Effects of Pre-Commercial Thinning on Stand Composition, Stand Structure, and White Spruce Diameter Growth in White Spruce Stands in Interior Alaska

Written for:
Tanana Chiefs Conference Forestry Program
Fairbanks, Alaska

Written by:
Robert A. Ott, Ph.D.
RAO Ecological Consulting / Photographic Services
Bennington, Vermont

January 2010

ABSTRACT

During an inventory on Native allotments in interior Alaska, the Tanana Chiefs Conference Forestry Program (TCC Forestry) identified dense stands of small diameter white spruce (*Picea glauca*) that had the potential to benefit from a release through pre-commercial thinning. However, with the unique growing conditions present in the northern boreal forest, the response of white spruce stands to pre-commercial thinning could not be anticipated from published studies, and no research on this topic has been conducted in Alaska. As a result, TCC Forestry conducted a pre-commercial thinning of white spruce stands near the communities of Tanacross and Tok, and monitored those stands for six years.

In 1998, five treatment monitoring plots were located within pre-commercially thinned white spruce stands on two Native allotments. Four control plots were installed in nearby unthinned spruce forest. The six year re-measurement of all control and treatment plots was conducted during the summer of 2004. The following tree-related variables were compared between control and treatment plots in order to determine the effects of pre-commercial thinning: species composition, diameter class distribution of white spruce, white spruce mortality rates, and diameter growth rates of white spruce.

Tree species composition was not significantly different between unthinned control plots and thinned treatment plots, although average and median levels of white spruce were larger in the treatment plots. White spruce comprised the large majority of trees in both the unthinned control plots and the thinned treatment plots; quaking aspen (*Populus tremuloides*) comprised the remainder of the trees.

The diameter class distributions of white spruce in the unthinned control plots were right-skewed, with the large majority of trees concentrated in the smallest diameter classes. Trees in the control plots were primarily in the 0-2 inch diameter class (<2.5 inches diameter breast height). The diameter class distributions of white spruce in the thinned treatment plots were more varied than those of the control plots. Whereas spruce in the control plots were concentrated primarily in the smallest diameter class (0-2 inch), spruce in the treatment plots, with one exception, were distributed across larger diameter classes.

Annual mortality rates of white spruce were not significantly different between the unthinned control plots and the thinned treatment plots. Spruce mortality was low for both control and treatment plots, exceeding 1.0% per year only for one treatment plot for the three year period from the time of thinning to the time of installment of the monitoring plot. No spruce mortality occurred in four of the five treatment plots during the monitoring period from 1998 through 2004.

The average diameter growth of spruce trees in the thinned treatment plots exceeded the growth of spruce in the unthinned control plots for all but the eight inch diameter class. Diameter growth of white spruce, however, was not significantly different between the treatment and control plots.

INTRODUCTION

In many forested regions, pre-commercial thinning is a commonly used silvicultural practice in overstocked stands. By controlling stand density through thinning, the growth rates of trees remaining in a stand can be increased because of reduced competition for light, water, nutrients, and growing space. Pre-commercial thinning is typically conducted in stands of young trees; ages of forest stands subjected to pre-commercial thinning in temperate and boreal zones that were identified in published studies ranged from 6 to 36 years (Hibbs et al. 1989, Lamson 1983, Miller et al. 1999, Morris et al. 1994, Peltola et al. 2002, Peterson et al. 1997, Rice et al. 2001, Ruel et al. 2003).

Unlike forests stands in temperate and lower latitude boreal forests, a canopy of dense spruce (*Picea* spp.) in the northern boreal forest of North America results in the development of a moss mat that initiates soil cooling, resulting in slow nutrient cycling rates and stagnation of the forest stand (Chapin et al. 2006). As a result, small diameter spruce trees are not necessarily young trees. Reducing the canopy cover through thinning is expected to increase growth of the residual crop trees not only by reducing competition for light, water, nutrients, and growing space, but also by increasing soil temperature, which will result in increased nutrient cycling rates.

In interior Alaska, white spruce (*Picea glauca*) is the primary commercial tree species, and is the one that is most often managed. During an inventory on Native allotments in interior Alaska, the Tanana Chiefs Conference Forestry Program (TCC Forestry) identified dense stands of small diameter white spruce that had the potential to benefit from a release through pre-commercial thinning. Not all of these stands were young, but white spruce has the capacity to add substantial volume after it is released from competition, even when trees are centuries old (R. Ott, personal observation). However, with the unique growing conditions present in the northern boreal forest, the response of these white spruce stands to pre-commercial thinning could not be anticipated from published studies, and no research on this topic has been conducted in Alaska. As a result, there was uncertainty as to whether the benefits derived from pre-commercially thinning white spruce stands (e.g. increased growth rates, shorter rotation periods) offset the cost of conducting the treatments.

In order to quantify the diameter growth response of white spruce to a pre-commercial thinning, TCC Forestry installed monitoring plots in white spruce stands on two Native allotments near the communities of Tok and Tanacross, Alaska in 1998. This report summarizes the six year results of this monitoring project.

STUDY SITE

All monitoring plots were situated in a white spruce forest between the communities of Tok and Tanacross in eastern interior Alaska, about 200 miles southeast of Fairbanks. This spruce forest that regenerated after a forest fire was about 80 years old, and was comprised of a mixture of sapling- and pole-sized trees. Moss (species unidentified) was the dominant understory plant and averaged 60% cover. Moss cover ranged from 10% where drier microsites were dominated by a quaking aspen (*Populus tremuloides*) overstory, to 75% under closed canopy spruce forest. The primary vascular understory plant was lowbush cranberry (*Vaccinium vitis-idaea*). The site index of this spruce forest is 60-65 with an index age of 100 years (J. Sprankle, TCC Forestry, personal communication).

Monitoring plots in pre-commercially thinned white spruce stands (treatment plots) were located on 160 acres on Native allotment F-12112 and on 40 acres on allotment FF-14461B (Figure 1). Monitoring plots in unthinned spruce stands (control plots) were located adjacent to the two Native allotments where the thinned treatment plots were situated.

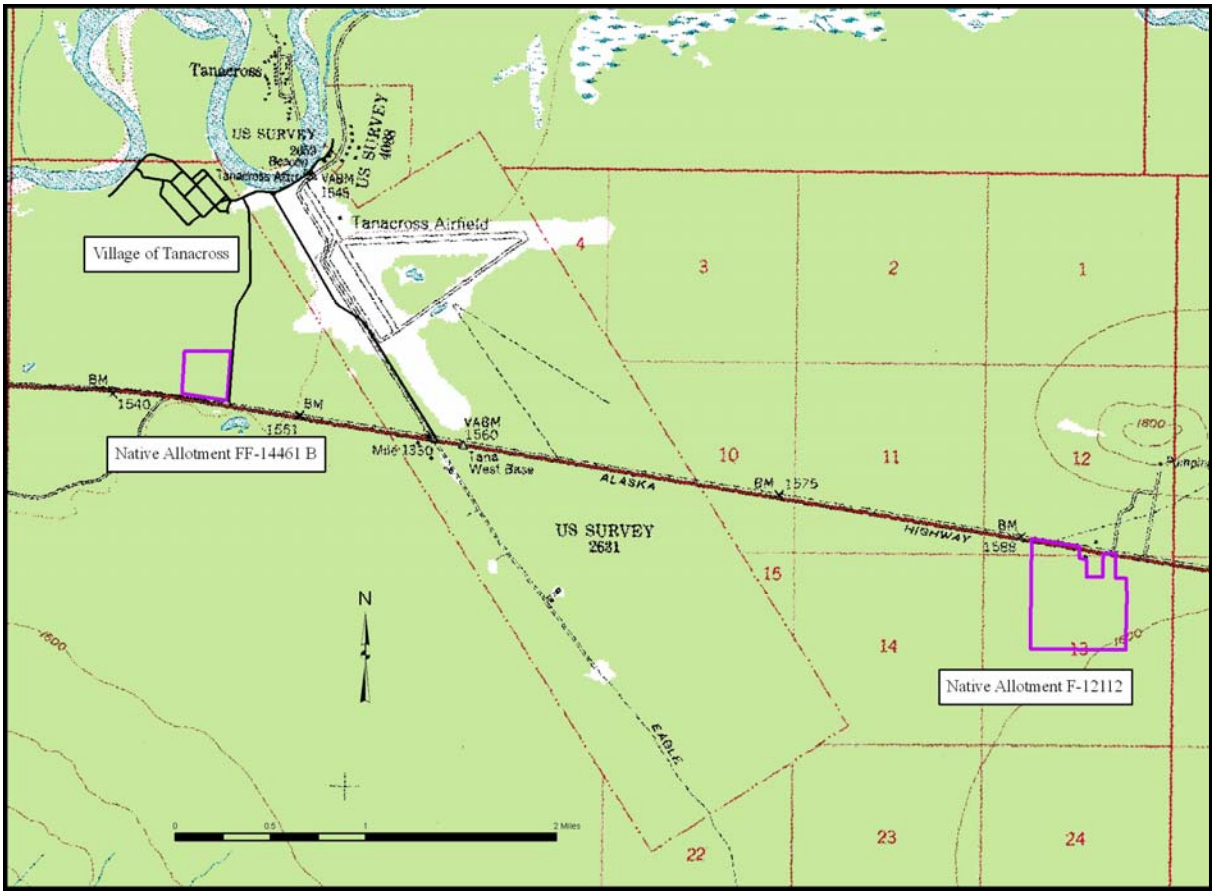

Figure 1: Locations of Native allotments F-12112 and FF-14461B.

Thinning was conducted with the intent of increasing the white spruce component in the stands, maximizing white spruce survival, and retaining trees that were expected to maximize their growth after thinning. The thinning guidelines designated a target tree spacing of 8.0 feet by 8.0 feet (680 trees/acre) while retaining trees with the following characteristics: straight boles, single stems, disease free, generally healthy with a full crown, and relatively fast growing (typically the largest trees).

Overall tree density in unthinned control plots averaged 4,089 trees/acre, with white spruce density averaging 3,865 trees/acre and aspen averaging 224 trees/acre. Overall tree density in thinned treatment plots averaged 636 trees/acre, with an average white spruce density of 604 trees/acre, and an average aspen density of 32 trees/acre (Table 1). Pre-commercial thinning resulted in an overall average reduction of 3,453 trees/acre (84.4% decrease), with a reduction of 3,261 spruce trees/acre (84.4% decrease) and a reduction of 192 aspen trees/acre (85.7% decrease). The range of total tree densities in the treatment plots ranged from 40.4% less than the target tree density (680 trees/acre) in plot NP8 to 34.6% greater than the target tree density in plot I1.

The average total tree density in the thinned treatment plots equated to a tree spacing of 8.3 feet by 8.3 feet, which was very close to the target tree spacing of 8.0 feet by 8.0 feet. Tree spacing in the treatment plots ranged from 6.9 feet by 6.9 feet in plot I1 to 10.4 feet by 10.4 feet in plot NP8.

Table 1. Tree density (stems/acre) in unthinned control plots and pre-commercially thinned treatment plots in white spruce stands in interior Alaska.

Control		**Trees/acre**			**Treatment**		**Trees/acre**		
plots	***n***	**Spruce**	**Aspen**	**Total**	**plots**	***n***	**Spruce**	**Aspen**	**Total**
IC1	1583	7410	505	7915	**BP5**	96	425	55	480
PC1	258	1150	140	1290	**GP6**	105	510	15	525
PC2	318	1405	185	1590	**I1**	183	855	60	915
PC3	1112	5495	65	5560	**NP2**	171	840	15	855
					NP8	81	390	15	405
Average		3865	224	4089			604	32	636
Median		3450	163	3575			675	35	690
St. Dev.		3090	194	3208			227	23	232
V[a]		79.9	86.6	78.5			37.6	71.9	36.5

METHODS

Data Collection

Most of the thinning on the Native allotments occurred before there were plans or funding to monitor the effects of the thinning. As a result, it was not possible to match monitoring plots in the thinned stands based on pretreatment conditions, with the control plots in unthinned stands. Therefore, in order to meet the assumption of having random samples to conduct statistical tests, all monitoring plots were randomly located within both thinned and unthinned white spruce stands.

Monitoring plots were installed in the summer of 1998. Five treatment plots were installed within the thinned spruce stands on the two Native allotments; four treatment plots were installed on allotment F-12112 (Figure 2), and one treatment plot was installed on allotment FF-14461B (Figure 3). Four of the treatment plots were installed three years after thinning (1995), and one treatment plot was installed one year after thinning (1997) (Figures 2 and 3). Four control plots were installed within 660 feet (10 chains) in nearby unthinned spruce forest; three control plots were located adjacent to allotment F-12112 (Figure 2), and one control plot was located adjacent to allotment FF-14461B (Figure 3). In order to minimize edge effects, plot edges had to be ≥60 feet from the boundaries of the stand (from unthinned boundaries for treatment plots, and from thinned boundaries for control plots). Monitoring plots were square 1/5 acre plots, and were oriented so that plot sides faced in the cardinal directions. Plot corners were staked and labeled, and locations of plot centers were recorded with a hand-held GPS (Global Positioning System) receiver.

Individual trees were marked with a numbered aluminum tag within treatment and control plots. Within each thinned treatment plot, all live trees ≥4.5 feet tall were tagged at about four feet. In addition, dead trees in the treatment plots were tagged because these trees were alive at the time the thinning was conducted—information on dead trees was used to calculate tree mortality rates. Within each unthinned control plot, all live trees ≥2.0 inches DBH (diameter at

[a] V is the symbol for the coefficient of variation, which is the standard deviation expressed as a percentage of the population mean. V is used to compare the relative amount of variation between populations with different means (Sokal and Rohlf 1981).

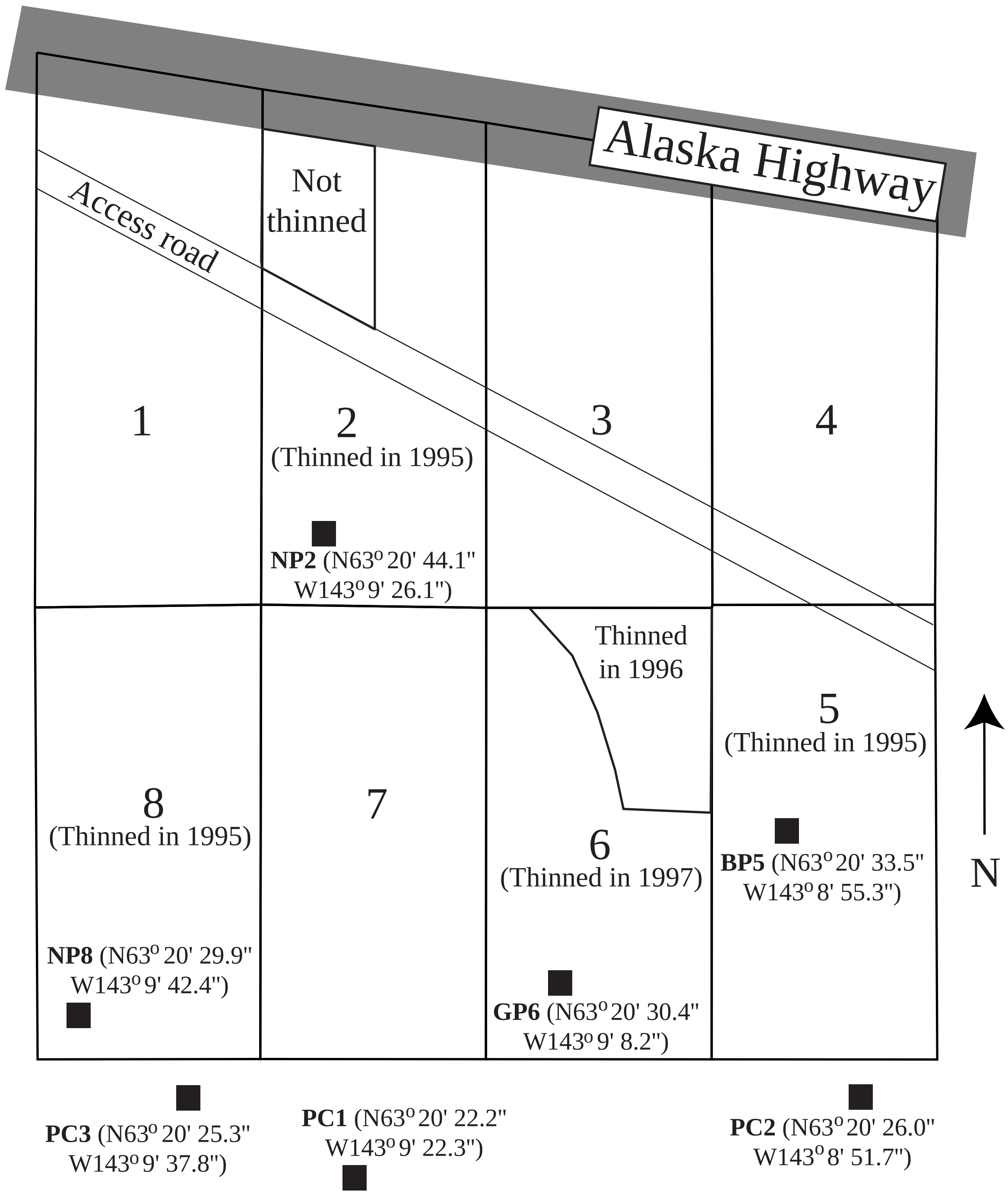

Figure 2. Locations of treatment plots (BP5, GP6, NP2, NP8) in a pre-commercially thinned white spruce stand on Native allotment F-12112, and locations of control plots (PC1, PC2, PC3) in the adjacent unthinned spruce stand. Plot sizes and locations are not drawn to scale. The numbers 1-8 identify the subdivisions of the original allotment.

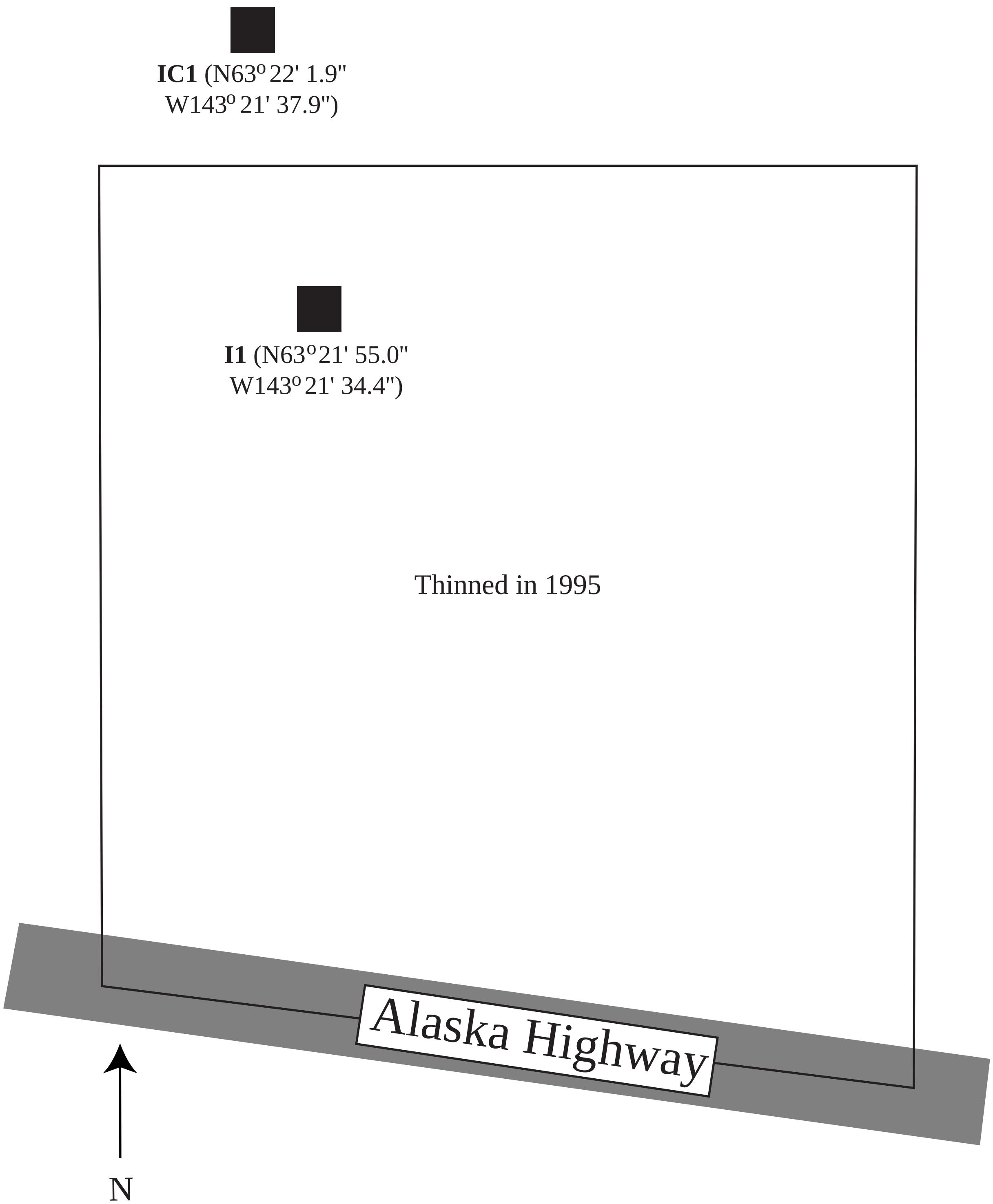

Figure 3. Location of treatment plot I1 in a pre-commercially thinned white spruce stand on Native allotment FF-14461B, and locations of control plot IC1 in the adjacent unthinned spruce stand. The allotment, plot sizes, and plot locations are not drawn to scale.

breast height; 4.5 feet above the root collar) were tagged at about four feet. In addition, all live trees ≥1.0 inch DBH but <2.0 inches DBH were tagged within a square 1/10 acre plot that was centered within each of the larger 1/5 acre control plots. This smaller plot was installed within each of the control plots because of the large number of smaller trees present in the unthinned stands. It was felt that the number of smaller trees located within the smaller 1/10 acre plots was more than adequate to monitor growth response of these smaller diameter trees. Within all monitoring plots, the species and DBH of each tagged tree were recorded, and the location where DBH was measured was marked with a paint line on the north side of each tree. Within the control plots, any untagged trees ≥4.5 feet tall were counted—this information was used in the determination of tree species composition and tree density.

The six year re-measurement of all control and treatment plots was conducted during the summer of 2004. Tagged trees were recorded as live or dead, and their diameters were measured.

Data Analyses

The following tree-related variables were compared between control and treatment plots in order to determine the effects of pre-commercial thinning: species composition, diameter class distribution of white spruce, white spruce mortality rates, and diameter growth rates of white spruce. The assumption was made that these variables were similar between the control plots and treatment plots prior to thinning. Non-parametric statistical tests were used to compare variables between the treatment and control plots because of the small sample sizes involved in this study (i.e. four control plots and five treatment plots), and because the assumption that the data are drawn from a given probability distribution (e.g. normal distribution) is not required.

Species composition and the diameter class distribution of white spruce were calculated using data from trees ≥4.5 feet tall. In the unthinned control plots, these data included all tagged trees, plus the additional live, small-diameter trees that were not tagged but met the minimum height requirement of 4.5 feet. In the thinned treatment plots, these data included all live, tagged trees, plus the tagged dead trees that were alive at the time of thinning, but had died prior to installation of the monitoring plots. The Mann-Whitney test, a nonparametric statistical procedure for testing the null hypothesis of equal population medians (Daniel 1990), was used to determine if the tree species composition was statistically different ($p<0.05$) between the unthinned control plots and the thinned treatment plots.

Tree mortality rates in the unthinned control plots were calculated from the time the monitoring plots were installed until the time the plots were re-measured. Tree mortality rates in the thinned treatment plots were calculated for three time periods: (1) from the time of thinning until the time the monitoring plots were installed, (2) from the time the monitoring plots were installed until the time the plots were re-measured, and (3) from the time of thinning until the time the monitoring plots were re-measured.

The Mann-Whitney test was used to determine if the white spruce mortality rate in the unthinned control plots was significantly different ($p<0.05$) than the spruce mortality rates for the three time periods in the thinned treatment plots. The Wilcoxon matched-pairs signed-ranks test (Daniel 1990) was used to determine if the mortality rates were significantly different ($p<0.05$) in the thinned treatment plots for the first two time periods listed above. This statistical test was used because the mortality rates were compared for the same plots (i.e matched pairs), but for two different time periods.

The growth response of white spruce to pre-commercial thinning was quantified by comparing diameter growth of tagged trees between thinned treatment plots and unthinned control plots. The diameter growth of spruce was summarized in two ways: (1) by averaging the actual increase in diameter, in inches, for each diameter class; and (2) by averaging the percentage increase in diameter, compared to the average 1998 diameter, for each diameter class.

The Mann-Whitney test was performed on the average percentage growth increase of white spruce in order to determine if diameter growth was significantly different ($p<0.05$) between control and treatment plots. The percentage growth form of the data was used to perform the statistical analysis because it met all of the assumptions of the Mann-Whitney test[b] (Daniel 1990).

RESULTS AND DISCUSSION

Species Composition

Tree species composition was not significantly different between unthinned control plots and thinned treatment plots, although average and median levels of white spruce were larger in the treatment plots (Table 2). White spruce comprised the large majority of trees in the unthinned control plots (averaging 92.5%) as well as the thinned treatment plots (averaging 94.7%). Quaking aspen comprised the remainder of the trees in both the control and treatment plots. Although tree species composition was similar between control and treatment plots, species composition was less variable in the thinned treatment plots (Table 2).

These results suggest that pre-commercial thinning did not achieve the management objective of increasing the white spruce component of these stands. However, the average increase of 2.2% in the spruce component equates to an additional 14 spruce trees per acre on average.

Table 2. Tree species composition (%) in unthinned control plots and pre-commercially thinned treatment plots in white spruce stands in interior Alaska.

Control		**(%)**		**Treatment**		**(%)**	
plots	***n***	**Spruce**	**Aspen**	**plots**	***n***	**Spruce**	**Aspen**
IC1	1583	93.6	6.4	**BP5**	96	88.5	11.5
PC1	258	89.1	10.9	**GP6**	105	97.1	2.9
PC2	318	88.4	11.6	**I1**	183	93.4	6.6
PC3	1112	98.8	1.2	**NP2**	171	98.2	1.8
				NP8	81	96.3	3.7
Average		92.5	7.5			94.7	5.3
Median		91.4	8.7			95.3	4.8
St. Dev.		4.8	4.8			3.9	3.9
V		5.2	64.0			4.1	73.6

Diameter Class Distribution of White Spruce

The diameter class distributions of white spruce in the unthinned control plots were right-skewed, with the large majority of trees concentrated in the smallest diameter classes. This trend existed for individual control plots as well as for the diameter distribution of plot averages (Figure 4).

[b] The assumptions of the Mann-Whitney test are (1) that the data are a random sample of observations; (2) the samples are independent from each other; (3) the observed variable is a continuous random variable; (4) the measurement scale is at least ordinal; and (5) the distributions of the two populations differ only with respect to their locations (i.e. they have different medians), if they differ at all (Daniel 1990).

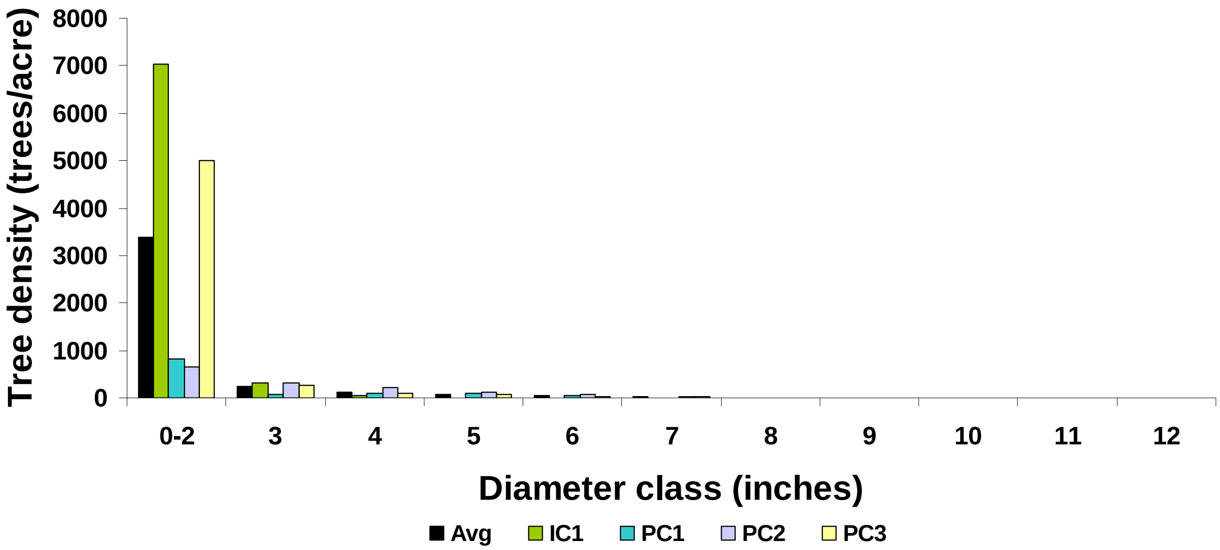

Figure 4. Frequency distributions of white spruce by diameter class in 1998 in four unthinned control plots, plus the average (Avg) of the four plots. The 0-2 inch diameter class includes all live trees ≥4.5 feet tall up to 2.4 inches DBH. This diameter class includes tagged trees as small as 1.0 inch DBH as well as live, untagged trees ≥4.5 feet tall (refer to the Methods section for further details). The midpoints for all other one inch diameter classes are shown. The histograms are based on a total sample size of 3,091 white spruce in the control plots. Not shown are five trees/acre in the 14 inch diameter class in control plot PC3.

Trees in the control plots were primarily in the 0-2 inch diameter class (<2.5 inches DBH) in the following percentages and tree densities:

Control Plot	Percentage of total trees	Tree density (trees/acre)
Plot IC1	94.9	7,035
Plot PC1	70.9	815
Plot PC2	45.9	645
Plot PC3	90.9	4,995
Plot average	87.3	3,373

The diameter class distributions of white spruce in the thinned treatment plots were more varied than those of the control plots (Figure 5). The diameter class distributions of spruce were right-skewed in treatment plots I1 and NP2, as well as the average of the treatment plots. The majority of trees in plots I1 and NP2 were concentrated in the 0-2 inch diameter class (66.7%, 570 trees/acre and 51.8%, 435 trees/acre respectively), but these diameter class distributions were not as skewed as those of the control plots. White spruce in treatment plot NP8 was broadly distributed across the 0-2 inch to eight inch diameter classes, with 10.3% (40 trees/acre) to 15.4% (60 trees/acre) of the trees being represented in each diameter class; these diameter classes contained 91.1% (355 trees/acre) of the trees in plot NP8. Spruce in treatment plot BP5 also were broadly distributed across several diameter classes, with percentages ranging from 10.6% (45 trees/acre) in the three inch diameter class to 27.1% (115 trees/acre) in the six inch diameter class. The 0-2 inch to six inch diameter classes contained 90.6% (385 trees/acre) of the spruce in plot BP5. Spruce in treatment plot GP6 peaked in diameter classes three through five, with 77.4% (395 trees/acre) of the trees being contained within these diameter classes.

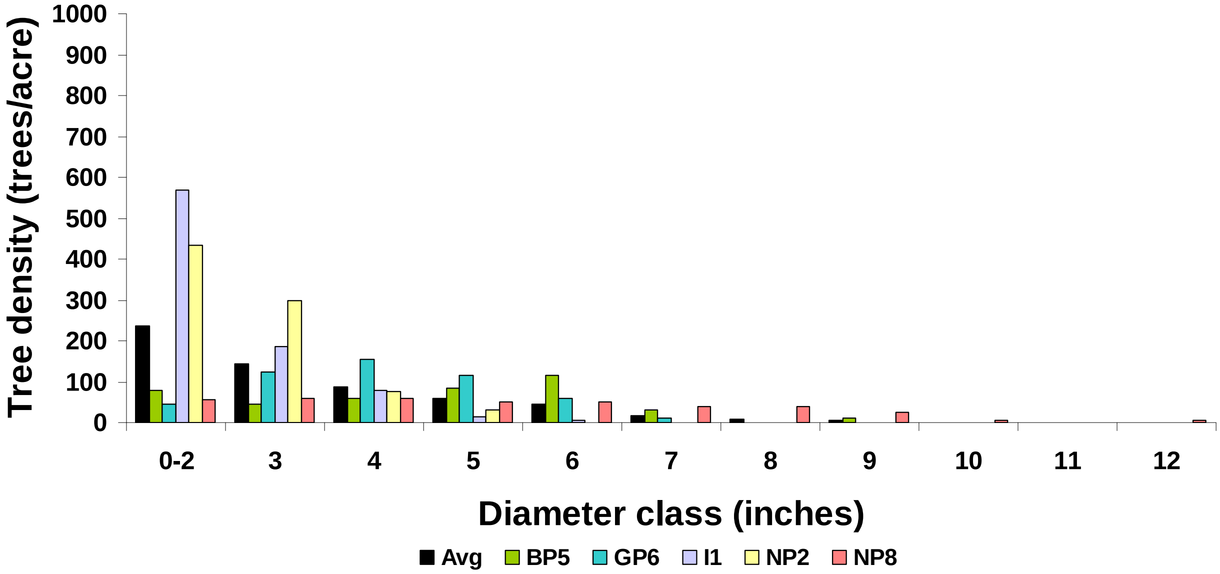

Figure 5. Frequency distributions of white spruce by diameter class in 1998 in five pre-commercially thinned treatment plots, plus the average (Avg) of the five plots. The 0-2 inch diameter class (0.0 to 2.4 inches) includes trees from 0.3 to 2.4 inches DBH. This smallest diameter class spans a range of 2.4 inches so that a direct comparison could be made with the diameter distributions of unthinned control plots in Figure 4. The midpoints for all other one inch diameter classes are shown. The histograms are based on a total sample size of 604 white spruce in the treatment plots that were alive at the time the thinning was conducted. Note that the maximum value of the Y-axis is 1,000 trees/acre, compared to the maximum value of 8,000 trees/acre in Figure 4.

Whereas spruce in the control plots were concentrated primarily in the smallest diameter class (0-2 inch), spruce in the treatment plots, with exception of plot I1, were distributed across larger diameter classes (three to 12 inches) in the following percentages and tree densities:

Treatment Plot	Percentage of total trees	Tree density (trees/acre)
BP5	81.2	345
GP6	91.2	465
I1	33.3	285
NP2	48.2	405
NP8	85.9	335
Plot average	60.8	367

In general, pre-commercial thinning resulted in a flattening of the diameter class distribution of white spruce. Besides greatly reducing overall spruce density, the effect of pre-commercial thinning was the removal of trees in the smallest diameter classes, thereby increasing the proportion of larger diameter trees. The flattening of the diameter class distribution was a direct result of the management intent of the thinning, which was to retain the spruce trees with the greatest potential to increase their growth in response to the thinning. These trees were generally the ones with the fullest crowns and relatively fast growth; which tended to be the largest trees with dominant crown positions and with the largest diameters. As a result, less dominant trees with smaller diameters tended to be selected for removal during thinning.

White Spruce Mortality Rates

Annual mortality rates of white spruce were not significantly different between the unthinned control plots and any of the three time periods for the thinned treatment plots for which spruce mortality was calculated (Table 3). Spruce mortality was low for both control and treatment plots, exceeding 1.0% per year only for treatment plot NP2 for the three year period from the time of thinning to the time of installment of the monitoring plot. No spruce trees died in control plot PC1 from 1998 through 2004, or in treatment plots GP6 and NP8 from the time of thinning (1997 and 1995 respectively) until 2004. In addition, no spruce mortality occurred in four of the five treatment plots during the monitoring period from 1998 through 2004. Spruce mortality rates were highly variable, with standard deviations exceeding the average mortality rates for both control and treatment plots (Table 3).

Annual spruce mortality rates in the thinned treatment plots were significantly different during the period from the time of thinning until the installation of monitoring plots in 1998, and during the monitoring period from 1998 through 2004 (Table 3). From the time that thinning occurred until the monitoring plots were installed, white spruce mortality rates varied from 0.0% to 1.19% per year, and averaged 0.47% per year. In contrast, no spruce mortality occurred for four of the five treatment plots during the monitoring period from 1998 through 2004, and averaged 0.02% per year. Therefore, spruce mortality in the treatment plots in the first few years following thinning was on average, 23.5 times greater, than spruce mortality during the subsequent six year monitoring period.

Table 3. White spruce annual mortality rates (% per year) in unthinned control plots and pre-commercially thinned treatment plots in white spruce stands in interior Alaska. The dates in parentheses are the year in which each treatment plot was thinned. Standard deviations of spruce mortality rates are shown in brackets. Spruce mortality rates from the time of thinning until plot installation in 1998 were calculated based on the number of dead trees that were present in the plots at the time of plot installation—dead trees were removed during thinning, so those present at the time of plot installation had died after thinning was completed.

	Annual Mortality Rate (% per year)		
Plot	**From thinning to plot installation in 1998**	**From plot installation in 1998 to re-measurement in 2004**	**From thinning to re-measurement in 2004**
Control plots			
IC1	—	0.03	—
PC1	—	0.00	—
PC2	—	0.41	—
PC3	—	0.09	—
Control plot average	—	0.13 [0.19]	—
Treatment plots			
BP5 (1995)	0.39	0.00	0.13
GP6 (1997)	0.00	0.00	0.00
I1 (1995)	0.78	0.00	0.26
NP2 (1995)	1.19	0.10	0.46
NP8 (1995)	0.00	0.00	0.00
Treatment plot average	0.47 [0.52]	0.02 [0.04]	0.17 [0.20]

White spruce mortality rates were low in both unthinned control plots and thinned treatment plots, suggesting that pre-commercial thinning did not result in elevated mortality of the residual crop trees. However, mortality rates in thinned stands before the treatment plots were installed greatly exceeded the mortality of those same stands after monitoring began. This fact indicates that pre-commercial thinning did influence tree mortality for several years, although spruce mortality was low for both time periods.

When thinning was initiated on the Native allotments, the slash that was generated quickly attracted northern spruce engraver beetles (*Ips perturbatus*) and the slash became infested with beetle larvae. In the process, some residual live spruce trees were also attacked and killed by the engraver beetles. Adult beetles that emerged from the infested slash and standing trees overwintered in the forest duff. The following spring and summer, the adult beetles that overwintered deposited eggs in new slash that was generated during continued thinning activity, along with attacking stressed standing live spruce trees. A new generation of beetle larvae developed in the slash and standing trees, and the cycle continued. The relatively high average spruce mortality rate at the beginning of the pre-commercial thinning program can be explained by the elevated engraver beetle activity resulting from the availability of abundant brood material, primarily in the form of spruce slash.

In response to the elevated engraver beetle activity, several steps were taken to minimize further infestation:

1) A beetle trapping program was initiated using telescoping Lindgren funnel traps and pheromone bubble caps;
2) Thinning was conducted only in mid to late summer after the majority of adult beetles had emerged from the forest duff and dispersed in their search for brood habitat to deposit their eggs; and
3) Spruce slash greater than four inches in diameter at the small end was scored with a chainsaw to remove strips of bark and phloem. Scoring resulted in enhanced drying of the phloem, rendering it unsuitable as brood habitat.

After these steps were taken, engraver beetle attacks on the residual spruce trees were minimized. This reduction in engraver beetle infestation explains the reduced spruce mortality rates that were observed during the monitoring period from 1998 through 2004.

White Spruce Diameter Growth

The average diameter growth of spruce trees in the thinned treatment plots exceeded the growth of spruce in the unthinned control plots for all but the eight inch diameter class (for those diameter classes that contained trees from both treatment and control plots). This growth pattern existed regardless of whether average diameter growth was expressed in inches (Figure 6), or as the average percentage increase compared to the average 1998 diameter for each diameter class (Figure 7). Diameter growth of white spruce, however, was not significantly different between the treatment and control plots.

The pattern of spruce diameter growth varied between the treatment and control plots when growth was plotted as the average diameter increase expressed in inches (Figure 6). The distribution of diameter growth in the treatment plots was approximately normally distributed, with growth gradually increasing from the <1 inch through the four inch diameter classes, and then gradually decreasing again (except for the nine inch diameter class) from the five inch to 12 inch diameter classes. Average diameter growth of spruce trees in the treatment plots ranged from 0.23 inch in the <1 inch diameter class to 0.54 inch in the four inch diameter class. In the treatment plots, the standard deviation of average spruce diameter growth expressed in inches ranged from ±0.05 in the one inch diameter class to ±0.26 in the six inch diameter class.

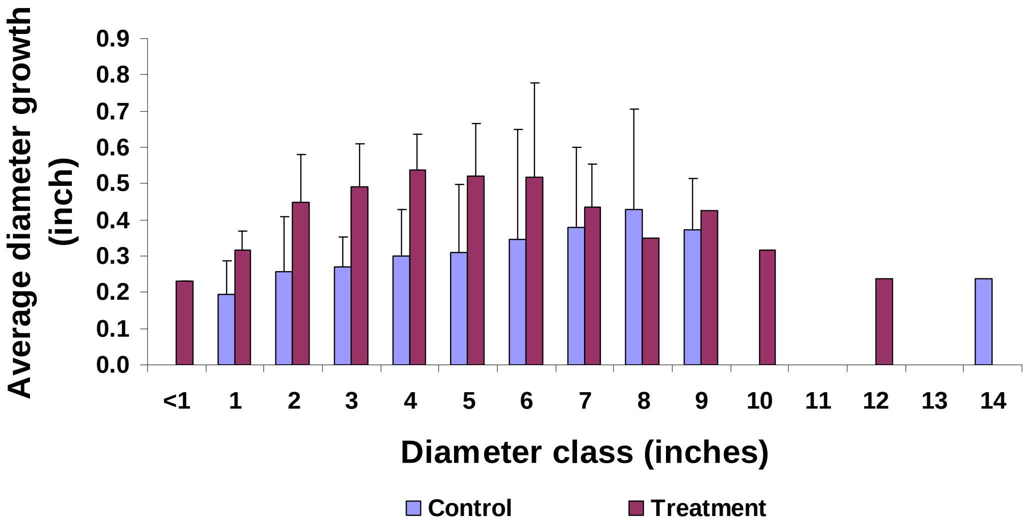

Figure 6. Diameter growth of white spruce trees from 1998 through 2004, averaged by diameter class, in unthinned control plots and pre-commercially thinned treatment plots. Diameter classes are identified by their midpoints, with the exception of the <1 inch class, which includes spruce trees ≥4.5 feet tall with a diameter <0.5 inch. Average growth was calculated for four control plots (i.e. n = 4) with 1,212 tagged spruce trees and five treatment plots (i.e. n = 5) with 589 tagged spruce trees. Standard deviation bars are shown.

The distribution of spruce diameter growth in the control plots was left-skewed, with growth increasing with increasing diameter from the one inch through the eight inch diameter classes, and then decreasing through the 14 inch diameter class (Figure 6). Average diameter growth of control plots ranged from 0.19 inch for the one inch diameter class to 0.43 inch for the eight inch diameter class. In the control plots, the standard deviation of average spruce diameter growth expressed in inches ranged from ±0.08 in the three inch diameter class to ±0.30 in the six inch diameter class.

The difference in average diameter growth of spruce between treatment and control plots ranged from -0.08 inch in the eight inch diameter class to 0.24 inch in the four inch diameter class (Figure 6).

For both treatment and control plots, the distribution of spruce diameter growth expressed as the percentage increase for each diameter class was right-skewed, with the greatest percentage growth in the smallest diameter classes (Figure 7). The shape of these growth curves was best described as a decreasing exponential function (treatment plots, r^2=0.9779; control plots, r^2=0.9623). The range of average diameter increase for spruce trees in the treatment plots was 2.0% in the 12 inch diameter class to 59.3% in the <1 inch diameter class. The range of average diameter increase for spruce trees in the control plots was 1.7% in the 14 inch diameter class to 16.2% in the one inch diameter class. In treatment plots, the standard deviation of average spruce diameter growth expressed as a percentage ranged from ±2.0 in the seven inch diameter class to ±6.0 in the two inch diameter class. In control plots, the standard deviation of average spruce diameter growth expressed as a percentage ranged from ±1.2 in the nine inch diameter class to ±7.5 in the one inch diameter class. The difference in average spruce diameter growth between treatment and control plots ranged from -1.1% in the eight inch diameter class to 14.5% in the one inch diameter class (Figure 7).

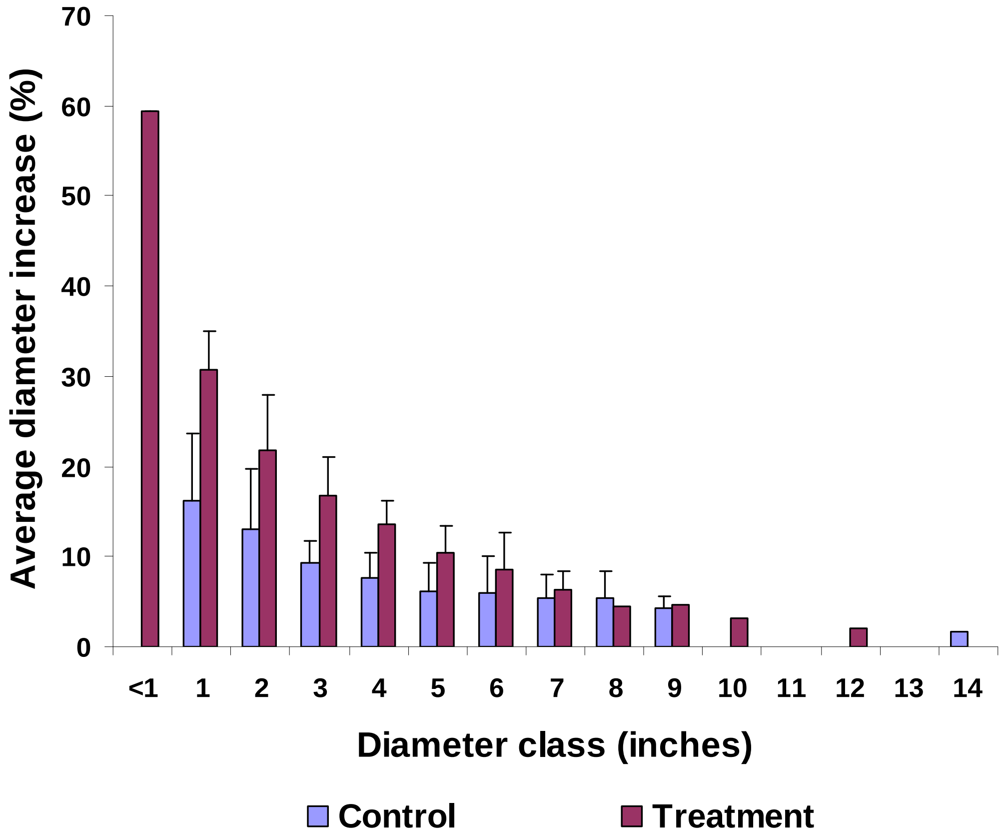

Figure 7. Average diameter growth of white spruce trees from 1998 through 2004 in unthinned control plots and pre-commercially thinned treatment plots. Diameter growth was expressed as the average percentage increase in diameter compared to the average 1998 tree diameter for each size class. Diameter classes are identified by their midpoints, with the exception of the <1 inch class, which includes spruce trees ≥4.5 feet tall with a diameter <0.5 inch. Average growth was calculated for four control plots (i.e. $n = 4$) with 1,212 tagged spruce trees and five treatment plots (i.e. $n = 5$) with 589 tagged spruce trees. Standard deviation bars are shown.

CONCLUSION

Pre-commercial thinning resulted in essentially unaltered species composition. Both treatment and control plots were largely dominated by white spruce, with the secondary tree component consisting of quaking aspen.

In general, pre-commercial thinning resulted in a flattening of the diameter class distribution of white spruce. Besides greatly reducing overall spruce density, the effect of pre-commercial thinning was the removal of trees in the smallest diameter classes, thereby increasing the proportion of larger diameter trees.

Annual mortality rates of white spruce were not significantly different between the unthinned control plots and the thinned treatment plots. Spruce mortality was low for both control and treatment plots, exceeding 1.0% per year only for one treatment plot for one of the time periods in which mortality was calculated.

Although overall mortality rates were low, mortality rates in thinned stands before the treatment plots were installed greatly exceeded the mortality of those same stands after monitoring began, indicating that pre-commercial thinning influenced tree mortality for several years. When thinning was initiated on the Native allotments, the slash that was generated quickly attracted northern spruce engraver beetles and the slash became infested with beetle larvae. In response to the elevated engraver beetle activity, several steps were taken to minimize further infestation. After these steps were taken, engraver beetle attacks on the residual spruce trees were minimized, resulting in reduced spruce mortality rates in the thinned treatment plots.

The average diameter growth of spruce trees in the thinned treatment plots exceeded the growth of spruce in the unthinned control plots. Diameter growth of white spruce, however, was not significantly different between the treatment and control plots.

ACKNOWLEDGMENTS

I would like to thank the United States Department of the Interior, Bureau of Indian Afffairs, Forest Development Program, and the Tanana Chiefs Conference Forestry Program for financial support provided for this project. I also thank Aaron, Daniel, Fabian, Graham, Jake, Karola, and Simone for their assistance. All aspects of this project, with the exception of this report, were conducted while the author was employed as the Research Forester by the Tanana Chiefs Conference Forestry Program.

LITERATURE CITED

Chapin, F.S, III, L.A. Viereck, P.C. Adams, K. Van Cleve, C.L. Fastie, R.A. Ott, D. Mann, and J.F. Johnstone. 2006. Successional processes in the Alaskan boreal forest. Pages 100-120 *in* Chapin, F.S., III, M.W. Oswood, K. Van Cleve, L.A. Viereck, and D.L Verbyla. Alaska's changing boreal forest. Oxford University Press, New York.

Daniel, W.W. 1990. Applied nonparametric statistics. Second edition. PWS-Kent Publishing Company, Boston.

Hibbs, D.E., W.H. Emmingham, and M.C. Bondi. 1989. Thinning red alder: Effects of method and spacing. Forest Science 35: 16-29.

Lamson, N.I. 1983. Precommercial thinning increases diameter growth of Appalachian hardwood stump sprouts. Southern Journal of Applied Forestry 7: 93-97.

Miller, R.E., E.L. Obermeyer, and H.W. Anderson. 1999. Comparative effects of precommercial thinning, urea fertilizer, and red alder in a Site II, coast Douglas-fir plantation. USDA Forest Service, Pacific Northwest Research Station, Research Paper PNW-RP-513.

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

Peltola, H., J. Miina, I. Rouvinen, and S. Kellomäki. 2002. Effect of early thinning on the diameter growth distribution along the stem of Scots pine. Silva Fennica 36: 813–825.

Peterson, J.A., J.R. Seiler, J. Nowak, S.E. Ginn, and R.E. Kreh. 1997. Growth and physiological responses of young loblolly pine stands to thinning. Forest Science 43: 529-534.

Rice, J.A., G.B. MacDonald, and D.H. Weingartner. 2001. Precommercial thinning of trembling aspen in northern Ontario: Part 1 – Growth responses. The Forestry Chronicle 77: 893-901.

Ruel, J.-C., C. Larouche, and A. Achim. 2003. Changes in root morphology after precommercial thinning in balsam fir stands. Canadian Journal of Forest Research 33: 2452-2459.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry. Second edition. W.H. Freeman and Company, New York.