REGENERATION OF MODERATE-YIELD CONIFER FORESTS AT FORDING COAL'S FORDING RIVER OPERATIONS

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ABSTRACT

The Fording River Mine, operated by Fording Coal Limited, is located in the Rocky Mountains of British Columbia at elevations ranging from 1650 to 2285 meters. Reclamation research has been conducted at the mine since 1969 to develop techniques for restoring the forest resource and critical wildlife habitat. In 1986, research trials were initiated to test the effects of delayed legume interseeding on the survival and growth of conifer seedlings in plantations on reclaimed coal waste rock. Previous reclamation work had indicated that planting conifer seedlings into an existing cover of agronomic grasses and legumes resulted in high seedling mortality, due to competition for moisture and nutrients. Delayed legume interseeding was tested as a technique that would allow early establishment of conifer seedlings without excessive competition, but would subsequently provide increased soil nitrogen capital through symbiotic nitrogen fixation. Analysis of different lengths of interseed delays on this trial indicates that the best nutritional status and growth performance are achieved through a two-year delay, which allows sufficient time for seedling establishment in the absence of ground-cover competition, but quickly provides the benefits of enhanced nutritional status, as well as providing erosion protection, forage, and increased habitat diversity. This paper presents the 15-year results from these trials.

INTRODUCTION

The Fording River Mine, operated by Fording Coal Limited, is located near Elkford in the Rocky Mountains of southeast British Columbia. The mine site encompasses an area of approximately 3160 hectares, of which 550 have been reclaimed to date. Mining operations commenced in 1971 with the first coal shipment in early 1972. The mine operation is within the Engelmann Spruce – Subalpine Fir biogeoclimatic zone, and ranges in elevation from 1650 to 2285 meters above sea level. The valley bottom and lower slopes are mainly forested with Engelmann spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*), with minor occurrences of subalpine fir (*Abies bifolia*) and Douglas-fir (*Pseudotsuga menziesii*). Occasional stands of alpine larch (*Larix lyallii*) occur on north and east slopes at elevations above 1800 meters. Stands of spruce, lodgepole pine, whitebark pine (*Pinus albicaulis*), and trembling aspen (*Populus tremuloides*), mixed with grass-shrub communities occur on south and west aspects.

The Canada Land Inventory classed the upper Fording River area into various resource uses, including Moderate Yield Forest (3.6-4.9 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) on the valley bottom and lower mountain slopes. Reclamation research has been conducted at the mine since 1969, with a major focus since 1980 being the development of techniques for restoring productive forest stands on reclaimed sites.

The results of early reforestation research where conifer seedlings were planted into a cover of agronomic grasses and legumes showed high seedling mortality, most likely due to competition for moisture and nutrients from the agronomic cover. Although high seedling survival is important to successful reforestation, other considerations such as the contribution of agronomic species to the stabilization of surface erosion on slopes, improvement of soil nitrogen capital and contributions to soil organic matter content could not be overlooked. Additional research was undertaken to determine the optimal timing for planting conifers with an agronomic legume ground cover. The legume ground cover was investigated because legume species have the capacity for symbiotic nitrogen fixation, and nitrogen is the primary nutritional limitation to forest production in British Columbia (Ballard and Carter, 1985), both in natural forest stands and on disturbed sites such as cutblocks and mine sites. Fertilization is the conventional option for addressing nitrogen limitations in forest stands, but is not likely cost effective on severely disturbed sites. Although previous research has shown substantial nitrogen fixation by legumes in forest plantations, at the time of Fording's trial initiation very little information was available on the specific effects of a legume ground cover on conifer plantation survival and growth performance (Trowbridge, 1992).

METHODS

Replicated trials to test legume interseeding of conifer plantations were installed in 1986 on resloped waste rock at an elevation of approximately 1700 meters. A total of eight plots were installed in the trial, with 500 lodgepole pine and 600 Engelmann spruce planted in each plot at spring and fall planting dates between 1986 and 1988. Four of the eight plots were then interseeded with birdsfoot trefoil (*Lotus corniculatus*) in May 1990, while the other four plots remained as unseeded controls. The combination of different plant dates with a common seeding date yielded the following delays in seeding following planting: 2, 2.5, 3, 3.5, and 4 years for spruce; and 2, 2.5, 3, and 3.5 years for pine. The interseeded replicates were fertilized at the time of seeding, with all plot replicates fertilized in spring of the following year. Fertilizer used was monoammonium phosphate (12-51-0) applied at a rate of 400 kg/ha at each application (for further details of plot installation, see Fording Coal Ltd., 1989 and 1997.)

In 1998, the trial plots were selectively thinned to alleviate excessive competition caused by the extremely dense initial planting density (10,000 stems/hectare). Post-thinning stand density is approximately 1600 stems/hectare. Thinned stems and slash were moved off of plot locations to avoid confounding the effects of the interseeding treatments. Observations during 2001 monitoring indicate that the conifers on this site have responded well to release following thinning, with the pre- and post-thinning years clearly visible in the growth of the retained trees.

Monitoring of survival and growth parameters on this trial was conducted annually between 1986 and 1996. After the 1996 monitoring, assessment frequency was reduced to a five-year interval, to reflect the changing emphasis in this trial from survival monitoring to growth performance monitoring. The most recent monitoring was conducted in 2001. Assessment has generally been conducted in late summer. In 2001, each tree in the trial was measured for stem diameter at breast height (1.3 m), total height, and age above breast height (to allow determination of site index). Diameter was measured with sliding calipers, total height was measured with a telescoping height pole, and age at breast height was determined by annual whorl count. In addition, a foliar sample was taken from each tagged tree, to form a composite sample derived from 15-20 trees for each treatment replicate. Foliar samples were taken from current year’s growth in the third quarter of the tree as measured from the ground. All sampling and analytical techniques follow Ballard and Carter, 1985.Site indices were determined from the largest-diameter candidate tree per treatment replicate, and were calculated using SiteTools Version 3.2m software developed by the B.C. Ministry of Forests (calculations based on growth-intercept height equations developed by Nigh, 1997 [lodgepole pine] and Nigh, 1999 [white spruce]). The number of years required for trees to reach breast height was determined by taking the count for years above breast height and subtracting this value from the tree’s known total age.

RESULTS

Parameters that have been monitored since trial installation include seedling survival and indicators of seedling growth performance, including total height, annual height increment, basal diameter, and foliar nutrient status.

Survival

Results from adjacent legume-interseeded conifer trials on coal waste rock had indicated that survival of conifers increased if interseeding was delayed by 1-2 years following planting, as opposed to seeding prior to or at the time of planting. One of the objectives of the 1986-1988 trials was to determine if a longer interseed delay (2-4 years) would further improve or otherwise affect survival. Results of monitoring on this trial between 1987 and 1996 indicated that the survival of conifers is not increased using interseed delays longer than two years.

Growth Performance

Results from monitoring of growth performance indicators in the first ten years of this trial indicated that plant nutrition, total height, annual height increment, and basal diameter were all increased on the interseeded treatments, in comparison to the unseeded controls. Average improvement in height growth on the interseeded replicates was 20 percent for pine and 28 percent for spruce, versus the unseeded plots.

Results from the 2001 assessment of this trial are presented graphically in Figure 1. These results continue to show significantly increased growth performance on the interseeded plots, in comparison to the unseeded controls. Mean increases in diameter growth on the interseeded replicates versus controls were 83 percent for spruce and 65 percent for pine (as compared to 3-12 percent and 10-17 percent increases for spruce and pine, respectively, as measured in 1996). Mean increases in total height on the interseeded replicates were 44 percent for spruce and 36 percent for pine (versus 28 percent and 20 percent increases for spruce and pine, respectively, as measured in 1996). These larger percent increases measured in 2001 indicate a continuing effect of interseeding treatments on diameter and total height growth since 1996.

For both pine and spruce, there was a decrease in the years required for trees to reach breast height on the interseeded treatments, in comparison to the unseeded controls. For both species, the average time to breast height on interseeded plots was 10 years, versus 14 years for spruce and 13 years for pine on the unseeded plots. This finding reflects the positive effect of interseeding on early growth, which results in a 3-4 year advantage for young interseeded seedlings, and thus more rapid stand regeneration.

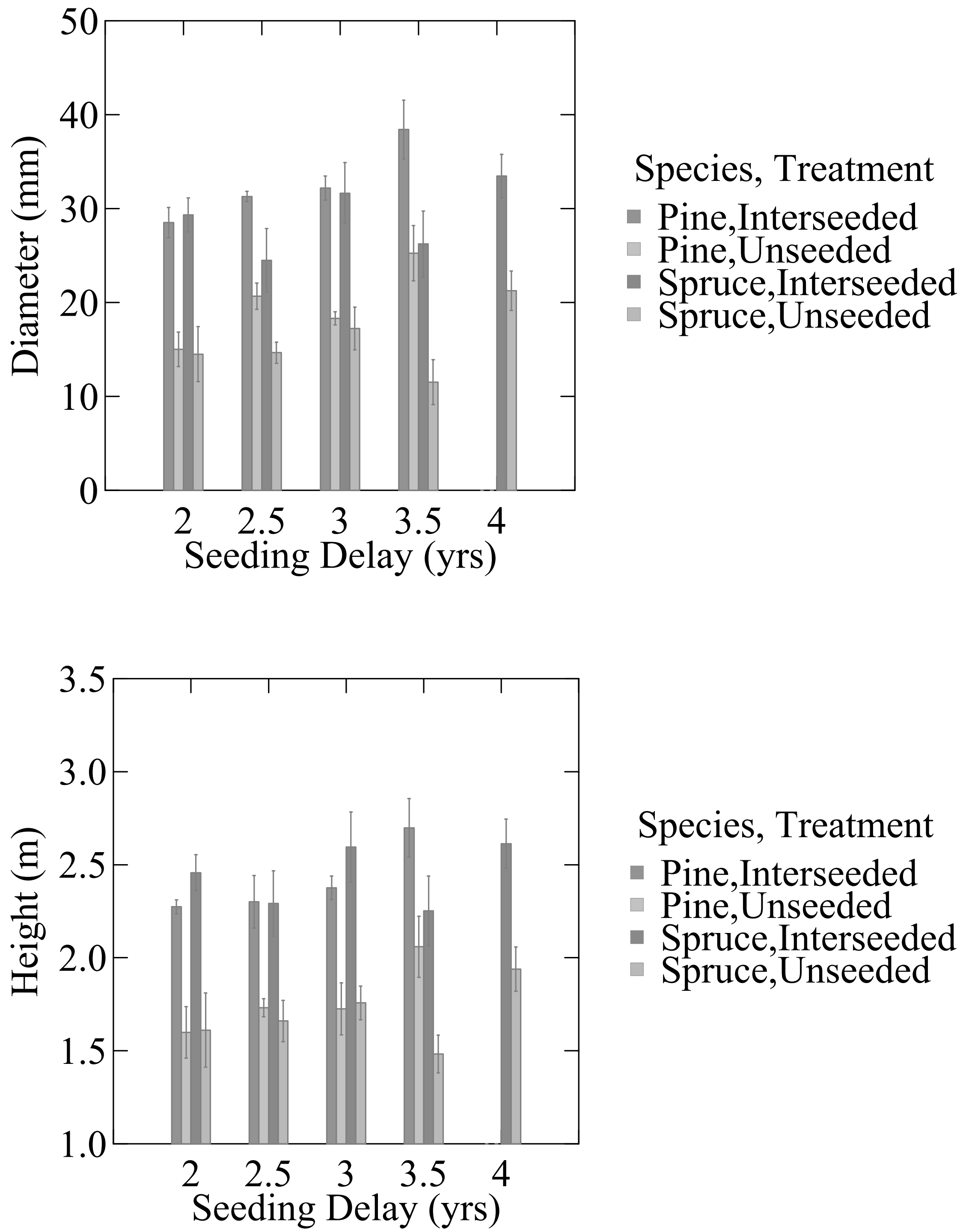

FIGURE 1 Growth Performance of Conifers on the Legume Interseeding Trial

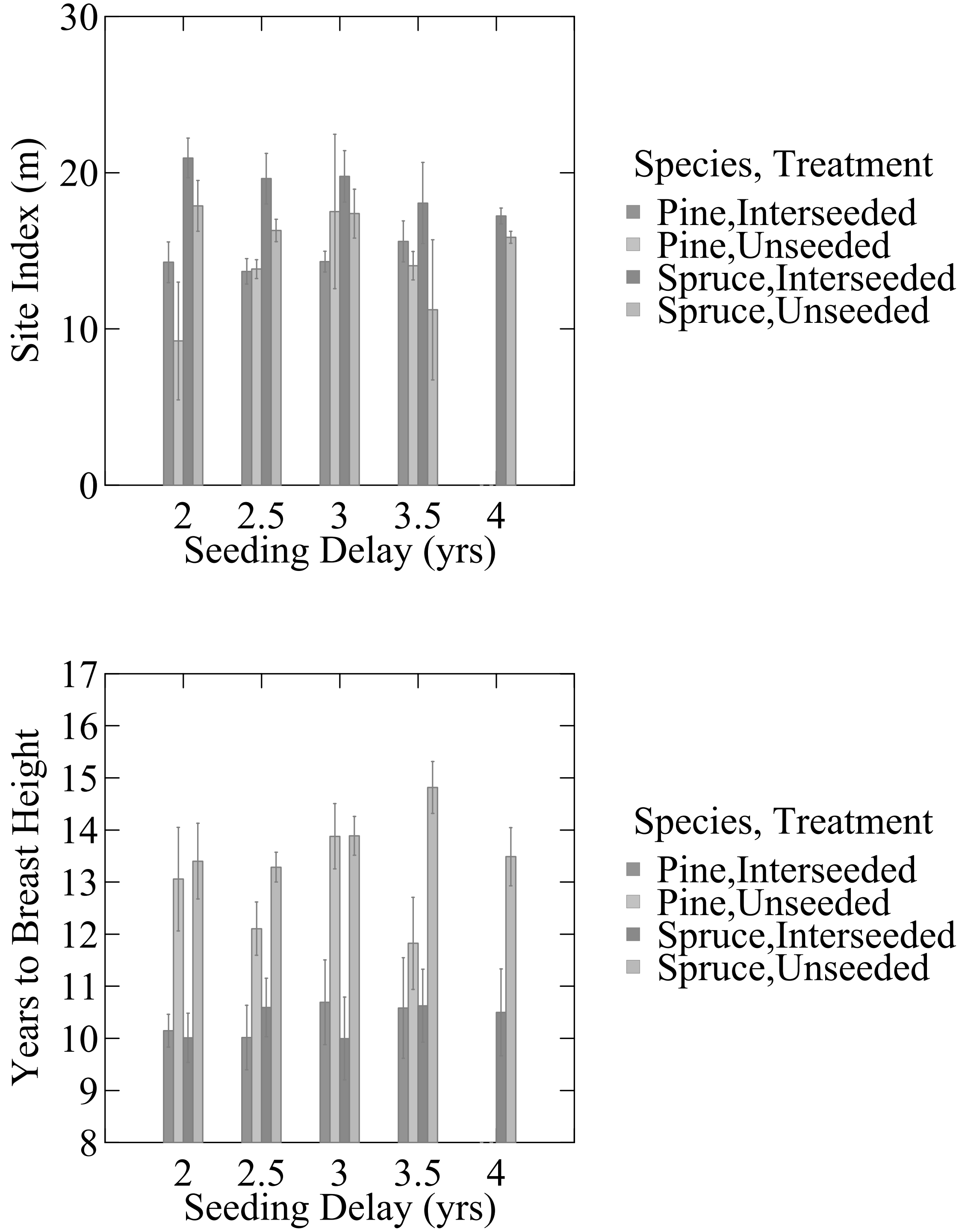

FIGURE 1 (cont'd.) Growth Performance of Conifers on the Legume Interseeding Trial

Site index data show a significant positive effect of interseeding for spruce, with site index averaging 19.1 meters on interseeded plots versus 15.7 meters on unseeded plots, but not for pine, which showed less than a one-meter increase in site index on interseeded treatments. These findings contradict information provided by the Ministry of Forests' site index species conversion tool, which suggests that the site index for pine on a given site will be slightly more than the site index for spruce on the same site. These findings also contradict current height and age data collected in the 2001 trial monitoring, which show equal growth performance of spruce and pine both before and after reaching breast height (e.g. spruce and pine show the same mean total height and the same mean years to breast height). This information indicates that the site index curves developed for the province expect more rapid early growth for pine than for spruce, as has been documented on cutblocks adjacent to the Fording River mine site. These curves do not appear to apply perfectly to reclaimed coal spoil, which produces roughly equal growth performance in pine and spruce for the first 13-15 years after planting, according to the current trial data. This indicates that the long-term growth performance of conifers on reclaimed coal spoil will have to be monitored to determine the limitations of site index projections for older reclaimed stands.

During the 2001 monitoring, presence and origin of damage to measured trees was recorded, as this damage disqualifies the tree for determination of site index. Approximately 5-13 percent of both spruce and pine trees in these plots had two or more leaders (forked stems), likely resulting primarily from mechanical damage such as snow press. An additional 10-13 percent of pines had significant stem damage resulting from antler rubbing. This damage is likely caused by elk, which use the C Spoil site heavily. Stem damage resulting from antler rubbing was not observed on spruce.

<u>Nutrient Status</u>

Analysis of foliar nutrient data from the legume interseeding trials indicates that nitrogen, phosphorus, potassium, sulfur, copper, and iron status are increased on interseeded plots relative to unseeded controls, while boron, calcium, magnesium, manganese, and zinc status is better on the unseeded plots. Of these elements, nitrogen, phosphorus, and boron are of particular interest, due to the fact that the data show deficiencies for these elements in comparison to published standards (Ballard and Carter, 1985). These deficiencies are summarized in Table 1.

TABLE 1 Delayed Seeding Trial Foliar Nutrient Status					
Nutrient	Species	Treatment	Measured Value	Comparison to Published Standard	Measured Local Cutblock Values
Nitrogen (%)	Spruce	Interseeded	1.17	Severely Deficient	
		Unseeded	1.05	Severely Deficient	0.94
	Pine	Interseeded	1.08	Severely Deficient	
		Unseeded	0.94	Very Severely Deficient	1.02
Phosphorus (%)	Spruce	Interseeded	0.22	Adequate	
		Unseeded	0.17	Adequate	0.19
	Pine	Interseeded	0.16	Adequate	
		Unseeded	0.12	Slight-Moderate Deficiency	0.15
Boron (ppm)	Spruce	Interseeded	13.3	Possible Deficiency	
		Unseeded	17.2	Deficiency Unlikely	15.0
	Pine	Interseeded	11.6	Possible Deficiency	
		Unseeded	15.4	Deficiency Unlikely	19.2

On interseeding treatments, mean foliar nitrogen concentrations are increased by approximately 11 percent for spruce and 15 percent for pine, in comparison to unseeded controls. This result indicates that the nitrogen-fixing ground cover is continuing to enhance the nitrogen status of interseeded sites. This enhancement is important because nitrogen is likely the nutritional factor that is most influential on forest productivity both on reclaimed coal spoil and in adjacent cutblocks. Improved nitrogen status on interseeded treatments is likely the primary reason contributing to better growth performance of conifers on these sites. Improved foliar nitrogen in conifers in legume-interseeded cutblock plantations has been documented by Trowbridge (1992), who also measured significant improvements in forest floor total and mineralizable nitrogen in legume-interseeded plots. It should be noted that although the foliar nitrogen levels reported in Table 1 for conifers on reclaimed coal spoil are classified as deficient in comparison to published provincial standards, they are substantially higher than those measured on adjacent forest cutblocks in the same period. This indicates that the nitrogen status on the interseeded plots is currently better than on comparable cutblock regeneration.

Foliar phosphorus levels are increased by approximately 29 percent for spruce and 33 percent for pine, in comparison to the unseeded controls. In the case of pine, this increase is enough to alleviate the phosphorus deficiencies reported on the unseeded plots. The reasons for this increase are unknown. It is possible that the higher foliar phosphorus concentrations on the interseeded plots reflect carry-over effects from the original fertilization treatments in 1990. It is also possible that there are soil chemical or biological differences on the interseeded treatments that increase availability of phosphorus for plant uptake. Foliar phosphorus levels on the interseeded trial plots are similar to those documented on the off-site cutblocks.

Foliar boron levels reported on the interseeded plots are approximately 29 percent lower for spruce and 33 percent lower for pine than those measured on the unseeded plots. For both species, these lower levels suggest that a boron deficiency is possible on the interseeded plots, whereas on the unseeded treatments it is unlikely. The probable mechanism behind these lower levels is the higher nitrogen status on the interseeded sites, which by increasing tree growth causes greater demand for other nutrients, to the point that they may become limiting to growth. However, the boron levels measured on the interseeded plots suggest only a possible or slight deficiency, and are not likely significantly limiting productivity of these stands at this time. The boron levels reported on the interseeded plots are lower than those reported on adjacent cutblocks.

DISCUSSION

Results from the 2001 assessment of the legume interseeding conifer trials indicate significantly increased overall growth performance and macronutrient status on interseeded plots, in comparison to unseeded controls. However, statistical analysis of survival, growth, and nutritional data by length of seeding delay generally indicates no significant differences. Previous monitoring has indicated that survival of spruce is increased through a two-year seeding delay, but that longer delays have no identifiable effect on survival. Graphical interpretation of the 2001 growth and nutritional data indicates that optimal spruce performance has been achieved on plots that were seeded two years after planting. These findings suggest that this species needs only a short window for establishment without competition, and then benefits from a rapid enhancement of site nutrient status through legume interseeding and fertilizing. As with spruce, no effects on pine survival were found for seeding delays longer than two years. Analysis of the growth and nutrition data from 2001 monitoring indicates that pine nutritional status is best with the short-delay treatments, but that growth performance is better on the long delay (3.5-year) treatment. However, it is possible that this latter effect is due not to interseeding delay length, but to absolute tree age. The trial plots were planted at an extremely high density, and pine is known to be susceptible to growth stagnation at high densities. Thus it is likely that the oldest pine seedlings in this trial suffered the least growth stagnation, as they were taller and had more developed root systems than the younger treatments, and thus did relatively better in inter-tree competition for light and nutrients.

Based on the above findings, it appears that a two-year seeding delay is the best interseed timing for enhancing conifer survival, nutritional status, and growth performance on reclaimed coal spoil.

CONCLUSIONS

Monitoring on the legume interseeding trial since installation in 1986 has consistently indicated an increase in conifer macronutrient status and growth performance resulting from interseeding treatment. This increase is still significant fifteen years after trial installation, and is in some cases greater than at earlier assessments. This finding indicates the continuing positive effects of the interseeded legume ground cover on forest productivity on these sites. Although this trial was not intended to determine potential forest productivity on reclaimed coal spoil (and probably reflects this productivity poorly, due to extremely high stand densities prior to thinning in 1998), the mean site index of 19.1 meters measured for spruce on this trial is similar to the mean site index of 19.5 meters measured on two off-site cutblocks (note that elevations of these cutblocks are 45 to 200 meters greater than the interseeding trial). Analysis of different lengths of interseed delays on this trial indicates that the best nutritional status and growth performance are achieved through a two-year delay, which allows sufficient time for seedling establishment in the absence of ground-cover competition, but quickly provides the benefits of enhanced nutritional status, as well as providing erosion protection, forage, and increased habitat diversity.

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