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Managing for Intimate Species
Mixtures in BC’s Boreal Forest

Y051304

University of Northern BC
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Title: Managing for Intimate Species Mixtures in BC’s Boreal Forest

FSP Project Number: Y051304

Abstract:
Mixedwood stands are composed mainly of aspen (*Populus tremuloides* [Michx.]) and white spruce (*Picea glauca* [Moench] Voss) and comprise the top two harvested species by volume in the Peace Forest District (PFD), however, because of under-utilization of this resource, the timber supply area (TSA) is at risk of losing up to 10% of the mixedwood or hardwood contribution to the annual allowable cut (AAC) (1). Current British Columbia (BC) policy guidelines discourage adaptive management when it comes to managing mixedwood stands (2). Research suggests however, that complex species mixtures have greater productive potential than single species stands (3, 4, 5).

The focus of this long-term study is the complex interactions between intimate mixtures of conifer and deciduous species that make up a highly significant portion of the northern and central interior of BC. The trial is comprised of two sites, the first, Woodlot 1217 and the second, the Rice Property, which now forms part of Tree Farm License 48. The approach has been to reduce aspen density in a linear fashion and monitor responses of residual aspen, underplanted white spruce (TFL 48), released white spruce (WL 1217), understory vegetation, and soil nitrogen (N) mineralization. This includes changes in plant communities, soil N dynamics, growth and yield of valuable timber resources, and changes in productive potential.

Although the response has been delayed, by 2004, aspen are beginning to show a response to the thinning treatments. Differences in spruce growth between treatments are not yet evident. Changes in understory vegetation were not found to vary between treatment and year. There are changes in soil mineralization and soil moisture between spring and fall and from 2001 to 2004. Growth and yield projections and subsequent economic analyses require the development or modification of an existing model that will reflect the growth of the underplanted spruce.
**Introduction:**

Mixedwood stands are composed mainly of aspen (*Populus tremuloides* [Michx.]) and white spruce (*Picea glauca* [Moench] Voss) and comprise the top two harvested species by volume in the Peace Forest District (PFD), however, because of under-utilization of this resource, the timber supply area (TSA) is at risk of losing up to 10% of the mixedwood or hardwood contribution to the annual allowable cut (AAC) (1). Current British Columbia (BC) policy guidelines discourage adaptive management when it comes to managing mixedwood stands (2). Research suggests however, that complex species mixtures have greater productive potential than single species stands (3, 4, 5).

Forest managers in boreal environments are interested in i) understanding the ecological benefits of mixedwood and broadleaf management, ii) reducing stand management expenditures, iii) strategies and practices which maintain or enhance site productivity and harvest levels, iv) mixedwood/broadleaf management as a vehicle to obtain eco-certification, and v) how to manage mixedwood stands for predictable and sustainable timber production.

The focus of this study is the complex interactions between intimate mixtures of conifer and deciduous species that make up a highly significant portion of the northern and central interior of BC. In order to achieve sustainable forest management (SFM), policy decisions must be based on sound ecological knowledge that is collected at various spatial and temporal scales. In order to assess the success of policy initiatives, a comparative framework is required. Because this study builds on an established long-term trial, the results are easily applied to monitoring programs, growth and yield analysis, and future provincial policy decisions.

The long term supply of timber is a key concern of sustainable forest management. However, the current regulatory framework presents an obstacle to achieving this. Existing Free-to-Grow guidelines in BC (2) do not provide quantitative targets for mixed broadleaf – conifer stands. Current research suggests crop trees (conifers) must be free of competition from deciduous species (9). Additionally, complex stands may contribute to biodiversity and First Nations’ objectives, and meet certification requirements. Timber harvesting objectives may be better met by improving growth and yield predictions based on long term data collection, and reducing misplaced spending on silvicultural activities that in fact do not improve productivity.

Current related research in the boreal forest is examining trends in conifer growth with regards to varying light levels (9, 10, 11, 12, 13, 14), mixedwood stand dynamics (15, 16, 17) and productivity of mixedwood stands (4, 18, 19, 20, 21). This project contributes to the study of spruce growth responses to varying densities of aspen which is directly applicable to operational management decisions. Historically mixedwood stands have been discouraged by using vegetation control techniques (11). However, when permitted to develop, they tend to be managed poorly due to a poor understanding of their dynamic processes and a lack of predictive models. By focusing on managing for intimate species mixtures through density management benefits of natural stand dynamics will be realized.
Methods:

Site Description
The trial is comprised of two sites, one being Woodlot (WL) 1217 that is located in the BWBSmw1 biogeoclimatic subzone (6), 100 kilometers northwest of Fort St. John. The stand, of fire origin, is a 45 year-old mixedwood stand dominated by even aged aspen in the overstory and multi-aged white spruce in the understory (7). The trial was established in 1998 (8). A second site is the Rice Property that now forms part of Tree Farm License (TFL) 48 and is located within the Dawson Creek TSA in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone. The site was once cleared for agriculture purposes, but now supports young aspen stands with underplanted white spruce, and older aspen stands experiencing successful natural ingress of white spruce. The trial was established in 2000.

Experimental Design
A. Rice Properties (TFL 48)
1. Young Aspen Stand
The experimental design for the young aspen site is a randomized block design replicated three times with each plot measuring 70x70 m as illustrated in Figure 1. The size of these plots allows for unbiased predictions of alternative treatment responses for reliable growth model behavior (24). In August 2000, the aspen were thinned by girdling and snapping to nominal treatment densities of 600 stems per hectare (sph), 1200 sph, 2500 sph, 5000 sph and maximum sph (no density reduction in the control, >5000 sph) within specific treatment plots. Within each of the 15 treatment plots, five 3.99 m radius permanent sample plots were located systematically in a 30x30 m area, leaving a 20 m or one tree length buffer zone around each plot. Pre-treatment aspen densities and basal area were assessed early June-July 2000. White spruce seedlings were planted at a density of 1600-1800 sph in all treatment areas in August 2000.

Height measurements were recorded for underplanted spruce in the fall of 2000, 2001 and 2002 as well as the spring of 2004 (fall 2003 height). Ground line diameter measurements were recorded in the fall of 2000, 2001 and 2002. Health codes were recorded in the spring and fall of 2001 and 2002, as well as in the spring of 2003 and 2004.

Diameters (dbh) were recorded for overstory aspen, cottonwood and willow in 2000, 2001, 2002 and the spring of 2004.

Vegetation plots, established in 2001, are 1x1 m in size and are all located 5 m at 45 degrees from each of the above described plot centers. Vegetation surveys (recording species and percent cover) were carried out at these plots in the fall of 2001, 2002, 2003 and 2004.

Nitrogen mineralization was assessed by using soil samples (collected biannually in the spring and fall of 2001, 2002, 2003 and 2004) which were excavated from mineral soil below the LFH layer. The soil excavations were sieved (0.5 cm) and thoroughly
homogenized by hand. All coarse woody debris and organic material was removed in preparation for chemical extraction.

For extractions, 50g of soil are treated with 100 ml of 1 M KCL to determine the extractable NH$_4^+$-N and NO$_3^-$-N. Mixtures must be shaken for one hour before refrigeration overnight at 4°C, allowing for solution settling. The following day samples are decanted and filtered through Whatman No. 40 filter paper. Sample extractions must be carried out as soon as possible or frozen at -40°C until processing. KCL standards are then prepared for analysis of purity and frozen at -40°C before analysis at the BC Ministry of Forests Analytical Laboratory.

Soil moisture (% moisture) readings were taken using a time domain refractometer (TDR) to determine if the aspen density treatments have an impact on soil moisture. Single diode, rugged housing probes (one, 30 cm segment) were used. Soil moisture readings were collected monthly throughout the growing season (May through October) in 2001, 2002, 2003 and 2004.

2. Oldgrowth Site
The experimental design for the oldgrowth site is similar to that established at the young aspen site. Four 30x30 m plots, as illustrated in Figure 1, were established in October 2000. Within each of these plots, five permanent sample plots were located (5.64 m radius - aspen and 3.99 m radius - underplanted spruce). The basal area and densities of the overstory aspen/spruce stand were determined in October 2000. White spruce seedlings were planted at a density of 1600-1800 sph throughout the oldgrowth area in August 2000.

Height measurements were recorded for underplanted spruce in the fall of 2000 and 2001, and the spring of 2004. Ground line diameter measurements were recorded in the fall of 2000 and 2001. Health codes were recorded in the spring and fall of 2001 as well as the spring of 2002, 2003 and 2004.

Diameter (dbh) measurements were recorded in the fall of 2000 for overstory aspen, cottonwood and spruce trees.

3. Clearcut Area
The clearcut area was planted with white spruce seedlings to a density of 1600-1800 sph in the summer of 2000. Seven plots were located in the clearcut area in November 2000. These plots were expanded to 20x20 m plots with a 15 m buffer in June 2001.

Height measurements were recorded in the spring and fall of 2001 as well as in the spring of 2004. Ground line diameter measurements were recorded in the spring and fall of 2001. Health codes were recorded in the spring and fall of 2001 as well as the spring of 2002, 2003 and 2004.
B. Woodlot 1217
The woodlot 1217 study site, located in northeast British Columbia, averaged of 3900 aspen stems per hectare (sph) with a site index (base age 50) of 20m and 1050 sph of spruce in the understory prior to treatment. Soils were classified as orthic gray luvisols characterized by silty clay loam of glacial lacustrine origin (29). Herbaceous vegetation was dominated by bluejoint grass (Calamagrostis canadensis (Michx.)), fireweed (Epilobium angustifolium L.), bunchberry (Cornus canadensis L.), creamy peavine (Lathyrus orchroleucuc Hook.), prickly rose (Rosa acicularus Lindl.), highbush cranberry (Viburnum edule [Michx.] Raf.), and lingonberry (Vaccinium vitis idaea L.).

Reconnaissance of the site was conducted in the summer of 1998. Clones could be distinguished off photos using shading and height attributes under a steroscope. Typing revealed four clones in the research area. The quality of clones is medium to good based on a site index of 20m for the stand. Selection criteria required the treatment sites (plots) be homogenous in understory and overstory with sufficient area available to establish ten
70m X 70m (0.49 ha) treatment plots, with a 30m X 30m measurement plot located in the geometric center of the plot. Each plot was located to reduce edge effect and to minimize stocking variability among plots (7).

Basal area was used as the biological element for meeting thinning percentages. We determined basal area by establishing five 3.99 meter plots in each of the treatment sites and summing the basal area (at breast height) for all trees in the plot. Basal areas for trees were calculated using; \( \frac{D^2}{2} \times \pi \), where \( D \) = diameter and \( A \) = basal area in square cm. Sites were then randomly selected for percent basal area retention. Using geometric spacing, each treatment site was reduced to its target basal area retention by gridling or physically cutting aspen on a stem per hectare target.

Thinning was completed in August 1998 following British Columbia Ministry of Forests Brushing Standards Agreement (29). The standards required the operation be conducted using the following conventions. Aspen stems < 10 centimeters (cm) diameter at breast height (dbh = 1.3 m) are physically thinned (cut at root collar). Aspen stems > 10 cm at 1.3 m were gridled at breast height. Gridling was performed using a hand tool that produced a 2.5cm wide cut, severing the cambium layer of the tree. Treatments ranged from 0% to 100% of the natural stand condition in increments of about 10% for a total of 10 installations (7).

In 2004 we used a series of 3.99m plots to attain a representative sample of aspen stems. We targeted a minimum number (12) stems from each plot. Thinning the plots reduced the number of stems in each plot, and this required us to increase the number of random 3.99m plot in order to attain sufficient number of aspen stems in each plot. An increment bore was used to extract one core from each aspen in our 3.99m plots, with an attempt to bore the pith of the tree each time. Diameter growth was measured for pre-treatment years 1993-1997 and for post-treatment years 1998-2002 using WinDENDRO software version 6.5 (Blain Quebec, Canada). We used a Hewett Packard ScanJet 4C/T scanner to measure width (mm) of tree rings.

Growth rings for aspen cores can be difficult to determine. A two times magnifying glass was used to determine ring location. Once the ring was identified it was marked with a fine point pencil. Prior to scanning all cores required sanding to remove rough edges and highlight growth rings for ease of scanning. All aspen stems were scanned from pith to the beginning of the cambium layer. Growth rates were measured from the middle of one mark to the middle of the next mark and onward to the beginning edge of the cambium layer.
Results:

A. Rice Properties (TFL 48)

Aspen Measurements – Young Aspen Stand

Young aspen growth on the Rice property trial shows a significant increase in diameter growth rates among treatment sites $F(4,1261) = 157862.438$, $p = 0.000$. However, there is no significant difference within treatments (data not shown). Table 1 shows the diameters measured in years 2000 through to 2002. The high-density plots had the smallest trees at the beginning and these trees also responded the least, and also the lowest SEM indicating tree diameters in these plots are more uniform. The low density plots (1200 and 600st/ha) had the largest diameters and also the largest SEM or variation.

Table 1. Mean aspen diameter increment (mm) (growth rate) and SEM for each treatment, years 2000, 2001 and 2002.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control*</th>
<th>5000</th>
<th>2500</th>
<th>1200</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean DBH 2000</td>
<td>65.5</td>
<td>75.89</td>
<td>84.79</td>
<td>99.15</td>
<td>109.32</td>
</tr>
<tr>
<td>SEM</td>
<td>0.95</td>
<td>1.56</td>
<td>1.87</td>
<td>3.29</td>
<td>3.05</td>
</tr>
<tr>
<td>Mean DBH 2001</td>
<td>64.00</td>
<td>78.22</td>
<td>88.06</td>
<td>102.24</td>
<td>109.79</td>
</tr>
<tr>
<td>SEM</td>
<td>1.00</td>
<td>1.59</td>
<td>1.78</td>
<td>3.49</td>
<td>2.92</td>
</tr>
<tr>
<td>Mean DBH 2002</td>
<td>66.36</td>
<td>78.78</td>
<td>87.45</td>
<td>104.19</td>
<td>112.94</td>
</tr>
<tr>
<td>SEM</td>
<td>1.03</td>
<td>1.60</td>
<td>1.93</td>
<td>3.42</td>
<td>3.37</td>
</tr>
</tbody>
</table>

* Greater than 5000 stems/ha.

Table 2, however, shows that there were no significant differences ($P=0.997$) among treatments in the mean diameter (dbh) growth of the 15 largest deciduous trees per treatment.

Table 2. Mean diameter (dbh) increment of the 15 largest overstory deciduous stems in each treatment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean dbh (cm) measured in Spring 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>15.14</td>
</tr>
<tr>
<td>1200</td>
<td>15.83</td>
</tr>
<tr>
<td>2500</td>
<td>14.74</td>
</tr>
<tr>
<td>5000</td>
<td>16.54</td>
</tr>
<tr>
<td>Control</td>
<td>13.96</td>
</tr>
</tbody>
</table>
Spruce Measurements – Young Aspen Stand, Oldgrowth and Clearcut Areas

Although there are no significant differences (P=0.420) in mean height growth of spruce among treatments (Figure 1), spruce planted in the clearcut are clearly taller than those growing in the oldgrowth or young aspen stands. The poorest spruce height growth is as expected in the control (>5000 sph of overstory deciduous stems).

![Figure 1. Change in mean height of underplanted spruce by treatment.](image1)

Although there are no significant differences (P=0.399) in mean diameter (ground line) growth of spruce among treatments (Figure 2), spruce planted in the clearcut were clearly larger in diameter at planting than those in the oldgrowth or young aspen stands.

![Figure 2. Change in mean diameter of underplanted spruce by treatment.](image2)
The majority of the underplanted spruce in each of the treatments are healthy (Figure 3). The largest percentage of dead trees is found in the oldgrowth stand. The clearcut has a number of trees that are sick or chlorotic; these trees will likely die in the near term.

Figure 3. Health of underplanted spruce in the spring of 2004

The majority of the underplanted spruce in each of the treatments have good form (Figure 4). The oldgrowth stand and the 2500 sph treatment in the young aspen stand have the least amount of damage (top damage and multiple tops). Most of the damage is due to browse by rodents.

Figure 4. Form of underplanted spruce in the spring of 2004
Vegetation Survey – Young Aspen Stand
Up to 59 species were surveyed in any given year (2001-2004). Species abundance curves illustrate relatively little difference in species abundance between treatment and year (Figure 5). Of the top 10 species, 7 of the 10 species are common in each year in each treatment.

![Graphs of vegetation survey data for years 2001 to 2004](image)

Figure 5. Rank abundance curves for the years 2001, 2002, 2003 and 2004.

Logarithmic trendlines for the 5000 sph treatment are summarized in Table 3. Slopes are similar for all years and $R^2$ values indicate goodness of fit in each year.

Table 3. Logarithmic trendline summary by year

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>-0.0405</td>
<td>-0.032</td>
<td>-0.0373</td>
<td>-0.0313</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.9596</td>
<td>0.9391</td>
<td>0.9362</td>
<td>0.9725</td>
</tr>
</tbody>
</table>

Kruskal–Wallis analysis indicated that species diversity and eveness indices were similar between treatments and years. Simpson’s diversity (Figure 6) and Simpson’s eveness (Figure 7) indices ranged between 10.26 and 17.88 and 0.28 and 0.48 respectively for all treatments in all years. Shannon-Wiener diversity (Figure 8) and eveness (Figure 9) indices ranged between 1.14 and 1.34 and 1.07 and 1.25 respectively for all treatments in all years.
Figure 6. Simpson’s diversity index (1/D) by treatment and year.

Figure 7. Simpson’s evenness (E) index by treatment and year.
Figure 8. Shannon-Wiener diversity (H’) index by treatment and year.

Figure 9. Shannon-Wiener eveness (J) index by treatment and year.
Soil Mineralization and Soil Moisture – Young Aspen Stand

Soil Mineralization
The 2004 results of the soil mineralization analysis (Figure 10) indicate that mean N-NO3 and N-NH4 values decrease over the growing season. The highest value for both of these nutrients is in the spring. There are no significant differences among the treatments for either the N-NO3 or N-NH4 in either the spring or the fall. There is a significant difference (P=0.04), however, between treatments when the difference between spring and fall values of N-NO3 are examined; the 600 sph treatment has a significantly larger difference between spring and fall values of N-NO3.

![Figure 10. Soil Mineralization Results for 2004.](image)

The difference between the spring and fall values of N-NO3 (Figure 11) were significant (P=0.000). The analysis shows that these values are decreasing over time from 2001 to 2004. The annual differences between the spring and fall values of N-NH4 (Figure 12) were not significant, however.
Figure 11. Difference between spring and fall N-NO3 values by year.

Figure 12. Difference between spring and fall N-NH4 values by year.
Soil Moisture
Due to technical problems experienced with the TDR unit, incomplete soil moisture data is available for the year 2003 and 2004. Data from 2002 (Figure 13) indicate that, as expected, soil moisture decreases steadily with increasing numbers of overstory deciduous stems.

Figure 13. Mean soil moisture readings by treatment in 2002.

When soil moisture is examined by growing season month (Figure 14), the greatest percentage of moisture is present in the soil in the spring - as expected. This percentage decreases as the growing season progresses.

Figure 14. Soil moisture readings by treatment block in 2002.
Growth and Yield Projection and Economic Analysis

Each of the following models, TWIGS, SORTIE and MGM, was used for growth and yield projections with Rice Property young aspen stand data (aspen and spruce). Each of the models resulted in the loss of all of the white spruce in the young aspen stand. Without surviving understory spruce, growth projections and economic analysis cannot be done.

Spruce growth on the Rice Properties was inadequate at 3 years to perform economic analyses, but it is hoped that year 5 data will be suitable for this analysis.

B. Woodlot 1217

Aspen Measurements

Aspen diameter growth increment displays a steady trend to increasing growth from 1999 to 2002 (Table 4). All treatment plots (except plot 4, all aspen treated) show either an increase in growth or no change in growth rate. There was a significant difference in growth among treatments $F(3,609) = 58.27, p = 0.000$ and between years $F(8,203) = 6.173, p = 0.000$.

<table>
<thead>
<tr>
<th>Plots</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean DBH 1999</td>
<td>1.02</td>
<td>1.16</td>
<td>1.14</td>
<td>1.02</td>
<td>1.24</td>
<td>1.05</td>
<td>1.01</td>
<td>1.13</td>
<td>1.29</td>
</tr>
<tr>
<td>SEM</td>
<td>0.12</td>
<td>0.13</td>
<td>0.10</td>
<td>0.09</td>
<td>0.08</td>
<td>0.09</td>
<td>0.06</td>
<td>0.09</td>
<td>0.13</td>
</tr>
<tr>
<td>Mean DBH 2000</td>
<td>0.93</td>
<td>1.07</td>
<td>1.24</td>
<td>1.04</td>
<td>1.79</td>
<td>0.95</td>
<td>0.97</td>
<td>1.17</td>
<td>1.31</td>
</tr>
<tr>
<td>SEM</td>
<td>0.08</td>
<td>0.12</td>
<td>0.08</td>
<td>0.06</td>
<td>0.08</td>
<td>0.09</td>
<td>0.07</td>
<td>0.08</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean DBH 2001</td>
<td>1.04</td>
<td>1.10</td>
<td>1.42</td>
<td>1.37</td>
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<td>0.94</td>
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<tr>
<td>SEM</td>
<td>0.11</td>
<td>0.12</td>
<td>0.11</td>
<td>0.13</td>
<td>0.14</td>
<td>0.11</td>
<td>0.08</td>
<td>0.12</td>
<td>0.18</td>
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<tr>
<td>Mean DBH 2002</td>
<td>1.04</td>
<td>1.45</td>
<td>1.58</td>
<td>1.60</td>
<td>2.24</td>
<td>1.09</td>
<td>1.28</td>
<td>1.37</td>
<td>1.84</td>
</tr>
<tr>
<td>SEM</td>
<td>0.09</td>
<td>0.18</td>
<td>0.12</td>
<td>0.15</td>
<td>0.12</td>
<td>0.13</td>
<td>0.11</td>
<td>0.11</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Figure 15 shows the growth response in percent between years 1999 and 2002 for aspen DBH for comparison. Pre-release diameter can have an effect on diameter growth after treatment. We therefore tested whether there was a difference in diameter growth rates and sizes prior to treatment. Pre-treatment test shows a significant difference in between plots, $F(8,203) = 5.197, p = 0.000$. However there was no difference when growth and treatment plots were tested within treatments $F(32,812) = 0.850, p = 0.706$. Furthermore, no significant differences in the pre-release diameters between sites ($F(9,321) = 1.74, p = 0.079$) was found.
Interestingly, plots 6 (80% aspen removed) and 10 (90% aspen removed) showed the greatest increase in diameter in year 2001 and 2002, having not shown a propensity for this increase in the first two years after release. However when we look at pre-release diameters for all plots (Figure 16) a trend does appear showing plots 6 (80% aspen removed) and 10 (90% aspen removed) having the greatest increments prior to release.
Spruce Measurements
Base line spruce measurements (height and diameter) were recorded in 2004 on Woodlot 1217. Additionally, wood cores were taken at breast height for spruce trees that were of sufficient diameter. These wood cores will be used to determine growth increment. Due to the small number of spruce trees sampled to date, this analysis has yet to be completed. It is anticipated that a journal article or report will be written on this topic in the future.

Vegetation Survey
A vegetation survey was not carried out in 2004. A vegetation survey was however carried out at plot establishment in 1998. The results of the survey are summarized in the following journal article published by the Society of American Foresters:


Soil Mineralization
No soil samples were collected on Woodlot 1217 in 2004.

Discussion:
Aspen Measurements
Diameter was selected as the response variable, rather than height because diameters are more responsive than height to changes in carbon allocation (30, 31) as would be found, with changes in ambient light, as a result of thinning or competition (32).

Thinning rapidly changes the environment that the tree occupies for its survival and growth. In order for a positive response to take place following treatment, the tree must be capable of taking advantage of the increased available resources. With improved light, moisture, and nutrients at the micro-environment level, the tree must be able plastic enough physiological to increase photosynthesis in a relatively short period to account for increases in respiration (33, 34, 35).

Incremental thinning treatments had a positive affect on the aspen growth component of the stand. All treatments showed a greater increase in growth than non-treated controls. Woodlot 1217 study site, interestingly shows a delay in response where growth response is the greatest (treatment plots 6 and 10). These sites also expressed the greatest pre-treatment growth rates which are likely contributing to the post-treatment growth success.

The response of aspen to the thinning treatment is consistent with observations of others (36, 37, 38, 39) although their response observed appears to have been delayed for up to two years post-treatment.

Although not as explicit as WL 1217, the Rice Property may also be showing a delayed response to treatment. It may be too early to make definitive judgments, but the 600st/ha treatment appears to be making a statement in the increment jump from 2001 to 2002. The other treatments are not expressing any dramatic growth increment changes at this
time. In addition the 600st/ha treatment possessed the largest trees at the time of treatment and this may be a factor in the response seen.

There was no difference among treatments when the 15 largest diameter deciduous stems were compared. It is likely that with each increase in stand density, the remaining stems in each treatment are smaller in diameter. Even though smaller in dbh, the quantity of these smaller stems takes resources that would be available to other trees if they were not there.

**Spruce Measurements**
Due to delayed mortality of the overstory deciduous stems in the young aspen stand, differences in spruce growth (height and diameter) between treatments are not yet evident. It is anticipated that as the canopy opens, that differences will become apparent.

**Vegetation Survey**
Although species abundance, diversity and eveness were not found to vary between treatment and year, it is obvious that the 5000 sph treatment has higher diversity than the other treatments. There are on average 5440 sph of overstory deciduous trees in the 5000 sph treatment compared to 8800 sph on average, of overstory deciduous trees in the control. The control or ‘natural’ stand may be too dense to support a diversity of vegetation. Additionally, when the trial was established, all attempts were made to assign the treatments to the plots randomly, however, ultimately, the treatments had to be assigned to those plots where they would meet the required overstory density. The lack of variation in the abundance, diversity and eveness of the vegetation may be due to the treated plots not being very different from their original or natural stand densities. Also, given the length of time the girdled aspen survived, the increases in light to the forest floor may not have been significantly different until 2003.

**Soil Mineralization and Soil Moisture**
As expected, there are biannual (spring vs. fall) differences in N-NO3 and N-NH4. In both cases, fall measurements were smaller than spring measurements. Additionally, changes in the nutrient levels over the years (2001 to 2004) has been slow, with the largest changes in N-NO3 occurring in 2004; no such changes have occurred for N-NH4. It is hypothesized that this is as a result of the length of time it took for the canopy to open up and more light to reach the forest floor.

As canopy and leaf area decrease there is an increase in soil moisture. Reduction of canopy and the subsequent effects on soil moisture were not evident in the short term due to delayed mortality with girdling.

**Growth and Yield Projection and Economic Analysis**
As the underplanted spruce did not survive in the SORTIEBC or other growth and yield projections, economic analysis cannot be done. We continue to obtain or modify an existing model that will reflect the growth of underplanted spruce.
Conclusions and Management Implications:

Aspen Measurements
Thinning of aspen to increase growth of aspen is achievable and can reduce the time and increase the productivity of a site producing merchantable wood at an earlier date in the rotation age. Two factors need to be considered when planning an operational thinning treatment. First the size of the trees should be considered, the greater the tree diameter size the sooner a growth response expressed. This however is a double-edged sword, thinning too late in age (larger trees), closer to rotation age, will not leave sufficient time in the rotation to recover the financial investment. However, thinning too early will result in a slower response to the treatment. The time to recover the investment may be longer than is fiscally responsible, when looking at the return on investment.

Site index is also important; we have not looked at thinning low to moderate sites. The current sites would be considered good (site index 20) in the boreal forests of North America. Further investigations will follow analyses at these sites to determine proper age and structure for thinning operations in the boreal forest.

Additionally, at the Rice Properties, it appears that the aspen stand was thinned when it was at maximum leaf area and ready to self thin naturally, therefore, the need to manually thin may not have been necessary.

Spruce Measurements
At this time, the spruce are still too small to make any definitive conclusions or to suggest any management implications as a result of the treatments.

Vegetation Survey
At approximately 20-25 years, an aspen stand reaches max. LAI. As the stand self thins or is thinned manually, light increases through the rest of the rotation. Changes in vegetation may therefore become evident in the future as the overstory stand matures.

Soil Mineralization and Soil Moisture
At approximately 20-25 years, an aspen stand reaches max. LAI. As the stand self thins or is thinned manually, light increases through the rest of the rotation. Changes in soil mineralization and soil moisture may therefore become evident in the future as the overstory stand matures.

Growth and Yield Projection and Economic Analysis
At this time the the spruce are too small to develop a tree list. Additionally, there are currently no useful models for underplanted stands. More research into the development of mixedwood models specifically designed for underplanted stands would be useful.
Literature Cited:


