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by

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ABSTRACT

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Key Words: conifer release treatments, stem quality, branching quality, glyphosate, herbicide, brush saw, *Pinus banksiana*, stem mortality.

In an industry where new science is ever-evolving, forest managers must constantly look towards research to guide best practices in achieving the highest quality forest product. Three common silvicultural treatments (aerial spray of Vision® herbicide, motor manual brush saw, and complete removal with repeated applications of Vision® herbicide) were used on two separate sites located in eastern and western Ontario. This study was conducted in order to determine the effect of both treatment and site (as well as the combination of the two factors) on both stem and branch quality of jack pine crop trees.

When consideration of tree mortality was included in the analysis, it was found that aerial spray yielded best overall results for both branch and stem quality and that the difference in treatment means can be considered statistically significant ($p < 0.05$).

When dead stems were removed from the analysis however, it was found that treatment type did not have a significant effect on stem quality. This did not remain true for branching quality, where tests of the remaining live trees showed a significant difference in values among the various treatments, with control providing best average branching quality scores. Finally, a significant difference was found to exist in stem quality between the two sites, with the E.B. Eddy site proving better average vales.

Average stem mortality was also investigated, and it was found that the addition of herbicide treatments yielded better stem survival of the jack pine crop trees, with the worst average stem survival occurring in the untreated sites.

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INTRODUCTION

The idea of herbicide use in forest management has been heavily debated since its first introduction into Ontario. Although a highly effective method of controlling competing vegetation in plantations in the boreal forest, additional, equally effective methods of forest management must be investigated due to increasing concern over aerial and ground spraying. This study will examine and compare crop tree growth and form as a function of the use of various herbicide and manual brush saw treatments within two different jack pine plantation forests in northern Ontario.

Jack pine plantations are found throughout northern Ontario, many of which are devoted to government research that seeks to determine best practices for managing popular industrial species. Located on the Spanish River, 76 km north of Webwood in northeastern Ontario, the E.B Eddy Forest supplies wood to the paper mill in Espanola, Ontario. In 1993, a field study was established at this site by the Ontario Forest Research Institute (OFRI) to examine the response of crop tree growth within three plantation stands in the forest, as well as the resulting biodiversity to various conifer release treatments. A similar trial was established in northwestern Ontario in 1992, within the Bending Lake forest, located 53 km north of Atikokan. This study aimed to focus on crop tree growth and form, with additional studies for analyzing small mammal species composition and population dynamics within the treated area. This thesis focuses on an analysis of the long-term remeasurement data taken from both of these two studies to determine the effect of treatment and site on both branching and stem quality of the jack pine crop trees.

ADDITIONAL MEASUREMENTS

Other measurements collected as a part of this study included various measurements of growth & yield, as well as measurements of biodiversity indicators. A brief description of the measurements taken for each of these is included below, however it is important to note that neither the growth and yield, nor the biodiversity measurement data were analyzed in this thesis.

Growth and Yield

Growth and yield (G&Y) measurements were completed during the 25th growing year (completed in July and August of 2019 for both sites). Data collection for G&Y surveys were conducted in accordance with the Provincial Growth and Yield Standards, as outlined in the PGP and PSP Reference Manuals (June, 2009). Data collected in 11.28 m radius plots included name of species, tree status, crown class, and quality class for each G&Y tree.

Biodiversity

Various measurements were included to develop an understanding for the biodiversity present. Biodiversity plots were established in a 20 m x 20 m area within each treatment. Within these plots, vegetation cover (%) was measured and recorded. To make the measurement process easier, vegetation was measured in seven different 'layers', which were defined prior to conducting the field work (see Table 1).

Table 1. Layer numbers and their associated vegetation.

Layer #	Type of Vegetation
1	Dominant tree cover
2	Subdominant tree cover
3	2-10 m shrub layer
4	0.5-2m shrub layer
5	<0.5 m shrub layer
6	Herb, grass, sedge, and fern layer
7	Bryophyte and lichen layer

OBJECTIVE

The purpose of combining data from both the E.B. Eddy and Bending Lake trials is to examine and compare the branching and stem form of the jack pine crop trees resulting from the application of various treatments, including: aerial sprayed herbicide application (Vision®), manual brush-saw cutting, complete removal (aerial Vision® spray followed by annual applications with a backpack sprayer), and no competition control. The main focus of this thesis will be to analyze the long-term effects that these treatments have on vegetation growth in both northwestern and northeastern Ontario forests. An analysis of these long-term data can help to provide valuable information about the effectiveness that various treatments have on a boreal species.

HYPOTHESIS

The statistical analysis that this thesis focuses on involves six null hypotheses; three addressing branching quality and three with addressing stem quality. These six null hypotheses are summarized below:

Ho: Treatment (aerial spray, brush saw, complete removal, and control) will have no significant effect (alpha=0.05) on branching quality of the jack pine crop trees.

Ho: Site (E.B. Eddy and Bending Lake) will have no significant effect (alpha=0.05) on branching quality of the jack pine crop trees.

Ho: The treatment x site interaction will have no significant effect (alpha=0.05) on branching quality of the jack pine crop trees.

Ho: Treatment (aerial spray, brush saw, complete removal, and control) will have no significant effect (alpha=0.05) on stem quality of the jack pine crop trees.

Ho: Site (E.B. Eddy and Bending Lake) will have no significant effect (alpha=0.05) on stem quality of the jack pine crop trees.

Ho: The treatment x site interaction will have no significant effect (alpha=0.05) on stem quality of the jack pine crop trees.

LITERATURE REVIEW

Jack pine (*Pinus* banksiana) is the most widely distributed tree in Canada and has historically played a crucial role in the forest industry, used predominantly for pulp and paper, as well as for lumber and timber (Eyre and LeBarron 1994; Rudolph 1985). Understanding its biology, response to growth of competition species, and historical treatments used in plantations is essential to this study.

<u>Biology and Habitat of *Pinus banksiana*</u>

Jack pine is often thought of as the most robust of the conifers, for it grows further north than any other species of pine and can succeed in low nutrient and low moisture soil, where many other species cannot. As can be seen in Figure 1, the broad natural range of jack pine in North America extends into the Northwest Territories, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Cape Breton Island, and Nova Scotia in Canada (Rudolph 1985).

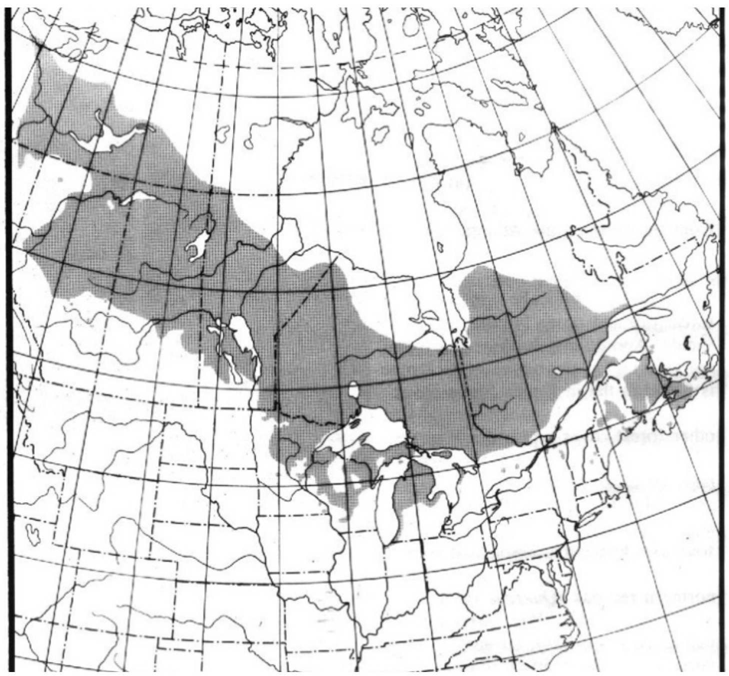

Figure 1. Natural range of jack pine in North America (Rudolph 1985).

Within this range, the climate that is typically associated with this species includes short, cool summers, followed by very cold winters, with moderate rainfall throughout the year (Rudolph 1985). Coarse soils, such as loamy sands or sands are ideal, where water is well- draining (Rudolph 1985). These conditions are often very harsh and the low moisture and nutrient availability of typical jack pine stands make it difficult for other species to flourish. However, where nutrients are available in natural mixed stands, jack pine is often associated with species such as red pine, white pine, trembling aspen, large toothed aspen, white birch, red oak, pin oak, black spruce, white spruce, balsam fir, and bur oak (Benzie 1977). Jack pine is considered a very shade intolerant species and it requires full light to reach optimal growth, which can produce a height of 1.3m (breast height) in 4-6 years (Bell, 1991). If ideal growing conditions are met, jack pine has the capability of surviving for 175 years, however this is often not reached in the wild and holds the shortest life span of all pine species (Eyre and LeBarron 1944). Maturity of the species is reached at 85 years, however, rotation periods range between 40-80 years (Eyre and LeBarron 1944; Rudolph and Laidly 1990). The regenerative success of jack pine is heavily dependent on presence of fire, as cones are generally serotinous and often require extreme heat to open and therefore release their seed (Eyre and LeBarron 1994, Gauthier et al. 1996). However, if fire is not present, jack pine often does not succeed well, and a jack pine dominated stand will often shift to being dominated by more shade tolerant species (Eyre and LeBarron 1994). This transition in species composition generally occurs in a sequential order, where *Alnus incana* (speckled alder) is the first to take over the stand, followed by *Corylus Americana* (hazelnut), *Cornus rostrate* (beaked hazelnut), *Betula papyrifera* (white birch), and, finally *Populus tremuloides* (trembling aspen) (Eyre and LeBarron 1944). Understanding the impact that the growth of these competing vegetation types has on quality and growth of the once jack pine dominated stand is essential.

Vegetation Competition

Although single species jack pine plantations are common practice in North America, mixed jack pine stands also serve important ecological roles, as the variety of species can provide improvement in soil quality, increase wildlife habitat area, and improve biodiversity (Longpré et al. 1994). Although these mixed stands can provide a boost to an ecosystem as a whole, it is important to understand the specific effects that competing vegetation growth can have on jack pine. A study published in 2000 by Bell and Ter-Mikaelian researched the impacts that the presence of herbaceous and woody plants had on jack pine growth. Growth responses to various types of commonly competitive vegetation (Large-leaved aster, upland willow, wild red raspberry, trembling aspen, white birch, green alder, Canada blue joint-grass, and fireweed) were studied and it was found that early vegetation competition was dominated by herbaceous plants over woody ones during the first year of growth (Bell and Ter-Mikaelian 2000). However, during the second year of growth, woody species were found to dominate 60-80% cover, thus reducing the photosynthetic capability of the shade intolerant jack pine. Although neither survival nor height growth of seedlings was significantly reduced, the extensive growth of herbaceous plants in particular was found to have a significant impact on diameter growth of the jack pine.

Not all species, however, pose a negative effect on jack pine growth. The presence of birch in jack pine stands has been found to yield higher results for jack pine volume and DBH in comparison to stands with mixture of birch and aspen (Longpré et al. 1994). These results imply that there may be a certain threshold of white birch (as well as other companion species) that may be present in a jack pine stand before having an adverse effect on jack pine volume. In addition, these results suggest that the nutrient availability provided by the presence of aspen and birch may not be the limiting resource for diameter growth in jack pine stands, but, instead, light availability.

Planting Spacing

In order to manage for ideal conditions of jack pine plantations, it is important to first understand the nature of those conditions. Light availability, which, as has been previously discussed, is crucial for the growth of jack pine, is often an outcome of stand density. A study conducted by Tong and Zhang (2005) investigated the response of stem quality and tree growth to four different spacings of plantings and precommercial thinning treatments. It was found that survival rates were higher in wider initial spacings for all aged trees, indicating that mortality occurs in a jack pine stand proceeding crown closure (Tong and Zhang 2005). It is thus recommended that jack pine be planted at a width of 7x7 ft or 9x9 ft, as this yields longer merchantable stems than tighter spaced stands (Tong and Zhang 2005). Although it is obviously desirable to maximize merchantable volume through wider spacing, it is important to understand the effect of quality in response to larger growing space. The use of precommercial thinning in the Tong and Zhang study not only resulted in a positive effect on diameter growth, it also meant that fewer trees were affected by stem forking. Although the forking of stems is common to jack pine, it is an undesirable quality, as they can reduce useable diameter, produce large knots, and cause crooks elsewhere in the stem (Tong and Zhang 2005).

<u>The Control of Competing Vegetation</u>

Herbicide use plays a key role in modern forest management practices, with an estimated 70,000 ha of Ontario forest land being treated annually with herbicides (Thompson and Pitt, 2011). Foresters are faced with a growing demand to manage forests productively, efficiently, and effectively due to "shrinking forestland, increasing population, and wood demand" (Wagner et al. 2004). Although they play a crucial part in Ontario's forest practices, herbicides have been subject to debate since their introduction to agriculture in the 1940's (Wagner et al. 2004).

Highly competitive undergrowth vegetation (such as raspberry, aspen, Canada blue-joint grass, alder, willow, cherry, etc.) are typically the target of a herbicide application, as these species, if left untreated, can inhibit crop tree growth and form (Thompson and Pitt 2011; Thompson and Pitt 2003), due to reasons previously discussed. The chemical compounds of these herbicides work to kill the vegetation by limiting the plants' ability to synthesize amino acids through targeting a specific enzyme (Thompson and Pitt 2011). This effect can be achieved in three different ways: through aerial spray of the herbicide, skidder-mounted ground spray, or through spraying manually with a backpack; with aerial spray being the most commonly used method of herbicide application in Ontario (Nipissing Forest Resource Management 2014). These methods prove to be highly effective in killing vegetation, which, in turn, has been shown to increase wood volume gains of crop trees by 50-450% in northern forests (Wagner et al. 2004). The use of 5 different chemical compounds have been permitted for aerial spray in Canada; 2,4-D, hexanizone, glyphosate, simanzine, and triclopyr, with glyphosate accounting for 90% of all herbicide use (Thompson and Pitt 2003). Aerial spray treatments of glyphosate prove to be a highly successful method and were found to be most cost-effective in comparison with aerial spray of triclopyr, motor-manual brush-cutting and mechanical brush-cutting (Bell et al. 1997). Although highly effective at controlling competing vegetation, it should be noted that, as a result of this, lower species richness and lower species diversity are often expected in herbicide-treated stands (Malik, Bell, and Gong 2002).

Mechanical brush saw treatment has also proved to be an effective method for controlling competing vegetation and has proved a popular treatment in the boreal forest. Mechanical conifer release treatments have often been viewed as alternatives to herbicide treatments and, thus, brush saw is often used in replace of aerial spray. The use of brush saw is even more prevalent in places like Québec, which banned the use of herbicides in forest management in 2011 and has since relied exclusively on mechanical treatments for controlling competing vegetation (Thiffault and Roy 2010). Although brush saw has proved to be effective at achieving initial stem mortality of competing vegetation, it has been found that species that have been removed with brush saw – such as trembling aspen, green alder, pin cherry, and beaked hazel – often respond by re-sprouting from cut stems (Malik, Bell, and Gong 2002). This re-sprouting effect enables the competing vegetation to grow back, thus, impacting growth of conifer crop trees. Despite this draw-back, partial cutting methods have been continued to be applied in the boreal forest, as they are considered an effective form of natural disturbance-based silviculture, which helps to achieve ecological objectives (Bose et al. 2013). Finally, in comparison with herbicide treatments, brush saw treatments do not achieve the same productivity and proves to be a much more costly method, at a rate of about $227/ha, compared to a cost of $152/ha for aerial herbicide applications (Bell et. al 1997; Lautenschlager et. al 1997). It is important to consider the costs and benefits associated with various types of treatments used in forest management.

MATERIALS

Materials used for this study varied depending on the type of measurement protocol (crop tree, growth and yield, or biodiversity measurements) being completed. Table 2 presents the materials used for the crop tree measurements only. It should be noted that, although all of these materials were used to collect data on the crop trees, no materials were required for the data that is used in this thesis (branching and stem quality), as these factors were measured visually on an index ranking system, which will be discussed further in the methods section.

Table 2. Materials used for conducting crop tree measurements.

Material	Measurement(s) Completed with Material
Diameter tape	Diameter of tree (at 1.3 m)
Small Calipers	Diameter of branches
Tube paint	Marking location of diameter
Vertex	Height of large trees, distance from tree to centre post, width of tree crown, tree mapping, plot layout
Transponder	Used in correspondence with vertex: height of large trees, distance from tree to centre post, width of tree crown, tree mapping, plot layout
Spray paint	Marking plot boundaries
Yellow posts	Marking plot centre
Metal pins	Marking crop trees
Compass	Tree mapping (azimuth of tree from plot centre), locating plots
GPS	Locating plots, locating crop trees

Figure 2 shows an example of a jack pine crop tree, which was marked with pink and orange flagging tape, as well as a pin to indicate the tree’s number. Blue tube paint indicates the location at which diameter was measured (~1.3m).

Figure 2. Jack pine crop tree in block 2 of an aerial spray-treated plot in E.B. Eddy

Some of the measurements done with the use of the vertex included measuring distances from the crop tree to plot centre (Figure 3) and measuring tree height (Figure 4).

Figure 3. Vertex used to determine the distance of tree to plot centre.

Figure 4. Vertex used to determine the height of large trees.

METHODS

In this study, data were collected from two different sites, referred to as the E.B. Eddy site and the Bending Lake site. At both of these sites, crop tree, growth and yield, and biodiversity data were collected. Each of these types of data were obtained using different methodologies and protocols. All data was collected by field crews of the Ontario Forest Research Institute (OFRI) during the summer of 2018. Data were recorded on a tablet, using a launch form function in Excel in order to optimize time and resources.

SITE DESIGN

Bending Lake

The Bending Lake site was divided into four study blocks, designed using a randomized complete block design. Silvicultural intensities included natural, extensive, basic, intensive, and elite levels. Each block in the Bending Lake site consisted of four different treatments: aerial herbicide application (Vision® spray), control (no treatment), manual brushsaw cutting, and complete removal using aerial Vision® spray, followed by annual Vision® applications with a backpack sprayer. Each treatment was >2ha in size, with the intensive sampling areas centred within the treatment areas.

E.B. Eddy

The E.B. Eddy trial was established with three different sites (blocks) of a randomized complete block design. Each block contains seven treatment types: 1) control (CON): untreated; 2) aerial spray (AS): aerial application of Vision® using a helicopter; 3) mist blower (MB): ground application of Release® using a brush saw with herbicide attachment in the fall; 4) basal bark (BB): basal bark application of Release® using backpack sprayer with a narrow angle flat fan tipped nozzle; 5) brush saw (BS): manual cutting treatment using a mechanical brush saw in the fall; and 5) complete removal (CR): annual removal using foliar applications of Vision®. It should be noted that only the AS, BS, CR, and CON treatment data were included in this thesis for crop tree measurement, to keep consistent with the E.B. Eddy methodology. Plot sizes at these sites are 50 m x 100 m, except for the CR and AS treatments, which are 40 m x 40 m and 100 m x 200 m, respectively. Measurements were completed at the end of the first growing season following treatment (1994), again at two years (1995), at three years (1996), at five ears (1998), and at ten years (2003). Remeasurements (at 25 years) were taken during July and August of 2019. The crop tree data used for this thesis is limited to only the 25-year remeasurement of the aerial spray, brush saw, complete removal, and control treated plots.

CROP TREES

The study included 480 trees, derived from 3 blocks at each of the 2 sites. Within each block there were 20 trees for each of the 4 different treatments. Each of the 480 trees was pinned and labelled at the time of establishment in order to identify them as crop trees. Crop trees were planted 10m apart, however, other natural and planted trees exist in-between. In order to keep track of the location of the growth and yield (G&Y) trees, GPS coordinates (NAD 83) were taken at Tree 1 and Tree 20 in each treatment of the Bending Lake site. These GPS locations are presented in the following tables.

Table 3. GPS coordinates (NAD 83) of Trees 1 and 20 in block 1 of the Bending Lake site.

B1	GPS Coordinate Tree	
Treatments	Tree # 1	Tree # 20
AS	N48 57.348 W92 01.840	N48 57.347 W92 01.860
BS	N48 57.303 W92 02.202	N48 57.318 W92 02.202
CR	N48 57.249 W92 02.247	N48 57.259 W92 02.237
CON	N48 57.366 W92 01.919	N48 57.363 W92 01.935

Table 4. GPS coordinates (NAD 83) of Trees 1 and 20 in block 2 of the Bending Lake site.

B2	GPS Coordinate	
Treatments	Tree # 1	Tree # 20
AS	N48 57.659 W92 02.923	N48 57.662 W92 02.947
BS	N48 57.621 W92 02.854	N48 57.630 W92 02.878
CR	N48 57.588 W92 02.786	N48 57.597 W92 02.811
CON	N48 57.687 W92 03.001	N48 57.694 W92 03.017

Table 5. GPS coordinates (NAD 83) of Trees 1 and 20 in block 3 of the Bending Lake site.

B3	GPS Coordinate Tree	
Treatments	Tree # 1	Tree # 20
AS	N48 57.780 W92 03.100	N48 57.779 W92 03.126
BS	N48 57.844 W92 03.175	N48 57.850 W92 03.197
CR	N48 57.737 W92 03.185	N48 57.721 W92 03.198
CON	N48 57.749 W92 03.047	N48 57.752 W92 03.060

Within the E.B. Eddy site, the UTM coordinates of five different crop trees were established and recorded for future reference within each treatment. The approximate coordinates for trees #1 and #20 for blocks 1-3 can be found in Tables 6-8 below.

Table 6. Approximate UTM coordinates for Trees 1 and 20 in block 1 of the E.B. Eddy site.

B1	UTM Coordinates	
Treatments	Tree #1	Tree #20
AS	17 T 0413443 5181717	17 T 0413442 5181687
BS	17 T 0413646 5181648	17 T 0413658 5181643
CR	17 T 0413475 5181630	17 T 0413466 5181610
CON	17 T 0413559 5181613	17 T 0413685 5181659

Table 7. Approximate UTM coordinates for Trees 1 and 20 in block 2 of the E.B. Eddy site.

B2	UTM Coordinates	
Treatments	Tree #1	Tree #20
AS	17 T 0410527 5180835	17 T 0410533 5180822
BS	17 T 0410444 5180695	17 T 0410461 5180659
CR	17 T 0410566 5180801	17 T 0410584 5180809
CON	17 T 0410896 5181221	17 T 0410877 5181207

Table 8. Approximate UTM coordinates for Trees 1 and 20 in block 3 of the E.B. Eddy site.

B3	UTM Coordinates	
Treatments	Tree #1	Tree #20
AS	17 T 0418828 5180090	17 T 0418867 5180094
BS	N/A	17 T 0418682 5180679
CR	17 T 0418873 5180051	17 T 0418900 5180032
CON	17 T 0418734 5180646	17 T 0418752 5180643

Crop Tree Measurements

Crop trees were analyzed using a number of different measurements. Measurements for each crop tree included site, date, time, assessor, tally persons, block, treatment, tree #, status, total height of tree, height to live crown, DBH, width of tree crown, branch diameter, stem quality, presence of gall rust, and other qualities regarding the tree that affect its health, form, or quality. Each of these crop tree measurements, as well as a description of each measurement, is presented in Table 9.

Table 9. Types of measurements performed on crop trees.

Measurement	Description of Measurement
Site	Bending Lake or E.B. Eddy
Date	Date of assessment
Time	Time of assessment
Assessor	Name of assessor
Tally Person	Name of tally person
Block	Block 1-4
Treatment	Aerial Spray Brush Saw Complete Removal Control (No Treatment)
Tree #	Tree number associated with pin (1 to 20)
Status	Dead- Tree (remains of a dead tree beside pin)

	Dead- No Tree (no remains of a tree beside pin)
	Healthy- Tree may have deformities but is otherwise healthy
	Unhealthy- Tree is showing obvious signs of poor overall health
	Missing- Both tree and pin are missing
Total Height	Height of tree from ground to highest live point
Height to Live Crown	Height of crown at lowest point of live foliage
DBH	Point of germination to 130 cm (if deformity occurs at DBH, adjust height to as close below DBH where no deformities exist)
Crown 1	Width of the crown (starting with the outer most branches on one side to the outer most branches directly opposite the other side of the tree)
Crown 2	Crown width perpendicular to Crown 1
Branch 1	Diameter of largest branch within 50 cm above or 50 cm below DBH, it was measured as close to tree bole as possible perpendicular to branch
Branch 2	Diameter of 2nd largest branch within 50 cm above or 50 cm below DBH, it was measured as close to tree bole as possible perpendicular to branch
Branch 3	Diameter of 3rd largest branch within 50 cm above or 50 cm below DBH, it was measured as close to tree bole as possible perpendicular to branch
Branch 4	Diameter of 4th largest branch within 50 cm above or 50 cm below DBH, it was measured as close to tree bole as possible
Branch 5	Diameter of 5th largest branch within 50 cm above or 50 cm below DBH, it was measured as close to tree bole as possible perpendicular to branch
Branch Quality	Evaluation of first 16 ft of tree stem and determining overall branch quality (larger or curved branches indicate poorer quality) 1- Very fine, lightly branching, diameters <30% of size of bole 2- Fairly fine moderate branching, diameters 31 to 40 % size of bole 3- Moderate to coarse branching, diameters 41 to 50% size of bole 4- Heavily branched with very coarse branching, diameters > 50 % size of bole
Stem Quality	Evaluation of first 16 ft of tree stem and determining overall stem quality (refers to quality of bole) 1- Normal straight tree no crook or defects 2- Slight crook or minor stem defects 3- Moderate crooks or stem defects 4- Major crooks or stem defects
Gall Rust	Yes or No if gall rust present on bole of tree
Comments	Additional comments that are helpful in describing other defects/unique qualities in the tree

Both stem and branch quality were evaluated visually using an index rating system, which classified the quality of branching and stem quality from 1-4, with a rating of 1 being of the best quality, and a rating of 4 being of the worst quality. An index score of 0 was assigned to dead trees. In order to keep measurements consistent across all assessors, a guide was used to help identify the various levels of quality in the field. The guides for stem and branching quality are presented in Figures 5 and 6.

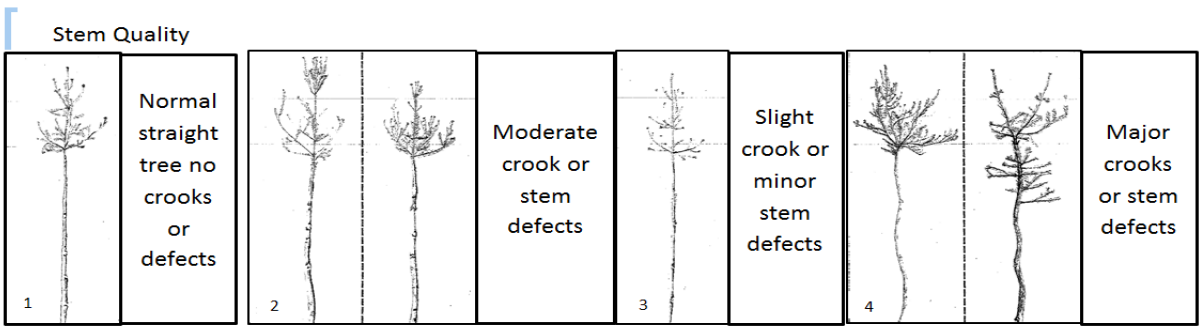

Figure 5. Stem quality index ranking guide used in the field.

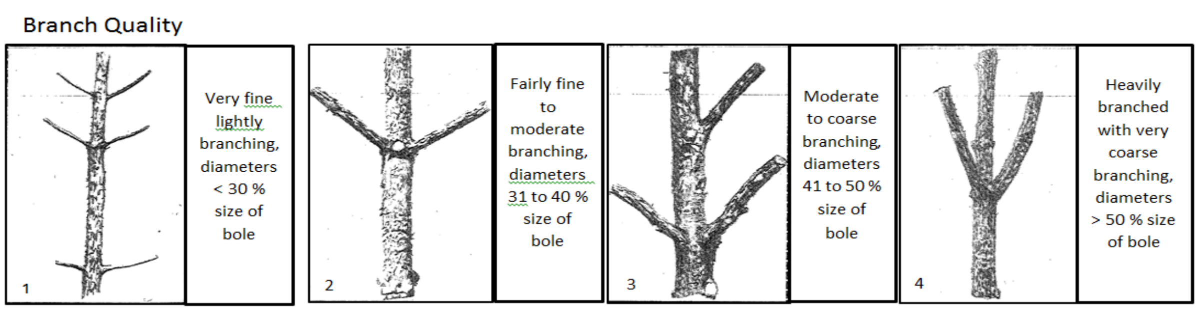

Figure 6. Branch quality index ranking guide used in the field.

DATA ANALYSIS

Once the data was collected in the field on a tablet, it was then transferred to various excel spreadsheets. This was done by staff members of OFRI and sent to the author after data was finished being entered. As previously discussed, all analyses done in this thesis were completed on only two types of data: branching and stem quality.

During the analysis of the data it was noted that the index ranking system used in the field lacked internal consistency (recall that each branching and stem quality was ranked on a scale of 1-4, with 1 representing best quality and 4 representing worst). To explain, dead or missing trees were denoted a ‘0’ automatically for their branching and stem qualities. Therefore, if the results were to be analyzed using the same 1-4 ranking system used in the field, then results based on calculated means would be misleading, as the presence of dead or missing trees would be contributing to lower (i.e. ‘better’) average branch and stem quality scores. Therefore, this system was reversed for data analyses, so that a ranking of 1 indicated poorest quality and a ranking of 4 indicated best quality, while a score of 0 was retained to denote dead trees. A simple search-and-replace algorithm was used in order to transform the original data to conform with this new system. Thus, all further discussion of the results will use this new system.

Although a total of 4 blocks were originally collected at Bending Lake, one of these blocks was eliminated by random selection from the data set in order to keep the Bending Lake sample size consistent with the 3 blocks of data available at the E.B. Eddy site. It should be noted that no environmental differences between the 4 Bending Lake blocks exist, other than their physical locations. This enabled the elimination of one of the blocks of data at the Bending Lake site to be undertaken without causing bias in the data.

The data was divided into branching quality and stem quality and was organized by treatment and site for each of these two factors. Averages were calculated for individual treatment x site combinations, as well as for overall treatment averages, overall site averages and, finally, an overall average of the entire data set. Standard deviations for each of these sets of data were also calculated. This was done for both the branching quality and stem quality data. Raw data, as well as calculated averages can be found in Appendices I and II, respectively.

An analysis of variance (2-way ANOVA) was completed for both the stem and branching quality to determine the influence that the treatment, site, and interaction of the two factors had on branching or stem quality.

The 2-way ANOVA are presented below.

$\mathbf{Y_{ijk} = \mu + S_i + T_j + ST_{ij} \;\; \varepsilon_{(i)j}}$ **, where**

$\mathbf{Y_{ijk}}$ = the response of the j^{th} replicate within the i^{th} factor and j^{th} factor

$\boldsymbol{\mu}$ = the overall mean

$\mathbf{S_i}$ = the fixed effect of the it^{h} factor (treatment)

1 = aerial spray, 2 = brush saw, 3 = complete removal, 4 = control

$\mathbf{T_j}$ = the fixed effect of the j^{th} factor (site)

1 = E.B. Eddy, 2 = Bending Lake

ST_{ij} = the interaction of the i^{th} factor (treatment) with the j^{th} factor (site)

$\varepsilon_{(ij)k}$ (error) = the random effect of the kth replicate within the i^{th} factor and j^{th} factor. The error is assumed to be identically and independently distributed according to a normal distribution with mean zero and variance.

In order to evaluate the effect of dead stems on the results, two additional ANOVA calculations (one for both stem and branching quality) were also completed with dead stems omitted from the dataset to determine the influence of treatment, site, and treatment x site interaction on the resulting jack pine quality.

Twenty crop trees were measured in each treatment, with 4 treatments in each block, with 3 blocks measured per site (20 crop trees x 4 treatments x 3 blocks x 2 sites = 480 samples). This enabled a large number of samples (and correspondingly small statistical error) to be used in the ANOVA calculations (n=480). This large sample size remained consistent for analyzing both branching and stem quality and was essential to ensure meaningful results.

RESULTS

Branching Quality

As shown in Table 10, with dead trees included in the analysis, the best average branching quality was found in the aerial spray plots, with an average of 2.19 for the combined E.B Eddy and Bending Lake sites compared to a grand mean of 1.84 for all treatments and sites. Brush saw plots had an average branching quality of 2.09, while complete removal and control sites saw the poorest average quality of 1.85 and 1.23, respectively. These trends remained true when analyzing data for just the Bending Lake site, with aerial spray producing the best quality branching, followed by brush saw, complete removal, and control (no treatment). E.B. Eddy saw the best average branching quality values in the brush saw sites, followed by aerial spray, complete removal, and control.

When these same means were calculated with the dead stems removed from the data set, overall branching quality improved, as would be expected with the zero values excluded from the mean calculations. However, these results without the dead stems did not show the same trends in quality between treatments and sites as the results with the dead stems included. Instead, best branching quality was found in the control sites, with an average of 3.15 for the combined E.B. Eddy and Bending Lake sites. Second best average branch quality was found in the brush saw sites (2.92), followed by aerial spray (2.71), with complete removal showing the worst average branching quality of 2.49. .

Table 10. Average branching quality (1-4) of crop trees by treatment, site, and overall averages with and without dead stems included.

Basis of Analysis	Site	Aerial Spray	Brush Saw	Complete Removal	Control
		Treatment			
With Dead	E.B. Eddy	2.20	2.37	2.02	1.22
	Bending Lake	2.18	1.82	1.68	1.25
	Total Average	**2.19**	**2.09**	**1.85**	**1.23**
Without Dead	E.B. Eddy	2.69	2.84	2.57	3.32
	Bending Lake	2.73	3.03	2.40	3.00
	Total Average	**2.71**	**2.92**	**2.49**	**3.15**

The ANOVA analysis (with the dead stems included) showed that the differences in the branching data among treatments are considered significant at 95% confidence level ($p<0.05$). It was found that treatment (aerial spray, brush saw, complete removal, and control) had a significant effect on crop tree branching quality. However, it was found that the influence of site (Bending Lake vs. E.B. Eddy) did not have a significant effect. Finally, the combination of both factors (treatment and site) did not yield a significant difference in branching quality (see Appendix III for ANOVA test data).

When dead stems were removed from the data and an additional ANOVA analysis was run, it was found that the differences in branching quality were statistically significant at 95% confidence level between treatments, with treatments ranked from best to worst being control, brush saw, aerial spray and complete removal. However, it was found that neither the influence of site nor the site x treatment interaction had a significant impact on branching quality.

Stem Quality

As shown in Table 11, with dead trees included in the analysis, aerial spray treated plots had better average stem qualities (2.09) compared to all other treatments in the combined E.B. Eddy and Bending Lake sites, compared to the grand mean of 1.67 for all treatments and sites. The next best ranked stem quality was associated with the brush saw plots, which had an average rating of 1.80, while the complete removal and control plots were found to have the poorest quality stems, with average ratings of 1.78 and 1.02, respectively. Slightly different results were found when considering the E.B. Eddy site in isolation, where the best stem quality was associated with brush saw treatment (2.40), followed by aerial spraying (2.28), complete removal (2.05), and finally control (1.10). Bending Lake, however yielded slightly different findings, with aerial spray providing the best results (1.90), followed by complete removal (1.52), brush saw (1.20), and control (0.93).

Results differed, however, when the dead stems were removed from the calculations. Although there wasn't a great deal of distinction between the results, the control treatment was associated with the best stem quality result (2.60), followed closely by aerial spraying (2.59), brush saw (2.51), and complete removal (2.40).

Table 11. Average stem quality (1-4) of crop trees by treatment, site, and overall averages with and without dead stems included.

Basis of Analysis	Site	Treatment: Aerial Spray	Brush Saw	Complete Removal	Control
With Dead	E.B. Eddy	2.28	2.40	2.05	1.10
	Bending Lake	1.90	1.20	1.52	0.93
	Total Average	**2.09**	**1.80**	**1.78**	**1.02**
Without Dead	E.B. Eddy	2.80	2.88	2.62	3.00
	Bending Lake	2.38	2.00	2.17	2.24
	Total Average	**2.59**	**2.51**	**2.40**	**2.60**

These differences in mean values for stem quality among treatments (with dead stems included in the analysis) were found to be significant through the ANOVA analysis at 95% (alpha=0.05) confidence level. Not only was it found that treatment had a significant effect on stem quality, the site, as well as the combination of both treatment x site, were determined to have a significant effect on stem quality as well (see APPENDIX III for ANOVA test results).

When dead stems were removed from the data set and an additional ANOVA was run, it was found that the differences in stem quality were not found to be statistically significant between treatments, however it was found that the differences were significant between sites. Finally, there was no significant difference found in stem quality as a result of the interaction of the two factors (site x treatment).

Combined Branching and Stem Quality

Figures 7 and 8 present the combined results of both branching and stem quality for each treatment x site combination. The scoring system for these combined results range from 0,0 to 4,4, for a total of 17 different criteria – with the first digit denoting the branching quality and the second digit denoting the stem quality for the same tree. Thus, a score of 0,0 indicates that the tree is dead (shown as black in Figures 7 and 18 and a score of 4,4 indicates that the tree shows best branching and stem qualities (shown in purple). As can be seen in Figures 7 and 8 the highest percentage of dead stems occurred in the control sites, in which 63% tree mortality was found in the E.B. Eddy site and 58% tree mortality was found in the Bending Lake site. However, no other obvious trends were noted to consistently hold true between both sites and among all four treatment strategies.

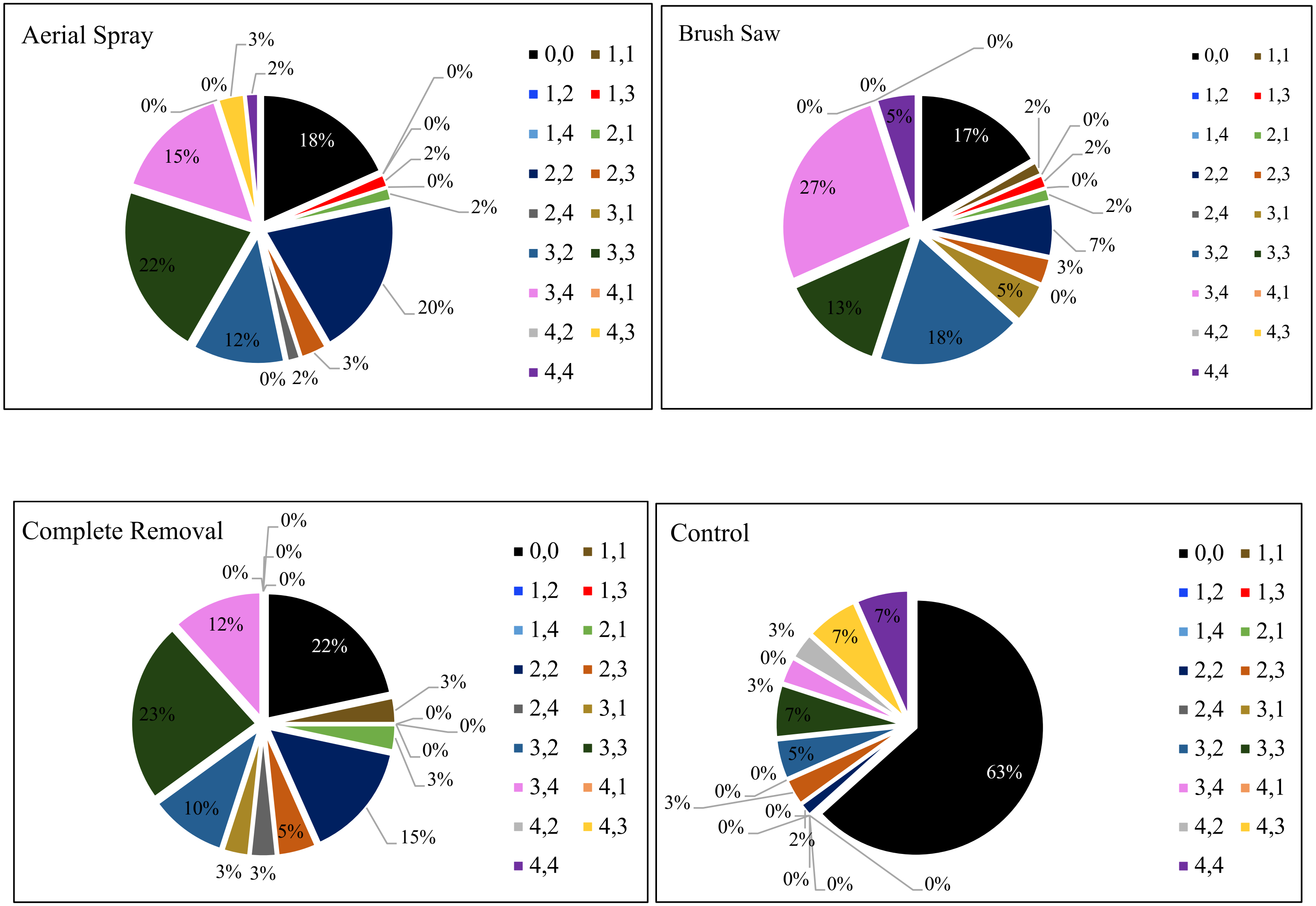

Figure 7. Percentage of trees showing various quality combinations (branching, stem) from 0,0 - 4,4 in each treatment in the E.B. Eddy site.

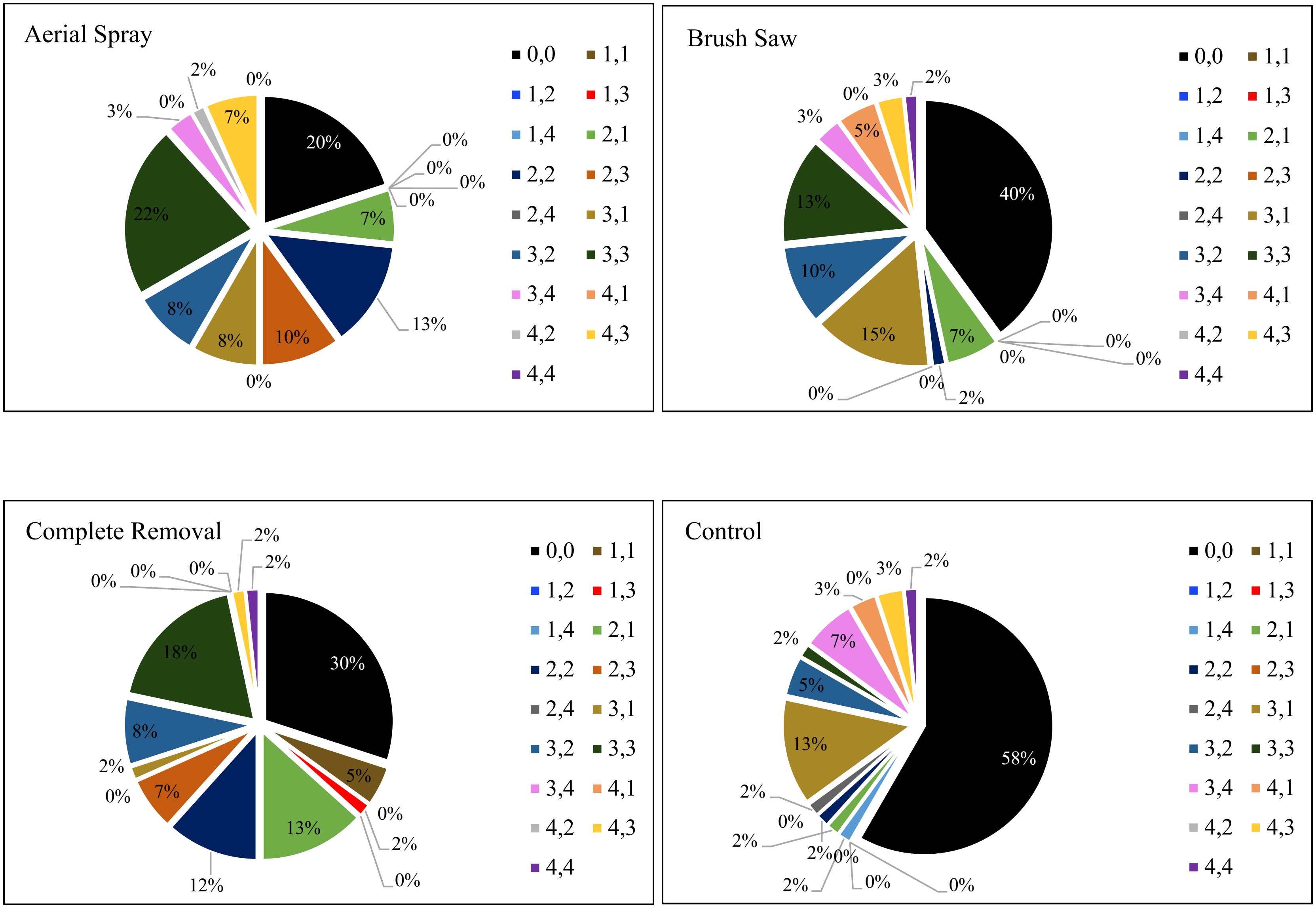

Figure 8. Percentage of trees showing various quality combinations (branching, stem) from 0,0 - 4,4 in each treatment in the Bending Lake site.

Stem Mortality

Considerable variation in stem mortality was found among the various treatment methods, as presented in Table 12. Control plots were found to contain the greatest number of dead stems among all treatments, with 73 of the 161 total dead stems found in control plots. Brush saw and complete removal contained 34 and 31 dead trees, respectively, with aerial spray treated plots accounting for just 23 of the total.

Table 12. Total number of dead crop trees by treatment.

Treatment	# Dead Trees
Aerial Spray	23
Brush Saw	34
Complete Removal	31
Control	73
Total	**161**

Figure 9 displays the percentage of dead stems by treatment, with control plots accounting for 46% of the total number of dead crop trees.

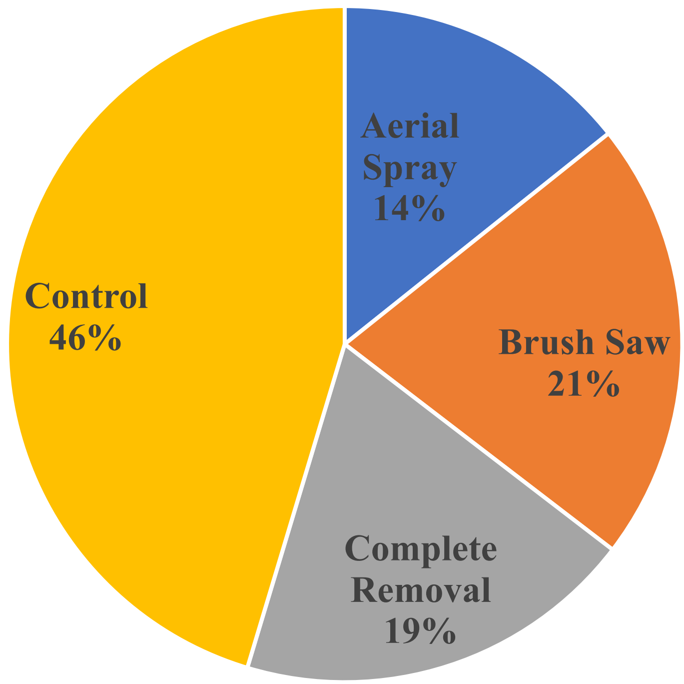

Figure 9. Percentage of total dead stems by treatment.

DISCUSSION

Significant differences in branching quality were found as a function of treatment when dead stems were either included or excluded from the analysis, although the ranking of treatment types based on best-to-worst results varied depending on whether dead stems were considered or not. With dead stems included in the analysis, the best-to-worst order of treatment types was aerial spray, brush saw, complete removal, and control, while with dead stems excluded from the analysis the best-to-worst order was control, brush saw, aerial spray, complete removal. Site was not found to significantly influence branching quality regardless of whether dead stems were included or excluded from the analysis.

When evaluating stem quality, treatment type was found to significantly affect the outcome only when dead stems were included in the analysis, where the best-to-worst order of treatment was aerial spray, brush saw, complete removal, and control. The E.B. Eddy site was found to have significantly better stem quality results than the Bending Lake site regardless of whether dead stems were included in the analysis or not.

The fact that significant differences in both average branching and stem qualities were found between treatments implies that the treatments are playing an important role in jack pine crop tree quality.

Effects of Treatment

It is important to first address the most important finding in this thesis; the effect that the treatments are having on both branching and stem quality are considered significant. This was found to hold true for all evaluations except those of stem quality when dead stems were excluded from the analysis. The positive effect of treatments on quality of jack pine is not an alarming finding, as this result agrees with those of past studies, which found that the addition of conifer release treatments aided in better-resulting form of jack pine crop trees (Man and MaDonald 2015). The trend of significantly better quality in sites treated with partial cut or herbicide may be due to a more prominent thinning effect of the treatments on competing vegetation, such as aspen and maple. As previously discussed, herbicide and partial cut treatments have long been used in forest management as conifer release treatments. Zhang, Chauret, Swift, and Duchesne (2006) found that intensively thinned stands produced less bending of lumber of the resulting crop trees with increasing thinning intensity. Therefore, a similar phenomenon is likely occurring in the treated sites of this study in that crop trees treated with partial cutting and herbicide treatments are responding with better form than in sites that are untreated.

As was highlighted above, when dead stems were removed from the analysis, it was found that stem quality was not significantly influenced by treatment. The lack of significance in the stem quality data in response to treatment applied can be considered, in itself, a significant finding. When interpreting these results of stem quality, it should be noted that jack pine is considered a species of naturally poor form (Tong and Zhang

2008). It is possible that the lack of significant response in stem quality when the dead stems were removed from the calculations may be simply due to the natural biology and growth pattern of the species. For example, jack pine exhibits poor form when compared with other species' growing patterns, such as balsam fir. It is also important to note that this poor natural form of jack pine growth tends to be exacerbated when planted in widely spaced stands (Janas and Brand 1988). Although it has been found that these wider-spaced plantings can yield better merchantable volume of the species, overall form generally suffers (Janas and Brand). Thus, tighter plantings of the crop trees may have resulted in better overall form, and as many studies have shown, better wood quality. This might also help to explain the slightly (though not significantly) better stem quality scores present in the control sites (when dead stems are removed from the analysis). For those trees that survive the competition in the stand, since there is no treatment being done to limit growth of competing species, there may simply not be adequate horizontal growing space in the stand for the jack pine to develop large, and therefore poor quality, branches. It is also important to consider that, even when the dead stems were removed from calculations, the resulting overall average stem quality across treatments of 2.52 is still considered of relatively moderate quality, but is not unusual for a species of naturally poor form.

Effects of Site

The lack of significant difference in branching quality between the sites may also be due to a variety of reasons. The nature of the two sites are very different from one another, meaning that the lack of significance in the results is not likely due to a similarity in site characteristics. For example, the sites are located in vastly different areas in the province, with the E.B. Eddy site being located in eastern Ontario and Bending Lake being located in the northwest portion of the province. The soils of both sites differ as well, with the Bending Lake site's soils considered coarse sand with significant coarse fragment, while the E.B. Eddy site has been classified as 'fine sand to silty loam' (Bell et al. 2011). Finally, the stand types of both sites differ considerably. Although both are considered jack pine stands, Bending Lake is classified as being jack pine/mixed wood dominant, with a rich shrub presence, while E.B. Eddy is more conifer dominant and includes jack pine and black spruce as being the dominant tree cover. Analyzing the differences in these two sites is important and may help to explain why the site seemed to be a significant factor in determining stem quality. For instance, the finer soil texture of the E.B. Eddy site may be contributing to the better trends in average stem quality compared to the Bending Lake site, since, as previously discussed, jack pine stands tend to be most successful in sandy sites. In a study conducted by Schmidt and Carmean (1988), site index for jack pine (total height of dominant and codominant jack pine trees) was analyzed on four vastly different sites, where a significant relationship between resulting site index and soil characteristics was found. Moreover, mean site indices were highest in glacial lacustrine and out-washed glacial sands, whose soil textures (sandy/silty) mirror those found at the E.B. Eddy site (Schmidt and Carmean 1988). As the E.B. Eddy site seems to possess soil characteristics that may be better suited for jack pine growth, it makes sense that this site would see better average stem quality as well. It is important to note, however, that although these results seemed to consistently prove best stem quality in the E.B. Eddy site, more information on soil and topography characteristics are needed in order to confirm these theories.

Stem Mortality

As expected, overall survival rates proved to be best in sprayed sites, with only 23 of the 120 aerial sprayed jack pine found to be dead or missing. These findings align with those of past studies, such as Burgess et al. (2010), which found that the survival of jack pine increased to 82% with the addition of intensive herbicide treatments. Oppositely, control sites yielded the greatest amount of dead crop trees compared to other treatments. This is likely due to the higher density in the untreated stands, with the overwhelming presence of species such as trembling aspen and maple limiting both growing space and light availability of the crop trees. With no treatment to control competing vegetation, it is obvious that such a shade intolerant species like jack pine would experience high mortality in these control sites.

Although the shortcomings of herbicide use have been investigated, the benefits that come from this treatment have provided justification for their continued use in forest management and thus must be discussed. As previously discussed, the results of this thesis found that stem mortality decreases in stands treated with herbicide, with aerial sprayed sites yielding best stem survival. Increased stem survival thus means increased merchantable volume that can be harvested from a chemically treated forest. The importance of this benefit should not be understated or overlooked when discussing how or why herbicide use has been justified by forest managers. This finding of increased stem survival agrees with those of past research studies, in which the addition of herbicides was found to increase the survival and/or long-term growth of conifer crop trees (Dimock, Beebe, and Collard 1983; Newton et al. 1992; White, Witherspoon-Joos, and Newton 1990; Malik, Bell, and Gong 2002). Moreover, growth response of jack pine has been found to be positively related to the level of herbaceous weed control used (Pitt et al. 1999). Although wood form and quality are desirable traits to the forest industry, survival of the species that is being harvested is arguably considered a more desirable trait.

A great amount of focus has been placed upon the application of herbicides to achieve vegetation control within forest management, however, few studies have determined the effects these treatments are having on the form of the desired crop trees. In the case of this thesis, treatment type has been found to have a significant effect on branching quality of jack pine crop trees, but not on overall stem quality when stem mortality is removed from the analysis. This may indicate the need to re-evaluate the costs vs. benefits provided by intensive silvicultural treatments such as herbicide use. In an early study investigating the potential for herbicide use in the boreal forest, jack pine was found to even be negatively impacted by the application of aerial sprayed herbicide treatments (Sutton 1984). It was argued based off these results that vegetation control is not synonymous with conifer release. The results of this study also found that none of the treatments used were found to be significantly benefiting the stem quality of the living jack pine crop trees. The results of this thesis align with these findings and bring into question the true net benefits of using herbicide treatments to improve the quality of jack pine. However, it is also important to consider stem mortality findings when questioning the use of intensive silvicultural treatments, such as aerial spray and partial cutting. As has been discussed, if these types of treatment can help significantly improve stem survival, then the continued use of these treatments may be justifiable.

It is vitally important to understand the trade-offs between the costs and benefits associated with herbicide use, especially at a time when forest managers are under constant pressure from the public and from Indigenous Peoples to look for alternative measures. This thesis does not provide enough information to make definitive decisions for forest managers, however, the lack of significant difference in jack pine stem quality of the live trees in response to vastly different silvicultural treatments should still be considered a significant, if not surprising result. It is important to note that there are limitations to assessing overall crop tree form by using a simple index ranking system and more robust data may be needed to make further conclusions about the effects of these treatments on overall form. For example, additional analyses on wood quality would benefit this study to show what the inherent wood properties are and if there is significance in lumber grades across treatments, which directly affects how industry will use or market this wood fibre. As previously mentioned, these additional types of tree form data were collected as a part of a larger study but were not included in this thesis so as to narrow its focus. Additional analyses on factors such as stem taper, basal area, merchantable volume, and average branch diameter may be necessary to draw further conclusions on this topic.

CONCLUSION

Analyzing the branching and stem qualities of jack pine crop trees resulting from varying combinations of treatment and site help to quantify the effect that both treatment and site have on these responses. Although there are limitations to the assumptions that can be drawn from the results of this thesis, it is important to recognize the significance of the findings; specifically, that significant differences in branching quality were found as a function of treatment when dead stems were either included or excluded from the analysis. When evaluating stem quality, treatment type was found to significantly affect the outcome only when dead stems were included in the analysis, and not when they were left out of the analysis.

Past research has shown that aerial spray should yield best tree form and, although this finding remained directionally true in this thesis, it did not prove true when analyzing stem form of just the live trees. This implies that, although intensive treatments may help to improve stem survival, they do not seem to be benefiting the stem quality of the remaining live jack pine trees. Although the use of herbicide has proved beneficial in achieving better stem survival, the findings of this thesis should be taken into account when weighing the net benefit of this treatment. With increasing concern over herbicide use in the boreal forest, managers are under pressure to prove its relevance in achieving quality wood for industry purposes. Considering the environmental and social costs associated with herbicide use, one might hope that the benefits (such as increasing stem quality) coming from its use would at least be considered significant.

More diverse types of measurements must be used to enhance these findings and to determine the full effect of various silvicultural treatments on overall wood quality. Meanwhile, the view that aerial spray is considered ‘top tier forest management’ may need to be reconsidered, as other treatments seem to perform at equal levels in achieving stem quality.

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APPENDICIES

APPENDIX I – RAW MEANS

Tables 13 and 14 present the raw data of branching stem quality index values, with 1 being of poorest quality and 4 being best. The presence of a 0 indicates that the tree is dead.

Table 13. Raw data of branching quality (1-4) by treatment and site.

Aerial Spray E.B.E	Aerial Spray BL	Brush Saw E.B.E	Brush Saw BL	Complete Removal E.B.E	Complete Removal B.L	Control E.B.E	Control B.L
2	4	3	0	2	2	0	0
3	0	0	0	1	0	3	4
3	2	0	3	2	3	2	0
3	3	3	3	3	3	0	0
2	3	0	0	2	0	4	0
3	4	3	4	0	3	3	0
3	3	0	3	0	2	4	3
0	2	2	0	3	3	4	0
0	2	3	0	2	2	0	0
0	0	3	0	0	2	3	0
3	2	2	0	3	0	0	3
3	3	2	0	3	3	4	0
0	0	2	2	3	0	0	0
4	3	2	3	2	3	3	0
3	0	3	0	3	0	0	0
3	4	3	3	2	2	0	0
4	0	1	3	3	2	0	0
3	2	3	3	2	2	0	3
3	4	1	4	2	0	0	0
2	3	3	3	2	1	0	0
3	3	3	3	0	0	0	3
3	2	3	0	3	0	4	1
3	3	3	3	3	2	4	0

3	2	3	0	3	0	4	3
3	2	2	2	2	2	3	0
0	2	3	3	2	1	0	0
2	3	0	3	2	0	2	3
2	3	3	0	3	2	3	3
3	2	3	2	3	0	2	3
3	3	3	3	0	2	3	0
3	0	3	3	0	2	3	3
0	3	0	0	3	0	0	0
1	3	3	3	3	2	0	0
2	2	0	0	3	2	0	0
3	0	2	3	2	3	0	0
2	2	3	3	3	3	0	2
2	3	3	3	3	0	4	0
0	3	3	4	2	0	0	0
2	0	3	0	3	1	4	0
2	3	3	2	0	0	3	0
3	2	3	0	1	3	0	0
2	0	3	4	3	2	0	0
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3	3	3	3	3	3	0	3
3	3	3	0	0	0	0	0
3	3	3	0	0	3	0	4
3	3	0	2	2	3	0	3
2	3	3	0	3	1	0	2
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2	2	0	3	0	2	0	0
3	0	4	0	3	3	0	4
0	2	3	3	0	2	0	3
2	3	3	0	2	2	0	0
2	3	3	3	0	0	0	3
4	2	3	0	0	4	0	4
0	3	3	4	3	3	0	0
3	0	4	0	3	4	0	3
3	3	4	4	3	2	4	3
3	0	3	0	3	3	0	0
0	4	0	3	3	3	0	3

Table 14. Raw data of stem quality (1-4) by treatment and site.

Aerial Spray	Aerial Spray	Brush Saw	Brush Saw	Complete Removal	Complete Removal	Control	Control
E.B.E	BL	E.B.E	BL	E.B.E	B.L	E.B.E	B.L
2	2	4	0	2	2	0	0
4	0	0	0	1	0	3	3
4	3	0	1	2	3	3	0
4	3	4	2	4	2	0	0
2	3	0	0	4	0	3	0
4	3	2	4	0	3	4	0
3	3	0	3	0	3	2	1
0	2	1	0	3	2	2	0
0	2	2	0	2	2	0	0
0	0	2	0	0	3	4	0
3	2	2	0	4	0	0	2
4	3	3	0	3	2	3	0
0	0	2	1	3	0	0	0
3	3	2	1	1	3	3	0
4	0	4	0	3	0	0	0
3	3	3	1	2	1	0	0
4	0	1	1	2	2	0	0
2	3	4	3	4	3	0	1
3	3	3	1	3	0	0	0
1	3	4	2	2	3	0	0
4	2	3	1	0	0	0	3
3	3	3	0	2	0	4	4
3	4	4	1	2	1	3	0
3	2	3	0	4	0	3	2
2	3	3	1	2	2	2	0
0	2	4	2	1	1	0	0
4	3	0	2	2	0	2	1
2	2	4	0	3	3	2	1
4	1	3	2	3	0	3	1
2	1	1	4	0	1	3	0
3	0	2	3	0	1	3	1
0	3	0	0	3	0	0	0
3	3	3	3	4	2	0	0

2	2	0	0	4	1	0	0
2	0	2	1	3	3	0	0
2	1	3	3	4	2	0	1
2	1	1	2	2	0	4	0
0	3	2	1	2	0	0	0
2	0	2	0	2	1	4	0
3	1	4	1	0	0	2	0
3	1	4	0	1	3	0	0
2	0	4	3	3	1	0	0
2	1	4	3	3	0	0	3
3	2	3	1	3	3	0	1
2	4	2	0	0	0	0	0
3	2	2	0	0	1	0	1
4	3	0	1	2	3	0	1
3	1	2	0	1	1	0	2
0	3	2	3	2	3	0	4
2	3	0	3	0	1	0	0
3	0	4	0	3	3	0	1
0	2	1	4	0	2	0	4
2	2	2	0	3	1	0	0
2	1	4	1	0	0	0	4
3	2	4	0	0	4	0	4
0	3	4	1	3	3	0	0
3	0	4	0	1	3	0	4
2	3	4	3	3	2	4	2
2	0	4	0	3	3	0	0
0	3	0	2	4	2	0	4

APPENDIX II – CALCULATED AVERAGES AND STANDARD DEVIATIONS

Calculated averages and standard deviation for branching quality data can be found in Tables 15 and 16.

Table 15. Average of the raw branching quality data by treatment and site.

Branching Quality (1-4)			
Treatment	E.B. Eddy	Bending Lake	Average by Treatment
Aerial Spray	2.20	2.18	2.19
Brush Saw	2.37	1.82	2.09
Complete Removal	2.02	1.68	1.85
Control	1.22	1.25	1.23
Average by Site	1.95	1.73	---
Grand Mean	---	---	**1.84**

Table 16. Standard deviation values of the raw branching data by treatment and site.

	Standard Deviation	
Treatment	E.B. Eddy	Bending Lake
Aerial Spray	1.19	1.24
Brush Saw	1.19	1.56
Complete Removal	1.19	1.27
Control	1.67	1.56

Calculated averages and standard deviation of the raw stem quality data can be found in Tables 17 and 18.

Table 17. Averages of the raw stem quality data by treatment and site.

	Stem Quality (1-4)		
Treatment	E.B. Eddy	Bending Lake	Average by Treatment
Aerial Spray	2.28	1.90	2.09
Brush Saw	2.40	1.20	1.80
Complete Removal	2.05	1.52	1.78
Control	1.10	0.93	1.02
Average by Site	1.96	1.39	---
Grand Mean	---	---	**1.67**

Table 18. Standard deviation values of the raw stem quality data by treatment and site.

Treatment	Standard Deviation E.B. Eddy	Bending Lake	Average by Treatment
Aerial Spray	1.32	1.22	1.27
Brush Saw	1.44	1.27	1.36
Complete Removal	1.37	1.24	1.31
Control	1.53	1.39	1.46

APPENDIX III – RESULTS OF ANOVA ANALYSIS

Table 19 shows the calculations of the two-factor analysis of variation (ANOVA) of the branching quality data, with the two fixed factors being treatment and site.

Table 19. Analysis of variance calculations for branching quality.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F-data	F-Crit a=0.05
Constant (Mean)	1628.03	1	1628.03	---	---
Treatment=S	66.62	3	22.21	11.80	F(3,472)= 2.62
Site=T	5.63	1	5.63	2.99	F(1,472)= 3.86
S x T	6.82	3	2.27	1.21	F(3,472)= 2.62
Error	887.90	472	1.88	---	---
Total (corr)	965.97	479	2.02	---	---
Raw Mean	2594.00	480	5.40	---	---

Table 20 shows the calculations of the two-factor analysis of variation (ANOVA) of the stem quality data, with the two fixed factors being treatment and site.

Table 20. Analysis of variance calculations for stem quality.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F-data	F-Crit A=0.05
Constant (Mean)	1343.35	1	1343.35	---	---
Treatment=S	76.12	3	25.37	13.92	F(3,472)= 2.62
Site=T	39.10	1	39.10	21.45	F(1,472)= 3.86
S x T	17.87	3	5.96	3.27	F(3,472)= 2.62
Error	860.55	472	1.82	---	---
Total (corr)	993.65	479	2.07	---	---
Raw Mean	2337.00	480	4.87	---	---

Table 21 shows the calculations of the two-factor ANOVA of the branching quality data when dead stems were omitted from the data set, with the two fixed factors being treatment and site.

Table 21. Analysis of variance of branching quality with dead stems removed.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F-data	F-Crit A=0.05
Constant (Mean)	2449.71	1	2449.71	---	---
Treatment=S	15.74	3	5.25	12.96	F(3,311)= 2.65
Site=T	0.08	1	0.08	0.19	F(1,311)= 3.89
S x T	2.50	3	0.83	2.06	F(3,311)= 2.65
Error	125.94	311	0.40	---	---
Total (corr)	144.29	318	0.45	---	---
Raw Mean	2594.00	319	8.13	---	---

Table 22 shows the calculations of the two-factor ANOVA of the stem quality data when dead stems were omitted from the data set, with the two fixed factors being treatment and site.

Table 22. Analysis of variance of stem quality with dead stems removed.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F-data	F-Crit A=0.05
Constant (Mean)	2021.34	1	2021.34	---	---
Treatment=S	1.90	3	0.63	0.70	F(3,311)= 2.65
Site=T	27.90	1	27.90	30.77	F(1,311)= 3.89
S x T	3.38	3	1.13	1.24	F(3,311)= 2.65
Error	281.99	311	0.91	---	---
Total (corr)	315.66	318	0.99	---	---
Raw Mean	2337.00	319	7.33	---	---