WORKING PAPER 43

Twelve-year Conifer and Vegetation Responses to Discing and Glyphosate Treatments on a BWBSmw Backlog Site

1999

BRITISH COLUMBIA

Ministry of Forests Research Program

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Citation
Biring, B.S., W.J. Hays-Byl and S.E. Hoyles. 1999. Twelve-year conifer and vegetation responses to discing and glyphosate treatments on a BWBSmw backlog site. Res. Br., B.C. Min. For., Victoria, B.C. Work Pap. 43/1999.

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EXECUTIVE SUMMARY

In 1982, an operational vegetation management trial (SX82502G-5) was established to examine the effectiveness of vegetation control treatments applied to a mechanically cleared backlog site in the moist warm Boreal White and Black Spruce biogeoclimatic subzone of British Columbia. Two plots of 1.2 ha were established on the site. One of the plots was disced, using a Komatsu D65 crawler tractor equipped with a breaking disc, prior to planting *Picea glauca* (white spruce) in spring of 1983. The herbicide glyphosate (Roundup® @ 2.4 kg a.i./ha) was applied to one-half of the disced and undisced plots in late summer. Both discing and glyphosate application resulted in the following treatment areas: (1) discing; (2) discing + glyphosate; (3) glyphosate; and (4) untreated control. The study site was remeasured in the fall of 1995 (seedling measurements) and summer of 1996 (vegetation assessments) to determine whether treatments had any lasting effect on white spruce seedlings and on the vegetation community.

Twelve years after treatment, discing improved white spruce basal diameter and had no significant effect on spruce height and crown diameter. However, glyphosate treatment significantly increased basal diameter, height, and crown diameter, and reduced height-to-diameter ratio of white spruce seedlings compared with the untreated seedlings. Treatments had no significant effect on the number of well-spaced spruce seedlings per hectare. However, only plots treated with glyphosate achieved the minimum free-growing requirements 12 years after white spruce planting. The spruce seedlings in the untreated control and disced plots were not free-growing based on the current free-growing standard (which does not accept deciduous species). Significantly higher deciduous density and percent cover were found in both plots compared with the glyphosate-treated plots.

Discing and glyphosate treatments significantly reduced deciduous percent cover, density, and height by inhibiting deciduous resprouting and/or by altering species abundance compared with the untreated control. The reductions in total vegetation cover in the glyphosate-treated plots largely reflect reductions in deciduous and shrub percent cover. These reductions in percent cover in glyphosate-treated plots resulted in significant increases in plant species diversity. The glyphosate treatment significantly reduced the cover of wildlife forage species. In the absence of vegetation control, deciduous density may be sufficient to restrict wildlife movement.

Yield projections for spruce based on simulations using TIPSY suggest that glyphosate application can reduce the rotation by up to 19 years compared with the untreated control. However, the glyphosate treatment also reduced deciduous timber volume by up to 46% compared with untreated areas. Since deciduous species are present as an overstorey in mixedwood stands, and should continue to occupy these stands at least to maturity, the deciduous volume should be included for total yield analysis. The deciduous volume estimated using WinVDYP in glyphosate-treated plots (< 128 m^3/ha) was one-fourth and one-half of the volume projected in the disced (170 m^3/ha) and untreated control (234 m^3/ha) plots, respectively.

ACKNOWLEDGEMENTS

We are grateful to Les Herring (Prince George Forest Region) for establishing the trial (SX82502G-5) in 1982 and relocating the study site for remeasurements (EP1195) in 1995. We thank George Harper (Research Branch) and Flaterud Contracting for their valuable assistance in data collection. The authors gratefully acknowledge suggestions and review comments provided by Andrea Eastham, Wendy Bergerud, Phil Comeau, Patrick Daigle, George Harper, Richard Kabzems, Paul Rehsler, and Vera Sit.

Funding for this project was provided by Forest Renewal BC under the B.C. Ministry of Forests Research Branch experimental project EP1195.

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1 INTRODUCTION

Vegetation management treatments are widely used to ensure establishment and growth of coniferous seedlings on reforested areas in British Columbia. In 1995/96, approximately 65 872 ha of Crown forest land received brushing treatment to ensure establishment and growth of young seedlings at a cost of $30 million (B.C. Ministry of Forests 1997a). In 1987, after amendments to the *Forest Act* (1979), brushing became an integral part of the strategy for reforestation success (i.e., free-growing standard) and a contract requirement or obligation for everyone who harvests Crown timber. Prior to this period, reforestation did not routinely address vegetation competition. As a result, a large backlog of not satisfactorily restocked (NSR) areas had accumulated. In 1995/96, the province had 957 000 ha of NSR land (B.C. Ministry of Forests 1997a).

During the past few decades, research on the silvicultural implications of vegetation management has focused on short-term information needs to support forest stand establishment. However, the demand for long-term information about issues such as free-growing, green-up, growth and yield, biodiversity, stand dynamics, and stand structure has increased substantially because of recent changes in provincial forestry legislation and policy (Province of British Columbia 1988; B.C. Ministry of Forests and BC Environment 1995). At the same time, public pressure to integrate all forest resources into silvicultural decision-making and to develop vegetation management alternatives to herbicides has intensified the need for longer-term information.

To produce long-term data on tree and vegetation community responses to vegetation management treatments, a B.C. Ministry of Forests experimental project (EP) 1195 (Harper and Biring 1995) was initiated to remeasure previously established vegetation management trials. During 1995 and 1998, several vegetation management trials throughout the province were evaluated for their usefulness in obtaining long-term conifer and vegetation community response data. The candidate research and operational trials were screened based on published and unpublished reports, experimental design, field surveys, and communication with operational staff. To date, various trials have been measured and reports published (Harper, Biring, and Heineman 1997; Harper, Herring, and Hays-Byl 1997; Harper et al. 1998; Whitehead and Harper 1998) to document the long-term implications of vegetation management practices. Along with the Stewart Lake project (Harper, Herring, and Hays-Byl 1997), the Sunset Prairie operational trial was selected for remeasurement in the Dawson Creek Forest District (total area about 2.9 million ha) within the Prince George Forest Region (Figure 1). Both trials were established by Les Herring (Prince George Forest Region) in 1982/83.

This working paper reports the results of the 1995/96 remeasurement of the Sunset Prairie operational trial SX 82502G-5. The trial was established to study the effects of discing and glyphosate treatments applied to a mechanically cleared backlog site for *Picea glauca* (white spruce) seedling establishment.

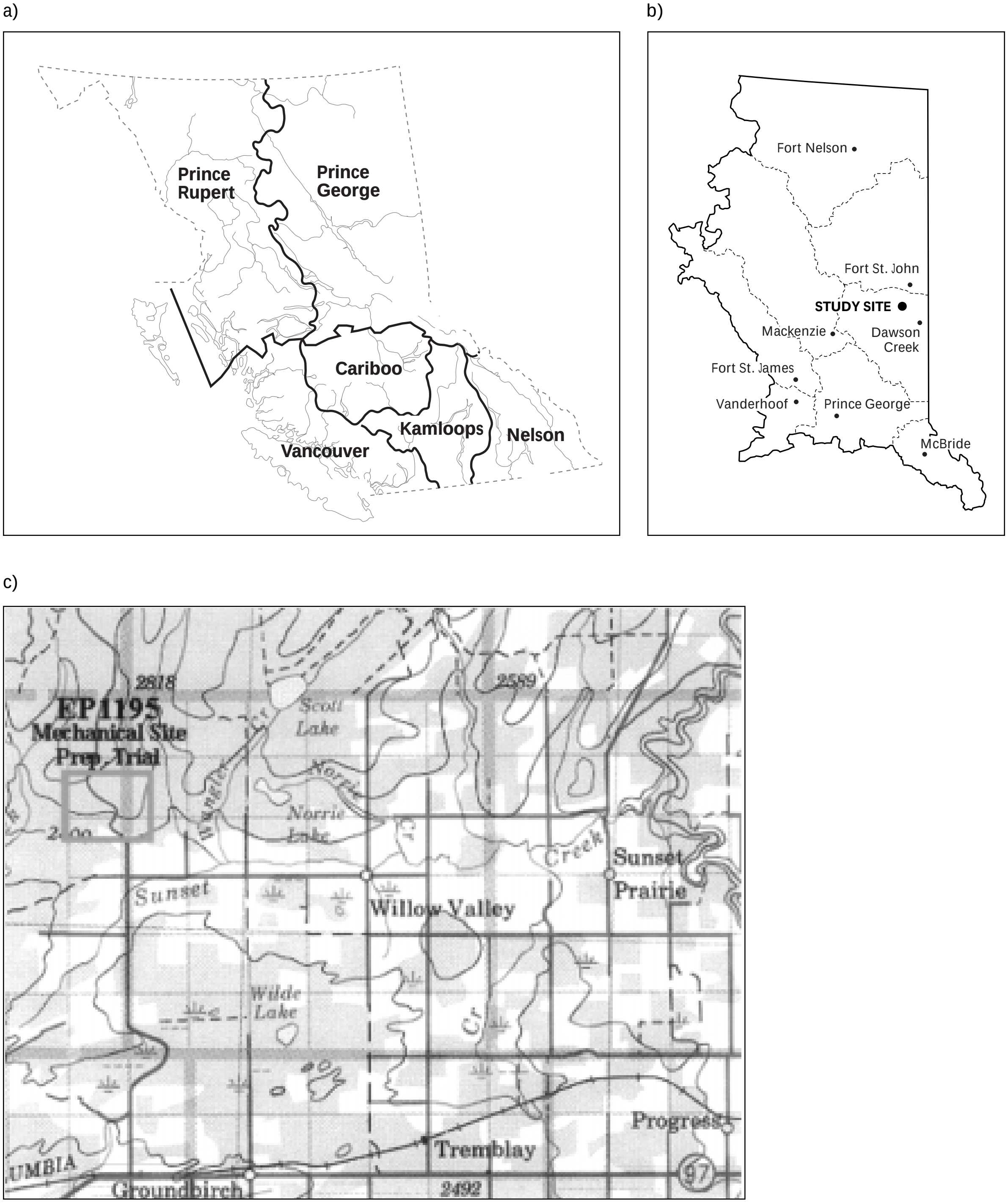

FIGURE 1 *Location maps for the study: a) British Columbia with forest region boundaries; b) Prince George Forest Region with forest district boundaries and study site near Dawson Creek; and c) detailed Sunset Prairie research area*

2 OBJECTIVES

The purposes of remeasuring this trial were:

- to assess the long-term effects of discing and glyphosate application on growth of white spruce seedlings;
- to document the number of well-spaced and free-growing white spruce seedlings 12 years after planting and treatment; and
- to assess the impacts of discing and glyphosate treatments on the development of neighbouring vegetation including deciduous trees that may contribute to future timber yield.

3 METHODS AND MATERIALS

3.1 Study Area

A mechanical site preparation trial was established at the Sunset Prairie research area in 1982 (Herring 1984). The trial site is located on the Stewart Lake Forest Service Road in the Dawson Creek Forest District. The area is situated within the Boreal White and Black Spruce moist warm (BWBSmw1) biogeoclimatic variant (Meidinger and Pojar 1991), at 900 m elevation. The site is characterized by moderate to well drained soil, south-east aspect, and 10% slope (Table 1).

TABLE 1 *Site characteristics of the Sunset Prairie research area*

Item	Description
District	Dawson Creek Forest District
Location	km 3 Stewart Lake Forest Service Road
Map sheet opening	93P086-03 polygons 47 and 68
Latitude/longitude	55° 52' 26"N/120° 59' 06"W
UTM Grid zone/TSA	10/41
UTM coordinates	East 626000; North 6193900
Elevation	900 m
Slope	10% avg.
Aspect	South-east
Biogeoclimatic zone	BWBSmw1 - 01
Moisture/nutrient regime	Moderate to well drained
Site class	Medium
Site history	Wildfire 1971, cleared and piled Oct. 1982, select discing Apr. 1983, planted May 1983, select herbicide Aug. 1983
Seedlot	White spruce seedlot 3962 Kiskatinaw provenance
Stock	2+0 bareroot
Planting date	May 1983

3.2 Study Design

To remove a dense mixed hardwood, shrub, and grass community which developed on the site following a wildfire in 1971 (Herring 1984) the site was mechanically cleared in October 1982. D-7 and D-8 crawler tractors equipped with Beale's brush rake blades were used to windrow the debris. This clearing resulted in moderate mineral soil exposure. An operational trial (SX82502G-5) was established in August 1983 (Herring 1984) to study the impacts of discing and herbicide treatments as described in the following sections.

3.2.1 Discing treatment To determine the effect of discing (a method of soil cultivation) on the re-establishment of the vegetation community on the mechanically cleared site, two 300 × 40 m (1.2 ha) plots were established. The discing treatment was randomly assigned to one of the plots. The plot was disced using a heavy tandem Rome breaking disc attached to a Komatsu D65 crawler tractor during dry and cool weather on April 21, 1983 (Herring 1984). At the time of discing, the soil was still frozen below 15 cm, and the disc offset was adjusted to an intermediate setting to allow good penetration. The discing resulted in good mineral soil exposure with moderate mixing of the organic matter and litter into the 20-cm-deep plow layer. The soil disturbance caused by discing allowed species to regenerate vegetatively and non-vegetatively, and resulted in a mixed community of *Calamagrostis canadensis* (bluejoint reedgrass), *Populus tremuloides* (trembling aspen), and *Populus balsamifera* spp. *balsamifera* (balsam poplar) suckers in the disced area (Herring 1988). These species were also found in the untreated control area.

A month after discing (late May 1983), 2-year-old (2+0 stock) white spruce seedlings (seedlot 3962, Kiskatinaw provenance) were planted in both disced and undisced plots. The discing treatment had elevated the soil in ridges, allowing the soil to dry out very quickly (Herring 1984). The stock condition at the time of planting was fair; however, hot, dry weather caused moisture stress after the seedlings were planted.

3.2.2 Glyphosate application To compare the effects of a herbicide treatment (glyphosate) to fall cleared, disced and undisced areas, herbicide was applied in August 1983 (Herring 1984). During herbicide application, both disced and undisced plots of 300 × 40 m (1.2 ha) were split into two (20 m wide) subplots. Glyphosate treatment was applied to the adjoining central subplots of 200 × 20 m (0.4 ha) leaving a 50 m buffer on both sides (Figure 2). Glyphosate application in disced and undisced areas resulted in the following treatment: (1) discing only; (2) discing + glyphosate; (3) no discing + glyphosate (glyphosate only); and (4) no discing + no glyphosate (untreated control). Treatments are described in more detail in Table 2. Glyphosate (Roundup® @ 2.4 kg a.i. /ha; spray volume 300 L/ha) was applied on August 26, 1983, under favourable conditions, using a backpack sprayer with hand-held boom.

3.3 Seedling Measurements

In each treatment area, planted white spruce seedlings were measured between October 31 and November 1, 1995 to provide information on seedling growth responses. Thirty spruce seedlings were selected for measurement using a systematic random sampling technique with random start (every third seedling selected along a transect) (Harper, Herring, and Hays-Byl 1997). The measured variables included seedling basal diameter, crown diameter (measured along cardinal axes N-S, E-W), and height in 1985, 1987, 1989, 1991, 1993, and 1995. Spruce seedlings were also assessed qualitatively for vigour based on a five-class scale (Appendix 1). To avoid edge effects, a 5-m-wide area along the treatment plot boundaries was not sampled.

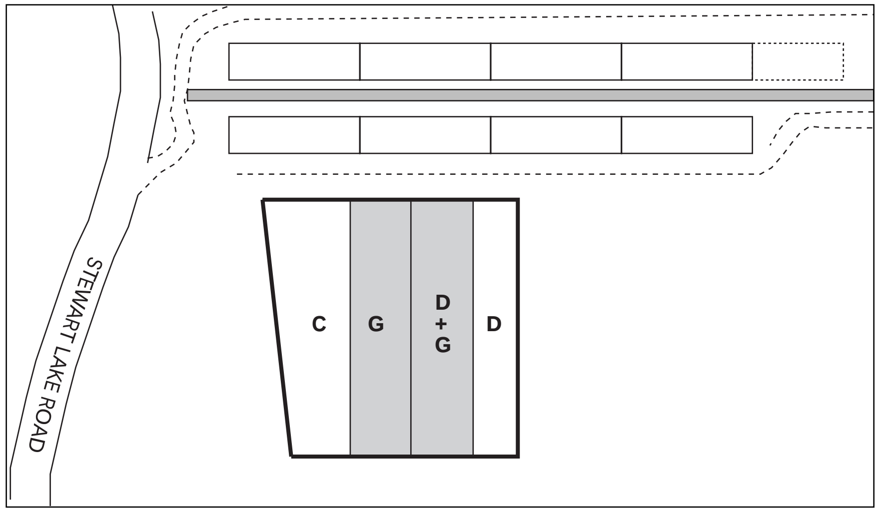

FIGURE 2 *Treatment plot layout: C = control; D = discing; G = glyphosate; and D+G = discing+glyphosate*

TABLE 2 *Description of treatments applied in the study*

Treatment	Description
Discing	Plots were disced using a heavy tandem Rome breaking disc attached to Komatsu D65 crawler during dry and cool weather on April 21, 1983. At the time of discing, the soil was still frozen below 15 cm, and the disc offset was adjusted to an intermediate setting to allow good penetration.
Discing + Glyphosate	Plots were disced using a heavy tandem Rome breaking disc attached to Komatsu D65 crawler during dry and cool weather on April 21, 1983. At the time of discing, the soil was still frozen below 15 cm, and the disc offset was adjusted to an intermediate setting to allow good penetration. To control vegetation community resprouted due to soil disturbance after site preparation, glyphosate (Roundup®) @ 2.4 kg a.i./ha (spray volume 300 L/ha) was applied on August 22, 1983, using a backpack sprayer with hand-held boom.
Glyphosate	To control mixed-shrub community the glyphosate (Roundup®) @ 2.4 kg a.i. /ha (spray volume 300 L/ha) was applied August 22, 1983, using a backpack sprayer with hand-held boom.
Untreated control	No treatment.

Three 3.99 m radius (0.005 ha) silviculture survey or Regeneration Measurement Plots (RMPs) were randomly established within each of the treatment areas in the fall of 1995 to tally total stems per hectare of coniferous and deciduous species, and to determine the number of free-growing crop trees per hectare (as required under the *Forest Practices Code of British Columbia Act* 1995). In each RMP, the height and basal diameter of five stems of deciduous (randomly selected) species were recorded.

3.4 Vegetation Assessments

Vegetation was assessed during July 1996 to provide information on vegetation community composition. Vegetation attributes (percent cover, modal height, and distribution of species) were recorded for each species, and density was recorded for coniferous and deciduous species using 3.99 m radius (0.005 ha) Vegetation Measurement Plots (VMPs) (Habitat Monitoring Committee 1996). Four VMPs were established in each treatment plot using a systematic random sampling technique with random start (20 m distance was maintained between adjacent VMPs). Again, to avoid edge effect, the 5-m-wide swath along the treatment plot boundaries was not sampled. Forage utilization (i.e., estimation of the proportion of the plant's current year's growth that has been used by wildlife) was rated on a six-class scale (Appendix 2).

3.5 Species Diversity

Plant species diversity indices and species richness (number of species) can be used to assess species diversity in each treatment area. Species richness was calculated from the total number of plant species in each VMP (i.e., four VMPs in each plot). Two types of indices (Krebs 1989) were used to assess plant species diversity: (1) the modified Simpson's Diversity Index (SDI) and (2) the modified Shannon-Wiener Diversity Index (SWI). The SDI places most weight on the common species in the sample. In contrast, the SWI places most weight on rare species in the sample. The species diversity indices were calculated from percent cover of each species present in VMPs for each treatment area. The indices were subsequently used to describe diversity as follows: (1) $SDI = 1/\sum(n/N)$ and (2) $SWI = e^{H'}$, where n = percent cover of each species; N = sum of cover of all species; $e = 2.718282$; and $H' = -(\sum(n/N * ln\ (n/N)))$.

3.6 Stand Yield Projections

To make long-term stand yield projections, site index (SI) for spruce was estimated for each treatment area using the growth intercept method (B.C. Ministry of Forests 1995; Nigh 1996). Based on the height and basal diameter data, five top-height trees (THT) from each treatment area were selected for calculating SI. The average SI for each treatment area was then used to project stand yield. The growth and yield simulation model TIPSY version 2.1 (Mitchell et al. 1998) was used to project spruce stand yield and for financial analysis. TIPSY is a **T**able **I**nterpolation **P**rogram for electronically retrieving **S**tand **Y**ield information. The SI for trembling aspen and balsam poplar were determined using Site Tools software (B.C. Ministry of Forests 1998b). The computer software WinVDYP (B.C. Ministry of Forests 1998c) was used to make yield projections for deciduous species. WinVDYP is a Windows® version of the **V**ariable **D**ensity **Y**ield **P**rediction (VDYP) model, an empirical yield prediction system for natural stands.

3.7 Statistical Analysis

Statistical analysis included a two-way analysis of variance (anova) (Table 3) which was calculated using SAS statistical software (SAS Institute Inc. 1985). The data from 30 sample spruce seedlings, three RMPs, and four VMPs in each treatment area were considered an experimental unit and used as replicates (pseudo-replicates) to test for significant differences between treatment means. Results from analysis based on pseudo-replication must be interpreted cautiously, because treatment differences are confounded by differences between plots in vegetation and site factors (i.e., soil type, moisture regime, and nutrient regime). In the analysis of these data the first step is to determine whether interaction (two variables, such as discing and glyphosate, interact when the simple effects of one variable depend on the levels of a second variable) is significant (Chen 1997). If the interaction is significant, then it is interpreted in terms of simple effect: the effect that a factor (i.e., glyphosate) demonstrates at a given level of another variable (i.e., disced, undisced, or control). If interaction is not significant, then it is interpreted in terms of main effect: the effect that reflects the general or average effect of a variable (i.e., discing, glyphosate). Polynomial contrasts were used to compare various treatments.

4 RESULTS AND DISCUSSIONS

Results from this study address management objectives or key issues that are important for stand establishment and beyond, including free-growing, stand development, vegetation community response, plant species diversity, and stand growth and yield. To address these issues, results from remeasurement of this operational trial are presented relative to the following key questions:

- How do the treatments influence white spruce growth, vigour, and condition?
- How do the treatments affect achievement of free-growing?
- How do the treatments influence deciduous stand development?
- How do the treatments influence the vegetation community composition?
- How do the treatments affect plant species diversity?
- How do the treatments influence wildlife habitat?
- How do treatments influence timber yield?

TABLE 3 *Two-way analysis of variance of treatment data*

Source of variation	Levels	Degrees of freedom	Sum of squares	Mean square	*F* - value
Discing	2	1	SSm	MSm = SSm/1	MSm/Mse
Glyphosate	2	1	SSh	MSh = SSh/1	MSh/Mse
Discing * Glyphosate		1	SSmh	MSmh = SSmh/1	MSmh/Mse
Error		x[a]	Sse	Mse = Sse/x	
Total		y[a]	SSt		

[a] Degrees of freedom for error and total depend on number of observations.

Results from the statistical analysis are discussed in more detail in the following subsections. Note that if treatment (i.e., glyphosate) is mentioned without any reference to a second variable (disced or undisced), the main effect (pooling data from two plots) is discussed.

4.1 Treatment Effects on White Spruce Growth and Vigour

Twelve years after application, vegetation management treatments had a measurable effect on basal diameter, height, and crown diameter growth of white spruce (Table 4; Appendix 3). Discing (main effect) improved basal diameter ($p = 0.081$) but had no significant effect on spruce height and crown diameter. On the other hand, glyphosate treatment (main effect) increased height and crown diameter (Table 4). Seedlings were significantly ($p \leq 0.0001$) taller (height > 285.7 cm) with wider crowns (crown diameter > 131 cm) in glyphosate treatment areas than those found in the untreated control and the disced area (height < 218.3 cm and crown diameter < 102 cm). The basal diameter of spruce seedlings after glyphosate application (> 55.2 mm) was significantly greater ($p \leq 0.0001$) than that of untreated control (29.8 mm) and disced seedlings (36.3 mm). Interaction between the two treatments (glyphosate × discing) was not significant for spruce height ($p = 0.52$) and crown diameter ($p = 0.29$) (Appendix 3). Discing had no effect when glyphosate was applied; however, discing increased seedling basal diameter when no glyphosate was applied. Polynomial contrasts (Appendix 3) also indicate that glyphosate application significantly ($p = 0.0001$) increased 12-year basal diameter, height, and crown diameter over that of disced and untreated control seedlings. Increases in height and basal diameter of white spruce after glyphosate application in this study are consistent with results reported in other studies (Wood and von Althen 1993; Sutton 1995; Harper, Herring, and Hays-Byl 1997).

Figure 3 illustrates the average spruce seedling height by treatment, from 1985 to 1995. Seedlings were significantly ($p \leq 0.016$) taller in the

TABLE 4 *Least square means for white spruce: basal diameter, height, height-to-diameter ratio, crown diameter, forked leader, and browsed leader in fall of 1995*

	Basal diameter (mm)		Height (cm)		Height-to-diameter ratio		Crown diameter (cm)		Stem volume index[a]		Forked leader (%)		Browsed leader (%)	
	Herbicide													
Mechanical	GLY[b]	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	55.4	36.3	285.7	218.3	52.0	61.6	131.0	102.0	424	146	30	43	23	67
None	55.2	29.8	286.2	204.6	51.9	70.7	137.0	97.7	432	100	27	43	33	30
Standard error[c]	1.9		11.1		1.8		4.8		211		—		—	

[a] Stem volume index = % of untreated stem volume.
[b] GLY = glyphosate.
[c] Standard error is same for the least square means in all four treatments.

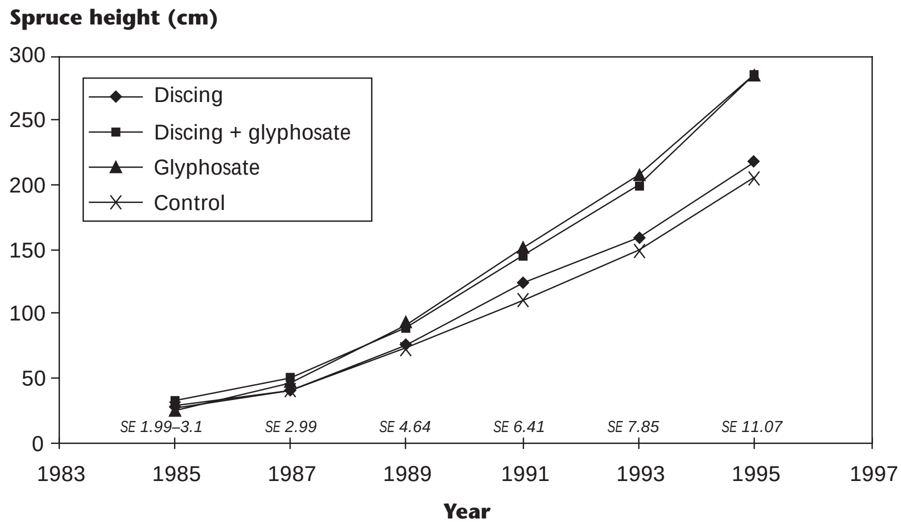

FIGURE 3 *Effect of treatments on white spruce height growth*

glyphosate-treated areas from 1989 to 1995 compared with disced and untreated seedlings (Figure 3; Appendix 4). This result suggests that glyphosate application may have a longer-lasting effect on spruce height compared with discing.

Various studies also indicate that diameter growth is more sensitive or responsive to surrounding vegetation than is height growth (Lanner 1985; Coates et al. 1991; Wagner 1994). In an environment with increased vegetation competition, diameter growth is reduced more rapidly compared with height growth, resulting in larger height-to-diameter ratios (HDR). The HDR tends to decrease from over 100 for shaded conifers to more optimal values near 50 (Harrington and Chan 1993). In this study, discing and/or glyphosate treatments significantly ($p \leq 0.0006$) (Appendix 3) reduced the HDR of spruce seedlings from a value over 70 in the untreated control to values of 62 and 52 in discing and glyphosate treatments, respectively (Table 4).

Vigour of spruce was improved by glyphosate treatment. Some 50% of spruce seedlings growing in glyphosate-treated plots exhibited good vigour (class 4), whereas spruce growing in the untreated control and disced plots exhibited vigour values ≤ 3 (moderate). In the untreated control plot, 43% of the trees exhibited moderate vigour (class 3) and 29% of the spruce exhibited poor vigour (class 1). The occurrence of forked leaders (Table 4) that may result from various factors (including vegetation press, snowpress, browsing damage, etc.) was more prevalent in the untreated control or disced area (43%) compared with the glyphosate-treated area (≤ 30%).

4.2 Treatments Effects on Achievement of Free-growing

Spruce seedlings were not tagged to assess their survival. However, a significantly ($p = 0.028$) higher spruce density was found in the glyphosate treatment plots (> 4200 sph) compared with the untreated control plot (2933 sph) (Figure 4). More than 1600 well-spaced spruce stems per hectare (sph) were tallied in all treatment plots including the control, thus all treatments are fully stocked based on current free-growing

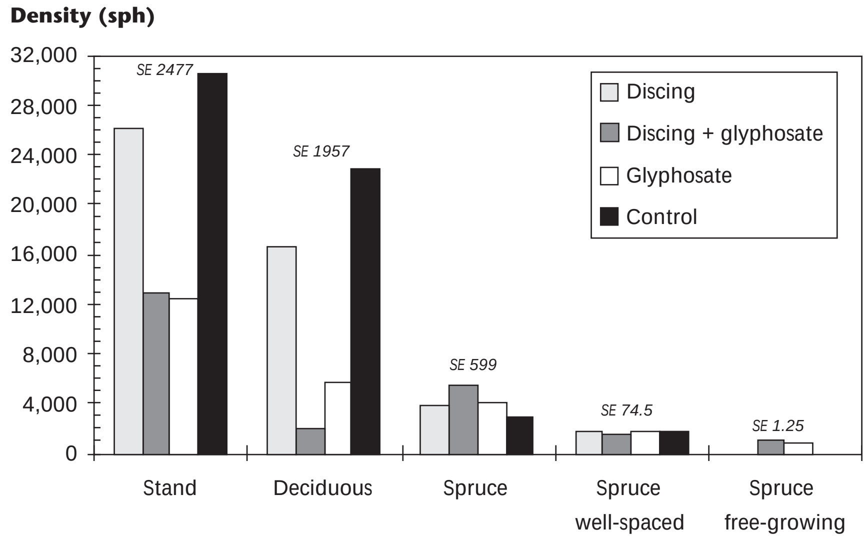

FIGURE 4 *Effects of treatments on density: stand, deciduous, spruce, spruce well-spaced, and spruce free-growing*

stocking standards for the Prince George Forest Region (B.C. Ministry of Forests and BC Environment 1995) (Figure 4). However, the information on the significance of the treatment in meeting free-growing requirement is also critical.

As stated in the Forest Practices Code's Operational Planning Regulation, Section 39 (1)(a)(vii), a healthy well-spaced tree in a free-growing stand must meet the required standards (i.e., minimum white spruce height 1.0 m and tree-to-brush height ratio 150%) of the height of the tree relative to competing vegetation within a 1 m radius cylinder of the tree trunk. At this stage (12 years after white spruce planting), only plots treated with glyphosate ($p = 0.0002$) meet the minimum (> 867 sph) free-growing requirements (B.C. Ministry of Forests and BC Environment 1995). On the other hand, data from the untreated control and discing (no glyphosate) areas indicate that the spruce stand is not free-growing (Figure 4; Appendix 5) and may become NSR (not satisfactorily restocked) based on current free-growing standards which do not accept deciduous species. Polynomial contrasts (Appendix 5) also indicate that glyphosate is significantly ($p = 0.001$) better compared with discing in meeting free-growing requirements 12 years after its application.

Recently, draft vegetation competition guidelines in the Prince George Forest Region were prepared to assist districts in determining free-growing status on areas with basic silviculture obligations for the 1998 field season (B.C. Ministry of Forests 1998a). The guidelines suggest that a combination of HDR of coniferous species and density of deciduous species can be used during a free-growing survey in deciduous tree complexes to determine whether the vegetation competition is deleterious. Therefore, coniferous HDR and deciduous stem density guidelines can provide additional information to the establishment to free-growing requirements (B.C. Ministry of Forests and BC Environment 1995). The use of coniferous HDR and deciduous stem density criteria is examined after requirements of a well-spaced tree of acceptable age and height have been evaluated. Based on this new criterion, none of the treatment area is free-growing due to higher deciduous densities (> 1000 sph) (Figure 4), although an HDR threshold of ≤ 60 (range between 40.1 and 63.9), which is required for white spruce to be declared a free-growing candidate, is found in glyphosate-treated plots (Table 4).

Within a mixedwood stand (i.e., untreated control plot) of understorey spruce and overstorey aspen and/or balsam poplar (i.e., 10% spruce and 90% deciduous by density), spruce must meet an HDR ≤ 70 requirement specified in the mixedwood stocking guidelines (B.C. Ministry of Forests 1997c) to be declared as free-growing or well-growing. At this stage of stand development (12 years after planting), a mean HDR value of 70.7 (range between 52.6 and 90.5) is found in the untreated control plot, slightly higher than the HDR requirement of 70 (Table 4). Thus, the result needs to be interpreted cautiously.

4.3 Treatment Effects on Deciduous Stand Development

In the summer of 1996, 13 years after treatment, deciduous density, basal diameter, and height were significantly reduced in both glyphosate-treated and disced plots compared with the plots where treatment was not applied (Table 5; Figure 4; Appendix 6). The deciduous densities found in glyphosate-treated plots (< 5800 sph) were one-third of those measured in the plots where glyphosate was not applied (> 16 733 sph). Polynomial contrasts also showed that glyphosate application significantly ($p \leq 0.004$) reduced deciduous density compared with discing and untreated control (Appendix 6). The deciduous density in the untreated control area was 22 933 sph, consisting of 54% *Populus tremuloides* (trembling aspen) and 46% *Populus balsamifera* spp. *balsamifera* (balsam poplar) (Table 5). In addition to reductions in deciduous density (16 733 sph), the discing treatment reversed the species composition (i.e., 46% aspen and 54%

TABLE 5 *Least square means for the density of deciduous species, balsam poplar, trembling aspen, Sitka or green alder, and willow; and for deciduous basal diameter and deciduous height in fall of 1995*

	Deciduous density[a] (sph)[b]		Balsam poplar density[c] (sph)		Trembling aspen density[d] (sph)		Sitka or green alder density[e] (sph)		Willow density[f] (sph)		Deciduous basal diameter (mm)		Deciduous height (cm)	
	Herbicide													
Mechanical	GLY[g]	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	2 133	16 733	2 067	9 067	67	7 667	3 800	3 267	1 400	1 667	29.7	41.0	250	367
None	5 800	22 933	4 733	10 533	1 067	12 400	533	3 933	1 933	533	40.2	45.6	333	500
Standard error[h]	1 957		3 516		4 332		1 797		931		2.3		42.5	

[a] Deciduous density includes both *Populus* spp.
[b] sph = stems per hectare.
[c] Balsam poplar = *Populus balsamifera* spp. *balsamifera*; [d] Trembling aspen = *Populus tremuloides*; [e] Sitka or green alder = *Alnus viridis*; [f] Willow = *Salix* spp.
[g] GLY = glyphosate.
[h] Standard error is same for the least square means in all four treatments.

balsam poplar). The glyphosate treatment resulted in less than 5800 sph, comprised of more than 82% balsam poplar and less than 18% trembling aspen (Table 5). This result suggests that both glyphosate and discing treatments modified deciduous composition compared with the untreated control (i.e., aspen dominated in the untreated control and balsam poplar dominated in disced and glyphosate).

Deciduous percent cover was significantly reduced in both discing (p = 0.009) and glyphosate (p = 0.0001) treatments compared with plots where treatment was not applied (Figure 5; Appendix 7). There was a significant (p = 0.018) interaction between glyphosate and discing. Further analysis using polynomial contrasts indicates glyphosate significantly (p = 0.014) reduced deciduous percent cover (< 11%) compared with untreated control (74%) (Appendix 7). Discing alone is not very effective (p = 0.07) in reducing deciduous percent cover (40%) compared with the untreated control plot (Figure 5). The absence of vegetation control treatment resulted in a mixedwood stand with 5-m-tall deciduous species in the overstorey and 2-m-tall suppressed spruce in the understorey. To achieve a stand dominated by spruce at the end of the rotation, brushing in combination with density management for deciduous species (i.e., 5000 sph of aspen or poplar) is required (B.C. Ministry of Forests 1997b).

4.4 Treatment Influences on the Vegetation Community

Both glyphosate and discing treatments changed species abundance (Figures 6–9). Total vegetation percent cover was significantly (p = 0.023) reduced in plots treated with glyphosate (180%) compared with the plots with no herbicide (i.e., untreated control 228% and discing only 204%) (Figure 5). When comparing percent cover of vertical strata (canopy), significant ($p \leq 0.001$) differences were found only in the shrub layer with the percent cover values less than 76% in glyphosate-treated areas compared with the untreated areas with percent cover of less than 138% (Figure 5). Further breakdown of the shrub layer into tall shrubs (> 1.3 m in height) and low shrubs (≤ 1.3 m in height) (Table 6) showed that

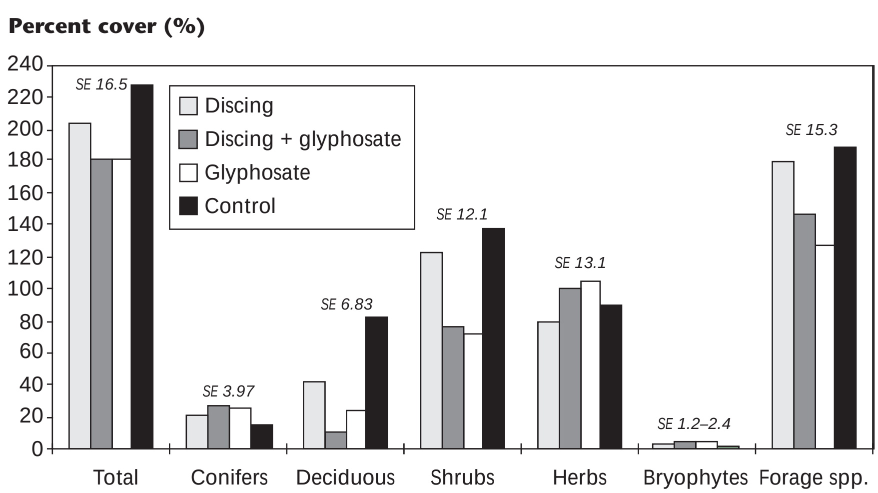

FIGURE 5 *Effects of treatments on percent cover: total (all species), conifers, deciduous, shrubs, herbs, bryophytes, and forage species*

FIGURE 6 *A vegetation community in a discing plot (August 13, 1996)*

FIGURE 7 *A vegetation community in a discing+glyphosate treatment plot (August 13, 1996)*

FIGURE 8 *A vegetation community in a glyphosate treatment plot (August 13, 1996)*

FIGURE 9 *A vegetation community in an untreated control plot (August 13, 1996)*

TABLE 6 *Least square means for the vegetation species percent cover and height for stratum B1, B2, and B in summer of 1996*

	Stratum B1[a] percent cover (%)		Stratum B2[b] percent cover (%)		Stratum B[c] percent cover (%)		Stratum B1 height (cm)		Stratum B2 height (cm)		Stratum B height (cm)	
	Herbicide											
Mechanical	GLY[d]	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	37.3	55.0	38.8	66.5	76.0	121.5	330	370	80	93	145	174
None	42.5	95.5	29.0	42.8	71.5	138.3	360	470	89	94	172	211
Standard error[e]	8.1		12.6		13.1		33±1		8.6±0.4		22.7±0.6	

[a] B1 = tall shrubs (>1.3 m in height; [b] B2 = low shrubs ≤ 1.3 m in height; [c] B = B1+B2 = all shrubs.
[d] GLY = glyphosate.
[e] Standard error is same for the least square means in all four treatments.

significant differences in percent cover and modal height were present only in the tall shrub layer (Appendix 8). The main species found in the tall shrub layer were *Alnus viridis* (Sitka or green alder) and *Salix* spp. (willow). The tall shrub density (Sitka or green alder + willow) in the untreated control and discing plots exceeded 4466 sph, and both treatments were dominated by alder (> 66%) (Table 5). The glyphosate treatment (without discing) resulted in 2466 sph of tall shrubs consisting of 78% willow and 22% alder (Table 5). Willow dominated the tall shrub layer in glyphosate-treated plots, whereas Sitka or green alder dominated the tall shrub layer in plots without any herbicide treatment (Table 5). The percent cover of herbaceous species and bryophytes was not significantly different between treatments (Figure 5; Appendix 7).

Figures 10 and 11 present the percent cover and modal height analysis of the five main species present on the site: *Aster conspicuus* (showy aster), *Epilobium angustifolium* (fireweed), *Lathyrus ochroleucus* (creamy peavine), *Populus* spp. (balsam poplar and/or trembling aspen), and *Rosa acicularis* (prickly rose). For fireweed and aspen, both height and percent cover were significantly (Appendix 9) reduced by glyphosate application compared with the untreated plots (Figures 10 and 11). The reduction in aspen ground cover within the glyphosate-treated area may have increased light availability for establishment of otherwise suppressed species (i.e., creamy peavine) (Figure 10).

Cover data for conifers exhibit an inverse relation to that of shrub and total vegetation cover with the glyphosate treatment. Percent cover of coniferous species significantly ($p = 0.043$) increased and almost doubled in glyphosate-treated areas (main effect) compared with the untreated (without glyphosate) areas (Figure 5). The control plot exhibited the lowest conifer cover (15%) while glyphosate-treated plots had cover values over 26%.

4.5 Treatment Effects on Plant Species Diversity

In the summer of 1996, 13 years after planting, glyphosate (main effect) had significantly increased the number of herbs ($p = 0.003$) and bryophytes ($p = 0.044$) compared with the untreated plots (Table 7; Appendix 11). The glyphosate treatment had no effect on the number of shrub species. Polynomial contrasts showed that glyphosate application significantly ($p = 0.016$) increased the number of herbs compared with discing only (Appendix 11). A count of the number of species was used to assess species richness in each subplot. In total, 43, 36, and 34 plant

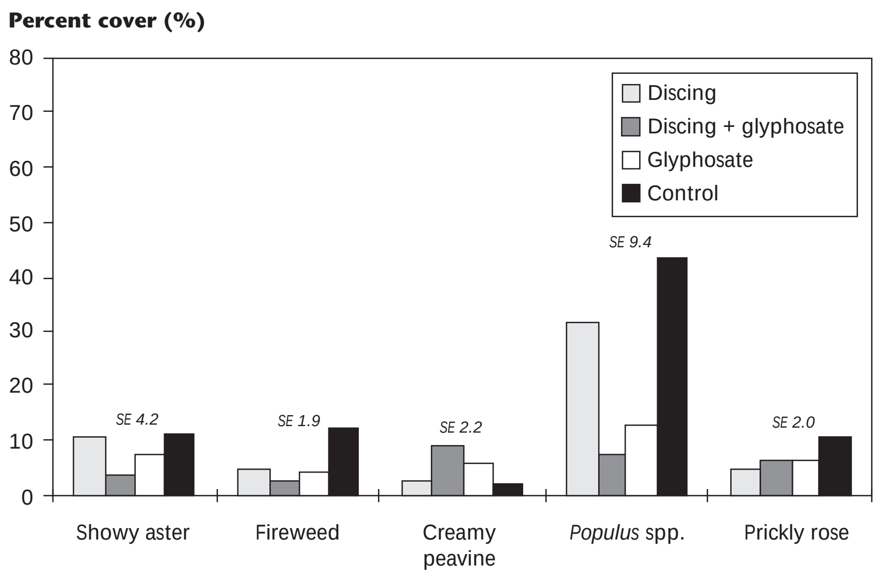

FIGURE 10 *Effects of treatments on percent cover of five main species*

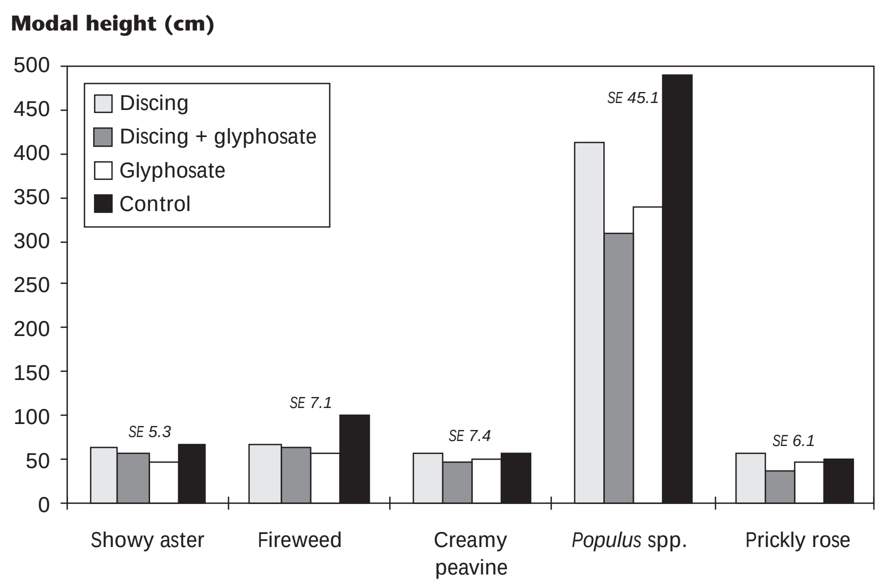

FIGURE 11 *Effects of treatments on modal height of five main species*

species were present in glyphosate (with and without discing), discing alone, and untreated control areas, respectively (Appendix 12).

The significant ($p = 0.006$) improvements in species richness in glyphosate-treated plots (≥29 species) compared with untreated (without glyphosate) plots (≤ 24 species) may be the result of increases in herbs and bryophytes. Modified Simpson's Diversity Index (SDI) and modified Shannon-Wiener Diversity Index (SWI) were used to test treatment effects on plant species diversity. The SWI, which places most weight on rare species in the sample, was significantly ($p = 0.005$) higher in glyphosate-treated plots (≥ 1.16) compared with the untreated control (1.04) and discing (1.01) plots. Polynomial contrasts showed that SWI was significantly ($p = 0.008$) lower in discing plots compared to the untreated control plot (Appendix 11). The SDI, which places most weight on the common species, did not differ significantly between treatments. Glyphosate application appears to improve plant species diversity by modifying the microenvironment (i.e., allowing more light to reach ground level), and by reducing the abundance of common species and allowing the rare species to flourish.

4.6 Treatment Impacts on Wildlife Habitat

Cover of wildlife forage species (Appendix 13) was significantly ($p = 0.01$) reduced by glyphosate application compared with no treatment (Figure 5). The glyphosate-treated plots had an average forage cover value of less than 147%, whereas significantly higher cover values of 179% and 189% were found in discing only and control plots, respectively. Polynomial comparison (Appendix 7) showed that discing, glyphosate, and discing + glyphosate treatments reduced forage species percent cover significantly ($p = 0.027$) compared with untreated control (Appendix 7).

Based on a six-class rating (Appendix 2), forage utilization ratings were generally nil (class 0) to slight (class 1), with classes 0 and 1 comprising at

TABLE 7 *Least square means for number of species (forage, shrubs, herbs, bryophytes), species richness, and diversity index (Simpson's, Shannon-Wiener) in summer of 1996*

	Number of forage species		Number of shrubs		Number of herbs		Number of bryophytes		Species richness		Modified Simpson's Diversity Index		Modified Shannon-Wiener Diversity Index	
	Herbicide													
Mechanical	GLY[a]	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	14	13	10	9	19	14	3	2	32	24	0.71	0.83	1.16	1.01
None	14	12	10	9	17	13	2	0	29	22	0.90	0.86	1.23	1.04
Standard error[b]	0.8		0.8		1.3		0.8		2.2		0.09		0.05	

[a] GLY = glyphosate.
[b] Standard error is same for the least square means in all four treatments.

least 62% of recorded values. The only notable difference in forage utilization values was that light utilization (class 2) occurred 22% of the time for the glyphosate-treated plots and between 11 and 14% for the other plots. Sitka or green alder, fireweed, trembling aspen, balsam poplar, and willow were all browsed consistently across all treatments (Appendix 13).

The qualitative measure of white spruce seedling condition in this study suggests various kinds of damage and abnormalities in different treatments. Wildlife damage to white spruce seedlings included clipped and browsed foliage and leaders, snapped or broken leaders, bark peeled or abraded, trampling injuries, cut stem, bent stem, and complete tree removal. The damage was observed in all treatments. However, damage was greater on spruce seedlings within the discing plot (67%) than in the glyphosate (33%) and untreated (30%) plots (Table 4).

Higher shrub cover in the disced area (Figure 5) may have resulted in higher browsing damage. Fewer occurrences of browsing damage to spruce in the untreated control plot may be due to higher deciduous density (Figures 4 and 9), which may have restricted wildlife movement in the plot. Lower shrub cover in the glyphosate area (Figure 5) may have resulted in less browsing damage to the spruce leaders.

4.7 Treatment Effects on Timber Yield

Twelve years after treatment application, results show a mean spruce height of 204.6 cm for the untreated control, gains of 6% for discing alone, and gains of 35% for glyphosate application after discing and glyphosate alone (Table 4; Figure 3). Sutton (1995) found a 36% height increase in white spruce that had received a vegetation control treatment compared with untreated spruce. Similarly, results show a mean spruce basal diameter of 29.8 mm in the control area, and gains of 22% in the disced area, and 86% in areas where glyphosate was applied. These increases in height and diameter growth in spruce have increased the spruce stem volume.

In 1995 (12 years post-treatment), a stem volume of 597 cm^3/ha was found in the untreated control plot. A stem volume index (percentage of untreated) of 146% for discing and 428% (average of disced and undisced plots) for glyphosate application was also recorded (Table 4). To determine whether treatments will have any long-term growth response that can be measured as changes in yield or wood volume, yield projections are necessary.

Spruce yield projections indicate that treated plots will reach maximum mean annual increment (MAI) or MAI culmination before the untreated plot (Table 8 and Figure 12). Based on MAI culmination, rotation length is 77 years for the untreated control (Table 8), and rotation length is reduced by 3 years (74 years) for discing, 13 years (64 years) for glyphosate application after discing, and 19 years (58 years) for glyphosate application alone. Based on the concept of biological maximization, if different plots are harvested at maximum MAI, there is no apparent difference in spruce yield (Table 8). However, if the plots are harvested at the same time (after 60 years), glyphosate treated plots have 41% higher stand volumes than untreated plots (Figure 13). This result suggests a gain of 41% in stand volume by investing $299/ha for glyphosate application. Tables 8 and 9 summarize treatments effects on timber yield before and after pre-commercial thinning (PCT), respectively. Simulations indicate that PCT to 1355 sph may improve stand volume by 40 m^3/ha in an untreated plot and by 47 m^3/ha in treated plots (Tables 8 and 9). However, to capture potential gains from PCT, harvest needs to be delayed from 6 to 9 years (Tables 8 and 9).

In spruce yield projections (Figure 12), the SI used for understorey spruce (Table 8) may not represent a true site index potential for this site due to suppressed seedlings. These values may underestimate the yield at an early stage because trees are not growing to their full potential. Conversely, using the SI value from the adjacent area (i.e., treated plots) is potentially biased and may overestimate the yield for the untreated control area because it ignores the effect of the deciduous overstorey on spruce growth.

Since deciduous species (i.e., balsam poplar and trembling aspen) are present as an overstorey on this site and are expected to occupy the site at least to maturity, it is logical to include deciduous volume for total yield analysis. However, no quantitative models are currently available for use in

TABLE 8 *Stand yield projections and financial analysis for spruce derived from* ***TIPSY*** *version 2.1*

	Silviculture costs ($/ha)		**Site index**		**Total stand vol. (m^3/ha)[a]**		**Age (yr)**		**Max. MAI (m^3/ha)**		**Net present value ($/ha)[b]**	
							Herbicide					
Mechanical	GLY[c]	None	GLY	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	1885	1586	22.0	19.6	426	427	64	74	6.66	5.77	-683	-788
None	1572	1273	23.7	19.0	427	431	58	77	7.36	5.59	-47	-561

[a] Operational adjustment factors used in analysis : OAF1 = 0.90; OAF2 = 1:00; combined OAF = 0.90.
[b] Economic analysis (see Appendix 14).
[c] GLY = glyphosate.

TABLE 9 *Stand yield projections and financial analysis for spruce after pre-commercial thinning to 1355 sph derived from* ***TIPSY*** *version 2.1*

	Silviculture costs ($/ha)		**Total stand vol. (m^3/ha)[a]**		**Age (yr)**		**Max. MAI (m^3/ha)**		**Net present value ($/ha)[b]**	
					Herbicide					
Mechanical	GLY [a]	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	2320	2006	473	468	71	82	6.66	5.71	-678	-860
None	2001	1668	472	471	64	86	7.37	5.48	-11	-665

[a] Operational adjustment factors used in analysis : OAF1 = 0.90; OAF2 = 1:00; combined OAF = 0.90.
[b] Economic analysis (see Appendix 14).
[c] GLY = glyphosate.

British Columbia to evaluate the long-term yield implications of complex multi-species and/or mixedwood stands.

To estimate yield of the mixed stands, WinVDYP software (B.C. Ministry of Forests 1998c) was used to make yield projections for deciduous species. The deciduous volume estimated in glyphosate-treated plots (< 128 m^3/ha) was one-fourth and one-half of the volume projected in the disced (170 m^3/ha) and the untreated control (234 m^3/ha) plots, respectively (Table 10 and Figure 13). The addition of trembling aspen and/or balsam poplar volume to the spruce volume in the mixed stand

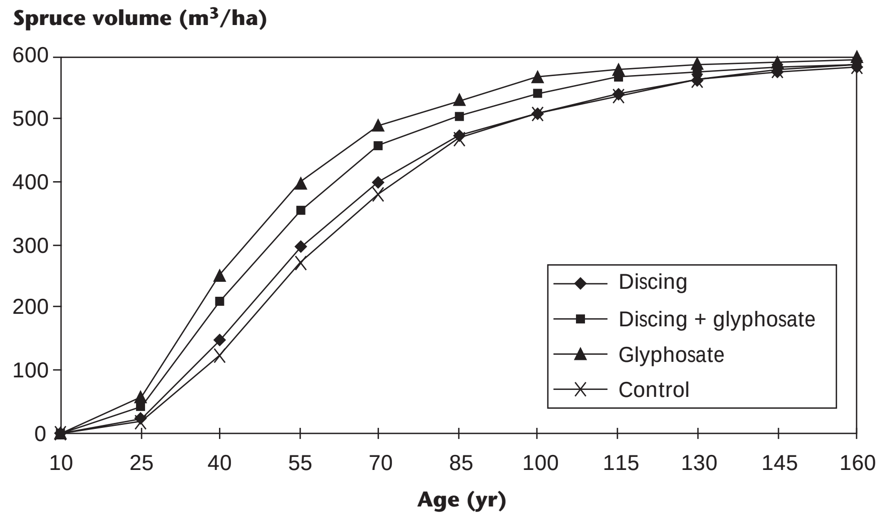

FIGURE 12 *White spruce yield projections derived from TIPSY version 2.1*

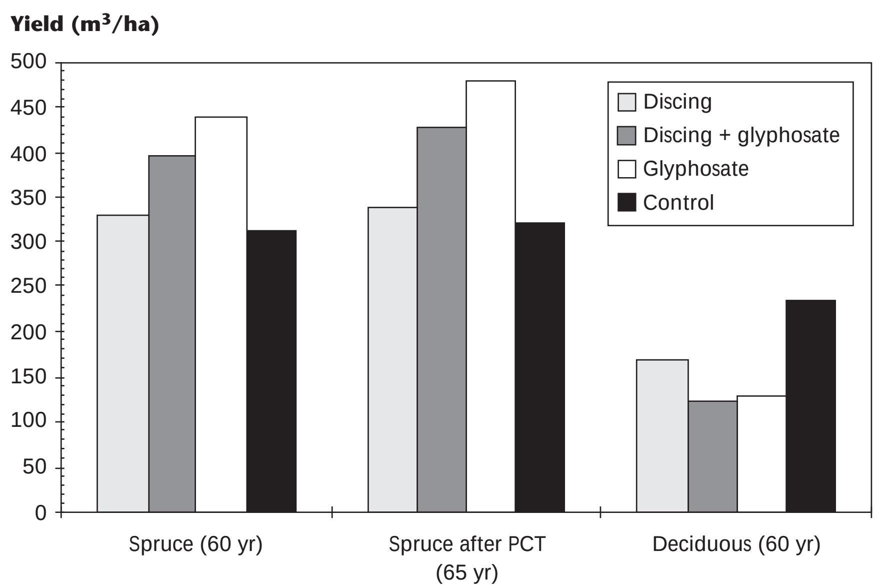

FIGURE 13 *Timber yield (7.5$^+$ cm) for white spruce before and after pre-commercial thinning (PCT), and for deciduous species*

TABLE 10 *Stand yield projection for deciduous species (60 years rotation age) derived from Win**VDYP***

	Trembling aspen site index		Balsam poplar site index		Trembling aspen volume (m^3/ha) [a]		Balsam poplar volume (m^3/ha)		Total deciduous volume (m^3/ha)	
	Herbicide									
Mechanical	GLY [b]	None	GLY	None	GLY	None	GLY	None	GLY	None
Discing	10.0	18.5	16.0	18.1	1	78	123	92	124	170
None	13.0	24.0	16.5	19.5	16	142	112	92	128	234

[a] Volume (7.5+ cm) of pure trembling aspen and balsam poplar stands were adjusted based on density (i.e., adjusted volume = 100 x species density/deciduous density).
[b] GLY = glyphosate.

(i.e., untreated control plot) can offset the loss in spruce yield resulting from not applying the treatment. The total timber yield (60 years rotation) projected for discing (509 m^3/ha) and glyphosate (534 m^3/ha) treated areas is less compared with the untreated control (545 m^3/ha) areas.

Economic analysis based only on white spruce using average values for the district (Appendix 14) indicates that net present values (NPVs) in all the treatments are negative due to the higher cost ($721/ha) of vegetation clearing associated with regeneration delay on a backlog site. Glyphosate treatment with an average treatment cost of $299/ha provides the highest NPV (Table 8). Conversely, discing with an average treatment cost of $313/ha results in the lowest NPV. While complete financial analysis of the treatments should include both coniferous and deciduous returns, model and data limit the analysis.

5 CONCLUSIONS

The results from 12th-year measurements suggest that:

- Controlling competing vegetation immediately after planting using glyphosate increased spruce height, crown diameter, and basal diameter, and reduced height-to-diameter ratio.
- Glyphosate application significantly improved white spruce height, resulting in a significant increase in the number of free-growing spruce per hectare 12 years after planting.
- Glyphosate application significantly reduced deciduous percent cover, density, and height.
- Glyphosate significantly reduced shrub cover (45% reduction) and wildlife forage species cover, and increased plant species diversity.
- White spruce yield projections suggest that deciduous domination in a stand, due to no vegetation control, can increase the rotation by up to 19 years. If managed as a mixedwood stand (i.e., untreated control plot), deciduous species can provide additional timber volume.

Because the lack of replication in this trial, interpretations of the results are applicable to the study site only. To increase confidence in generalizing results, much of the information presented in this report can be best obtained from replicated vegetation management research experiments. However, not many replicated trials are available to provide information on long-term implications of vegetation management. This study provides some insight into long-term implications of treatments and can be used as an indicator of long-term response to these treatments. The study also suggests that vegetation management treatments can contribute to achievement of management objectives (such as free-growing), when carefully planned and applied for stand establishment. The management of mixedwood stands in untreated areas will be yet another challenge to silviculturists.

APPENDIX 1 A list of vigour codes (Herring and Pollack 1985)

Code	Description
0	Dead.
1	Moribund: near death little or no visible shoot growth.
2	Poor: minimal shoot growth, small needle complement, etiolated shoot development, tendency for poor form due to inadequately rigid stem.
3	Moderate: overall growth rate and condition lower than open-grown seedling.
4	Good: growth rate and quality similar to open-grown seedling.

APPENDIX 2 A list of forage utilization classes and codes (Habitat Monitoring Committee 1996)

Code	Class	Range (%)	Description
0	Nil	0	Plants show no evidence of livestock or wildlife browse.
1	Slight	1–15	Plants have the appearance of very slight use; may be topped or slightly used.
2	Light	16–35	Plants may be topped, skimmed, or grazed in patches; low-value plants or ungrazed and 60–80% current leafage intact.
3	Moderate	36–65	Plants rather uniformly grazed; 15–25% of current leafage intact.
4	Heavy	66–80	Plants almost entirely used, with less than 10% of current leafage intact.
5	Extreme	> 80	Key plant species carry the grazing load and are closely cropped; no evidence of reproduction or current seed stalks of key species. Trampling damage and trailing are evident.

APPENDIX 3 *p*-values from ANOVA for white spruce: basal diameter, height, height-to-diameter ratio, and crown diameter in fall of 1995

Factor	*p*-value Basal diameter	Height	Height-to-diameter ratio	Crown diameter
Discing	0.081	0.55	0.016	0.85
Glyphosate	0.0001	0.0001	0.0001	0.0001
Discing * Glyphosate	0.097	0.52	0.013	0.29
Control vs Discing alone	0.017	0.38	0.0006	0.54
Discing only vs Glyphosate only	0.0001	0.0001	0.0003	0.0001
Control vs Glyphosate all	0.0001	0.0001	0.0001	0.0001
Control vs all others	0.0001	0.0001	0.0001	0.0001

APPENDIX 4 *p*-values from ANOVA for white spruce height 1985-1995

Factor	*p*-value 1985	1987	1989	1991	1993	1995
Discing	0.027	0.44	0.95	0.61	0.91	0.55
Glyphosate	0.64	0.027	0.0006	0.0001	0.0001	0.0001
Discing * Glyphosate	0.52	0.60	0.54	0.12	0.26	0.52
Control vs Discing alone	0.16	0.85	0.63	0.15	0.38	0.38
Discing only vs Glyphosate only	0.18	0.30	0.016	0.003	0.0001	0.0001
Control vs Glyphosate all	0.27	0.06	0.002	0.0001	0.0001	0.0001
Control vs all others	0.17	0.15	0.017	0.0001	0.0001	0.0001

APPENDIX 5 *p*-values from ANOVA for density of: stand, deciduous, spruce, spruce well-spaced, and spruce free-growing

Factor	*p*-value				
	Stand (sph)[a]	**Deciduous (sph)**	**Spruce (sph)**	**Spruce well spaced (sph)**	**Spruce free-growing (sph)**
Discing	0.096	0.036	0.087	0.40	0.45
Glyphosate	0.0001	0.0001	0.037	0.11	0.0001
Discing * Glyphosate	0.47	0.54	0.71	1.00	0.45
Control vs Discing alone	0.099	0.055	0.30	0.54	1.00
Discing only vs Glyphosate only	0.006	0.004	0.70	0.54	0.001
Control vs Glyphosate all	0.0001	0.0001	0.028	0.11	0.0002
Control vs all others	0.0005	0.0002	0.047	0.16	0.002

[a] sph = stems per hectare.

APPENDIX 6 *p*-values from ANOVA for the density (deciduous, balsam poplar, trembling aspen, Sitka or green alder, and willow), deciduous diameter, and deciduous height in fall of 1995

Factor	*p*-value						
	Deciduous (sph)[a]	**Balsam poplar[b] (sph)**	**Trembling aspen[c] (sph)**	**Sitka or green alder[d] (sph)**	**Willow[e] (sph)**	**Deciduous diameter (mm)**	**Deciduous height (cm)**
Discing	0.036	0.57	0.53	0.49	0.76	0.002	0.034
Glyphosate	0.0001	0.11	0.060	0.45	0.56	0.0006	0.013
Discing * Glyphosate	0.54	0.87	0.68	0.31	0.40	0.21	0.57
Control vs Discing alone	0.055	0.78	0.46	0.80	0.41	0.16	0.057
Discing only vs Glyphosate only	0.004	0.41	0.31	0.31	0.84	0.80	0.59
Control vs Glyphosate all	0.0001	0.14	0.056	0.45	0.35	0.0004	0.004
Control vs all others	0.0002	0.23	0.095	0.52	0.32	0.002	0.006

[a] sph =stems per hectare.
[b] Balsam poplar = *Populus balsamifera* spp. *balsamifera*.
[c] Trembling aspen = *Populus tremuloides*.
[d] Sitka or green alder = *Alnus viridis*.
[e] Willow = *Salix* spp.

APPENDIX 7 *p*-values from ANOVA for the vegetation species percent cover for: total (all species), coniferous, deciduous, herbs, shrubs, bryophytes, and forage species in summer of 1996

	***p*-value**						
Factor	**Total species**	**Coniferous**	**Deciduous**	**Herbs**	**Shrubs**	**Bryophytes**	**Forage species**
Discing	0.39	0.43	0.009	0.58	0.65	0.52	0.75
Glyphosate	0.02	0.043	0.0001	0.18	0.001	0.26	0.01
Discing * Glyphosate	0.38	0.58	0.018	0.80	0.43	0.66	0.36
Control vs Discing alone	0.25	0.33	0.07	0.18	0.019	0.67	0.034
Discing only vs Glyphosate only	0.26	0.25	0.007	0.25	0.030	0.49	0.16
Control vs Glyphosate all	0.18	0.31	0.014	0.55	0.046	0.57	0.051
Control vs all others	0.17	0.27	0.015	0.33	0.020	0.57	0.027

APPENDIX 8 *p*-values from ANOVA for the vegetation species percent cover and height for stratum B1, B2, and B in summer of 1996

	***p*-value**					
Factor	**Stratum B1[a] percent cover**	**Stratum B2[b] percent cover**	**Stratum B[c] percent cover**	**Stratum B1 height**	**Stratum B2 height**	**Stratum B height**
Discing	0.016	0.21	0.65	0.054	0.55	0.16
Glyphosate	0.0009	0.13	0.001	0.025	0.34	0.13
Discing * Glyphosate	0.051	0.59	0.43	0.39	0.67	0.83
Control vs Discing alone	0.004	0.21	0.38	0.052	0.91	0.27
Discing only vs Glyphosate only	0.30	0.057	0.019	0.81	0.80	0.94
Control vs Glyphosate all	0.0001	0.58	0.002	0.003	0.41	0.063
Control vs all others	0.0002	0.89	0.008	0.004	0.53	0.079

[a] B1 = tall shrubs > 1.3 m in height.
[b] B2 = low shrubs ≤ 1.3 m in height.
[c] B = B1+B2 = all shrubs.

APPENDIX 9 *p*-values from ANOVA for the vegetation species percent cover for: showy aster, fireweed, creamy peavine, *Populus* spp., and prickly rose in summer of 1996

Factor	*p*-value				
	Showy aster [a]	Fireweed [b]	Creamy peavine [c]	*Populus* spp.[d]	Prickly rose[e]
Discing	0.58	0.047	0.49	0.009	0.17
Glyphosate	0.24	0.023	0.037	0.0001	0.55
Discing * Glyphosate	0.75	0.12	0.52	0.018	0.20
Control vs Discing alone	0.65	0.78	0.27	0.18	0.55
Discing only vs Glyphosate only	0.39	0.52	0.054	0.090	0.61
Control vs Glyphosate all	1.00	0.15	0.91	0.29	0.46
Control vs all others	0.85	0.25	0.59	0.20	0.78

[a] Showy aster =*Aster conspicuus*.
[b] Fireweed = *Epilobium angustifolium*.
[c] Creamy peavine = *Lathyrus ochroleucus*.
[d] *Populus* spp. = trembling aspen and balsam poplar.
[e] Prickly rose = *Rosa acicularis*.

APPENDIX 10 *p*-values from ANOVA for the vegetation species modal height for: showy aster, fireweed, creamy peavine, *Populus* spp., and prickly rose in summer of 1996

Factor	*p*-value				
	Showy aster [a]	Fireweed [b]	Creamy peavine [c]	*Populus* spp.[d]	Prickly rose[e]
Discing	0.68	0.13	0.83	0.27	0.66
Glyphosate	0.052	0.004	0.31	0.015	0.063
Discing * Glyphosate	0.11	0.017	0.59	0.59	0.21
Control vs Discing alone	0.093	0.20	0.56	0.26	0.28
Discing only vs Glyphosate only	0.77	0.60	0.27	0.13	0.035
Control vs Glyphosate all	0.029	0.010	0.91	0.28	0.68
Control vs all others	0.028	0.019	0.87	0.22	0.87

[a] Showy aster =*Aster conspicuus*.
[b] Fireweed = *Epilobium angustifolium*.
[c] Creamy peavine = *Lathyrus ochroleucus*.
[d] *Populus* spp. = trembling aspen and balsam poplar.
[e] Prickly rose = *Rosa acicularis*.

APPENDIX 11 *p*-values from ANOVA for number of species (forage, shrubs, herbs, bryophytes), species richness, and diversity index (Simpson's, Shannon-Wiener) in summer of 1996

	***p*-value**						
	Number of forage species	**Number of shrubs**	**Number of herbs**	**Number of bryophytes**	**Species richness**	**Modified Simpson's Diversity Index**	**Modified Shannon-Wiener Diversity Index**
Discing	0.65	0.87	0.25	0.13	0.26	0.26	0.33
Glyphosate	0.11	0.28	0.003	0.044	0.006	0.71	0.005
Discing * Glyphosate	0.88	0.64	0.85	0.75	0.87	0.38	0.73
Control vs Discing alone	0.39	0.38	0.092	0.66	0.15	0.59	0.008
Discing only vs Glyphosate only	0.29	0.28	0.016	0.20	0.029	0.37	0.049
Control vs Glyphosate all	0.53	0.90	0.39	0.61	0.47	0.31	0.057
Control vs all others	0.43	0.65	0.19	0.59	0.27	0.35	0.017

APPENDIX 12 Impacts of treatments on species percent cover and modal height

Species		Mechanical site preparation							
		Discing				No discing			
	Herbicide application	Glyphosate		None		Glyphosate		None	
Common name	Scientific name	Percent cover (%)	Modal height (m)	Percent cover (%)	Modal height (m)	Percent cover (%)	Modal height (m)	Percent cover (%)	Modal height (m)
American vetch	*Vicia americana*	6.0	0.57	3.8	0.69	7.5	0.56	2.0	0.73
arctic lupine	*Lupinus arcticus*	0.5	0.25						
balsam poplar	*Populus balsamifera* spp. *balsamifera*	4.1	2.35	15.9	2.78	6.4	2.38	21.8	3.29
baneberry	*Actaea rubra*	0.5	0.18					1.0	0.35
black twinberry	*Lonicera involucrata*			1.0	0.70			1.0	0.76
bluejoint	*Calamagrostis canadensis*	47.5	1.26	48.3	1.18	55.0	1.18	40.0	1.35
bunchberry	*Cornus canadensis*	1.8	0.11	0.5	0.07	10.7	0.05	4.5	0.08
Canada goldenrod	*Solidago canadensis*	2.7	0.61			1.3	0.58	1.0	1.06
Canada violet	*Viola candensis*					1.0	0.14		
common dandelion	*Taraxacum officinale*	2.1	0.21	0.6	0.13	1.5	0.15	0.5	0.05
common red paintbrush	*Castilleja miniata*	1.2	0.61	1.5	0.51	4.3	0.55	0.5	0.44
common snowberry	*Symphoricarpos albus*							5.0	0.31
creamy peavine	*Lathyrus ochroleucus*	8.8	0.46	2.3	0.58	5.8	0.51	2.1	0.55
dwarf nagoonberry	*Rubus arcticus*	1.0	0.18	0.5	0.12				
early blue violet	*Viola adunca*	1.0	0.05						
false pixie-cup	*Cladonia chlorophaea*	0.5	0.02			1.0	0.02		
false Solomon's-seal	*Smilacina racemosa*			0.5	0.76				
fireweed	*Epilobium angustifolium*	3.0	0.63	4.8	0.69	4.0	0.55	12.0	1.00
fringed aster	*Aster ciliolatus*	0.5	0.62			0.5	0.60	2.0	0.45
glow moss	*Aulacomnium palustre*			0.8	0.02				
highbush-cranberry	*Viburnum edule*	1.3	0.22	2.3	0.38	3.0	0.52	8.0	0.63
juniper haircap moss	*Polytrichum juniperinum*	0.6	0.02			1.0	0.02		
narrow-leaved hawkweed	*Hieracium umbellatum*	0.8	0.87	0.5	0.88	0.7	0.55	0.5	0.95
northern bedstraw	*Galium boreale*	3.0	0.38	1.2	0.36	2.0	0.27	2.3	0.30
northern black currant	*Ribes hudsonianum*					0.5	0.25		
northern gentian	*Gentianella amarella*	0.7	0.43	0.5	0.50	0.8	0.42		
northern gooseberry	*Ribes oxyacanthoides*	1.7	0.47	0.8	0.44				
northern grass-of-Parnassus	*Parnassia palustris*			0.5	0.25				
orange-foot lichen	*Cladonia ecmocyna*					0.5	0.02		
palmate coltsfoot	*Petasites palmatus*	0.9	0.15	1.0	0.16	2.6	0.19	1.9	0.12
paper birch	*Betula papyrifera*	1.7	1.07	0.8	0.94	2.0	1.23	0.5	1.50
pearly everlasting	*Anaphalis margaritacea*					1.0	0.70		

APPENDIX 12 (Continued)

Species		Mechanical site preparation							
		Discing				No discing			
	Herbicide application	Glyphosate		None		Glyphosate		None	
Common name	Scientific name	Percent cover (%)	Modal height (m)	Percent cover (%)	Modal height (m)	Percent cover (%)	Modal height (m)	Percent cover (%)	Modal height (m)
pioneer cladonia (horn cladonia)	*Cladonia cornuta*			0.5	0.02			1.0	0.01
prickly rose	*Rosa acicularis*	6.3	0.35	4.8	0.55	6.5	0.45	10.5	0.50
purple reedgrass	*Calamagrostis purpurascens*	13.5	0.93			12.3	1.02		
pyramid spirea	*Spiraea pyramidata*	0.6	0.31	1.0	0.38	0.8	0.29	4.8	0.46
rayless alpine butterweed	*Senecio pauciflorus*					0.5	0.37		
red clover	*Trifolium pratense*	1.3	0.45	0.8	0.80	3.0	0.41		
red raspberry	*Rubus idaeus*	1.0	0.43			1.3	0.26		
red swamp currant	*Ribes triste*							0.5	0.10
red-osier dogwood	*Cornus stolonifera*							3.0	1.05
showy aster	*Aster conspicuus*	3.8	0.58	10.3	0.62	7.5	0.48	11.3	0.69
Sitka or green alder	*Alnus viridis*	13.8	2.62	32.2	2.62	5.6	3.06	15.8	3.53
slender cup lichen (brown- foot cladonia)	*Cladonia gracilis*			0.5	0.04				
small bedstraw	*Galium trifidum*					0.5	0.05		
soopolallie	*Shepherdia canadensis*	2.0	0.73	5.0	1.00	3.0	0.67	2.0	0.84
tall bluebells	*Mertensia paniculata*	2.0	0.13	0.7	0.08	1.5	0.09	8.0	0.23
toad pelt	*Peltigera scabrosa*	1.5	0.02	2.0	0.02	3.8	0.02		
torn club lichen (ribbed cladonia)	*Cladonia cariosa*	3.8	0.03			0.8	0.02		
trailing raspberry	*Rubus pubescens*	1.0	0.15	0.8	0.20	4.0	0.14	1.3	0.14
trembling aspen	*Populus tremuloides*	2.0	2.15	13.8	3.93	6.2	2.81	31.0	4.52
twinflower	*Linnaea borealis*	3.0	0.03			4.0	0.04	1.0	0.04
violet	*Viola* spp.							1.0	0.10
western meadowrue	*Thalictrum occidentale*			2.0	0.60				
white spruce	*Picea glauca*	9.6	2.00	10.3	1.72	13.1	2.21	7.3	2.41
wild lily-of-the-valley	*Maianthemum canadense*	0.5	0.10			1.0	0.08		
willow	*Salix* spp.	6.0	1.45	5.8	1.14	3.8	1.76	3.3	1.20
wood strawberry	*Fragaria vesca*	7.0	0.14	4.3	0.18	15.5	0.12	5.5	0.09
yarrow	*Achillea millefolium*	0.8	0.30	0.8	0.44	1.0	0.30		
Total number of species			**43**		**36**		**43**		**34**

APPENDIX 13 A list of wildlife forage species, with utilization classes

Species		Discing		No discing	
Common name	**Scientific name**	**Glyphosate**	**None**	**Glyphosate**	**None**
American vetch	*Vicia americana*	1[a], 2			
balsam poplar	*Populus balsamifera* spp. *balsamifera*	1, 3	1, 2, 4	1, 2^3	1, 2
black twinberry	*Lonicera involucrata*		3		
creamy peavine	*Lathyrus ochroleucus*	2			
fireweed	*Epilobium angustifolium*	1, 2^2	1, 2^2, 3	2^4	1, 3
highbush-cranberry	*Viburnum edule*		1^2, 2		2
northern bedstraw	*Galium boreale*	1			
northern gentian	*Gentianella amarella*			2	
paper birch	*Betula papyrifera*	2, 3, 4	3	3^2, 4^2	
prickly rose	*Rosa acicularis*	1			2
red clover	*Trifolium pratense*	1^3			
red-osier dogwood	*Cornus stolonifera*				3^2
Sitka or green alder	*Alnus viridis*	3, 4, 5	1, 3^2	2, 4	1, 2, 4
trembling aspen	*Populus tremuloides*	3^2, 4	2	2, 3^3	1, 2^2
white spruce	*Picea glauca*				2
willow	*Salix* spp.	2, 3^3	1, 2, 3^2	2^2, 3^2	2, 4

[a] Utilization classes code (Habitat Monitoring Committee 1996) for browsed species. Superscripts are the frequency of occurrence of a wildlife forage species in all treatment areas based on four VMPs.

APPENDIX 14 A list of assumptions and prices used in TIPSY 2.1 for economic analysis in all treatment areas

Silviculture Assumptions
Survey costs: $16/ha
Vegetation clearing costs: $721/ha
Discing costs: $313/ha
Planting costs: $536/ha
Brushing costs: $299/ha

Harvest Cost Assumptions
Harvest system: Ground skidding
Haul cycle time: 3.0 hours
Haul costs: $6.30/m^3
Development costs: $1050/ha
Overhead costs: $2909/ha
Other harvest costs: $0.00/m^3
Annual costs: $0.00/ha

Discount Assumptions
Discount rate: 4.0%
Real price increase: 0.0%
Real cost increase: 0.0%
Real increase duration: 25 years
Analysis base age: 0 years

Lumber Prices
2 × 4: $387.00/MBF
2 × 6: $379.00/MBF
2 × 8: $383.00/MBF
2 × 10: $464.00/MBF
Chips: $110/BDU

Pre-commercial Thinning (PCT) Assumptions

	Discing	Discing+Glyphosate	Glyphosate	Untreated control (no discing)
PCT costs ($/ha)	420	435	429	395
PCT age (years)	18	16	15	18
PCT trees removed (trees/ha)	1814	2229	2054	1141

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