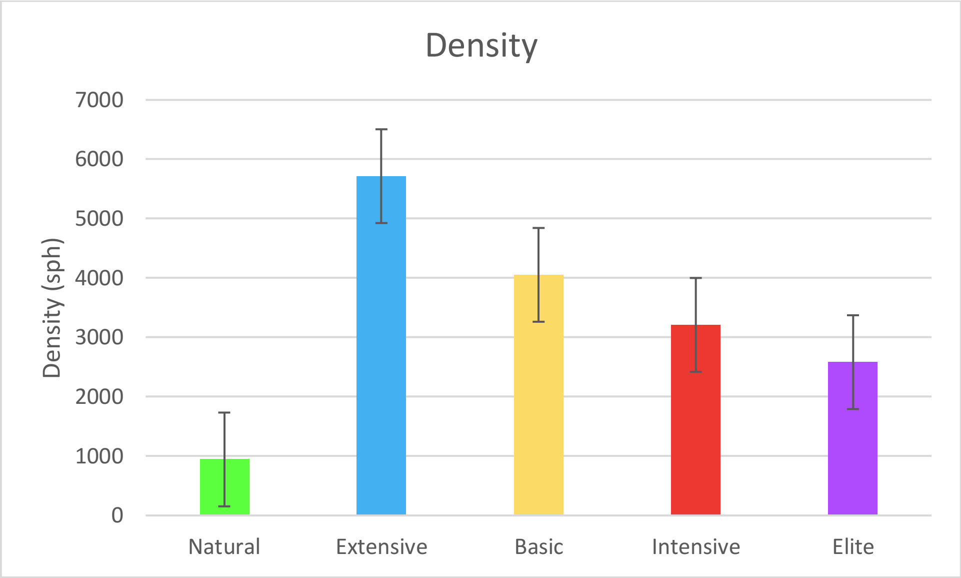


Figure 6. Average stand desnity from all silvicultural treatments.

4.1 Density management diagram

Using the metrics presented in this table the experimental units were plotted on the Shama and Zhang (2007) DMD to show variance amoung each of the 5 treatment types as each block is plotted in Figure 4. The colour of the points on the DMD corresponds to a silvicultural treatment . Each point is labelled with a number to represent the block within each treatment. The blocks from each treatment are clustered in generally the same area but show variation between the blocks.

The location of the points representing the blocks within the natural treament indicate that the stand is more mature than the stands within the 4 other treatments due to the lack of initial harvesting in 2002 when the plots were established resulting in a stand dynamic created by natural distrubance. The trees in the natural treatment blocks have maximum tree heights ranging from 20 – 23m and quadratic mean diameters ranging from rogughlt 15 – 16 cm^2. The desntiy of the natural treatment blocks are between 880 and 1040 stems per hectare. This places the cluster of points higher on the DMD between the blue RD 0.40 line representing productivity limit and the red RD 0.55 line representing the self-thinning line.

The trees in the extensive treatment blocks have maximum tree heights ranging from 8 – 8.9 m and quadratic mean diameters ranging from 6.7 – 7.7 cm^2. The density in these stands range between 1600 and 14,800 stems per hectare, the top end of the range being an outlier in the data that skews the distribution of the data set. This places the extensive points closer to the bottom of the graph but more spread out horizontally due to the range of stand densities and the outlier that is located off the right side of the graph.

Trees in the basic treatment blocks have maximum height ranging from 7.3-9m and quadratic mean diameters between 6.22 and 6.82 cm^2. The density within these block range between 3075–4838 stems per hectare. The points are located in the lower right area of the graph with slightly higher densities close to the blue RD 0.40 line for productivity limit.

The intensive treatment blocks have maximum height ranging from 7.9-8.4m and quadratic mean diameters between 6.98 and 7.45 cm^2. The stand densities within the blocks range from 3025-3450 stems per hectare. The intensive points are located just below the blue RD 0.40 productivity limit line on the graph and all 4 points are in a tighter cluster than the natural, extensive and basic points. This treatment and the elite treatment received fill in planting of 550 jack pine seedling per hectare in 2007.

The elite treatment blocks contained trees with maximum heights ranging from 7.9-8.8m and quadratic mean diameters ranging from 7.04-8.23cm^2. The stand densities were less consistent than expected ranging from 1600-3150 stems per hectare. This large range is due to the exclusion of 2 cells within the treatment blocks. These cells were excluded because they did not receive brush cutting as the other cells in the block and other blocks within the elite treatment. The points for each block are in the bottom right corner of the diagram but are slightly higher up and spread out due to the wide density range. All four points are located between the RD 0.15 canopy closure line and the blue RD 0.40 productivity limit line.

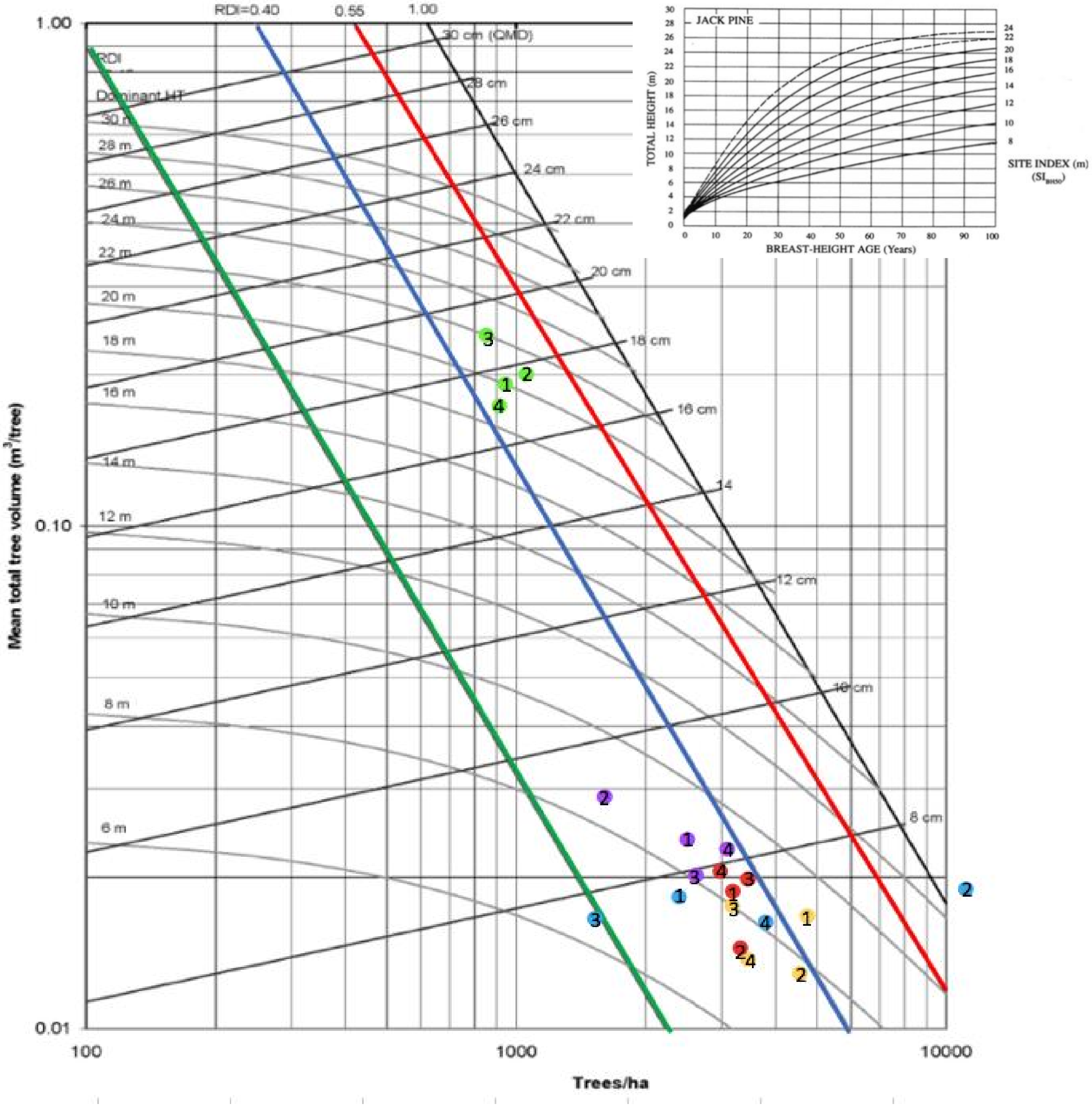


Figure 7. Sharma and Zhang (2007) jack pine Density management diagram with 20 experimental units from the NEIBIE network Sioux Lookout site plotted. Green dots = Natural, blue dots = Extensive silviculture, yellow dots = Basic silviculture, red dots = Intensive silviculture and purple dots = Elite silviculture.

The results from the ANOVA with the natural treatment showed a p value of 0.0003 which indicates a significant difference in stand density between treatments. The ANOVA that excluded the natural treatment resulted in a p value of 0.079 which is greater than the critical value of 0.05 indicating there is no significant difference in stand density between treatment types.

The results of the Tukey test used to examine similarities between groups which allows for a direct comparison between treatments. The results for this test are displayed in table 3. The closer the adjusted p value comparing the treatments is to 1 the more similar the stand density of the listed treatments are. The most similar treatments in terms of stand density 20 years post-harvest are the extensive and elite treatments with an adjusted p value of 0.997 and the least similar treatments are elite and basic.

Table 2. p values representing the similarity stand density between treatment types

Treatment	adjusted p
Elite-Basic	0.078
Extensive-Basic	0.15
Intensive-Basic	0.438
Extensive-Elite	0.997
Intensive-Elite	0.66
Intensive-Extensive	0.813

4.3 Timber Quality

To measure timber quality of jack pine in each experimental unit the collected count of AGS vs UGS trees can indicate a general trend in stand quality. The results of the counts of timber quality are not a direct indication of timber quality as not every tree was meausred and assigned the labell of either AGS or UGS. A summary of the avarage count of trees labelled AGS and UGS per treatment is displayed in Table 4. The treatment with the highest AGS to UGS ratio is the elite treatment with an avarage of 137 AGS trees and 55 UGS trees among the 4 blocks. The treatment with the lowest AGS to UGS ratio is the basic treatment with an average of 19 AGS trees and 160 UGS trees among the 4 blocks. These result are visually presented in Figure 8.

Table 3. Average count and percentages of acceptable growing stock (AGS) vs unacceptable growing stock (UGS) per treatment

Treatment	**AGS (%)**	**UGS (%)**	**Total**
Natural	19 (65.5)	10(34.5)	29
Extensive	89 (38.9)	140 (61.1)	229
Basic	19 (10.6)	160 (89.4)	179
Intensive	94 (49.5)	96 (50.5)	190
Elite	137 (71.4)	55 (28.6)	192

Figure 8. Average acceptable growing stock to unacceptable growing stock ratio for each silvicultural treatment

5.0 DISCUSSION

This section will include interpretation and discussion of the results. Key stand metrics will be examined, jack pine DMD plots will be analyzed, and timber quality will be evaluated. By relating these findings to existing observations in the literature, the practical applications of these results for jack pine forest management can be explored.

5.1 Density

The natural treatment area had the lowest stand density of all five silvicultural treatments, ranging between 881 and 1038 stems per hectare. As an untreated “control plot,” it wasn't initially harvested when the NEBIE Network was established in 2001 and received none of the silvicultural treatments applied to the other four treatment areas. Consequently, the trees in the natural treatment are more mature, with larger diameters and heights, but a lower stand density.

The natural stands fall between the zone of imminent mortality (RD 0.55) and the productive zone (RD 0.40) as defined by Sharma and Zhang (2007). This suggests that natural disturbances drove forest succession, leading to tree mortality and a lower stand density compared to the younger stands in the other four treatments. Currently, the trees in the natural treatment can continue growing at their current density without competition until they reach the self-thinning line (RD 0.55) described by Drew and Flewelling (1979).

The extensive treatment exhibited the largest range of stand densities of all the treatments ranging between 1,600 and 14,800 sph. However, the highest density of 14,8000 sph was found in block 2 and was considered an outlier in the data as it is abnormally high. This density places the point for block 2 beyond the feasible region of the DMD beyond the maximum biomass capacity line (RD 1.0). This significantly high density is block 2 could be due to ingress from natural regeneration where density is not controlled. The dominant height averaging near 8.5 m and qDBH averaging 7.2 cm places the extensive cluster of points near the bottom right-hand corner of the DMD.

The extensive treatment is the least intensive treatment applied to the block with the only forestry activities being the harvest in 2002. Post-harvest no other silvicultural activities were scheduled for such as seeding or planting so the stand was regenerated naturally. The unexpected and unexplained outlier in block 2 of the extensive treatment displays the possible risks of extensive management which is the lack of ability to ensure productivity and yield by controlling density (Benson 1988).

The basic treatment had the second highest density among the 5 treatments ranging from 3075 to 4338 stems per hectare. However, the trees in this treatment were the smallest in terms of average dominant height at 8.1 meters and average qDBH of 6.57 centimeters. Due to the smaller average tree size the points of this treatment are among the lowest points on the graph and are clustered close together.

The reason for the smaller tree size lies in the regeneration timeline. The basic treatment blocks were clearcut harvested in 2002 followed by site preparation in 2004 and aerial seeding in 2005. The regeneration of the target species, jack pine and black spruce, only began in 2005 after seeding. This block did not receive any planting of any further silvicultural activities so when compared to the two more intensively managed treatments is not reaching the full stocking potential of a higher stand density (Greene et al 1999). This could explain why the trees in this treatment are smaller in diameter and height than other treatments.

The intensive treatment points show less variation among 4 blocks in location on the DMD. The points representing blocks 1, 3, and 4 are in a tight cluster just left of the productivity limit line (RD 0.40). Block 2 is located slightly lower on the DMD due to a lower dominant height. The density within the intensive treatment ranges from 3025 to 3450 stems per hectare.

This uniformity in point distribution on the DMD stems from the intensive management approach. These blocks underwent clear-cutting in 2002, followed by site preparation in 2004 and aerial seeding of jack pine in 2005. Unlike the previous 3 less intensive treatments, they received an additional fill-in planting of jack pine 550 trees per hectre in 2007. This extra intervention may explain the more uniform distribution of points on the DMD and the slightly larger trees raising the points higher up on the diagram.

The elite treatment, the most intensive silvicultural approach, shows the least variation in the DMD results. Most points cluster just above the intensive treatment points, near the productivity limit line (RD 0.40). However, block 2 deviates slightly, exhibiting a lower density that pushes its point leftward on the DMD graph, closer to the canopy closure line (RD 0.15) The elite treatment received all the same management activities as the intensive treatment. The stand densities from the elite treatment are between 1,600 and 3,150 stems per hectare with block 2 having the lowest density. The trees within this treatment are larger than the previous 4 actively managed treatments which may be attributed to the fill in planting in 2007.

This anomaly in block 2 is due to a lack of pre commercial thinning in specific areas (cells D5 and D7) which was performed in each of the other blocks within the treatment. Due to this error the stem counts from these cells were excluded from the count used to calculate the stand density for block 2.

5.2 Statistical analysis

Two separate ANOVAs were performed to assess the differences in stand density between treatments. The first analysis included all 5 treatment types. The null hypothesis, which states there's no significant difference in stand density between treatments, was rejected with a highly significant p-value of 0.0003 when compared to the critical p value of 0.05.

Given this overwhelming result, a second ANOVA was conducted excluding the natural treatment. This allowed a more focused comparison of the four actively managed treatments (excluding the unharvested control). The results of this analysis showed no significant difference between treatment types with a p value of 0.079. This lack of significant difference might be due to the young age of the forest. The intensive and elite treatments are planned for pre-commercial thinning, commercial thinning, and fertilization in the future (Table 1, Bell et al., 2017). Since these treatments haven't been implemented yet, stand densities remain similar across all managed areas, potentially explaining the absence of significant variation.

To directly compare treatment density similarities a Tukey test was performed. This test allows for pairwise comparison between treatments. The results revealed the most similar stand densities to be between the extensive and elite treatments. Conversely, the elite and basic treatments exhibited the least similarity in density. This further supports the notion that the absence of thinning activities in the intensive treatment might be keeping its current density closer to the less intensively managed stands.

5.3 Stem quality

Stem quality for the jack pine in each silvicultural treatment was measured by labeling select trees within each block as AGS or UGS. While not every tree was evaluated, this method provides a general indication of trends within the data. Results are presented as average proportions of AGS vs. UGS trees for each treatment.

The highest ratio of AGS to UGS was in the elite treatment with 137 AGS trees and 55 UGS trees. This might be attributed to the 2007 fill-in planting, which increased stand density. Higher density is known to promote favorable stem qualities in timber production (McKinnon & Kayahara, 2006). Conversely, the basic treatment exhibited the lowest ratio of AGS to UGS trees, potentially due to the absence of fill-in planting and reliance solely on seeding and natural regeneration. Future thinning treatments for the intensive and elite treatments are planned and may further improve the stem quality of the stand within these treatments.

The results from this study suggest potential outcomes of future applications of intensive silviculture in the Sioux Lookout area to increase efficient production of quality wood fiber. While the data analyzed in this thesis is only 20 years post-harvest, trends show a correlation between intensive silviculture and density management to increased timber quality even before all planned treatment were applied. As demand for high-quality timber grows, so will the need for intensive silviculture on the appropriate site to maximize productivity. By selecting appropriate sites for implementing intensive silviculture, more forest area remains unmanaged and continue to grow and experience natural disturbance through the landscape and increase conservation of ecosystem values (Tittler et al 2015).

6.0 CONCLUSION

This thesis investigated and discussed the effects of silvicultural intensity on jack pine stand density and quality. While statistically significant differences in stand density between treatment types were not observed, trends in key stand metrics suggest a decrease in stand density with increasing silvicultural intensity 20 years after treatment application. Timber quality results indicated a general trend of improvement with increasing silvicultural intensity.

Future studies revisiting this research area in 20 years may reveal a more pronounced intensity effect on these results, particularly as stands approach harvest age. Research into the effects of intensive silviculture can have significant implications for Canadian forest management practices. Forest industry managers should consider the potential benefits of implementing intensive silviculture on suitable sites to enhance forest productivity and timber quality.

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APPENDIX

Table A1. Summary of key stand metrics for each experimental unit measured 20 years after treatment application.

	Block	Max Ht (m)	Count	Density (stems/ha)	Quadratic mean diameter (qDBH) (cm)	Average BA	AGS	UGS
Natural	1	22	150	938	15.18	181.0	8	6
	2	22.5	166	1038	15.98	200.5	0	8
	3	23.9	141	881	15.37	185.7	1	9
	4	20.9	147	919	16.11	203.9	67	19
Extensive	1	8.9	394	2463	7.31	42.0	1	206
	2	8.7	591	14775	6.71	35.4	350	235
	3	8	67	1675	7.70	46.5	0	36
	4	8.7	158	3950	7.17	40.4	6	83
Basic	1	9	774	4838	6.22	30.4	13	388
	2	7.6	189	4725	6.47	32.9	2	106
	3	8.7	123	3075	6.82	36.5	2	65
	4	7.3	143	3575	6.77	35.9	58	79
Intensive	1	8.1	503	3144	6.98	38.2	302	201
	2	7.9	129	3225	7.32	42.1	0	73
	3	8.3	138	3450	7.45	43.6	0	62
	4	8.4	121	3025	7.38	42.8	75	46
Elite	1	8.7	433	2706	8.23	53.2	384	49
	2	8.8	64	1600	7.63	45.8	162	50
	3	7.9	115	2875	7.04	39.0	0	59
	4	8.7	126	3150	7.45	43.6	0	61