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Affects of Pre-Commercial Thinning on Decay Levels in Balsam Fir Stands

Rob O'Keefe
Bob Murray
Tim McGrath

Timber Management Group
Forest Management Planning

Nova Scotia Department
of Natural Resources

NOVA SCOTIA
Natural Resources

Introduction

Balsam fir (*Abies balsamea* (L.) Mill.) is one of the main commercial softwood species in Nova Scotia, accounting for approximately 27% of the province's merchantable softwood volume (NSDNR, 2000). Balsam fir is relatively short lived and is generally more susceptible to decay than spruce (*Picea spp.*).

The pre-commercial thinning of softwoods stands (mainly balsam fir and spruce) has been an operational management practice in Nova Scotia since the early 60s. The use of this management activity has increased since then, peaking in the mid 80s (Figure 1). To date more than 120,000ha have been spaced in the province (Figure 1). Spacing provides the opportunity to control density and species composition in young stands. Research in Nova Scotia has shown that pre-commercial thinning shortens the rotation by 13 years, on average, compared to unmanaged stands (NSDNR, 1992).

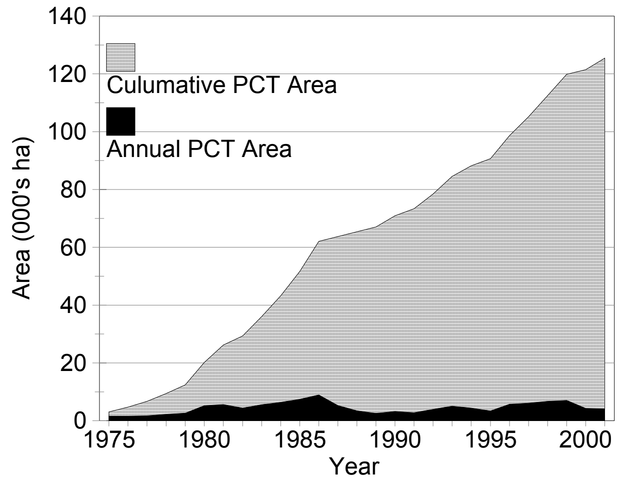

Figure 1. Nova Scotia pre-commercial thinning levels since 1975.

Losses associated with decay in the form of stem and butt rot, growth reductions, pre-mature windthrow and mortality are a constant threat to our major commercial softwood species in Nova Scotia yet, there is limited knowledge on these types of losses. Referred to by Whitney (1985) as the 'Hidden Enemy', there are no reliable external indicators of rot and even fruiting bodies are rare on infected living trees (Burns and Honkala, 1990). Decay surveys and professional experience have been the main sources of information on losses in Nova Scotia to date. There is far less understanding of losses from growth reductions and pre-mature windthrow. In northern Ontario, Whitney has estimated that on average there is a 30% gross merchantable volume loss (including scaled cull, tree mortality and pre-mature windthrow) from balsam fir stand types that were 70 years of age on average (Whitney, 1989).

In terms of decay losses from the heartwood of trees, the current literature generally classifies decay as either stem rot or butt rot (Basham, Mook and Davidson, 1953; USDA Forest Service, 2003). Stem rot infections enter through injuries to the trunk and/or living branches of trees, decaying the heartwood of a tree's main stem. The most common stem rot fungus documented in eastern North America is the red heart fungus (*Stereum sanguinolentum*). Butt rot fungi, on the other hand, typically enter through roots and/or basal area wounds, decaying heartwood of roots and lower stems of trees making them more susceptible to pre-mature windthrow (Davidson, 1951). Generally the proportion of gross volume lost to stem rot in natural stands is greater than that of butt rot (Burns and Honkala, 1990; Davidson, 1957). However, when growth reductions and/or premature windthrow are considered losses associated with butt rot have the potential to be far greater (Whitney, 1985).

Recent studies of butt rot and the relationship to pre-commercial thinning has suggested the incidence and amount of butt rot to be higher in treated stands (English and Warren, 2001). The spacing treatment introduces freshly cut stumps and wounds to lower stems providing avenues for pathogens to enter crop trees. Also, it has been theorized that under windy conditions crop trees in spaced stands experience more sway which is said to cause increased root damage. The damaged roots increase the likelihood of pathogens entering crop trees. To date, these theories lack convincing evidence. Studies have struggled with high levels of variation in the occurrence and amount of rot which is difficult to find simple explanations for. The inherent complexity of the problem has made transferring findings into practical forest management strategies problematic.

This survey was undertaken to acquire a better understanding of butt and stem rot losses in the natural and pre-commercially thinned balsam fir stand types of Nova Scotia. This report focused mainly on decay in logs from merchantable trees. The study examined whether the spacing treatment affected the incidence, amount and type of decay by species and product as compared to untreated stands. The study also examined stand age and its relationship to decay by treatment and type of rot.

Methods

Stand Selection

The survey targeted the population of pre-commercially thinned balsam fir stands that were at or nearing a harvestable condition. Potential locations were identified using historical crown land records of spacings as well as the current network of research permanent sample plots located in spaced stands. From these sources locations were selected based on the following criteria:

- Stands where balsam fir was the dominate species;
- Stands that were greater than 30 years of age;
- Stands where the treatment occurred more than 15 years ago and;
- Stands that had potential untreated control areas.

Assessment Procedures

At each of the selected locations a 10m radius plot (0.0314ha) was established in the spaced stand with a second plot of the same size being placed in an untreated (control) portion of the same stand, where possible. Also, an effort was made to locate the paired plots as close together as possible. The following assessment procedure was used for both the spaced and control plots.

Within each plot the d.b.h. (diameter at breast height) of all living trees were measured. Trees were then placed in 2cm diameter classes by species and merchantable trees (greater than 9.0cm in d.b.h.) were additionally placed in one of three product classes based on d.b.h. (Table 1).

Table 1. Product classification criteria for spruce and balsam fir.

Product	D.B.H. Outside Bark (cm)	
Class	Minimum	Maximum
Pulp Wood	9.1	13.9
Stud Wood	14	18.9
Saw Log	19	-----

A subset of trees within the plot were chosen for stem analysis. Moving clockwise from the north radius of the plot, three balsam fir trees and one spruce tree from each product class were selected as encountered. This resulted in performing stem analysis on potentially 9 balsam fir and 3 spruce for a total of 12 trees from each plot.

Before each tree was felled for stem analysis; crown class[1], live crown diameter, species and product class were recorded. Trees were felled at 15cm above ground level. Once felled, the length of clear bole and live crown were measured before trees were delimbed. Total height and heights to 6.6cm and 9.1cm tops were recorded.

Felled trees were sectioned at 1.3m and 2.0m above ground level then, sectioning was continued using 1.0m intervals for the total length of the tree (Figure 2). Following sectioning, both stump age (15cm above ground level) and breast height age (1.3m above ground level) were recorded. For each section, diameter inside bark and bark thickness were recorded. At breast height (1.3m above ground level) the growth increment was measured at 5 year intervals moving from the current years growth inwards.

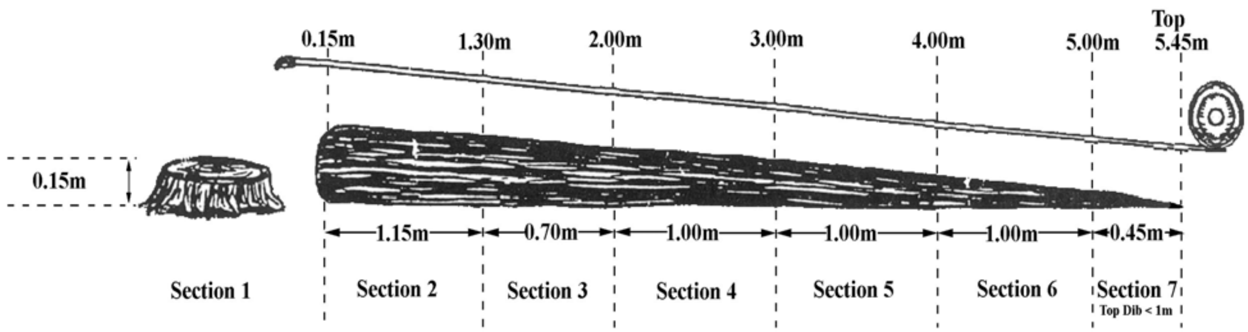

Figure 2. Overview of method of sectioning used for stem analysis.

At each section, the diameter of rot was recorded as the average of two perpendicular measurements. The length of rot along the section was also tallied, this sometimes required additional cross-sectional cuts to determine where rot began and ended within the section . The rot was then classified into one of six classes (Table 2). Examples of the types of rot encountered are presented in Figure 3.

Table 2. Summary of criteria used to classify rot.

Class	Description	Class	Description
1	Soft rot - no rings visible	4	Hard Rot
2	Soft rot - rings still visible	5*	Mechanical damage
3	Soft rot - presence of ants	6*	Cavities

* Classes 5 and 6 represented only a small portion of the recorded rot and were most frequently associated with the presence of hard rot, therefore these classes were grouped with class 4 when summarizing by hard and soft rot.

The hard and soft rot classification were used to indicate the severity of the heartwood rot and usability of the wood. Soft rot was recorded where the heartwood was noticeable softer than normal healthy heartwood generally representing advanced stages of decay. Discolored or

[1] The crown class of trees fell into one of the following categories; Dominant, Co-Dominant or Intermediate.

stained heartwood that was no softer than normal was classified as hard rot. Hard rot is generally associated with decay that is just beginning to become noticeable, sometimes referred to as incipient decay. Figure 3 presents examples of the hard and soft rot observed in the study.

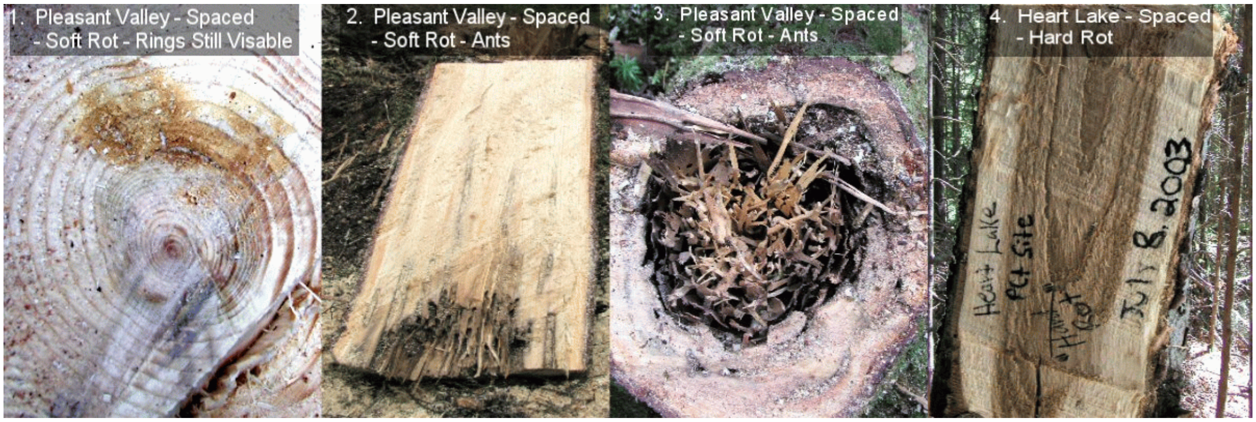

Figure 3. Various rot classes observed in assessment procedures.

Data Analysis

Plot data were compiled to summarize stand conditions in terms of average diameter, average height, density, basal area and volume statistics. Plot data were compiled using the Nova Scotia Department of Natural Resources Forest Inventory Cruise Program (NSDNR,1996).

For each individual tree selected for stem analysis, section volumes were derived using Smalian's Formula (Equation 1) and summed to produce gross tree volumes.

$$V=[(A_b + A_u)/2]*H$$

Where:

V = Volume (m^3)

H = Length of section (m)

A_b = Cross-sectional area at bottom of section (m^2)

A_u = Cross-sectional area at top of section (m^2)

Equation 1: Smalian's Formula for determining volume of a paraboloid frustum.

Rot volumes were also calculated for each section using Smalian's Formula (Equation 1), then summarized by type of rot for each tree. Rot volumes were further classed as either butt rot or stem rot depending on the location of the rot within the tree. Butt rot, as considered in this study, referred to rot pockets that had their maximum diameter at or below breast height (1.3m). While stem rot referred to pockets of rot that had their maximum diameter above breast height. Since it was possible for individual trees to have both butt and stem rot, tree level rot statistics were further separated according to this classification.

Cull volumes were obtained by applying an approach Davidson (1957) used in a similar study. Under this approach all portions of trees containing soft rot were culled. The remaining portions, irrespective of length were considered merchantable. It was intentionally decided not to use hard rot in the culling procedure as the wood may potentially be useable. Though simplistic, the approach provides a more accurate picture of potential volume loss due to rot than the rot volumes themselves. The cull estimates are likely to be conservative since, the location of rot along the stem and hard rot are potentially other sources of cull. Cull volumes were calculated for each section by multiplying the section volume by the percentage of section length containing soft rot. The cull volumes were summarized by type of rot for each tree in the database.

As described above in the assessment procedures, sampling within plots was stratified by product class (pulp wood, stud wood, saw log). This ensured that reliable estimates could be derived from each product class as well as for the population as a whole. Plot level statistics were derived as a function of weighted product level estimates (Equation 2). Product weights were calculated for every plot based on cruise information collected prior to sampling.

$$S_{plot} = (S_{pulp} * W_{pulp}) + (S_{stud} * W_{stud}) + (S_{saw} * W_{saw})$$

Where:

S_{plot} = Plot Level Statistic
S_{pulp} = Pulp Wood Product Statistic
W_{pulp} = Pulp Wood Weighting (%) for Current Plot
S_{stud} = Stud Wood Product Statistic
W_{stud} = Stud Wood Weighting (%) for Current Plot
S_{saw} = Saw Log Product Statistic
W_{saw} = Saw Log Weighting (%) for Current Plot

Equation 2: Determining plot level statistics from product level statistics .

The incidence and amount of rot was expressed as a percentage at the plot level. Paired plots at a single location were statistically analyzed using a paired t-test to determine if significant differences (0.05 level) existed between spaced and control plots. Preliminary analysis of the data revealed the differences were not normally distributed. Therefore, the data was transformed to comply with the normality assumption of the statistic. The square-root transformation was used to normalize the data. The percent volume in butt and stem rot was also statistically analyzed for stand age dependent relationships. Spaced stands were further analyzed using ‘years since treatment’ as the independent variable. The analysis was done using simple linear regression to determine where significant relationships exist.

Results

Survey Description

The survey was started in June 1995 with the last plot finished by December 1995. Over this time period 23 locations were visited (Figure 4) where 43 plots were established with stem analysis being completed on 381 trees. During the validation of the data, six locations were removed (Figure 3) reducing the sample to 17 locations, 34 plots and 294 trees. The Silica Lake, Seven Mile Stream and Moose River locations were removed because no control plots could be established. The Barren Hill, McKeen Road and North Interval locations were removed because of large age discrepancies (greater than 10 years difference) between the control and treated plots. However, the removed data were later used for regression analysis, where data pairing was not a requirement of the statistic.

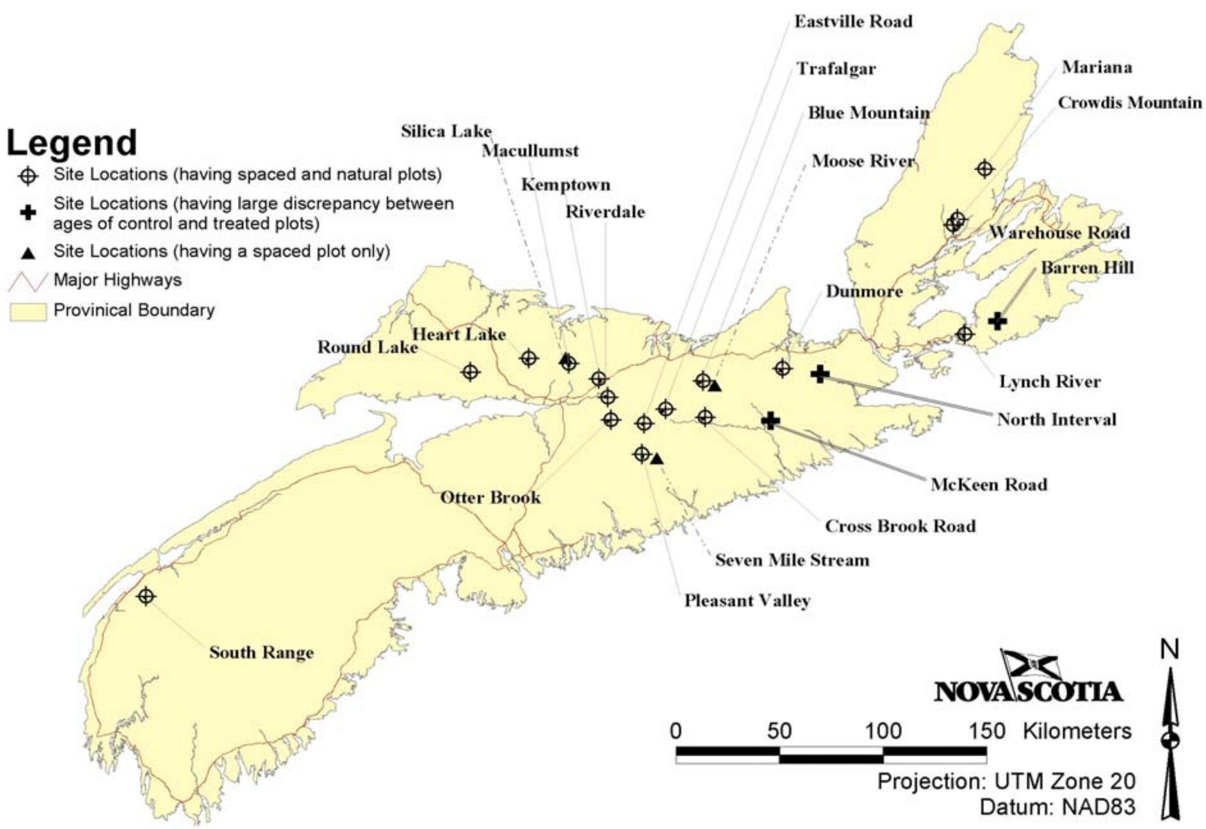

Figure 4. Locations visited in the 1995 balsam fir decay survey.

Of the 17 locations visited, stand ages ranged from 31 to 66, averaging 43 years at stump height. The average number of 'years since treatment' was 23 and ranged from 16 to 29 at time of assessment. Table 3 summarizes the stand-level statistics for treated and control plots. Plot level statistics by location are contained in Appendix I. Spaced plots on average were two years older than their associated control plots. Both the control and treated plots showed similar species composition even though densities were greatly reduced through treatment. Total basal area and volume was higher in the control plots yet the spaced plots contained more merchantable volume. Merchantable volume within spaced plots was comprised of far more stud wood and saw log volume (72%) compared to the control plots (47%).

Table 3. Compiled stand level statistics for treated and control plots.

Stand-Level Statistic	**Treatment** Spaced	Control
Stump Age (years)	42	44
Breast Height Age (years)	36	38
Years Since Treatment (years)	23	NA
Merchantable Height (m)	11.9	11.7
Total Diameter (cm)	14.2	8.7
Merchantable Diameter (cm)	16.3	13.6
Total Density (stems/ha)	2631	10204
Merchantable Density (stems/ha)	1818	2420
Total Basal Area (m^2/ha)	39.1	52.8
Merchantable Basal Area (m^2/ha)	36.4	36
Species Composition (by % basal area)		
Balsam Fir	84	83
Spruce	15	14
Other	1	3
Total Volume (m^3/ha)	217.6	263.4
Merchantable Volume (m^3/ha)		
Pulp Wood	50.2	90.6
Stud Wood	93.2	60.6
Saw Log	43.8	25.2
Hardwood/Larch	1.9	8.1
Total Merchantable	189.2	184.6

Of the 294 trees sectioned and analyzed, 247 or 84% were balsam fir trees and 47 or 16% were spruce (Figure 4). Of the 247 balsam fir trees 134 or 54% were from spaced stands and 113 or 46% were from the control stands (Figure 5). Balsam fir trees were mainly dominant or co-dominant with only 7% of trees falling in the intermediate crown class (Figure 5). Of the balsam fir trees, the percentage break-down by product was 41%, 41% and 18% for pulp wood, stud wood and saw log, respectively (Figure 5). The product distribution by treatment differed as saw logs occurred less frequently in control plots (Figure 6). Stand ages taken at stump height ranged from 31 to 66 years with stands being 43 years old on average (Figure 7).

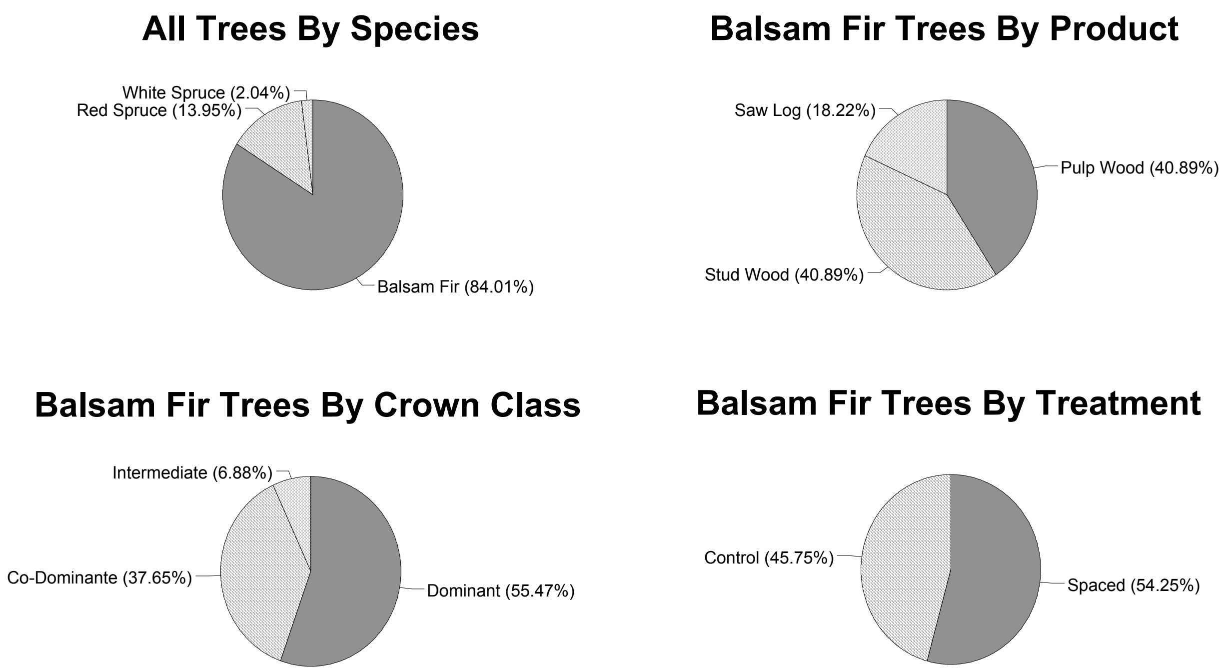

Figure 5. Distribution of sampled trees by species, product, crown class and treatment.

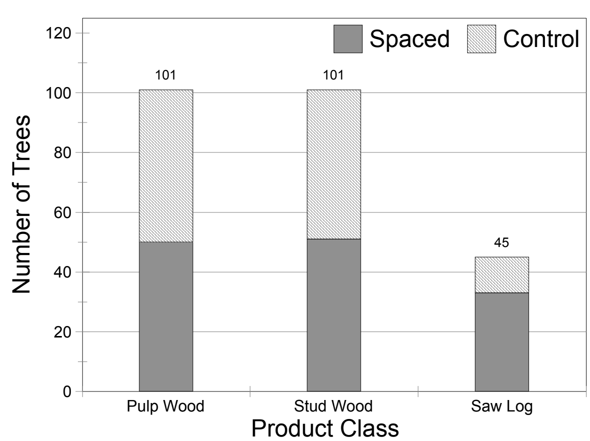

Figure 6. Distribution of balsam fir trees sampled by product and treatment.

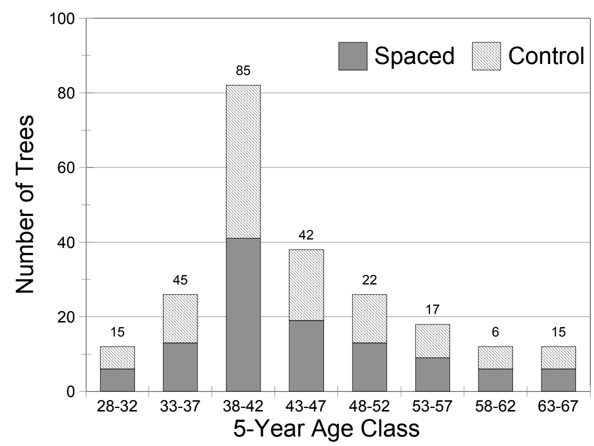

Figure 7. Distribution of balsam fir trees sampled by age class and treatment.

Incidence of Rot

Large differences in the occurrence of rot by species were evident. Forty-four percent of balsam fir trees showed signs of decay while decay was only found in 8% of the spruce sampled. Spruce data was not further stratified by product or treatment because of the small sample size (47 trees). Within the balsam fir data, rot occurred most frequently in the saw log product class (Figure 8). Even when the trees were further stratified by treatment the same trend was evident. More detailed summaries on the incident of rot by location are contained in Appendix II.

The occurrence of rot in balsam fir averaged 52% and 36% for spaced and control plots respectively (Figure 9). Larger differences were evident once the rot was separated into butt rot and stem rot. Butt rot occurred more frequently in the spaced plots (47%) compared to the controls (25%) and, the observed difference was statistically significant[2] (p-value=0.010). Stem rot, on the other hand, occurred more frequently in the control plots (14% vs. 7%) however, this difference was not statistically significant (p-value=0.106).

Figure 8. Percentage of balsam fir trees having decay by product and treatment.

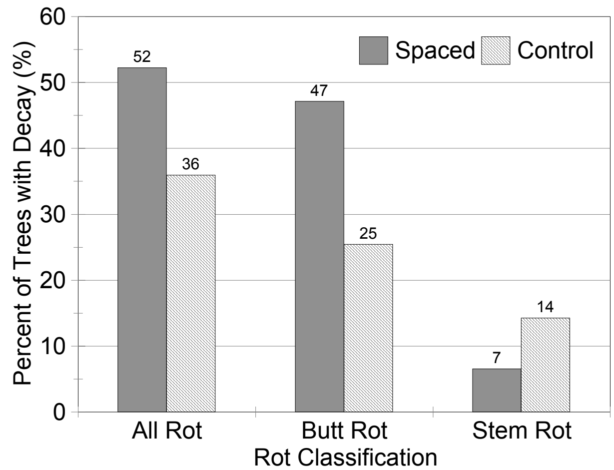

Figure 9. Percentage of balsam fir trees having decay by rot classification.

The percentage of balsam fir trees with rot by stand age and treatment (Figure 10) indicated that the occurrence of rot was not strongly related to stand age. Separating the occurrence of rot into butt rot (Figure 11) and stem rot (Figure 12) showed that the occurrence of stem rot increased noticeably with age for both spaced and control plots. No age related trends were evident for butt rot (Figure 11) however, butt rot showed an increasing trend with 'years since treatment' (Figure 13).

2 See Appendix III for details on the statistical analysis.

Figure 10. Occurrence of rot in balsam fir by age class and treatment.

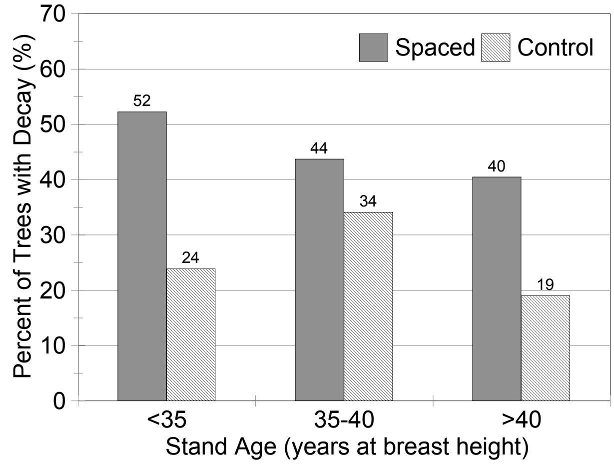

Figure 11. Occurrence of butt rot in balsam fir by age class and treatment.

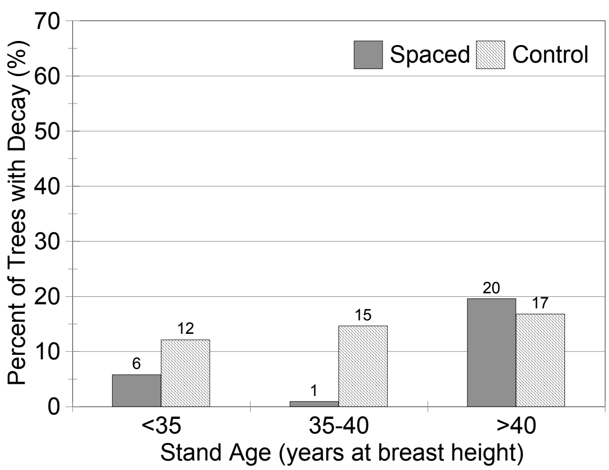

Figure 12. Occurrence of stem rot in balsam fir by age class and treatment.

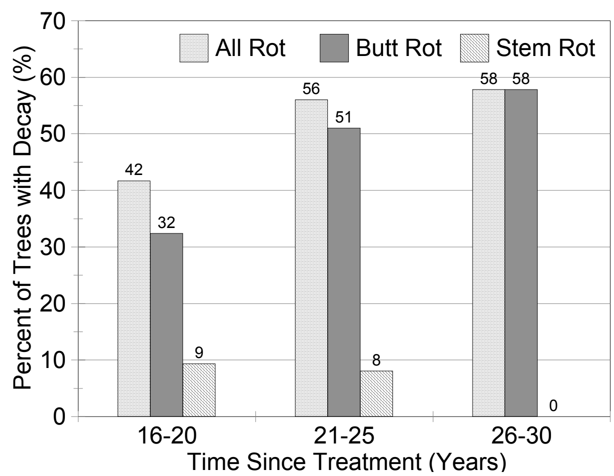

Figure 13. Occurrence of rot in balsam fir by 'years since treatment' and rot classification.

Amount of Rot

Consistent with the incidence of rot, large differences existed in the amount of rot observed by species. For balsam fir, rot averaged 1.21% of total tree volume sampled compared to 0.36% rot in the spruce volume sampled. Within the balsam fir data set the percentage of volume lost to rot was highest for the saw log product class (Figure 14). When the trees were further stratified by treatment the same trend was evident (Figure 14). More detailed summaries on the amount of rot by location are contained in Appendix II.

The percent of balsam fir volume in decay was 6% higher for control plots as compared to the spaced plots (Figure 15). Separating butt and stem rot showed larger differences between treatments (Figure 15). The percentage of balsam fir volume in butt rot was 3.8 times higher in the spaced stands while stem rot was 4.0 times higher in the control stands (Figure 15). The observed differences between treatments for butt rot was statistically significant (p-value=0.003) however, the stem rot differences were not (p-value=0.063)[3].

Figure 14. Percentage of balsam fir volume in decay by product and treatment.

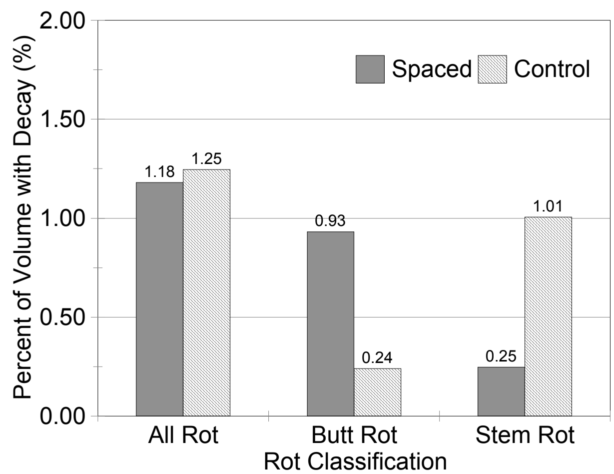

Figure 15. Percentage of balsam fir volume in decay by rot classification.

The percentage of balsam fir volume in rot showed a stronger relation to stand age (Figure 16) than did the occurrence of rot in balsam fir (Figure 10). The percentage of volume in butt rot did not show any trends with stand age (Figure 17). In support, no significant (0.05 level) regression lines were constructed. The percentage of stem rot showed a more pronounced trend with stand age (Figure 18). For spaced and control plot data, significant (0.05 level) regression lines were constructed. The control plot regression described more of the observed variation (R^2 of 0.357 vs. 0.235). When the percentage of rot was summarized by 'years since treatment' the butt rot trend improved (Figure 19) yet, no significant (0.05 level) regression line could be constructed.

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[3] See Appendix III for details on the statistical analysis.

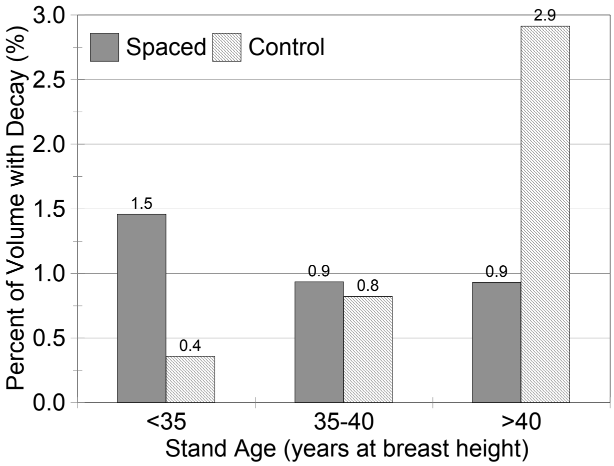

Figure 16. Percentage of balsam fir volume in rot by age class and treatment.

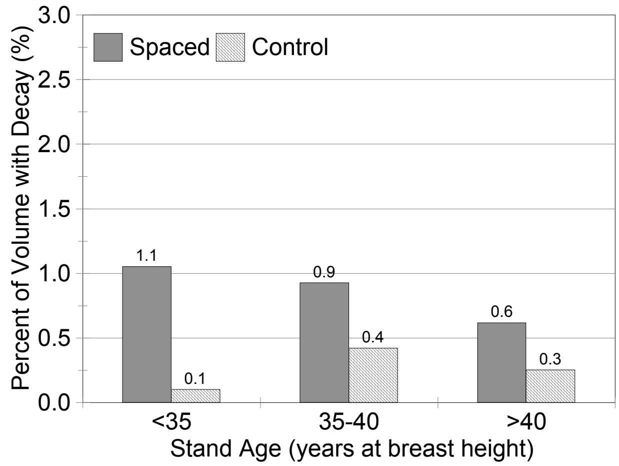

Figure 17. Percentage of balsam fir volume in butt rot by age class and treatment.

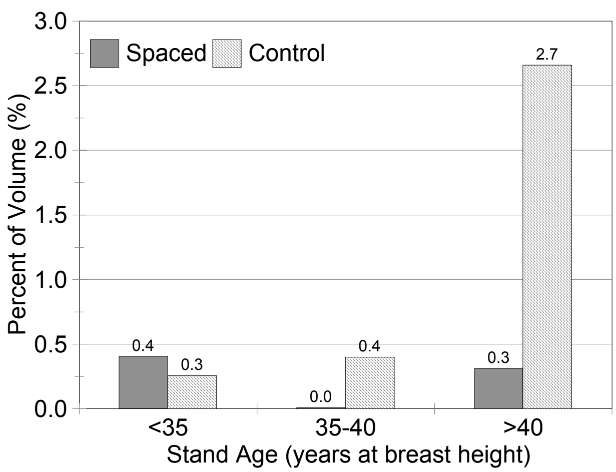

Figure 18. Percentage of balsam fir volume in stem rot by age class and treatment.

Figure 19. Percentage of balsam fir volume in rot by 'years since treatment' and rot classification.

Potential Cull Losses
Consistent with the amount of rot, large differences existed in culled volume by species. For balsam fir, culled volume averaged 3.90% of tree volume sampled compared to 0.00% cull in the spruce. Within the balsam fir data set the percentage of culled volume was highest for the saw log product class (Figure 20). When the trees were further stratified by treatment the same trend was evident. Culled volumes across product classes were consistently lower for the control plots. The spaced plots experienced more severe culling because 86% of rot found in spaced plots was butt rot and most butt rot (87%) was classified as soft rot.

The percent of balsam fir volume in cull was 1.59 times greater for spaced stands as compared to the controls (Table 4 and Figure 21).When the amount culled was further stratified by the types of rot, more distinct differences were evident between treatments. The percentage of balsam fir volume culled due to butt rot was 1.6 times higher in the spaced stands while volume culled due to stem rot is 43 times higher in the control stands.

Table 4. Culled volume as percent of balsam fir volume sampled by treatment and rot classification.

Rot	Treatment		
Classification	Spaced	Control	Total
Culled Butt Rot	4.77	2.23	5.13
Culled Stem Rot	0.02	0.79	0.57
Total Cull	4.79	3.02	5.7

Figure 20. Percentage of balsam fir volume culled by product and treatment.

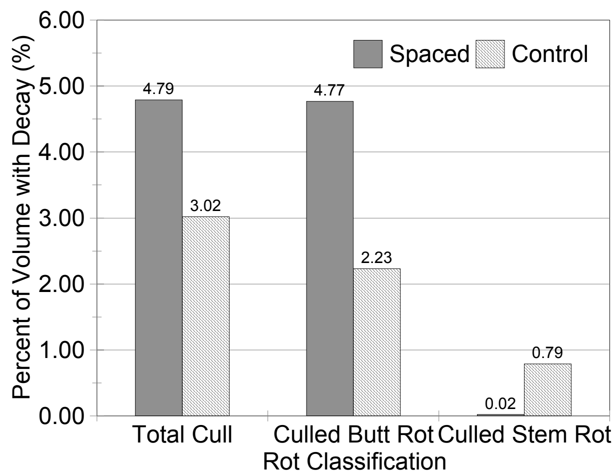

Figure 21. Percentage of balsam fir volume culled by treatment and rot classification.

Summary of Results

A summary of results from the decay survey of older balsam fir dominated pre-commercial thinnings are as follows:

Incidence of Rot:

- Decay occurred more frequently in balsam fir than spruce (44% vs. 8%).

- The incidence of rot in balsam fir was highest for the saw log product class (79%).

- The incidence of overall rot levels in balsam fir was higher for spaced (52%) than control (36%) plots. Further separation showed butt rot occurred more frequently in spaced stands (47% vs. 25%) and stem rot occurred more frequently in control stands (14% vs. 7%). Only the difference in butt rot was statistically significant (p-value=0.010).

Amount of Rot:

- Percentages of gross tree volume lost to decay were far higher in balsam fir than spruce (1.21% vs. 0.36%).

- The percentage of balsam fir volume in rot was consistently higher for the saw log product class (1.9%).

- The percentage of balsam fir volume in rot was 6% higher in the control plots versus the spaced plots (1.25% vs. 1.18%). Separating butt and stem rot, percent volume in butt rot was 3.8 times higher in spaced stands (0.93% vs. 0.24%) with the difference being significant (p-value=0.003). Percent volume in stem rot was 4.6 times higher in control stands (0.01% vs. 0.25%). This difference was not statistically significant (p-value=0.063).

- The percent of balsam fir volume in stem rot showed an increasing trend with stand age for spaced and control plot data. Significant (0.05 level) regression lines were constructed that described 24% and 36% of observed variation respectively (R^2=0.357 and R^2=0.235).

- The percent of balsam fir volume in butt rot showed no apparent trend with stand age. However, when butt rot levels were examined with ‘years since treatment’ an increasing trend was observed yet, no significant (0.05 level) regression line could be constructed.

Potential Cull Losses:

- Cull estimates were far higher in balsam fir than spruce (3.90% vs. 0.00%) and the percentage of balsam fir culled was consistently higher for the saw log product class (7.8%).

- The percentage of balsam fir volume culled was 1.6 times higher in the spaced plots versus the control plots (4.79% vs. 3.02%). Separating butt and stem rot, percent volume culled to butt rot was 2.1 times higher in spaced stands (4.77% vs. 2.23%) while, percent volume culled to stem rot was 40 times higher in control stands (0.79% vs. 0.02%).

Discussion

The results of the survey showed that the pre-commercial thinning treatment significantly affected the occurrence and amount of butt rot and stem rot in balsam fir stands. The stands on average were 44 years of age (ranged from 31 to 66 years) and 'years since treatment' averaged 23 (ranged from 16 to 29). Butt rot occurred more frequently (47% vs. 25%) and affected more volume (0.93% vs. 0.24%) in the spaced stands while stem rot occurred more frequently (14% vs, 7%) and affected more volume (1.01% vs 0.25%) in the control stands.

The increased incidence and amount of butt rot found in the spaced stands is consistent with recent findings reported by English and Warren in Newfoundland (2001). English and Warren (2001) observed that the volume of butt rot increased 7-26 times and the incidence doubled as a result of treatment. The differences found in this study were not as large, yet the observed increase in the amount and occurrence of butt rot were statistically significant (p-values of 0.003 and 0.010). The larger differences observed in the Newfoundland study may be attributed to the small sample size (only two locations sampled) and/or the younger average age (33 vs. 44 years) of the stands sampled. The magnitude of both the percent trees and percent volume affected in the Newfoundland study (English and Warren, 2001) was much lower than observed in this study (Incidence:19% vs. 47%; Amount: 0.25% vs. 0.93%). This difference could be due to differences in stand/site characteristics and/or sampling procedures. This study supports current theories that suggest pre-commercially thinning balsam fir stands increases the butt rot levels by way of pathogens entering through freshly cut stumps, wounds and damaged roots (as a result of increased root movement).

In this study it was found that stem rot was higher in the control plots as compared to the spaced plots. Stem rot accounted for 81% while butt rot account for 19% of the total rot volume found in the control plots. The higher stem rot levels are similar to Davidson's findings for the Green River watershed in New Brunswick (Davidson, 1951) where he observed that 67% of rot was due to stem rot with the remaining attributed to butt rot. Davidson's study concluded that stem rots were a more important cause of loss in natural balsam fir stands. For the spaced plots in this study the reverse relationship was found. Butt rot accounted for 79% of the total rot volume with stem rot accounting for 21%. This reversal in relative proportions by rot type could not be found documented in previous literature. However, the literature does show that the main infection courts of stem rot are through dead or broken branch stubs (Davidson, 1951; Davidson, 1957; Burns and Honkala, 1990; USDA Forest Service, 2003) although wounds, damaged tops and seams are other likely infection courts. Therefore it can be theorized the physical interaction among crowns in the canopy would be reduced in spaced stands resulting in fewer wounds, decreasing the likelihood of infection. This is supported by the Davidson and Etheridge (1963) finding that stated infections of S. sanguinolentum (i.e. hard rot) are higher in unthinned stands. Aditionally, it is generally accepted that trees in spaced stands are more vigorous therefore wounds and branch stubs grow over more quickly and are less likely to get infected (USDA Forest Service, 2003).

The incidence of butt rot in spaced and control plots showed little indication of a stand age dependant relationship. English and Warren in Newfoundland (1999) in a survey of spaced stands that focused on similar age classes, observed an increasing trend in occurrence of butt rot with stand age. The fact that no relationship was found in this study may be the cumulative effect of site characteristics not accounted for (i.e. site, slope, site history, aspect, etc.). Davidson (1957) reports that butt rots vary in frequency by location and he further suggests that site would have a large influence on the variation. Others have also reported site as having an influence on the occurrence of butt rot (Whitney, 1989, USDA Forest Service, 2003). When the occurrence and amount of butt rot was looked at in terms of 'years since treatment', both showed a positive increasing trend. This result was consistent with findings from the Newfoundland study (English and Warren, 1999).

The most consistent stand age relationship observed was for the incidence and amount of stem rot in the control plots. In spaced plots an increasing trend with age was also observed yet the incidence and amount was much lower than observed in control plots. Additionally, significant (0.05 level) regression lines were constructed. The increasing trend for stem rot and stand age observed in the control plots was consistent with what Davidson (1951) observed in his New Brunswick study. Davidson's study (1951) focused on stands much older yet the increasing trend was evident in the younger age classes he sampled. The regression line constructed (stand age and percent volume in stem rot) fit the data relatively well explaining 36% of the observed variation at the plot level (R^2=0.357).

This survey found that the pre-commercial thinning treatment significantly affected the incidence, amount and type of rot occurring in balsam fir stands. In terms of culled losses there were two offsetting effects occurring. First, culled butt rot was 2.1 times higher as a result of treatment. Secondly, the amount of volume being culled to stem rot is being virtually eliminated through treatment. The overall effect is a 37% increase in cull losses as a result of treatment (4.79% in spaced vs, 3.02% in control). Whitney (1985) in his study of root and butt rots in northern Ontario found losses in the range of 30% for balsam fir (losses included scaled cull, pre-mature windthrow and tree mortality) however, his finding were associated with much older stands (stand ages of ~70 vs. ~40 years). In the same study it was found that losses to windthrow were negligible until stands reached 50 years of age. Any losses associated with increased butt rot levels may be off set by having the opportunity to harvest stands at an earlier age. The

NSDNR (1994) study reported that on average pre-commercial thinning shortened rotation by 13 years. This report has shown that butt rot levels increase as a result of treatment yet further research is needed to better quantify whether or not the increased butt rot levels negatively affect stand yield.

The results concerning butt rot in balsam fir suggest that site may be an important factor behind the large variations observed in its incidence and amount. Appropriate site selection may reduce the amount of losses as a result of treatment and increase the overall benefit obtained from treatment. Through site specific treatment, it could be possible to minimize the incidence and amount of butt rot while still having the benefit of reduced stem rot levels thereby maximizing the return of the spacing treatment.

This survey also reaffirmed that rot is far less of a concern for the spruces and the current practice of favoring spruce over balsam fir in spacing treatments will reduce future losses from rot (stem or butt). The lower levels of rot in spruce has also been confirmed in previous studies by English and Warren in Newfoundland (1999) and Whitney in Ontario (1985).

This study determined that the relative amounts of butt and stem rot change once a stand has been spaced. Further research is needed to better understand associated losses which include cull, pre-mature windthrow, mortality and growth reductions. As well, further research is needed to better understand the influence of environmental factors (site, aspect, slope, site history, etc.). Also, there needs to be a better understanding of the pathogens themselves and how they interact with the environment and stand characteristics. The high variation in butt rot among locations visited in this study are likely the result of pathogen and site characteristics that were not accounted for.

Management Recommendations

The findings of this survey suggest several general recommendations to consider when pre-commercially thinning balsam fir dominated softwood stands in Nova Scotia.

Selecting Balsam Fir Stands to Space
When selecting areas to pre-commercially thin certain stand characteristic should be favored:

- The more productive sites should be targeted in an attempt to minimize the length of rotation and maintain a vigorously growing stand which is a deterrent to pathogen infection.
- Stands having a spruce component should be targeted to facilitate shifts in species composition to the more rot resistant spruce through treatment.
- Targeting stands with small diameters (i.e. treating early) may reduce chances of butt rot infection from freshly cut stumps (Morrison and Johnson, 1999; NRC, 2003).

Implementing the Spacing Treatment
During the implementation of the spacing treatment there are several points to consider:

- In the spacing operation spruce should be favored wherever possible due to its higher resistence to rot.
- Care should be taken to minimize damage to lower stems of crop trees as such wounds become infection courts for pathogens.

Timing of Final Harvest
When scheduling treated stands for final harvest the following should be considered:

- Stands should be harvested as soon as they become economically mature. The MAI-maximizing rotation age could decrease once rot and cull levels are taken into consideration. Further research is need to better quantify the impacts.
- When scheduling stands for harvest, based on expected yield by product, it is important to keep in mind that the saw logs consistently showed the highest incidence and amount of rot.

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Appendix I. Plot Level Compilation Statistics by Location (Stand Statistics)

		Stand Summary Statistics - Compiled with 'Product Cruise 2.0' (NSDNR, 1996)										
Location	Treatment	Stump Age (yrs)	Breast Height Age (yrs)	Years Since Treatment (yrs)	Merch. Height (m)	Total Diameter (cm)	Merch. Diameter (cm)	Total Density (stems/ha)	Merch. Density (stems/ha)	Total Basal Area (m^2/ha)	Merch. Basal Area (m^2/ha)	Species Composition[2] (%BA[1])
Blue Mountain	Spaced	40	35	29	10.8	11.3	13.1	4,173	2,836	41.8	38.1293	BF96S4
	Unspaced	40	34	--	9.9	5.5	11.4	24,268	2,357	58.2	23.9022	BF100S0
Cross Brook Roac	Spaced	47	40	27	12.8	14.5	15.4	2,582	2,231	42.5	41.6412	BF100S0
	Unspaced	50	44	--	11.8	7.6	13.2	12,419	2,164	56.0	29.8352	BF86S3O12
Crowdis Mountain	Spaced	42	38	24	10.6	16.4	17.2	1,753	1,498	36.9	34.7377	BF99S0
	Unspaced	48	42	--	11.5	11.7	15.2	4,873	2,197	52.6	39.7702	BF100S0
Dunmore	Spaced	31	27	25	13.4	14.8	20.3	2,518	1,243	43.2	40.0704	BF100S0
	Unspaced	33	28	--	12.1	9.0	13.1	9,204	3,185	58.8	43.242	BF99S1
Eastville Road	Spaced	41	36	16	12.5	14.6	15.9	1,915	1,500	31.9	29.6751	BF51S41O8
	Unspaced	39	33	--	12.5	7.5	13.8	12,102	2,420	52.9	36.3485	BF72S28
Haert Lake	Spaced	45	37	23	12.6	16.1	18.0	2,196	1,655	44.8	42.2216	BF79S19O2
	Unspaced	45	37	--	11.0	10.8	14.9	6,526	2,768	59.4	48.3746	BF48S52
Kemptown	Spaced	38	32	18	12.4	13.2	16.1	2,799	1,749	38.2	35.7883	BF94S6
	Unspaced	40	34	--	11.5	7.8	12.8	9,236	2,421	44.3	30.9858	BF97S0
Lynch River	Spaced	34	28	24	13.4	15.4	18.1	2,358	1,656	43.7	42.4816	BF96S4
	Unspaced	40	34	--	11.6	10.0	15.7	6,815	2,132	53.8	41.2209	BF84S16
Macullumst	Spaced	51	44	24	12.9	16.9	17.4	1,820	1,692	40.9	40.3306	BF63S37
	Unspaced	54	48	--	12.8	10.9	15.4	6,851	2,870	63.6	53.4672	BF71S26O3
Marianna	Spaced	36	32	29	7.7	12.3	15.8	3,250	1,594	38.4	31.2359	BF99S0
	Unspaced	42	38	--	8.3	7.9	12.4	9,904	2,325	48.9	28.1944	BF98S0
Otter Brook	Spaced	53	45	29	13.2	15.5	16.6	1,658	1,371	31.3	29.6351	BF83S17
	Unspaced	62	50	--	11.9	7.4	13.3	7,165	1,400	31.1	19.4698	BF89S7O4
Pleasant Valley	Spaced	38	33	18	11.5	11.6	13.3	4,460	2,963	47.4	41.391	BF85S11O4
	Unspaced	35	30	--	12.3	7.1	13.1	14,205	2,485	56.7	33.6872	BF90S9O1
Riversdale	Spaced	40	34	18	12.5	14.5	15.5	2,067	1,748	33.9	33.0867	BF78S22
	Unspaced	43	36	--	13.2	8.0	13.1	11,310	2,997	57.1	40.1204	BF89S9O2
Round Lake	Spaced	64	56	22	13.4	18.7	19.7	1,430	1,272	39.5	38.8598	BF66S34
	Unspaced	66	57	--	15.0	13.2	16.6	4,683	2,644	64.0	57.1891	BF56S44
South Range	Spaced	37	32	25	13.3	14.4	17.5	2,644	1,594	43.3	38.1895	BF96S2O2
	Unspaced	40	35	--	12.9	11.4	13.3	4,934	2,164	50.0	30.2854	BF76S2O23
Trafalgar	Spaced	46	39	18	10.6	11.1	13.9	3,819	2,196	36.9	33.267	BF36S64
	Unspaced	45	38	--	11.0	6.5	12.6	15,414	2,421	51.0	29.9653	BF63S35O1
Warehouse Road	Spaced	36	30	25	8.4	10.9	13.0	3,282	2,103	30.3	27.9843	BF100S0
	Unspaced	32	25	--	9.0	6.1	12.1	13,566	2,197	39.0	25.0928	BF100S0
Total	**Spaced**	**42**	**36**	**--**	**11.9**	**14.2**	**16.3**	**2,631**	**1,818**	**39.1**	**36.4**	**BF84-S15-O1**
	Unspaced	**44**	**38**	**23**	**11.7**	**8.7**	**13.6**	**10,204**	**2,420**	**52.8**	**36.0**	**BF83-S14-O3**

Appendix II. Plot Level Compilation Statistics by Location (Rot Statistics)

		Rot Summary Statistics									
		% Trees Affected by Species		% Volume Affected by Species		% Balsam Fir Trees Affected by Product			% Balsam Fir Vol. Affected by Product		
Location	**Treatment**	**Balsam Fir**	**Spruce**	**Balsam Fir**	**Spruce**	**Pulp Wood**	**Stud Wood**	**Saw Log**	**Pulp Wood**	**Stud Wood**	**Saw Log**
Blue Mountain	Spaced	59.3	33.3	1.102	0.143	66.7	33.3	--	1.636	0.240	--
	Unspaced	34.7	--	0.355	--	33.3	66.7	--	0.277	0.933	--
Cross Brook Road	Spaced	67.6	--	1.836	--	66.7	66.7	100.0	0.236	1.994	8.207
	Unspaced	5.4	--	0.677	--	0.0	66.7	--	0.000	3.809	--
Crowdis Mountain	Spaced	24.6	--	0.292	--	33.3	0.0	66.7	1.216	0.000	0.158
	Unspaced	46.9	--	0.643	--	33.3	66.7	100.0	0.553	0.034	11.286
Dunmore	Spaced	65.8	--	0.269	--	0.0	100.0	33.3	0.000	0.596	0.007
	Unspaced	44.3	0.0	0.374	0.000	33.3	100.0	100.0	0.441	0.237	0.108
Eastville Road	Spaced	4.6	45.4	0.003	3.503	0.0	0.0	100.0	0.000	0.000	0.036
	Unspaced	0.0	0.0	0.000	0.000	0.0	0.0	--	0.000	0.000	--
Haert Lake	Spaced	49.1	0.0	1.308	0.000	33.3	66.7	33.3	2.736	0.843	1.478
	Unspaced	8.7	0.0	0.022	0.000	0.0	33.3	100.0	0.000	0.008	0.240
Kemptown	Spaced	25.0	66.7	0.176	2.981	0.0	33.3	100.0	0.000	0.091	0.604
	Unspaced	40.7	--	0.333	--	33.3	100.0	100.0	0.064	1.694	0.013
Lynch River	Spaced	85.7	0.0	1.720	0.000	50.0	100.0	100.0	0.004	2.673	1.033
	Unspaced	80.6	0.0	1.417	0.000	66.7	100.0	100.0	2.812	0.318	2.246
Macullumst	Spaced	28.6	16.7	1.660	1.510	0.0	33.3	66.7	0.000	1.959	1.636
	Unspaced	24.7	15.4	0.101	0.229	0.0	66.7	66.7	0.000	0.125	0.273
Marianna	Spaced	36.1	--	1.756	--	33.3	33.3	66.7	1.990	1.101	3.127
	Unspaced	68.5	--	1.027	--	66.7	100.0	--	0.951	1.570	--
Otter Brook	Spaced	68.3	0.0	0.403	0.000	66.7	66.7	100.0	0.378	0.033	2.048
	Unspaced	38.6	0.0	5.350	0.000	33.3	66.7	--	6.596	2.365	--
Pleasant Valley	Spaced	66.7	0.0	3.786	0.000	66.7	66.7	--	4.993	0.178	--
	Unspaced	11.6	0.0	0.006	0.000	0.0	66.7	--	0.000	0.018	--
Riversdale	Spaced	49.6	0.0	1.402	0.000	66.7	33.3	0.0	4.126	0.043	0.000
	Unspaced	94.5	0.0	2.606	0.000	100.0	66.7	100.0	2.671	2.608	1.731
Round Lake	Spaced	58.3	0.0	0.723	0.000	33.3	66.7	66.7	0.319	0.947	0.555
	Unspaced	44.4	0.0	7.798	0.000	33.3	66.7	--	7.846	7.756	--
South Range	Spaced	73.2	0.0	1.833	0.000	66.7	66.7	100.0	0.116	1.557	2.788
	Unspaced	30.4	0.0	0.453	0.000	0.0	100.0	50.0	0.000	0.041	2.473
Trafalgar	Spaced	62.8	0.0	1.064	0.000	66.7	33.3	--	1.297	0.325	--
	Unspaced	0.0	0.0	0.000	0.000	0.0	0.0	--	0.000	0.000	--
Warehouse Road	Spaced	62.6	--	0.729	--	66.7	33.3	--	0.943	0.093	--
	Unspaced	37.2	--	0.017	--	33.3	66.7	--	0.011	0.039	--
Total	**Spaced**	**52.2**	**13.5**	**1.180**	**0.678**	**42.2**	**49.0**	**71.8**	**1.176**	**0.745**	**1.668**
	Unspaced	**36.0**	**1.4**	**1.246**	**0.021**	**27.5**	**66.7**	**89.6**	**1.307**	**1.268**	**2.296**

Appendix II (con't). Plot Level Compilation Statistics by Location (Balsam Fir Butt and Stem Rot Statistics)

		Balsam Fir Butt Rot and Stem Rot Summary Statistics								
		% Trees Affected by Rot Type			% Volume Affected by Rot Type			% Volume Culled by Rot Type		
Location	**Treatment**	**Butt Rot**	**Stem Rot**	**Total Rot**	**Butt Rot**	**Stem Rot**	**Total Rot**	**Butt Rot**	**Stem Rot**	**Total Rot**
Blue Mountain	Spaced	59.3	0.0	59.3	1.102	0.000	1.102	3.228	0.000	3.228
	Unspaced	0.0	34.7	34.7	0.000	0.355	0.355	0.000	0.000	0.000
Cross Brook Road	Spaced	67.6	0.0	67.6	1.836	0.000	1.836	7.710	0.000	7.710
	Unspaced	5.4	2.7	5.4	0.641	0.036	0.677	1.246	0.000	1.246
Crowdis Mountain	Spaced	18.8	5.8	24.6	0.253	0.039	0.292	3.256	0.261	3.517
	Unspaced	45.4	1.5	46.9	0.253	0.390	0.643	3.247	0.000	3.247
Dunmore	Spaced	65.8	0.0	65.8	0.269	0.000	0.269	3.927	0.000	3.927
	Unspaced	16.5	27.8	44.3	0.069	0.305	0.374	1.447	0.000	1.447
Eastville Road	Spaced	4.6	0.0	4.6	0.003	0.000	0.003	0.593	0.000	0.593
	Unspaced	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000
Haert Lake	Spaced	49.1	0.0	49.1	1.308	0.000	1.308	8.297	0.000	8.297
	Unspaced	8.7	0.0	8.7	0.022	0.000	0.022	1.102	0.000	1.102
Kemptown	Spaced	25.0	0.0	25.0	0.176	0.000	0.176	0.145	0.000	0.145
	Unspaced	40.7	3.2	40.7	0.063	0.271	0.333	0.719	0.000	0.719
Lynch River	Spaced	85.7	0.0	85.7	1.720	0.000	1.720	12.799	0.000	12.799
	Unspaced	61.3	19.4	80.6	0.554	0.863	1.417	11.082	0.000	11.082
Macullumst	Spaced	20.9	7.6	28.6	1.340	0.320	1.660	0.000	0.000	0.000
	Unspaced	22.6	2.2	24.7	0.054	0.047	0.101	1.079	0.000	1.079
Marianna	Spaced	36.1	0.0	36.1	1.756	0.000	1.756	13.318	0.000	13.318
	Unspaced	37.1	64.8	68.5	0.189	0.838	1.027	2.146	0.000	2.146
Otter Brook	Spaced	68.3	0.0	68.3	0.403	0.000	0.403	7.212	0.000	7.212
	Unspaced	10.5	33.3	38.6	0.309	5.041	5.350	2.601	6.057	8.659
Pleasant Valley	Spaced	37.9	28.8	66.7	1.918	1.868	3.786	1.244	0.000	1.244
	Unspaced	11.6	0.0	11.6	0.006	0.000	0.006	0.728	0.000	0.728
Riversdale	Spaced	31.8	17.8	49.6	0.026	1.376	1.402	0.796	0.000	0.796
	Unspaced	94.5	5.5	94.5	1.880	0.726	2.606	8.311	0.000	8.311
Round Lake	Spaced	32.1	51.2	58.3	0.112	0.611	0.723	3.033	0.000	3.033
	Unspaced	11.1	44.4	44.4	0.012	7.786	7.798	0.559	4.050	4.608
South Range	Spaced	73.2	0.0	73.2	1.833	0.000	1.833	9.733	0.000	9.733
	Unspaced	30.4	3.0	30.4	0.017	0.436	0.453	2.467	3.406	5.872
Trafalgar	Spaced	62.8	0.0	62.8	1.064	0.000	1.064	1.700	0.000	1.700
	Unspaced	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000
Warehouse Road	Spaced	62.6	0.0	62.6	0.729	0.000	0.729	4.107	0.000	4.107
	Unspaced	37.2	0.0	37.2	0.017	0.000	0.017	1.130	0.000	1.130
Total	**Spaced**	**47.2**	**6.5**	**52.2**	**0.932**	**0.248**	**1.180**	**4.770**	**0.015**	**4.786**
	Unspaced	**25.5**	**14.3**	**36.0**	**0.240**	**1.005**	**1.246**	**2.227**	**0.795**	**3.022**

Appendix III - Statistical Analysis

Affect of Treatment on Mean Rot Levels (Paired-Sample T Test)
The statistical analysis involved testing the significance of the mean treatment differences (μ_d; spaced - control) of four variables from the population of balsam fir trees sampled. The variables tested were:

1. Percent occurrence of butt rot (POB)
2. Percent volume in butt rot (PVB)
3. Percent occurrence of stem rot (POS)
4. Percent volume in stem rot (PVS).

The data is presented in Tables A-1 and A-2. The statical analysis tested four null hypotheses (H_o) stated as; $\mu_{d\text{-}POB} = 0$, $\mu_{d\text{-}PVB} = 0$, $\mu_{d\text{-}POS} = 0$ and $\mu_{d\text{-}PVS} = 0$ with their associated alternative hypotheses (H_a) stated as; $\mu_{d\text{-}POB} <> 0$, $\mu_{d\text{-}PVB} <> 0$, $\mu_{d\text{-}POS} <> 0$ and $\mu_{d\text{-}PVS} <> 0$. Differences indicated spacing increased the occurrence and amount of butt rot and decreased the occurrence and amount of stem rot.

Table A-1. Occurrence and amount of butt rot by treatment and location.

	Percent Occurrence of Decay (%)			Percent Volume in Decay (%)		
Location	**Control**	**Spaced**	**Diff.**	**Control**	**Spaced**	**Diff.**
Blue Mountain	0.00	59.31	59.31	0.000	1.102	1.102
Cross Brook Road	5.43	67.63	62.20	0.641	1.836	1.195
Crowdis Mountain	45.41	18.83	26.59	0.253	0.253	0.000
Dunmore	16.48	65.83	49.35	0.069	0.269	0.200
Eastville Road	0.00	4.56	4.56	0.000	0.003	0.003
Heart Lake	8.75	49.11	40.36	0.022	1.308	1.286
Kemptown	40.72	24.97	-15.75	0.063	0.176	0.113
Lynch River	61.26	85.74	24.48	0.554	1.720	1.166
Macullumst	22.57	20.95	-1.62	0.054	1.340	1.286
Marianna	37.05	36.06	-0.99	0.189	1.756	1.567
Otter Brook	10.49	68.34	57.85	0.309	0.403	0.094
Pleasant Valley	11.61	37.87	26.25	0.006	1.918	1.912
Riversdale	94.51	31.78	-62.73	1.88	0.026	-1.854
Round Lake	11.10	32.13	21.03	0.012	0.112	0.099
South Range	30.37	73.19	42.82	0.017	1.833	1.816
Trafalgar	0.00	62.80	62.80	0.000	1.064	1.064
Warehouse Road.	37.20	62.62	25.42	0.017	0.729	0.712
Mean	**25.47**	**47.16**	**21.69**	**0.240**	**0.932**	**0.692**
Standard Deviation	**24.63**	**22.34**	**34.19**	**0.452**	**0.703**	**0.899**
Standard Error	**6.16**	**5.59**	**8.55**	**0.113**	**0.176**	**0.225**

Table A-2. Occurrence and amount of stem rot by treatment and location.

	Percent Occurrence of Decay (%)			Percentage Volume in Decay (%)		
Location	**Control**	**Spaced**	**Diff.**	**Control**	**Spaced**	**Diff.**
Blue Mountain	34.69	0.00	-34.69	0.355	0.000	-0.355
Cross Brook Road	2.71	0.00	-2.71	0.036	0.000	-0.036
Crowdis Mountain	1.46	5.80	4.34	0.390	0.039	-0.352
Dunmore	27.84	0.00	-27.84	0.305	0.000	-0.305
Eastville Road	0.00	0.00	0.00	0.000	0.000	0.000
Heart Lake	0.00	0.00	0.00	0.000	0.000	0.000
Kemptown	3.23	0.00	-3.23	0.271	0.000	-0.271
Lynch River	19.37	0.00	-19.37	0.863	0.000	-0.863
Macullumst	2.16	7.64	5.48	0.047	0.320	0.273
Marianna	64.81	0.00	-64.81	0.838	0.000	-0.838
Otter Brook	33.33	0.00	-33.33	5.041	0.000	-5.041
Pleasant Valley	0.00	28.80	28.80	0.000	1.868	1.868
Riversdale	5.49	17.81	12.32	0.726	1.376	0.650
Round Lake	44.44	51.22	6.78	7.786	0.611	-7.175
South Range	2.96	0.00	-2.96	0.436	0.000	-0.436
Trafalgar	0.00	0.00	0.00	0.000	0.000	0.000
Warehouse Road	0.00	0.00	0.00	0.000	0.000	0.000
Mean	14.26	6.55	-7.72	1.005	0.248	-0.758
Standard Deviation	19.16	13.58	21.36	2.050	0.532	2.075
Standard Error	4.79	3.39	5.34	0.513	0.133	0.519

Table A-3 presents the results of the analysis. The significance values for change in the occurrence and amount of butt rot were less than the 0.05 critical value. This is evidence to reject two ($H_{o\text{-}POB}$, $H_{o\text{-}PVB}$) of the four null hypothesis and accept the alternatives ($H_{a\text{-}POB}$, $H_{a\text{-}PVB}$).

Table A-3. Summary statistics for the paired sample t-test comparing rot levels between control and spaced plots.

Category	t	df	p-value
Butt Rot Analysis			
Percent Occurrence of Butt Rot	2.92	16	0.010
Percent Volume in Butt Rot	3.45	16	0.003
Stem Rot Analysis			
Percent Occurrence of Stem Rot	-1.71	16	0.106
Percent Volume in Stem Rot	-2.00	16	0.063

Regression Analysis with Amount of Rot

Simple linear regression lines were constructed to test whether significant relationships existed between rot levels and stand age or 'years since treatment'. The following sections summarize regression results for butt rot and stem rot. The regression analysis utilized data from the 6 locations (3 control plots and 6 spaced plots) previously removed for data pairing issues in the comparative statistical analysis.

Butt Rot

The regression lines showing the relationship between percent volume in butt rot and stand age for control and spaced plots are presented in Figures A-1 and A-2 respectively. Figure A-3 presents the regression line between the percent volume in butt rot and 'years since treatment' for spaced plots. None of the three regressions were significant at the 0.05 level (Table A-4).

Table A-4. Butt rot regression statistics.

	Regression Statistic			
Regression Analysis	**ANOVA F (Sig.)**	**Correlation Coefficient (R)**	**Coefficient of Variation (R^2)**	**Standard Error of the Estimate (Syx)**
Butt Rot and Stand Age - Control	3.5 (.09)	0.366	0.149	2.172
Butt Rot and Stand Age - Spaced	0.1 (.93)	-0.017	0.000	0.899
Butt Rot and 'Years Since Treatment' - Spaced	0.1 (.72)	0.078	0.006	0.896

Stem Rot

The regression lines showing the relationship between percent volume in stem rot and stand age for control and spaced plots are presented in Figures A-4 and A-5 respectively. Figure A-6 presents the regression line between the percent volume in stem rot and 'years since treatment' for spaced plots. Two of the three regressions were significant at the 0.05 level. The significant regression line constructed for control plots described the observed variation relatively well. The stem rot regression with stand age for the spaced plot data yielded weaker results (R^2=0.235 vs. R^2=0.357).

Table A-5. Stem rot regression statistics.

	Regression Statistic			
Regression Analysis	**ANOVA F (Sig.)**	**Correlation Coefficient (R)**	**Coefficient of Variation (R^2)**	**Standard Error of the Estimate (Syx)**
Stem Rot and Stand Age - Control	10.0 (.005)	0.597	0.357	1.636
Stem Rot and Stand Age - Spaced	6.4 (.019)	0.484	0.235	1.527
Stem Rot and 'Years Since Treatment' - Spaced	0.1 (.844)	0.104	0.002	1.746

Figure A-1. Regression line for percent volume in butt rot and stand age (breast height) for control plots.

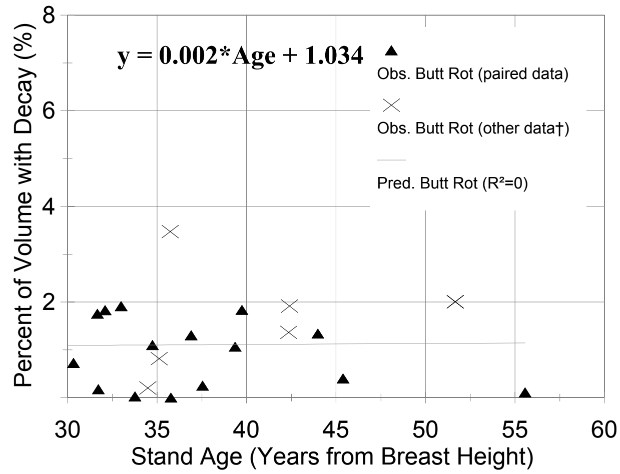

Figure A-2. Regression line for percent volume in butt rot and stand age (breast height) for spaced plots.

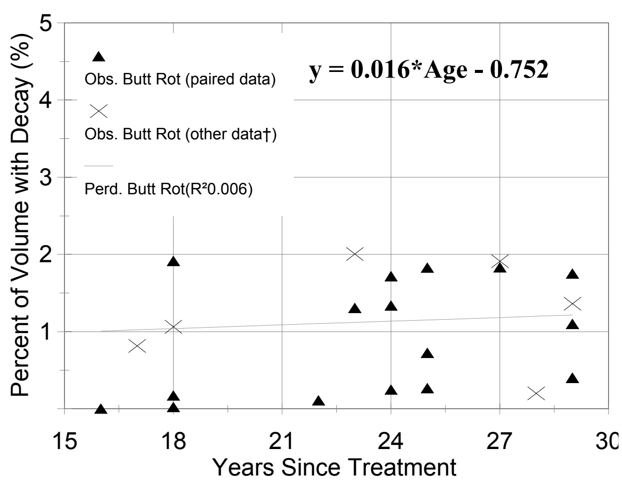

Figure A-3. Regression line for percent volume in butt rot and 'years since treatment'.

† Represents data previously removed for data pairing issues in the comparative statistical analysis.

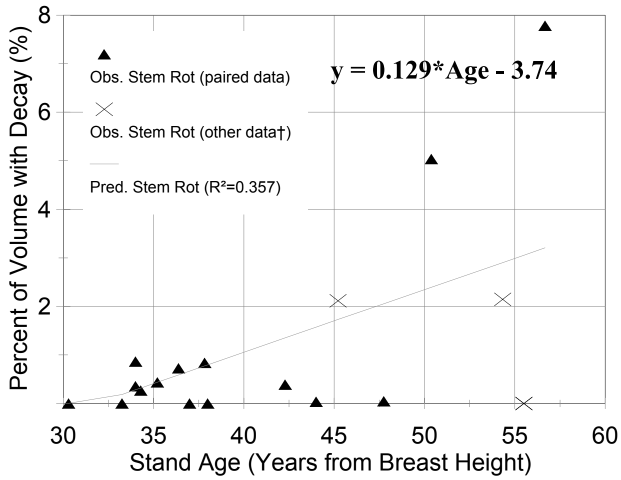

Figure A-4. Regression line for percent volume in stem rot and stand age (breast height) for control plots.

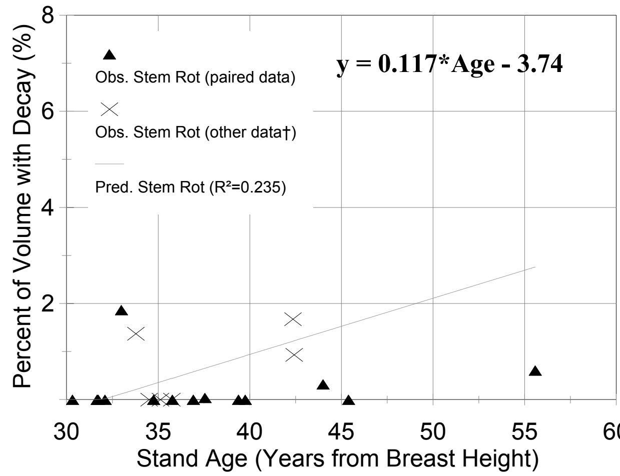

Figure A-5. Regression line for percent volume in stem rot and stand age (breast height) for spaced plots.

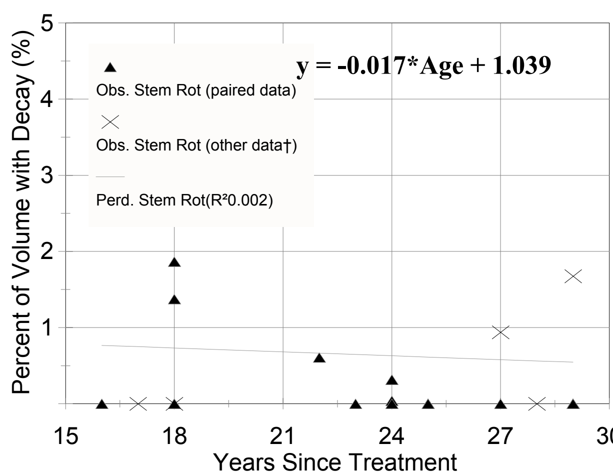

Figure A-6. Regression line for percent volume in stem rot and 'years since treatment'.

† Represents data previously removed for data pairing issues in the comparative statistical analysis.