# Regeneration alternatives for upland white spruce after burning and logging in interior Alaska

**R.V. Densmore, G.P. Juday, and J.C. Zasada**

**Abstract**: Site-preparation and regeneration methods for white spruce (*Picea glauca* (Moench) Voss) were tested near Fairbanks, Alaska, on two upland sites which had been burned in a wildfire and salvage logged. After 5 and 10 years, white spruce regeneration did not differ among the four scarification methods but tended to be lower without scarification. Survival of container-grown planted seedlings stabilized after 3 years at 93% with scarification and at 76% without scarification. Broadcast seeding was also successful, with one or more seedlings on 80% of the scarified 6-m$^2$ subplots and on 60% of the unscarified subplots after 12 years. Natural regeneration after 12 years exceeded expectations, with seedlings on 50% of the 6-m$^2$ subplots 150 m from a seed source and on 28% of the subplots 230 m from a seed source. After 5 years, 37% of the scarified unsheltered seed spots and 52% of the scarified seed spots with cone shelters had one or more seedlings, but only 16% of the unscarified seed spots had seedlings, with and without funnel shelters. Growth rates for all seedlings were higher than on similar unburned sites. The results show positive effects of burning in interior Alaska, and suggest planting seedlings, broadcast seeding, and natural seedfall, alone or in combination, as viable options for similar sites.

**Résumé** : La préparation de terrain et les méthodes visant la régénération de l'épinette blanche (*Picea glauca* (Moench) Voss) ont été étudiées près de Fairbanks, en Alaska, sur deux stations des hautes terres qui avaient subi un incendie forestier et avaient fait l'objet d'une coupe de récupération. Après 5 et 10 ans, la régénération d'épinette blanche ne différait pas selon les quatre méthodes de scarifiage mais tendait à être moins abondante sans scarifiage. Après 3 ans, la survie des plants en récipients s'est stabilisée à 93% avec scarifiage et à 76% sans scarifiage. L'ensemencement à la volée a aussi été efficace, au moins un semis étant présent dans 80% des placettes de 6 m$^2$ ayant été scarifiées et dans 60% des placettes non scarifiées après 12 ans. La régénération naturelle après 12 ans dépassait les attentes, avec des semis dans 50% des placettes de 6 m$^2$ situées à 150 m d'une source de semences et dans 28% de celles situées à 230 m d'une source de semences. Après 5 ans, 37% des placeaux d'ensemencement scarifiés non abrités et 52% des placeaux scarifiés avec abris coniques présentaient un ou plusieurs semis mais seulement 16% des placeaux non scarifiées contenaient des semis, sans égard à la présence d'un abri. Les taux de croissance de tous les semis étaient supérieurs à ceux observés sur stations semblables non brûlées. Les résultats démontrent les effets positifs du feu en Alaska de l'intérieur et suggèrent que la plantation, l'ensemencement à la volée et l'ensemencement naturel, seuls ou en combinaison, constituent des options viables pour des stations comparables.

[Traduit par la rédaction]

## Introduction

White spruce (*Picea glauca* (Moench) Voss) occurs in productive stands on upland south-facing slopes or on floodplains in interior Alaska. On upland sites, white spruce may form pure stands or be mixed with varying amounts of hardwoods, primarily paper birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx.). Natural regeneration of white spruce usually follows stand-replacing fires, with a fire return interval of 150–250 years (Lutz 1956; Viereck 1975; Youngblood 1995). White spruce does not always regenerate to adequate levels following fire and may be replaced by other species (Viereck and Schandelmeier 1980; Foote 1983). Seedfall and suitable microsites for seedling establishment are the most common limiting factors for natural regeneration (Zasada 1985; Zasada et al. 1992; Coates et al. 1994).

Natural regeneration of white spruce is often inadequate after harvesting of white spruce, both in Alaska and throughout the range of white spruce (Zasada and Gregory 1969; Dobbs 1972; Fox et al. 1984; Zasada 1986; Zasada et al. 1992; Coates et al. 1994). To compensate for unpredictable natural seedfall, white spruce seeds may be artificially sown at desirable densities or seedlings planted. Planted seedlings generally overcome site conditions that limit germination and initial establishment. Site preparation increases the number of microsites suitable for seedling establishment by removing organic layers, reducing competing vegetation, and

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altering microtopography (Zasada and Grigal 1978; Orlander et al. 1990).

Combinations of direct seeding, planting, and site-preparation methods have been tested and used operationally to increase white spruce regeneration on harvested sites throughout Canada (Stiell 1976; Gardner 1983; McMinn 1982, 1986; Wood and Dominy 1988; Dominy and Wood 1986; Coates et al. 1994). In interior Alaska, combinations of spot seeding, planting, and site preparation were tested following harvesting on a floodplain site (Youngblood and Zasada 1991). On harvested upland sites, blade scarification was used to increase the number of seedlings from natural seedfall (Zasada and Grigal 1978; Wurtz and Zasada 1987; Packee 1990), and spot seeding with and without plastic shelters was tested on scarified and unscarified microsites (Putman and Zasada 1986). However, treatment combinations comparing direct and natural seeding, planting, and site-preparation methods have not been systematically evaluated on an operational scale on upland burned or harvested sites in interior Alaska.

The 1983 Rosie Creek wildfire near Fairbanks, Alaska, burned productive white spruce stands, which were then salvage logged, providing us with an excellent opportunity to study white spruce regeneration (Juday 1985*a*, 1985*b*). We selected two study sites within the burn: one site dominated by white spruce before the fire and the other dominated by paper birch with varying amounts of white spruce. On both sites, our study compared the survival, distribution, and growth of white spruce seedlings after 5, 10, and 12 years among all or a subset of treatment combinations of five site-preparation methods (single disc trench, double disc trench, blade, patch, and unscarified) and five regeneration methods (planting container-grown seedlings, unsheltered seed spots, scarified seed spots with cone shelters or unscarified spots with funnel shelters, broadcast seeding, and natural seedfall). We also measured seedling microsite dimensions and vegetative cover and evaluated the effect of these microsite characteristics on seedling survival and growth.

## Study sites

The two study sites are within the Bonanza Creek Experimental Forest near Fairbanks, Alaska. The soil on both sites is Fairbanks silt loam and consists of deep, well-drained, nearly level to steep silty soils that formed in loess parent material (Furbish and Schoephorster 1977). All trees on both sites were killed by crown fire during the Rosie Creek fire in late May 1983 (Juday 1985*a*).

The ridgetop study site (64°44′N, 148°19′W, elevation 310–340 m) is level to gently sloping. A mixed stand of paper birch and white spruce was present prior to the fire. Salvage logging was completed in August 1985. Logging had little effect on vegetative cover. Dense, vigorous stands of herbaceous plants, dominated by *Calamagrostis canadensis* (Michx.) Beauv. (bluejoint reedgrass), *Epilobium angustifolium* L. (fireweed), and *Equisetum pratense* L. (horsetail), established during the three growing seasons following the fire and prior to site preparation.

The slope study site (64°44′N, 148°17′W, elevation 200–300 m) is located on a spur ridge which runs east-southeast from the main Bonanza Creek ridge. Most of the site is on south-southeast facing slopes. The site was dominated by mature white spruce prior to the fire, with scattered aspen and paper birch. Salvage logging was completed in August 1985. Logging reduced vegetative cover and exposed some mineral soil. At the time this study was begun, herbaceous plant cover, particularly of *C. canadensis*, was sparse compared with the ridgetop site.

## Materials and methods

We used a replicate block split-plot design. Each study site included three replicate 4.0-ha blocks, which were divided into five 0.8-ha plots. Site-preparation treatments were randomized among the 0.8-ha plots within replicate blocks. Each 0.8-ha plot was divided into five 0.16-ha plots. Regeneration treatments were randomized among 0.16-ha plots within 0.8-ha plots. Each 0.16-ha regeneration plot was divided into two hundred twenty-six 6.0-$m^2$ subplots.

### Site-preparation methods

We tested five site-preparation treatments: single disc trench, double disc trench, patch, blade, and unscarified. The unscarified plots had small areas of mineral soil exposed by the fire and subsequent salvage logging.

Site preparation was conducted August 22 to September 12, 1985. The TTS-35 Disc Trencher created two furrows 0.5 m wide and 2.1 m apart. For the single disc trench treatment, we scarified with parallel passes to expose mineral soil on 15% of the treated area. For the double disc trench treatment, we repeated the disc trencher scarification in a pattern perpendicular to the first scarification. This "double disc" treatment exposed mineral soil on approximately 25% of the area and created different microsites where furrows intersected. A Bracke-type patch scarifier was used to produce patches of mineral soil approximately 0.3 × 0.6 m in size and 2.1 m apart. This "patch" treatment exposed mineral soil on 10% of the treated area. We blade scarified with a crawler tractor bulldozer to produce strips of mineral soil which ran the length of the plot but were interrupted at irregular intervals by the debris piles. This "blade" treatment exposed mineral soil on 29% of the treated area. The microtopography around seedlings is shown for each site-preparation method in Table 1.

### Regeneration methods

We tested five regeneration methods: planted seedlings, unsheltered seed spots, scarified seed spots with cone shelters or unscarified seed spots with funnel shelters, broadcast seeding, and natural seedfall. For seedlings and direct seeding, we combined six seed lots, which were collected in 1983 in unburned areas near the study sites.

White spruce seedlings were grown at the Alaska State Forest Nursery. Seeds were planted in late February 1984 in 65-$cm^3$ Ray Leach containers, grown in the greenhouse until late May 1984, hardened off, moved outside at the nursery, shipped in box containers to Fairbanks in early June 1986, and stored in the shade until planted. We planted seedlings on the slope study site and on replicate block 1 of the ridgetop study site June 2–12, and the remainder of the ridgetop site June 30 – July 3. One seedling was planted in each 6.0-$m^2$ subplot. Seedlings were planted on the sides of scarified trenchs, and within 0.5 m of the edges of patch and blade scarified areas (Table 1).

We sowed the unsheltered seed spots, seed spots with cone and funnel shelters, and broadcast seeding treatment plots May 16–30, 1986. For unsheltered spots, we dispensed 5–10 seeds from a shaker. For sheltered spots, we sowed seeds with a tool that dispensed three to eight seeds and inserted a photodegradable, translucent, plastic seed shelter into the soil. On scarified spots, the seeds were under a Cerkon cone (Putman and Zasada 1986), which was open at the tip and pressed into the soil at the bottom. On unscarified spots, the seeds were within a Cerbel funnel whose open tip was inserted into the organic layer as close to mineral soil as possible. Each 6.0-$m^2$ subplot contained one seed spot. The

**Table 1.** Scarified microsite dimensions, and microsite vascular plant cover of container-grown white spruce seedlings two growing seasons after scarification, by site-preparation method and site.

| Site preparation method | Distance (cm)* | | | Cover (%)** | | | |
|---|---|---|---|---|---|---|---|
| | Depth | Closest edge | Opposite edge | CC | EP | EA | Total |
| **Ridgetop site** | | | | | | | |
| Single disc | 16*ac* | 20*b* | 39*b* | 22*a* | 22*a* | 4*ab* | 52*ab* |
| Double disc | 19*a* | 20*b* | 39*b* | 22*a* | 18*a* | 3*b* | 47*ab* |
| Patch | 17*a* | 28*ab* | 52b | 16*a* | 14*a* | 3*ab* | 34*b* |
| Blade | 18*a* | 38*a* | 99*a* | 14*a* | 13*a* | 2*b* | 32*b* |
| Unscarified | — | — | — | 21*a* | 22*a* | 9*a* | 56*a* |
| **Slope site** | | | | | | | |
| Single disc | 14*b* | 18*b* | 32*b* | 6*a* | 16*a* | 4*a* | 31*b* |
| Double disc | 16*ab* | 18*b* | 36*b* | 9*a* | 17*a* | 3*a* | 36*b* |
| Patch | 14*b* | 19*b* | 35*b* | 10*a* | 20*a* | 4*a* | 39*b* |
| Blade | 19*a* | 34*a* | 71*a* | 8*a* | 19*a* | 4*a* | 35*b* |
| Unscarified | — | — | — | 11*a* | 33*a* | 6*a* | 56*a* |

**Note:** Values are means ± SE from three plots. Values within a column with the same letter are not significantly different at the 0.05 level of probability.

*Depth is distance from top of mineral soil layer down to seedling root collar; closest edge is distance from the seedling to the closest edge of the scarified trench, patch, or bladed strip; and opposite edge is the distance from the seedling to the opposite side of trench, patch, or bladed strip.

**Cover on seedling-centered 0.5 $m^2$ circular plots. CC, *Calamagrostis canadensis*; EP, *Equisetum pratense*; EA, *Epilobium angustifolium*; total, all vascular plants, including shrubs and tree seedlings.

plastic shelters disintegrated after the first growing season. For broadcast-seeded plots, we sowed 1.0 kg/ha with a cyclone seeder evenly over each 0.16-ha plot.

## Evaluation

For measurements of white spruce regeneration, we evaluated fifty 6 $m^2$ subplots in the center of each 0.16-ha plot. The planted seedling or seed spot in each of the 50 subplots was marked with numbered tags on stakes at time of planting or sowing.

We counted the number of live container-grown seedlings in late July 1986. We then transferred markers from dead seedlings to live seedlings to provide a sample of 50 live seedlings for measurements of seedling size, and we measured the height and diameter (5 cm above the stem base) of each marked seedling. We measured survival in August 1987, 1988, 1989, and 1990, and in 1988, 1989, and 1990 we also remeasured the height and diameter of the live marked planted seedlings. After 5 years, many of the seedlings on the ridgetop site in two replicate blocks were stunted. These two blocks had been planted 3 weeks after the slope site and the first ridgetop replicate block were planted. We excavated vigorous and stunted seedlings. The plants were examined by J. McBeath (unpublished data), who found that the roots of the stunted seedlings were infected with a common greenhouse fungus (*Pithium* sp.).

We recorded the number of live seedlings at each marked seed spot in August 1986, 1987, 1988, 1989, and 1990, and we also measured the height of the tallest seedling on each marked seed spot in 1988, 1989, and 1990.

On the broadcast-seeded plots, we marked the seedling closest to the center of each of the fifty 6.0-$m^2$ subplots with a numbered tag on a stake in August 1986. On scarified plots, we marked seedlings only in the scarified areas. In 1987 and 1990, we recorded the marked seedlings as dead or alive and measured height. In 1987, we also estimated total seedling density on scarified plots by locating and counting all seedlings in the scarified areas of five randomly selected 6.0-$m^2$ subplots.

In August 1995, after 10 growing seasons, we scaled down our evaluation because of limited funding. We selected the single disc, blade, and unscarified site-preparation treatments. On these site-preparation treatments, we evaluated planted seedlings only on the slope site, because planted seedlings on the ridgetop site had been affected by the root pathogen. We measured the height and diameter of each live planted seedling. We evaluated the unsheltered seed spots on both sites and the sheltered seed spots only on the ridgetop site. We recorded the number of live seedlings at marked spots and measured the height of the tallest live seedling at each spot. We classified all seedlings as free-to-grow or as shaded by competing vegetation. Free-to-grow seedlings were defined as having (*i*) no herbs or low shrubs taller than the seedling within 0.5 m of top of seedling and (*ii*) the seedling not under canopy of tall shrub (alder or willow) or tree (aspen or paper birch).

In August 1997, after 12 growing seasons, we again had limited funding for evaluation. We focused on measuring the broadcast-seeded and natural-seedfall plots. These regeneration methods had been very difficult to evaluate accurately in earlier years when the seedlings were hidden in the vegetation. In 1997, we evaluated only the single disc and unscarified site-preparation methods. For both broadcast-seeding and natural-seedfall plots, we counted all the white spruce seedlings on both scarified and unscarified areas of each of the fifty 6.0-$m^2$ subplots and marked each seedling with a numbered tag. The natural seedfall treatment plots contained only seedlings originating from seed dispersed from unburned trees on the edge of the study area. The broadcast-seeded plots contained seedlings originating from the broadcast seeding and also seedlings originating from natural seedfall. We counted and marked all the seedlings in the broadcast-seeded plots because we could not distinguish between seedlings originating from broadcast seeding and seedlings originating from natural seedfall. We classified all seedlings as free-to-grow or as shaded by competing vegetation, as described above. We also measured the distance from the center of each broadcast-seeded and natural-seedfall plot to the nearest edge of the burn with live mature white spruce.

## Microsite measurements

At the end of the 1987 growing season, we randomly selected 10 subplots with live, marked seedlings in each plot with planted seedlings or unsheltered seed spots. For each planted seedling in a scarified plot, we measured three microtopographic characteristics: the vertical distance from the top of the mineral soil layer down to

**Table 2.** Results of an ANOVA in a replicate block split-plot design for percentage of subplots with one or more seedlings, followed by comparison of means for treatments which differed significantly.

(A) ANOVA results.

| | Ridgetop | | | Slope | | |
|---|---|---|---|---|---|---|
| Source of variation | df | *F* | $p > F$ | df | *F* | $p > F$ |
| **Five years** | | | | | | |
| Block (B) | 2 | 0.82 | 0.4512 | 2 | 0.65 | 0.5289 |
| Site preparation (SP) | 3 | 1.35 | 0.3429 | 3 | 2.21 | 0.1882 |
| Regeneration (R) | 3 | 38.81 | 0.0001 | 3 | 15.63 | 0.0001 |
| R × SP | 9 | 0.85 | 0.5832 | 9 | 0.24 | 0.9838 |
| **Ten years** | | | | | | |
| Block (B) | 2 | 1.23 | 0.3826 | 2 | 0.30 | 0.7588 |
| Site preparation (SP) | 1 | 2.06 | 0.2879 | 1 | 3.33 | 0.2097 |
| Regeneration (R) | 1 | 0.99 | 0.3753 | 1 | 184.00 | 0.0002 |
| R × SP | 1 | 0.63 | 0.4711 | 1 | 1.66 | 0.2668 |

(B) Comparison of means.

| Regeneration method | Ridgetop | Slope |
|---|---|---|
| **Five years** | | |
| Unsheltered seed spots | 27*c* | 47*b* |
| Seed spots with shelter | 48*b* | 56*b* |
| Broadcast seeded | 86*a* | 84*a* |
| Planted seedlings | 93*a* | 92*a* |
| **Ten years** | | |
| Unsheltered seed spots | | 34*b* |
| Planted seedlings | | 89*a* |

**Note:** Five-year data compare treatment combinations of single disc, double disc, patch, and blade site-preparation methods with planted seedlings, unsheltered seed spots, seed spots with cone shelters, and broadcast seeding regeneration methods. Ten-year data compare treatment combinations of single disc and blade site-preparation methods with unsheltered seed spots and seed spots with cone shelters regeneration methods on the ridgetop site, and with planted seedlings and unsheltered seed spots on the slope site. The dependent variable is the percentage of the fifty 6.0-$m^2$ subplots in each plot with a live planted seedling; a seed spot with one or more live seedlings; or for broadcast seeding, one or more live seedlings within the subplot. Values within a column with the same letter are not significantly different at the 0.05 level.

the root collar of the seedling; the horizontal distance between the seedling stem and the closest edge of the scarified patch, trench, or bladed strip; and the horizontal distance between the seedling stem and the farther side of the scarified area. For each scarified seed spot, we only measured the horizontal distance between the stem of the largest seedling and the closest edge of the scarified area. We estimated vegetative cover, by species, within 0.5-$m^2$ circular plots with the seedling at the center.

## Data analysis

For planted seedlings we calculated the percentage of the fifty 6.0-$m^2$ subplots in which the marked planted seedling was alive. For seed spots, we calculated the percentage of the fifty 6.0-$m^2$ subplots in which the marked spot had one or more live seedlings. For broadcast-seeded and natural-seedfall plots we calculated the percentage of fifty 6.0-$m^2$ subplots with one or more white spruce seedlings. These variables all refer to the occurrence of a live white spruce seedling, whether planted or from seed, within a specified area, the 6.0-$m^2$ subplot, and are used as the same variable in analyses. For the 5-year evaluation of scarified broadcast-seeded plots, we estimated the percentage of subplots with seedlings by multiplying the mean 1987 seedling density per 6.0 $m^2$ subplot by the percentage survival of marked seedlings from 1987 to 1990. We calculated seedling density for broadcast seeded and natural seedfall as the mean number of seedlings per 6.0-$m^2$ subplot, including only those plots with one or more white spruce seedlings.

The Statistical Analysis System (SAS Institute Inc.1988) was used for data analyses. The value utilized in analysis was the plot mean for each parameter. Percentages were arcsine transformed before analysis. We analyzed data for the two sites separately because the variable site was not replicated. For the 5- and 10-year evaluations, we analyzed the percentage of subplots with seedlings for scarified treatment combinations with an analysis of variance (ANOVA) model for a replicate block split-plot design. We then used ANOVA procedures to compare the percentage of sheltered and unsheltered unscarified spots with seedlings and to compare height and diameter measurements of planted spruce seedlings among site-preparation methods. We compared treatment means with the Ryan–Einot–Gabriel–Welsch multiple range test (SAS Institute Inc. 1988).

On the natural-seedfall and broadcast-seeded plots, we evaluated the effect of distance from the seed source at the edge of the burn. Zasada (1985) measured natural seedfall in our study area and found a inverse linear relationship between seedfall and the log of the distance from the edge of the burn, with approximately 70% of the seed falling within 20 m of the edge of the burn and 85% of the seed falling within 50 m. For the 12-year data, we used scatterplots and linear regression to examine the relation between the percentage of subplots with seedlings and the log of the distance of the plot from the edge of the burn. For natural seedfall, site-preparation methods were compared with an analysis of covariance procedure with the log of the distance from the seed source as a covariant. Broadcast-seeding results were not related to distance, and site-preparation methods were compared with an ANOVA procedure.

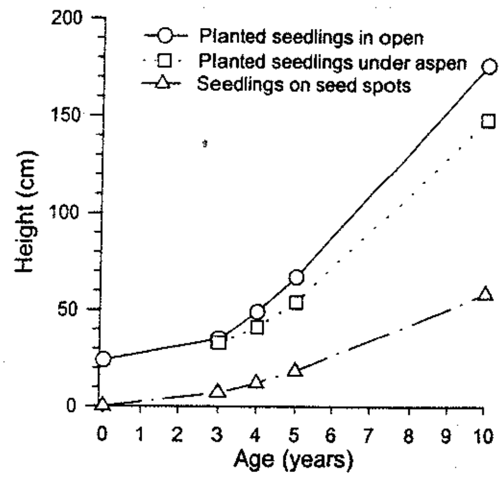
For direct-seeded seedlings, a plot mean for seedling height was

**Table 3.** Percentage survival of planted white spruce seedlings after 1, 3, 5, and 10 years by site-preparation method and site.

| Site-preparation method | 1 year | 3 years | 5 years | 10 years |
|---|---|---|---|---|
| **Ridgetop site** | | | | |
| Single disc | 96±3.2 | 90±4.0 | 87±5.3 | — |
| Double disc | 100±0.0 | 96±2.0 | 95±3.3 | — |
| Patch | 96±1.8 | 95±1.4 | 95±1.8 | — |
| Blade | 98±0.6 | 94±1.6 | 93±1.8 | — |
| Unscarified | 92±2.7 | 81±6.3 | 80±8.3 | — |
| **Slope site** | | | | |
| Single disc | 90±3.6 | 88±4.4 | 88±4.4 | 87±1.2 |
| Double disc | 94±4.0 | 93±2.7 | 93±2.7 | — |
| Patch | 94±2.4 | 91±4.8 | 91±4.8 | — |
| Blade | 98±1.6 | 94±2.0 | 94±2.0 | 91±2.0 |
| Unscarified | 96±3.2 | 72±6.2 | 70±6.7 | 69±6.4 |

**Note:** Values are means ± SE from three plots. Dashes represent absence of data.

**Fig. 1.** Growth of white spruce from planted container-grown seedlings and from seeds sown on unsheltered spots on the slope site.




calculated only if a minimum of 12 seedlings was measured. Many plots had fewer than 12 seedlings. Therefore, the seedling heights for direct seed regeneration methods are presented as means with standard errors without further analysis.

We analyzed the 1987 microsite data from the planted seedlings to describe the microsites created by each site-preparation method. We conducted ANOVAs using each parameter (microtopography, vegetative cover) separately as the dependent variable in a randomized complete block design with site preparation as the treatment. We compared treatment means with the Ryan–Einot–Gabriel–Welsch multiple range test. We used correlation analysis and scatterplots to evaluate the relationship between the microsite factors, which had been measured when the spruce seedlings were small, and the height of planted white spruce on the slope site in 1995, ten years after planting.

We also compared the microsites of seed spot seedlings that survived from 1987 until 1990 with seed spot seedlings that died between 1987 and 1990. The 1990 data were used because few seedlings died after 1990. We calculated the mean ± SE for each microsite variable for live and dead seedlings separately for scarified and unscarified plots within each site. All differences were small, and no further analyses were performed.

## Results

### Effects of site preparation

The percentage of 6-m$^2$ subplots with white spruce seedlings did not differ significantly among single disc, double disc, patch, and blade site-preparation methods after 5 years and, after 10 years, did not differ significantly between single disc and blade (Table 2). However, the percentage of unsheltered spots with seedlings tended to be higher with blade scarification than with other methods on the ridgetop site (Table 4). The lowest values were on unscarified plots for both planted seedlings and seeded spots (Tables 3 and 4). After 12 years, the percentage of 6-m$^2$ subplots with one or more seedlings did not differ significantly between single disc and unscarified for broadcast seeding or natural seedfall on the ridgetop ($p > 0.63$ and 0.25, respectively) and slope ($p > 0.17$ and 0.52) sites, although values for broadcast seeding tended to be lower without scarification.

The height and diameter of planted white spruce seedlings did not differ significantly among site-preparation methods after 5 years on the ridgetop ($p > 0.88$ and 0.83, respectively) and slope ($p > 0.51$ and 0.26) sites or after 10 years on the slope site ($p > 0.82$ and 0.71) (Table 5). We did not have enough direct-seeded seedlings for statistical comparison, but seedling height after 5 years was similar on unscarified and scarified treatments (Table 6).

### Effects of regeneration methods

On scarified plots, after 5 years, the percentage of subplots with white spruce seedlings was significantly higher for planted seedlings and broadcast seeding than for sheltered and unsheltered seed spots (Table 2). The percentage of spots with seedlings was significantly higher for sheltered than for unsheltered spots on the ridgetop site but not on the slope site. After 10 years, the difference between sheltered and unsheltered spots on the ridgetop site was not significant. The percentage of unsheltered and sheltered (with funnels) unscarified seed spots with seedlings was not significantly different after 5 years on the ridgetop ($p > 0.27$) and slope ($p > 0.24$) sites, or after 10 years on ridgetop site ($p > 0.28$).

After 5 years, planted seedlings on both sites were approximately four times taller than seedlings produced by direct seeding (Tables 5 and 6, Fig. 1). After 10 years, the average height of planted seedlings was approximately three times the height of seedlings produced by unsheltered spot seeding. After 5 years, seedlings from the three direct-seeding methods, sheltered and unsheltered seed spots and broadcast seeding, were very similar in height (Table 6).

Survival for container-grown seedlings was high and relatively stable after the third growing season (Table 3). Survival was 90 ± 1.8% (mean ± SE, $n = 30$) after 3 years, and 89 ± 1.8% (range 57–98%) after 5 years. Ten-year survival was measured only on single disc, blade, and unscarified treatments on the slope site. Five- and 10-year survival on this subset of plots was 85 ± 4.2% ($n = 9$, range 57–96%) and 82 ± 4.3% (range 53–96%), respectively. The growth rate of planted seedlings increased over time (Table 5, Fig. 1). The mean total height of seedlings on the slope site

**Table 4.** Percentage of sheltered and unsheltered seed spots with at least one white spruce seedling after 1, 3, 5, and 10 years by site-preparation method and site.

| Site-preparation method | Unsheltered seed spots | | | | Sheltered seed spots | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 3 years | 5 years | 10 years | 1 year | 3 years | 5 years | 10 years |
| **Ridgetop site** | | | | | | | | |
| Single disc | 47±2.4 | 30±10.0 | 27±11.8 | 19±11.2 | 73±3.6 | 54±9.7 | 48±10.6 | 33±7.7 |
| Double disc | 43±17.3 | 26±9.6 | 19±10.0 | — | 85±7.8 | 54±6.2 | 40±8.2 | — |
| Patch | 43±2.9 | 22±3.8 | 19±7.7 | — | 81±5.2 | 76±4.1 | 60±5.3 | — |
| Blade | 60±4.8 | 54±2.5 | 44±4.0 | 39±5.5 | 74±9.5 | 53±10.9 | 48±11.7 | 40±8.1 |
| Unscarified | 28±8.1 | 19±3.3 | 17±4.7 | 13±4.7 | 47±7.9 | 8±4.1 | 8±1.2 | 6±2.0 |
| **Slope site** | | | | | | | | |
| Single disc | 61±12.4 | 40±9.0 | 32±9.1 | 23±8.1 | 76±4.1 | 61±6.4 | 59±5.2 | — |
| Double disc | 79±5.5 | 54±3.3 | 47±2.4 | — | 84±11.1 | 60±5.0 | 53±9.3 | — |
| Patch | 78±10.3 | 62±7.7 | 56±5.3 | — | 78±11.2 | 58±8.7 | 54±12.9 | — |
| Blade | 79±5.9 | 56±3.8 | 53±5.3 | 45±3.1 | 70±15.0 | 57±11.7 | 56±13.1 | — |
| Unscarified | 61±14.5 | 17±5.2 | 13±5.4 | 10±4.1 | 48±5.3 | 29±8.1 | 24±8.3 | — |

**Note:** Values are the means ± SE from three plots. Seeds on scarified treatments were covered with a cone, and seeds on unscarified treatment were placed in a funnel. Dashes represent absence of data.

**Table 5.** Height and diameter of white spruce seedlings 5 and 10 years after planting as containerized seedlings by site and site-preparation method.

| Site-preparation method | Five years | | | Ten years | | |
|---|---|---|---|---|---|---|
| | *n* | Height (cm) | Diameter (cm) | *n* | Height (cm) | Diameter (cm) |
| **Ridgetop site** | | | | | | |
| Single disc | 3 | 55±5.0 | 0.8±0.06 | — | — | — |
| Double disc | 3 | 53±5.3 | 0.8±0.09 | — | — | — |
| Patch | 3 | 51±3.4 | 0.8±0.07 | — | — | — |
| Blade | 3 | 56±9.2 | 0.9±0.17 | — | — | — |
| Unscarified | 3 | 50±5.1 | 0.8±0.11 | — | — | — |
| All | 15 | 53±2.3 | 0.8±0.04 | — | — | — |
| Block 1, early planting | 5 | 61±3.7 | 1.0±0.07 | — | — | — |
| Blocks 2 and 3, late planting | 10 | 49±1.8 | 0.8±0.03 | — | — | — |
| **Slope site** | | | | | | |
| Single disc | 3 | 62±3.3 | 1.0±0.10 | 3 | 165±6.8 | 2.9±0.33 |
| | | | | 2[a] | 173±0.5 | 3.3±0.10 |
| | | | | 1[b] | 148 | 2.1 |
| Double disc | 3 | 76±8.3 | 1.1±0.05 | — | — | — |
| Patch | 3 | 64±8.2 | 0.9±0.14 | — | — | — |
| Blade | 3 | 73±5.5 | 1.2±0.07 | 3 | 185±14.7 | 3.4±0.37 |
| Unscarified | 3 | 60±8.7 | 1.0±0.07 | 3 | 165±14.1 | 3.0±0.20 |
| All | 15 | 67±3.2 | 1.0±0.04 | 9 | 171±8.2 | 3.1±0.19 |

**Note:** Values are mean ± SE of the plot means for height and diameter of live marked seedlings. *n*, number of plots.
[a]Plots in the open.
[b]Plot under an aspen stand.

was 67 cm (range 12–139 for individual seedlings) after 5 years, and 178 cm (range 52–305 cm) after 10 years.

On scarified spots, germination and initial seedling establishment were good at the end of the first growing season (Table 4). However, mortality in subsequent seasons was high. At the end of the first growing season, the percentage of unsheltered spots with seedlings was 61 ± 4.3% ($n$ = 24), declined to 43 ± 3.9% after 3 years, to 37 ± 3.8% (range 4–64) after 5 years, with a continued reduction after 10 years on the subset of treatments measured. For sheltered spots, the percentage of spots with seedlings the end of the first growing season was 78 ± 2.9% ($n$ = 24), declined to 59 ± 2.8% after 3 years, and to 52 ± 3.3% (range 24–74%) after 5 years. The percentage of unscarified seed spots with seedlings tended to be substantially less (Table 4). The growth rate for seedlings on unsheltered spots increased over time, with seedlings reaching a mean height of 50 cm (range 6–178 cm) after 10 years (Table 6, Fig. 1). After 5 years, the mean height of seedlings was greater on spots with more than one seedling (18.3 cm, $n$ = 670) than on spots with one seedling (14.1 cm, $n$ = 480).

For broadcast seeding, the percentage of fifty 6-m$^2$ subplots with at least one seedling was 100 ± 0.0% ($n$ = 30) at the end of the first growing season (Table 7). After 5 years,

**Table 6.** Height (cm) of white spruce seedlings after 5 and 10 years on treatment combinations of direct seeding methods and site-preparation methods, by site.

| | Unsheltered seed spots | | | | Sheltered seed spots | | | | Broadcast seeded | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | 5 years | *n* | 10 years | *n* | 5 years | *n* | 10 years | *n* | 5 years |
| **Ridgetop site** | | | | | | | | | | |
| Single disc | 1 | 11 | 1 | 34 | 3 | 15±2.9 | 2 | 44±8.2 | 3 | 14±0.7 |
| Double disc | 1 | 12 | | — | 3 | 14±2.6 | | — | 3 | 15±2.2 |
| Patch | 2 | 11±0.6 | | — | 3 | 11±2.2 | | — | 3 | 12±2.4 |
| Blade | 3 | 13±1.7 | 3 | 43±3.8 | 3 | 13±1.1 | 2 | 42±6.4 | 3 | 13±2.5 |
| Unscarified | 1 | 19 | 0 | — | 0 | — | 0 | — | 1 | 11 |
| **Slope site** | | | | | | | | | | |
| Single disc | 2 | 18±0.5 | 2 | 56±2.3 | 3 | 21±3.3 | | — | 2 | 18±1.5 |
| Double disc | 3 | 21±2.5 | | — | 3 | 15±2.3 | | — | 3 | 16±2.3 |
| Patch | 3 | 18±2.7 | | — | 3 | 17±1.9 | | — | 3 | 17±1.6 |
| Blade | 3 | 20±6.7 | 3 | 63±19.4 | 3 | 20±2.5 | | — | 3 | 22±2.8 |
| Unscarified | 1 | 15 | 0 | — | 2 | 16±3.3 | | — | 2 | 12±3.1 |

**Note:** Values are mean ± SE of plot means for the height of live marked seedlings. *n*, number of plots with ≥ 12 live seedlings.

**Table 7.** Percentage of fifty 6.0-$m^2$ subplots with at least one white spruce seedling after 1, 5, and 12 years for broadcast seeding and after 12 years for natural seedfall, by site-preparation method and site.

| Site preparation method | Broadcast seeded | | | | Natural seedfall | |
|---|---|---|---|---|---|---|
| | 1-year frequency | 5-year frequency | 12-year frequency | 12-year density | 12-year frequency | 12-year density |
| **Ridgetop site** | | | | | | |
| Single disc | 100±0.0 | 73±11.4 | 71±7.7 | 4.4±0.8 | 61±21.7 | 6.0±3.2 |
| Double disc | 100±0.0 | 79±17.4 | — | — | — | — |
| Patch | 100±0.0 | 93±5.4 | — | — | — | — |
| Blade | 100±0.0 | 99±0.0 | — | — | — | — |
| Unscarified | 100±0.0 | — | 60±9.2 | 3.7±0.6 | 22±7.5 | 1.5±0.2 |
| **Slope site** | | | | | | |
| Single disc | 100±0.0 | 73±14.4 | 89±6.3 | 5.3±1.4 | 51±9.0 | 1.7±0.3 |
| Double disc | 100±0.0 | 83±13.6 | — | — | — | — |
| Patch | 100±0.0 | 93±5.4 | — | — | — | — |
| Blade | 100±0.0 | 87±10.9 | — | — | — | — |
| Unscarified | 100±0.0 | — | 61±6.4 | 2.7±0.3 | 24±15.6 | 2.9±1.4 |

**Note:** Values are the mean ± SE from three plots. Density values are the number of seedlings per subplot with white spruce seedlings. Broadcast seeded data for the 12-year evaluation may include seedlings originating from natural seedfall. On natural seedfall plots, the only seed source was natural seedfall. Dashes represent absence of data.

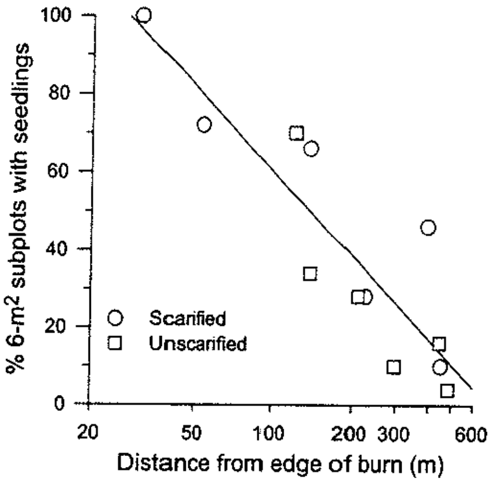
this percentage was still high at 87 ± 4.4% ($n$ = 24) on scarified plots. After 12 years, the percentage of subplots with seedlings was 70 ± 5.2% (range 38–100%) on the subset of treatments measured. Comparison between the 5- and 12-year evaluations was difficult because seedlings were counted only on the scarified areas of scarified plots for the first 5 years, whereas the 12-year evaluation counted every seedling on the entire plot, including unscarified areas, and seedlings from natural seedfall could not be excluded from the count. Scatterplots and linear regression of frequency against the log of distance from the edge of the burn did not show a distance effect (ridgetop, $p > 0.53$, $R^2 = 0.10$; slope, $p > 0.66$, $R^2 = 0.05$). This indicated that natural seedfall did not have a major effect on the percentage of subplots with seedlings.

For natural seedfall, the overall percentage of plots with one or more white spruce seedlings 43 ± 8.4% ($n$ = 12, range 4–100%) after 12 years on single disc and unscarified plots (Table 7, Fig. 1). On the ridgetop site, there was an inverse linear relationship between the percentage of subplots with seedlings and the log of the distance from the edge of the burn ($Y = 206.5 - 32.9X$; $R^2 = 0.97$, $p = 0.0002$). On the slope site, the linear relationship was not as strong ($Y = 237.0 - 32.0X$; $R^2 = 0.59$, $p = 0.0764$). An overview of the data from both sites indicated that approximately 50% of the 6-$m^2$ subplots had one or more seedlings at a distance of 150 m from the seed source at the burn edge and that approximately 30% of the subplots still had seedlings at 230 m from the burn edge (Fig. 2). Seedlings from natural seedfall were from more than one cohort; a separate study within the same burn showed that seedlings established from natural seedfall in 1984, 1988, and 1991 (G.P. Juday, unpublished data).

## Effects of site and microsite

The growth rate of direct-seeded seedlings differed between the two sites (Table 6). After 5 years, mean seedling height was 13 cm on the ridgetop site and 18 cm on the

Fig. 2. Percentage of fifty 6.0-m$^2$ subplots with one or more white spruce seedlings from natural seedfall as a function of the log of the distance from the seed source at the edge of the burn ($Y = 203.2 - 31.1X$; $R^2 = 0.79$, $n = 12$, $p = 0.0001$).




slope site. The height difference persisted after 10 years, when the mean seedling height on unsheltered spots was 40 cm (range 6–135 cm for individual seedlings) on the ridgetop site and 59 cm (range 7–178 cm) on the slope site. Planted seedlings on the ridgetop site were smaller than seedlings on the slope site after 5 years (Table 5). However, many seedlings on the ridgetop site were infected with a root pathogen.

Our microsite measurements, taken 2 years after scarification, reflected site differences (Table 1). On the ridgetop site, the patch and blade treatments reduced the vegetative cover around the seedlings as compared with the unscarified treatment, but the single and double disc treatments did not reduce vegetative cover. On the slope site, all treatments reduced vegetative cover. Vegetation around the seedlings was dominated by *C. canadensis*, *Equisetum pratense*, and *Epilobium angustifolium*, which formed approximately 96% of the vegetative cover on all plots. The composition of the vegetation around the seedlings differed between the sites. The ridgetop site had more *C. canadensis* (43% of the total cover vs. 23% on the slope site) and less *Equisetum pratense* (41% of the total cover vs. 54% on the slope site).

The microtopography and herb and low shrub cover of planted seedling microsites did not appear to have a long-term effect on seedling growth. After 10 years, all of the planted seedlings that we measured were in a free-to-grow status in relation to herbs and low shrubs. The height of planted seedlings on the slope site after 10 years was significantly correlated only with two of the variables measured 2 years after planting, *Equisetum pratense* cover ($r = 0.27$, $p = 0.0113$) and *Epilobium angustifolium* cover ($r = 0.33$, $p = 0.0001$), and these two variables were not correlated ($r = 0.04$, $p = 0.7446$). However, after 10 years, 10% of the planted seedlings were shaded by aspen, and the seedlings growing under an aspen canopy were shorter (Table 5, Fig. 2).

Survival of seedlings on unsheltered spots on both sites between the second and fifth growing season did not differ for any microsite variable. After 10 years, approximately 92% of the seedlings on unsheltered spots were in a free-to-grow status in relation to herbs, low shrubs, aspen, and birch. After 12 years, approximately 53% of the seedlings from broadcast seeding and natural seedfall were shaded by aspen or paper birch.

## Discussion

Our study demonstrated several alternatives for regenerating white spruce on similar sites in interior Alaska under the particular conditions of this study, i.e., fire followed by salvage logging. These alternatives differ from those normally prescribed for white spruce regeneration in the western boreal forest. First, natural seedfall alone produced good regeneration over much of the study area, with one or more seedlings on 55% of the 6-m$^2$ subplots (a minimum of 900 seedlings/ha) located 120–150 m from the edge of the burn, and seedlings on 28% of the subplots that were 230 m from the edge.

Second, we found that broadcast seeding produced good regeneration, with 70% of 6-m$^2$ plots having one or more seedlings (a minimum of 1150 seedlings/ha) after 12 years. These results suggest that broadcast seeding may be an effective method for similar sites. Gardner (1983) also reported high frequency (79%) for broadcast seeding on scarified floodplain sites in the Yukon; however, broadcast seeding failed on unscarified sites, and broadcast seeding in the southern range of white spruce has generally given poor results (Stiell 1976; Coates et al. 1994). Broadcast seeding was more successful than seed spots because the sowing rate of approximately 300 seeds per 6.0-m$^2$ subplot distributed the seeds into a variety of microsites, and at least one seed per subplot landed on a microsite suitable for germination and seedling establishment. In contrast, the single seed spot in each 6.0 m$^2$ subplot had 3–10 seeds in a small area (<0.25 m$^2$) with a limited range of microsite conditions. Success from spot seeding could be increased by increasing the density of spots and thus sampling more safe sites.

Fire effects, combined with variable amounts of disturbance from salvage logging, may have accounted for our success with broadcast seeding and natural seedfall, particularly on unscarified sites. The Rosie Creek burn had thinner organic layers, lower vegetative cover, and more suitable microsites for white spruce establishment relative to nearby unburned, logged sites (Zasada and Grigal 1978; Densmore 1985; Foote and Viereck 1985; Putman 1985; Zasada 1985; Wurtz and Zasada 1988). However, on a nearby upland logged site, naturally regenerated white spruce seedlings were present on 65% (based on 1-m$^2$ plots) of the unscarified seedbeds and 100% of the blade scarified surfaces after 13 years (Wurtz and Zasada 1987). The minimum natural seedfall was >200 seeds/m$^2$, compared with our estimated minimum seed input of 60 seeds/m$^2$ from broadcast seeding and natural seedfall combined, suggesting that increased seed input compensated for fewer microsites.

Third, planting container-grown seedlings with scarification was the most reliable regeneration method, with 89% survival after 10 years, resulting in 1500 well-distributed seedlings/ha. Results were equally good among the single and double disc, patch, and blade scarified site-preparation methods, probably because vascular plant species composition and cover on seedling microsites was similar for all four methods. Planting seedlings without scarification was less effective, with 69% survival after 10 years. Planting has generally been an effective method for regenerating white spruce on floodplain sites in Alaska (Youngblood and Zasada 1991) and throughout the range of white spruce (Stiell 1976; Gardner 1983; McMinn 1986; Coates et al. 1994). Furthermore, planted seedlings were three times taller than seedlings from direct seeding after 10 years. However, our problems with seedlings infected with a root pathogen underlines the hazards that white spruce seedlings face between the propagation facility and field planting.

White spruce growth on our sites was similar among scarification methods and without scarification for both planted seedlings and seedlings produced by direct seeding. In contrast, planted seedlings on unburned floodplain sites on the nearby Tanana River and in the Yukon Territory were generally larger with than without scarification (Gardner 1983; Youngblood and Zasada 1991). Wurtz and Zasada (1987) reported the opposite result on an unburned, harvested site on similar soils and aspect. After 13 years, naturally regenerated white spruce were taller on unscarified than on blade scarified microsites. This difference is even more pronounced after 25 years and is partly attributed to the large number of paper birch, alder, willow, and aspen seedlings on scarified plots and their low occurrence on unscarified plots (J.C. Zasada, unpublished data).

Both planted seedlings and direct-seeded seedlings grew faster on our burned sites than seedlings on nearby unburned floodplain sites (Krasny et al. 1984; Youngblood and Zasada 1991) or on a Yukon floodplain site (Gardner 1983). Fire effects may account for the relatively rapid growth of white spruce on our sites, with and without scarification. The Rosie Creek burn increased soil temperatures and available nutrients (Van Cleve et al. 1987; Dyrness et al. 1989). Similar results were reported for the nearby floodplain sites, where growth of planted seedlings on an intensely burned unscarified area was equal to the best growth on scarified unburned plots (Wurtz 1988; Wurtz and Zasada 1988), and in British Columbia, where white spruce growth was better on unscarified, burned areas than on bladed, unburned areas (McMinn 1982; Ballard and Hawkes 1989).

White spruce growth also differed between our burned sites, with more rapid growth on the slope site than on the ridgetop site. We attribute this difference in part to the direct and indirect effects of environmental factors related to slope, with less insolation on the relatively level ridgetop site as compared with the south- and southeast-facing slope site. As a result, soils on the slope site were warmer and drier than the ridgetop site. What seem to be small differences in temperature environment in the southern range of white spruce are very important in these high-latitude forests, where north slopes at the same elevation as our study sites often have permafrost and are dominated by black spruce stands with low productivity (Van Cleve et al. 1986). The species composition of the vegetative cover on seedling microsites also differed between sites, even though the total vegetative cover was similar. The ridgetop site had more *C. canadensis*, a serious competitor that can exclude or stunt white spruce seedlings (Lieffers and Macdonald 1993). *Calamagrostis canadensis* also colonized scarified areas from seed, as has been reported for other sites by Lieffers and Macdonald (1993).

## Conclusions

Silvicultural systems in the western boreal mixedwood forests have evolved to the point where planting is used almost to the exclusion of seeding or natural regeneration to regenerate white spruce (Navratil et al. 1991; Lieffers and Beck 1994). The rationale for this is based on the inconsistency of results from broadcast seeding and natural regeneration and the advantages that planting brings in terms of control of stocking and spacing. However, planting has not proved to be uniformly successful, and there is a search for ecologically sound and economically efficient methods to meet regeneration needs on a site-specific basis. Our study provides a comparison of how different site-preparation methods and regeneration materials can be applied to a particular disturbance regime in the most northern and western boreal mixedwood sites. Although these methods were not used in combination on any plot it is possible to envision how planting, artificial seeding, and natural regeneration might be combined to achieve a desired regeneration goal for a given site. Evaluation of treatments will require combinations of various alternatives for different disturbance scenarios placed in the context of site classification. Using this information it will then be possible to model consequences of various scenarios as proposed by Rupp (1998).

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