L A N D   M A N A G E M E N T   H A N D B O O K

4 5

Brushing and Grazing Effects on Lodgepole Pine, Vascular Plants, and Range Forage in Three Plant Communities in the Southern Interior of British Columbia:

Nine-Year Results

1 9 9 8

British Columbia
Ministry of Forests
Research Program

Brushing and Grazing Effects on Lodgepole Pine, Vascular Plants, and Range Forage in Three Plant Communities in the Southern Interior of British Columbia:

Nine-Year Results

Suzanne Simard, Jean Heineman,
and Phil Youwe

British Columbia
Ministry of Forests
Research Program

Canadian Cataloguing in Publication Data
Simard, S. (Suzanne)
Brushing and grazing effects on Lodgepole pine, vascular plants and range forage in three plant communities in the southern interior of British Columbia : nine year results

(Land management handbook ; 45)

Includes bibliographical references: p.
ISBN 0-7726-3663-X

1. Lodgepole pine — Weed control — British Columbia. 2. Lodgepole pine — British Columbia — Growth. 3. Sitka alder — Control — British Columbia. 4. Willows — Control — British Columbia. 5. Calamagrostis — Control — British Columbia. 6. Weeds — Control — British Columbia. 7. Range management — British Columbia. I. Heineman, Jean. II. Youwe, Phil. III. British Columbia. Ministry of Forests. Research Branch. IV. Title. V. Series.

SD397.P585S55 1998 634.9′55′09711 C98-960249-4

Prepared by
Suzanne Simard and Phil Youwe
B.C. Ministry of Forests
Kamloops Forest Region
515 Columbia Road
Kamloops, BC V2C 2T7
and
Jean Heineman
2125 East Fifth Avenue
Vancouver, BC V5N 1M5
for
B.C. Ministry of Forests
Research Branch
Third Floor, 712 Yates Street
Victoria, BC V8W 3E7

Published by
B.C. Ministry of Forests
Forestry Division Services Branch
Production Resources
595 Pandora Avenue
Victoria, BC V8W 3E7

Copies of this and other Ministry of Forests titles may be obtained, subject to supply, from:
Crown Publications Inc.
521 Fort Street
Victoria, BC V8W 1E7
(250) 386-4636

Conifer and vegetation responses to manual and chemical brushing of the Dry Alder, Willow, and Pinegrass vegetation communities in the southern interior of British Columbia were monitored for 8–9 years, in three separate, but related, studies: Devick Lake Study, Ellis Creek Study, and Upper McKay Creek Study. Forage production and livestock use were also assessed to provide information about the effects of silvicultural brushing treatments on the range resource.

Results and discussion are presented individually for the three studies, but because they employed a similar methodology, it is described in a single section at the beginning of the report. Abstracts for each study are found at the beginning of the individual study sections (see Table of Contents).

This project was initiated by Ron Gray, Stand Tending Forester, of the Kamloops Forest Region. The study was designed and installed by Suzanne Simard in 1986, after thoughtful review by Alan Vyse, Les Herring, John Pollack, and Wendy Bergerud. The study was then monitored and reported on by Bryce Bancroft of Madrone Consultants Ltd. in 1987–1990 (Bancroft et al. 1991), and monitored again by Silver Ring Forestry Ltd. in 1995. Data analysis was carried out by Jean Heineman and Don Sachs.

The authors gratefully acknowledge review of this report by Ron Gray, Phil Comeau, George Harper, Brian Wikeem, and Chris Easthope.

Support for this project was provided by the Canada–British Columbia Partnership Agreement on Forest Resource Development (FRDA I 1985–1990 and FRDA II 1991–1996), and the B.C. Ministry of Forests. Support for preparation of this report in 1995–1996 was provided by Forest Renewal British Columbia and the B.C. Ministry of Forests.

DISCLAIMER

The use of herbicide trade and manufacturer names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the B.C. Ministry of Forests of any product or service to the exclusion of any others that may also be suitable.

Preface iii

Acknowledgements iv

Disclaimer v

Overall Project Description 1

1 Introduction 1

2 Methodology 1
2.1 Criteria for Site Selection 1
2.2 Experimental Design and Treatments 2
2.2.1 Devick Lake (*Dry Alder* Complex) and Ellis Creek (*Willow* Complex) Studies 2
2.2.2 Upper McKay Creek (*Pinegrass* Complex) Study 2
2.3 Measurements 2
2.3.1 Silviculture measurements 2
2.3.2 Range measurements 3
2.4 Statistical Analysis 3

DEVICK LAKE STUDY: Effects of brushing and grazing on lodgepole pine, the *Dry Alder* plant community, and range forage on an MSdm2 site near Kamloops, B.C. 5

Abstract 5

1 About the *Dry Alder* Complex 5

2 Specific Objectives 6

3 Study Area 6

4 Treatments 7

5 Results 7
5.1 Silviculture Results 7
5.1.1 Lodgepole pine 7
5.1.2 All vegetation 7
5.1.3 Target vegetation 9
Sitka alder 9
Fireweed 11
5.1.4 Competition index 12
5.1.5 Effects of cattle grazing on lodgepole pine and vegetation 12
5.2 Range Results 13
5.2.1 Forage production 13
Native grasses 13
Domestic grasses 13

Forbs 15
Total forage production 15
5.2.2 Livestock use 16
5.2.3 Non-target vegetation abundance and species richness 16

6 Discussion 17

ELLIS CREEK STUDY: Effects of brushing and grazing on lodgepole pine, the *Willow* plant community, and range forage on an MSdm1 site near Penticton, B.C. 19

Abstract 19

1 About the *Willow* Complex 19

2 Specific Objectives 20

3 Study Area 21

4 Treatments 21

5 Results 21
5.1 Silviculture Results 21
5.1.1 Lodgepole pine 21
5.1.2 All vegetation 23
5.1.3 Target vegetation 24
Willow 24
Timothy 25
5.1.4 Competition index 27
5.1.5 Effects of cattle grazing on lodgepole pine and vegetation 27
5.2 Range Results 27
5.2.1 Forage production 27
Native grasses 27
Domestic grasses 27
Forbs 28
Total forage 30
5.2.2 Livestock use 30
5.2.3 Non-target vegetation abundance and species richness 30

6 Discussion 31

UPPER McKAY CREEK STUDY: Effects of brushing on lodgepole pine, the *Pinegrass* plant community, and range forage on an IDFdk1 site near Lillooet, B.C. 35

Abstract 35

1 About the *Pinegrass* Complex 35

2 Specific Objectives 36

3 Study Area 36

4 Treatments 37

5 Results 37
5.1 Silviculture Results 37
5.1.1 Lodgepole pine 37
5.1.2 All vegetation 39
5.1.3 Target vegetation 39
Pinegrass 39
5.1.4 Competition index 41
5.2 Range Results 41
5.2.1 Forage production 41
Native grasses 41
Forbs 42
Total forage 42
5.2.2 Non-target vegetation abundance and species richness 42

6 Discussion 43

Overall Conclusions 44

APPENDICES
1 Mean abundance of non-target vascular species in the *Dry Alder* Complex (Devick Lake Study) 46
2 Mean abundance of non-target vascular species in the *Willow* Complex (Ellis Creek Study) 49
3 Mean abundance of non-target vascular species in the *Pinegrass* Complex (Upper McKay Creek Study) 52

REFERENCES 54

TABLES
1-1 Analysis of variance (ANOVA) for the Devick Lake Study (*Dry Alder* Complex) 4
1-2 Analysis of variance (ANOVA) for the Ellis Creek Study (*Willow* Complex) 4
1-3 Analysis of variance (ANOVA) for the Upper McKay Creek Study (*Pinegrass* Complex) 4
Devick Lake Study
2-1 Lodgepole pine treatment means and p-values as determined by ANOVA 1986–1995 ... 8
2-2 Vegetation treatment means and p-values as determined by ANOVA 1986–1995 10
2-3 Results of ANOVAS (p-values) comparing forage production among grazing and brushing treatments 1986–1995 13
2-4 Cumulative mean species abundance and species richness for forbs, grasses, low shrubs, and tall shrubs 16
Ellis Creek Study
3-1 Lodgepole pine treatment means and p-values as determined by ANOVA 1986–1995 ... 22
3-2 Vegetation treatment means and p-values as determined by ANOVA 1986–1995 26
3-3 Results of ANOVAS (p-values) comparing forage production among grazing and brushing treatments 1986–1995 28
3-4 Cumulative mean species abundance and species richness for forbs, grasses, low shrubs, and tall shrubs 31

Upper McKay Creek Study

4-1 Lodgepole pine treatment means and p-values as determined by ANOVA 1987–1995 ... 38
4-2 Vegetation treatment means and p-values as determined by ANOVA 1987–1995 ... 40
4-3 Cumulative mean species abundance and species richness for forbs, grasses, low shrubs, and tall shrubs ... 43

FIGURES

Devick Lake Study

2-1 Lodgepole pine height 1986–1995 ... 7
2-2 Lodgepole pine stem diameter 1986–1995 ... 9
2-3 Modal vegetation height 1986–1995 ... 9
2-4 Overall vegetation cover 1986–1995 ... 9
2-5 Sitka alder height 1986–1995 ... 11
2-6 Sitka alder cover 1986–1995 ... 11
2-7 Comparison of height growth between lodgepole pine and Sitka alder ... 11
2-8 Fireweed height 1986–1995 ... 12
2-9 Fireweed cover 1986–1995 ... 12
2-10 Competition index 1986–1995 ... 12
2-11 Sitka alder height in grazed and ungrazed plots 1986–1995 ... 13
2-12 Forage production by grazing and brushing treatments 1986–1995 ... 14
2-13 Native grass production 1986–1995 ... 15
2-14 Domestic grass production 1986–1995 ... 15
2-15 Forb production 1986–1995 ... 15
2-16 Total forage production 1986–1995 ... 16

Ellis Creek Study

3-1 Lodgepole pine height 1986–1995 ... 23
3-2 Lodgepole pine stem diameter 1986–1995 ... 23
3-3 Comparison of height growth between lodgepole pine and willow ... 24
3-4 Modal height of all vegetation 1986–1995 ... 24
3-5 Total vegetation cover 1986–1995 ... 24
3-6 Willow height 1986–1995 ... 25
3-7 Willow cover 1986–1995 ... 25
3-8 Timothy height 1986–1995 ... 25
3-9 Timothy cover 1986–1995 ... 27
3-10 Competition index 1986–1995 ... 27
3-11 Native grass production 1986–1995 ... 28
3-12 Domestic grass production 1986–1995 ... 28
3-13 Forage production in grazed and ungrazed plots, by brushing treatment ... 29
3-14 Forb production 1986–1995 ... 30
3-15 Total forage production 1986–1995 ... 30

Upper McKay Creek Study

4-1 Lodgepole pine height 1987–1995 ... 37
4-2 Lodgepole pine stem diameter 1987–1995 ... 37
4-3 Modal height of all vegetation 1987–1995 ... 39
4-4 Total vegetation cover 1987–1995 ... 39
4-5 Pinegrass height 1987–1995 ... 39
4-6 Pinegrass cover 1987–1995 ... 41
4-7 Competition index 1987–1995 ... 41
4-8 Native grass production 1987–1995 ... 41
4-9 Forb production 1987–1995 ... 42
4-10 Total forage production 1987–1995 ... 42

Overall Project Description

1 INTRODUCTION

Programs to manage competing vegetation in the southern interior of British Columbia have grown steadily since 1980, but quantitative information regarding the effect of treatment on conifer growth, plant community health, and livestock range productivity is required to justify the continued expenditure. In 1994–1995, it was estimated that the Kamloops Forest Region manually brushed 7500 ha at an average cost of $560/ha, and chemically brushed 1105 ha at an average cost of $360/ha (J. Boateng, pers. comm., March 1996). These high treatment costs must be weighed against both positive and negative effects on timber, range, and ecosystem values.

In British Columbia, forests provide 8.3 million ha of summer and fall livestock range, and account for nearly 80% of the total area of Crown land grazed. Clearcut logging enhances access for cattle, thereby increasing opportunities for range use, but range and silviculture management objectives for these sites often conflict. In the Kamloops Forest Region, approximately 3500 ha/year are seeded with domestic grass/forb mixtures to enhance the quality and production of cattle forage. Silviculturists, meanwhile, may prescribe brushing treatments in an attempt to reduce vegetation competition for conifer seedlings.

From a short-term silviculture perspective, brushing treatments are considered effective when they allow seedlings to release, improve growth rates, and reduce the time required to reach free-growing. A number of vegetation complexes have been identified in the southern interior of B.C. that compete with conifer seedlings (Kimmins and Comeau 1990). However, little is known about threshold competition levels for these plant communities, above which seedling performance may be negatively affected, but below which it is unaffected or even enhanced. Over the long-term, treatment effects on site productivity and biodiversity are also important considerations.

From a range perspective, brushing treatments may severely reduce forage production and grazing capacity. For example, herbicides may injure both forbs and grasses (Conard and Emmingham 1984), resulting in shifts in species composition and the relative proportions of different forage types. Forb and grass species grazed by cattle vary in nutritive value, palatability, digestibility, and how highly they are preferred by stock (McLean and Tisdale 1960).

A series of research trials was established in 1986–1987 in the Kamloops Forest Region to study the effectiveness of chemical and manual treatment methods for controlling competing vegetation, and to study the impact these brushing treatments have on the range resource. The three trials discussed herein are concerned with the release of lodgepole pine *(Pinus contorta* var. *latifolia)* growing in competition with the *Dry Alder*, *Willow*, and *Pinegrass* plant communities, as well as with the effects of chemical and manual brushing treatments on forage production and livestock use. It is hoped that the collection of both silviculture and range data will contribute to the development of guidelines to help managers integrate the use of these resources.

2 METHODOLOGY

2.1 Criteria for Site Selection

The sites were chosen to satisfy the following conditions:

1. Three sites were chosen that were representative of competing vegetation as follows: Devick Lake Study — the *Dry Alder* Complex; Ellis Creek Study — the *Willow* Complex; Upper McKay Creek Study — the *Pinegrass* Complex.
2. Conifers on each site were regarded as suppressed by neighbouring vegetation, but vigorous enough to respond to release treatments.

3. Each site was deemed appropriate for treatment in the operational brushing program of the Kamloops Forest District.
4. Vegetation could be treated with a back-pack sprayer.
5. The site was uniform with respect to vegetation, topography, and moisture regime.

2.2 Experimental Design and Treatments

2.2.1 Devick Lake (*Dry Alder* Complex) and Ellis Creek (*Willow* Complex) Studies

These two studies employed grazing as a treatment. A split-plot design was used, where grazing treatments were assigned to whole plots and brushing treatments to split-plots. The two grazing treatments were (1) grazed (unfenced whole plots) and (2) ungrazed (fenced whole plots). The whole plots were replicated twice in a randomized block design (n = 2).

The grazing treatments were randomly assigned to two large whole plots in each replicate block, where each whole plot was composed of three split-plots. The split-plots were 50 × 60 m (0.3 ha); when the three split-plots were arranged side-by-side within a whole plot, whole plots were 150 × 60 m (0.9 ha). Each split-plot included a 5 m surrounding buffer, so that the area receiving a brushing treatment was 40 × 50 m (0.2 ha). Within each split-plot, twenty 10 m^2 (r = 1.78 m) subplots were systematically located in a 4 × 5 grid. Each subplot was centred on the lodgepole pine seedling closest to the grid point. Lodgepole pine and woody target specimens in each subplot were tagged to enable remeasurement.

2.2.2 Upper McKay Creek (*Pinegrass* Complex) Study

This study examined brushing treatment effects only, not grazing. The brushing treatments were replicated three times in a randomized complete-block design.

Four brushing treatments were randomly located within each of three blocks, and each plot contained 20 subplots. Each plot was 50 × 60 m (0.3 ha), including a surrounding 5 m buffer strip, so that the actual treated area was 40 × 50 m (0.2 ha). The subplots had an area of 10 m^2 (r = 1.78 m), and were centred on the measured lodgepole pine seedlings. They were located by laying out a 4 × 5 grid within each treatment plot and choosing the closest pine to each grid point as subplot centres. Lodgepole pine seedlings were tagged to enable remeasurement.

2.3 Measurements

2.3.1 Silviculture measurements

Silviculture measurements were made prior to treatment, according to Herring and Pollack (1985). For the Devick Lake and Ellis Creek studies, pre-treatment assessment took place within one week of treatment, but for the Upper McKay study, treatment delays resulted in pre-treatment assessments being completed 10 months prior to hexazinone application and one year prior to glyphosate application.

In all three studies, lodgepole pine seedlings were assessed for height, current year height increment, stem diameter (measured at the root collar), vigour (0 = dead; 1 = poor; 2 = fair; 3 = medium; 4 = good), and dominance (0 = leaders above vegetation; 1 = threatened; 2 = overtopped). Percent cover and height of target species were measured, and cover and modal height of all vegetation in the subplot were estimated. The abundance of all vascular plant species in each subplot was estimated (1 = trace; 2 = common; 3 = abundant). The cumulative mean abundance of the species was estimated for each of four growth forms (forbs, grasses, low shrubs, and tall shrubs).

Relative growth rates (RGR) were calculated for height and stem diameter of lodgepole pine. For example:

$$\text{Relative Height Growth 1987} = (\text{Height 87} - \text{Height 86}) / \text{Height 86}.$$

Stem volume of lodgepole pine was estimated using the formula for a cone:

$$\text{Stem volume} = (\pi((\text{Stem diameter}/2)^2) * (\text{Height})) / 3.$$

Competition index (CI) was calculated as:

$$\text{CI} = ((\text{Target species 'a' height} \times \text{cover}) + (\text{Target species 'b' height} \times \text{cover}) \text{ etc.}) / 100.$$

Measurements were repeated 1, 2, 3, and 8 or 9 years following treatment. In addition, lodgepole pine seedlings were assessed for their tolerance to treatment, and target vegetation was assessed for treatment impact using the Expert Committee on Weeds (ECW)[1] rating system.

2.3.2 Range measurements

In all three studies, aboveground biomass of three forage components (native grasses, domestic grasses, and forbs) was estimated in July–August of each sampling year, as closely as possible to the baseline measurement date. Biomass of each forage component (kg/ha) was estimated by (1) visually estimating wet weight in every subplot, (2) measuring moisture content in a subset of subplots (minimum of 5) by clipping, weighing, drying, and re-weighing the forage components, and (3) using the measured moisture content to estimate dry weight in the remaining subplots. The measured wet weights were also used to calibrate visual estimates of wet weight in the remaining subplots. Weights were estimated (and/or clipped) within a 0.5 m^2 circular frame in each of the 20 silviculture subplots. The frame was located 1.5 m from the subplot centre in a randomly selected cardinal direction (N,S,E,W). Assessments were made on the same spot each year, except in subplots where vegetation had been clipped. In subplots that had been clipped the previous year, the frame was moved in one cardinal direction clockwise. For the final assessment in 1995, the frame was again located in a randomly selected cardinal direction from the subplot centre.

At Devick Lake and Ellis Creek, livestock utilization levels were visually estimated after grazing was completed each fall between 1987 and 1990, but not in 1995. Utilization was based on the relative amount of current season's annual growth removed by grazing, on a scale of 1 to 5: 1 = slight (1–19%); 2 = light (20–39%); 3 = moderate (40–59%); 4 = heavy (60–79%); 5 = extreme (80–100%). Livestock utilization was not assessed at Upper McKay Creek because cattle were not grazed on that site.

2.4 Statistical Analysis

Analysis of Variance (ANOVA) was used to test for significant differences among treatment means (α = 0.10), as shown in Table 1-1 (Studies 1–2) and Table 1-2 (Study 3). The analysis was performed on treatment plot means because the design was balanced, the means were more normally distributed than the subsamples, and the objective was to investigate main effect differences rather than variation among subsamples within split-plots (Sit 1995). Pine seedling variables tested were total height, height increment, relative height growth, stem diameter, relative diameter growth, and stem volume. Vegetation variables tested were overall modal height, total cover, target species-specific height, cover, and ECW rating, as well as competition index. Range variables tested were biomass of the forage components (native grass, domestic grass, forb, and total). Seedling vigour and dominance, as well as livestock use (Devick Lake and Ellis Creek), were summarized in frequency tables. Mean separation was carried out using the Waller-Duncan Bayes Least Significant Difference test for 1986–1989 data, and Tukey's HSD test for 1995 data. Analysis was carried out using SAS (1985) for 1986–1989 data and SYSTAT (1992) for 1995 data.

1 ECW is based on subjective estimation of the level of vegetation control for a plant species, as expressed by degree of top kill, defoliation, abnormal growth form, or mortality. A 0–100% rating scale is used, where 0 indicates no control and 100 indicates complete control. (Herring and Pollack 1985, citing Walstad and Wagner 1982 and Expert Committee on Weeds Abstracts 1983).

TABLE 1-1 *Analysis of variance (ANOVA) for the Devick Lake Study (* Dry Alder *Complex)*

Source of variation	Factor type	Level	Degrees of freedom	Expected F-test (df)
Total			knm – 1 = 11	
Block	random	n = 2	n – 1 = 1	MS_B/MS_{E2} (1,4)
Grazing	fixed	m = 2	m – 1 = 1	MS_G/MS_{E1}
Error 1			(n – 1) (m – 1) = 1	MS_{E1}
Brushing	fixed	k = 3	k – 1 = 2	MS_B/MS_{E2} (2,4)
Graze*Brush	fixed		(m – 1) (k – 1) = 2	MS_{GB}/MS_{E2} (2,4)
Error 2			m(n – 1) (k – 1) = 4	MS_{E2}

TABLE 1-2 *Analysis of variance (ANOVA) for the Ellis Creek Study (*Willow *Complex)*

Source of variation	Factor type	Level	Degrees of freedom	Expected F-test (df)
Total			knm – 1 = 15	
Block	random	n = 2	n – 1 = 1	MS_B/MS_{E2} (1,4)
Grazing	fixed	m = 2	m – 1 = 1	MS_G/MS_{E1}
Error 1			(n – 1) (m – 1) = 1	MS_{E1}
Brushing	fixed	k = 4	k – 1 = 3	MS_B/MS_{E2} (2,4)
Graze*Brush	fixed		(m – 1) (k – 1) = 3	MS_{GB}/MS_{E2} (2,4)
Error 2			m(n – 1) (k – 1) = 6	MS_{E2}

TABLE 1-3 *Analysis of variance (ANOVA) for the McKay Creek Study (*Pinegrass *Complex)*

Source of variation	Factor type	Level	Degrees of freedom	Expected F-test (df)
Total			kn – 1 = 11	
Block	random	n = 3	n – 1 = 2	
Treatment	fixed	k = 4	k – 1 = 3	MST/MSE (3,6)
Error			(n – 1) (k – 1) = 6	

Devick Lake Study:
Effects of brushing and grazing on lodgepole pine, the *Dry Alder* plant community, and range forage on an MSdm2 site near Kamloops, B.C.

ABSTRACT

A research trial was established in 1986 in the southern interior of British Columbia to study the effectiveness of glyphosate applied at 3 litres/ha (1.07 kg ai/ha) and 6 litres/ha (2.14 kg ai/ha) for releasing naturally regenerated lodgepole pine seedlings and controlling the *Dry Alder* Complex. Pine seedlings, two target species (Sitka alder and fireweed), and range forage were assessed for the first 3 years, and again in the 9th year following treatment.

Sitka alder was severely injured by both levels of glyphosate during the 9 years of this trial, but by 1995 height was no longer significantly reduced in comparison to the Control. Alder cover in 1995, however, was still less than 2% in the glyphosate treatments, compared with 27% in the Control. Fireweed height also was reduced for 3 years by both levels of glyphosate, but cover was affected for only 1 year. Glyphosate at 6 litres/ha did not have a significantly greater impact on alder than glyphosate at 3 litres/ha, but the higher application rate did reduce fireweed height significantly more, in 1988 and 1989, than the lower rate.

Chemical brushing of the *Dry Alder* Complex had no significant effect on lodgepole pine seedlings on this site, in spite of the impact on both target species. The site had been manually brushed 2 years previously, and, at the onset of this trial, alder had recovered to only 1 m height and 18% cover. Pine seedlings in the Control grew taller than alder in 1987, in spite of having no further treatment. It was concluded that, following the 1984 manual brushing, Sitka alder and fireweed were not present in sufficient abundance to pose a competitive threat to lodgepole pine seedlings, and further treatment with glyphosate had been unnecessary.

Glyphosate at both 3 and 6 litres/ha had a negative effect on range values at Devick Lake. Four years after treatment, native and domestic grass production were less than half of Control levels. Forbs recovered more quickly than grasses, resulting in changes in the relative proportions of forage components.

1 ABOUT THE ***DRY ALDER*** COMPLEX

The *Dry Alder* Complex is one of the vegetation communities identified as a competitive threat to conifer seedlings in the southern interior of British Columbia (Kimmins and Comeau 1990). It is typically composed of three major species: Sitka alder (*Alnus viridis* ssp. *sinuata*), fireweed (*Epilobium angustifolium*), and pinegrass (*Calamagrostis rubescens*), and it occurs on dry to fresh sites in the Interior Cedar–Hemlock (ICH), Montane Spruce (MS), and Sub-Boreal Spruce (SBS) biogeoclimatic zones.

Sitka alder is common in the understory of pine forests of the southern interior of British Columbia, and because it varies widely in shade tolerance (Klinka and Scagel 1984), the sudden increase in light levels following harvesting often stimulates a rapid growth response. Sitka alder may increase in height and cover to levels where it is competing with conifer seedlings for light and/or soil resources, and where it is causing physical damage to seedlings through snowpress (Haeussler et al. 1990). Although there is no well-defined threshold at which Sitka alder becomes a competitive threat to seedling survival and growth, Simard (1990) found that the stem diameter of lodgepole pine seedlings decreased when alder cover exceeded between 10 and 35%, depending on site quality. Below that threshold, seedlings appeared to have benefited from the presence of alder.

Sitka alder has several attributes that make it beneficial to conifer growth. It is particularly well known for its ability to fix nitrogen; however, Sachs and Comeau (1991) recently found nitrogen fixation rates of Sitka alder in the southern interior of British Columbia to be lower than those measured on Vancouver Island (Binkley 1981, 1982). Even so, Sachs and Comeau (1991) suggest that when alder cover is less than 35%, which is suggested as a competition threshold by Simard (1990), it will contribute from 1.5 to 8 kg/ha/year of nitrogen to a site. Sitka alder also contributes organic matter and cycles nutrients to the forest floor during litterfall, thereby improving long-term site productivity (Crocker and Major 1955; Sachs and Comeau 1992). Sachs and Comeau (1992) used the FORECAST model to simulate the effects of Sitka alder removal on lodgepole pine yield following clearcutting in Montane Spruce forests, and found that reductions in Sitka alder density below 2500 clumps/ha resulted in lower pine yield, particularly when coupled with slashburning and/or whole-tree harvesting. There also is evidence that alder may contribute directly to lodgepole pine nutrition through shared associations with common ectomycorrhizal fungi. In a study in Sweden, Arnebrant et al. (1993) found that *Alnus glutinosa* (L.) translocated fixed nitrogen directly to lodgepole pine through interconnecting mycelium of the ectomycorrhiza *Paxillus involutus*.

Sitka alder is considered to have limited value as a wildlife browse species; however, some birds feed on the seeds and ungulates use it for cover (Haeussler et al. 1990). Small mammals such as showshoe hares, red squirrels, and voles commonly find cover in Sitka alder and may browse neighbouring seedlings in lodgepole pine plantations (e.g., Sullivan 1985; Simard 1990).

Previous studies have shown that Sitka alder abundance may be reduced by both glyphosate and manual cutting. Biring et al. (1993) report 60–90% injury to Sitka alder when glyphosate was applied at 1.5–2.1 kg ai/ha (4–6 litres/ha) from May through October. Lloyd and Heineman (1994b) observed 50–70% reductions in Sitka alder crown volume and height when glyphosate was applied at 6 litres/ha anytime between May and October, with reductions lasting for at least 3 years.

Fireweed, which is commonly present in the *Dry Alder* Complex, also competes with conifer seedlings in the southern interior of British Columbia, although it is more of a problem on subhygric sites than on mesic sites (Lindeburgh 1995). Fireweed may become dominant on freshly logged sites within 1–2 years, and often persists for a decade or more (Haeussler et al. 1990). It produces copious amounts of wind-borne seed, and once established, it spreads rapidly by seed and rhizomes (Rowe 1983). Fireweed damages young seedlings mainly through snowpress of dead shoots, and also by reducing light levels under its canopy (Comeau et al. 1989). Once a forest canopy develops, however, fireweed generally dies out (Haeussler et al. 1990). A variety of studies indicate that glyphosate effectively reduces both height and cover of fireweed (Expert Committee on Weeds 1984, 1985; Lloyd and Heineman 1994c), but reports vary on how long treatment effects last. Cattle and mule deer are both reported to have a high preference for fireweed (Willms et al. 1980).

2 SPECIFIC OBJECTIVES

The specific silviculture objectives of this study were:

1. To study the effects of two levels of broadcast foliar glyphosate (trade name Vision®) application (3 litres/ha and 6 litres/ha) on growth of naturally regenerated lodgepole pine seedlings and abundance of two target species (Sitka alder and fireweed) over a period of 9 years.
2. To study the effects of grazing (grazing, no grazing) on growth of lodgepole pine and abundance of Sitka alder and fireweed.
3. To study trends in abundance of other vascular plant species that may have been affected by brushing or grazing treatments.

The specific range objectives were:

1. To determine the effects of glyphosate application on the survival and production of domestic grasses, native grasses, and forbs that are key range species.
2. To contribute to guidelines for accommodating reductions in grazing capacity due to silvicultural activities.

3 STUDY AREA

This study site is located on a single cutblock near Devick and Community Lakes in the Kamloops Forest District, approximately 50 km northeast of Kamloops. The site was clearcut in 1977, and drag scarified in 1978, after which it regenerated naturally to lodgepole pine. In spring 1979, the site was aerially seeded with a “range seed mix” to improve forage production. By 1984, a dense stand of Sitka alder had developed, and the site was manually brushed with chainsaws to release pine seedlings. At the time this trial was established in 1986, alder had recovered to 103 cm tall and 18% cover, fireweed was

65 cm tall with 7% cover, and lodgepole pine seedlings were 88 cm tall with stem diameters of 1.8 cm.

The site is at an elevation of 1200 m in the MSdm2/01 (Thompson Dry Mild variant of the Montane Spruce zone, site series 01) (Lloyd et al. 1990). The study site is situated on a shallow (2%) slope with a northerly aspect, in mid-slope position. Soil is moderately well-drained and is classified as a Brunisolic Gray Luvisol (Canadian Soil Survey Committee 1978). Texture varies from silt loam (0–5 cm) to sandy clay loam (5–30 cm). Coarse fragment content is 20% in the top 30 cm of soil. Most roots are located in the top 10 cm. The forest floor is 10 cm thick and is classified as Orthihemihumimor (Klinka et al. 1981).

The study site occurs within the Devick Lake Unit of the Sullivan Valley stock range. Cattle graze on the unit from July 1 to September 20, at a stocking level of approximately 1300 animal unit months. The unit is grazed on a rotational basis where cattle are moved between blocks on the basis of utilization standards and the age of the cutblocks. Prescribed levels of use for this unit are 75% for domestic species, 35% for pinegrass, and 50% for other grasses and forbs.

4 TREATMENTS

The three brushing treatments were (1) control, (2) glyphosate applied at a rate of 3 litres/ha (1.07 kg ia/ha), and (3) glyphosate applied at a rate of 6 litres/ha (2.14 kg ai/ha).

Glyphosate treatments were applied between 0:500 and 10:00 h on August 15, 16, and 17, 1986, when alder leaves were fully developed and conifer buds had set. During application, skies were clear, wind speeds were less than 8 km/h, temperatures ranged between 3 and 18° C, and relative humidity ranged between 30 and 90%. Glyphosate was mixed with water and delivered as a broadcast spray at a rate of 100 litres/ha using CP-3 hand-pump backpack sprayers. All vegetation, including conifers, were broadcast sprayed with the glyphosate mix.

5 RESULTS

5.1 Silviculture Results

5.1.1 Lodgepole pine

There was no improvement in lodgepole pine growth from 1986 to 1995 as a result of treatment of the *Dry Alder* Complex with glyphosate at 3 litres/ha or 6 litres/ha. There were no significant differences in lodgepole pine height, 1-year height increment, stem diameter, stem volume, relative height growth, relative diameter growth, or vigour among the Control and the two glyphosate treatments.

Height of lodgepole pine increased from about 90 cm in 1986 to 500 cm in 1995, and was virtually identical in all treatments throughout the trial (Figure 2-1; Table 2-1). Although there were reductions in alder height as a result of treatment with glyphosate, it had no effect on trends in lodgepole pine height (Figure 2-7).

The stem diameter of lodgepole pine seedlings averaged 1.8 cm in 1986 and increased to 8–9 cm in all treatments by 1995 (Figure 2-2; Table 2-1).

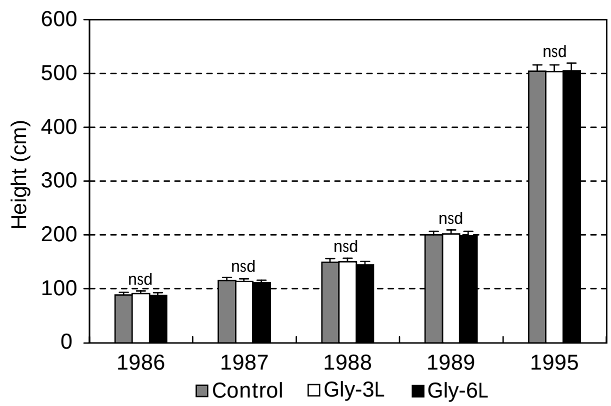

FIGURE 2-1 *Lodgepole pine height 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \le 0.10$; histograms are means and error bars are one standard error.*

Vigour of most pine seedlings in the trial was moderate or good, and trends in vigour did not vary among treatments (data not shown). Dominance values ranged between 0 and 1 across all treatments; most pine were above surrounding vegetation and free-growing, even at the beginning of the trial. Although it was not quantified, the density of lodgepole pine stems was observed to be high in 1995. Seedlings were often growing in dense clumps.

5.1.2 All vegetation

Prior to treatment in 1986, the dominant shrub species were Sitka alder, black gooseberry (*Ribes lacustre*), and red raspberry (*Rubus ideaus*),

TABLE 2-1 *Lodgepole pine treatment means and p-values as determined by ANOVA 1986–1995*

	Height (cm)	1-year height increment (cm)	Stem diameter (cm)	Stem volume (cm^3)	Relative height growth	Relative diameter growth
Pre-treatment—1986						
Brushing						
Control	88.28*a		1.84 a	130.55 a		
Glyph-3L/ha	91.24 a†		1.84 a	126.38 a		
Glyph-6L/ha	87.75 a		1.75 a	112.83 a		
p-value	*0.8777*		*0.8200*	*0.8660*		
Grazing						
Ungrazed	79.93 b		1.61 b	89.17 a		
Grazed	98.25 a		2.00 a	156.99 a		
p-value	*0.0263*		*0.0647*	*0.1170*		
1 year post-treatment—1987						
Brushing						
Control	115.38 a	27.79 a	2.50 a	573.97 a	0.33 a	0.41 a
Glyph-3L/ha	113.13 a	28.44 a	2.59 a	612.03 a	0.37 a	0.63 a
Glyph-6L/ha	110.73 a	22.30 a	2.53 a	568.12 a	0.35 a	0.58 a
p-value	*0.8637*	*0.1522*	*0.7473*	*0.9170*	*0.5619*	*0.1944*
Grazing						
Ungrazed	101.25 b	23.07 a	2.29 a	430.10 a	0.29 a	0.48 a
Grazed	124.90 a	26.62 a	2.78 a	739.32 a	0.43 a	0.60 a
p-value	*0.0063*	*0.1153*	*0.1493*	*0.1290*	*0.4896*	*0.5946*
2 years post-treatment—1988						
Brushing						
Control	149.45 a	34.01 a	3.17 a	559.71 a	0.32 a	0.29 a
Glyph-3L/ha	150.19 a	37.33 a	3.30 a	599.17 a	0.33 a	0.39 a
Glyph-6L/ha	144.05 a	33.99 a	3.40 a	622.83 a	0.35 a	0.30 a
p-value	*0.7248*	*0.2370*	*0.6058*	*0.8690*	*0.2100*	*0.3200*
Grazing						
Ungrazed	133.78 b	32.74 a	3.01 b	457.55 b	0.34 a	0.34 a
Grazed	162.44 a	37.63 a	3.57 a	735.26 a	0.33 a	0.31 a
p-value	*0.0480*	*0.2417*	*0.0192*	*0.0360*	*0.5254*	*0.6017*
3 years post-treatment—1989						
Brushing						
Control	199.61 a	49.69 a	4.05 a	1145.47 a	0.37 a	0.30 a
Glyph-3L/ha	201.53 a	51.24 a	4.12 a	1216.79 a	0.40 a	0.28 a
Glyph-6L/ha	198.62 a	52.92 a	4.35 a	1321.21 a	0.38 a	0.26 a
p-value	*0.9739*	*0.4710*	*0.5854*	*0.7590*	*0.1490*	*0.5434*
Grazing						
Ungrazed	183.86 b	48.84 a	3.84 b	964.74 b	0.41 a	0.29 a
Grazed	216.57 a	53.83 a	4.51 a	1501.29 a	0.35 a	0.27 a
p-value	*0.0048*	*0.1600*	*0.0564*	*0.0800*	*0.2682*	*0.4419*
9 years post-treatment—1995						
Brushing						
Control	504.33 a	58.30 a	8.55 a	11087.68 a	0.29 a	0.21 a
Glyph-3L/ha	503.50 a	53.44 a	7.71 a	9468.26 a	0.32 a	0.18 a
Glyph-6L/ha	505.24 a	55.96 a	7.85 a	9635.44 a	0.35 a	0.22 a
p-value	*0.8360*	*0.1710*	*0.2650*	*0.3860*	*0.5730*	*0.6580*
Grazing						
Ungrazed	481.04 b	54.52 a	7.60 a	8715.63 a	0.37 a	0.22 a
Grazed	528.85 a	57.33 a	8.51 a	11509.46 a	0.27 a	0.18 a
p-value	*0.0430*	*0.3610*	*0.3660*	*0.1860*	*0.1680*	*0.8160*

* Mean.

† Means with the same letter (within each column and under each treatment heading) are not significantly different from one another at $p > 0.10$.

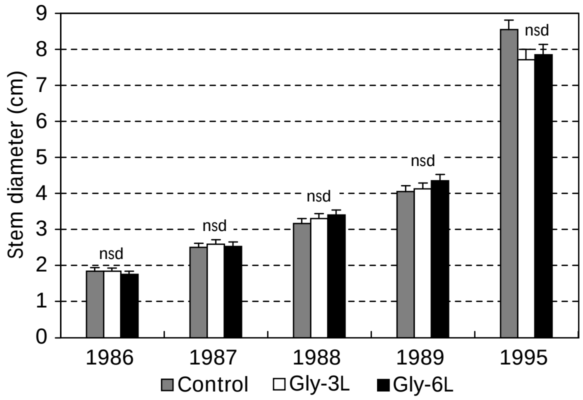

FIGURE 2-2 *Lodgepole pine stem diameter 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

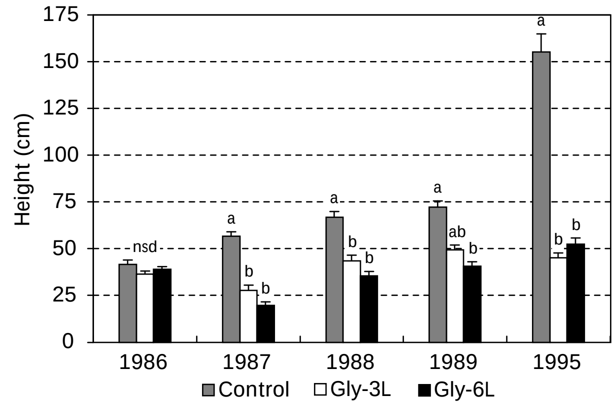

FIGURE 2-3 *Modal vegetation height 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at α ≤ 0.10; nsd = no significant difference; histograms are means and error bars are one standard error.*

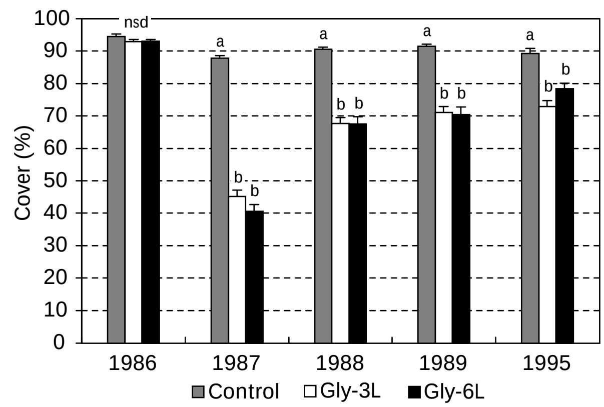

FIGURE 2-4 *Overall vegetation cover 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at α ≤ 0.10; nsd = no significant difference; histograms are means and error bars are one standard error.*

dominant grass was pinegrass (*Calamagrostis rubescens*), and dominant herbs were bunchberry (*Cornus canadensis*), showy daisy (*Erigeron speciosus*), wild strawberry (*Fragaria virginiana*), palmate coltsfoot (*Petasites palmatus*), and arctic lupine (*Lupinus arcticus*). Following glyphosate treatment, abundance of the shrubs and pinegrass was reduced, but abundance of some herbs (e.g., heart-leaved arnica [*Arnica cordifolia*], white hawkweed [*Hieracium albiflorum*], and twinflower [*Linnaea borealis*]) increased through the 9 years of the study.

Modal vegetation height was significantly reduced by both levels of glyphosate in comparison to the Control for the entire 9 years of this trial (Figure 2-3; Table 2-2). Height in the Control increased from 42 cm in 1986 to 155 cm in 1995, whereas height averaged only 49 cm in the two glyphosate treatments in 1995.

Overall vegetation cover was significantly reduced by glyphosate treatments in comparison to the Control, and this reduction was maintained through the 9 years of the trial. Cover values in the Control were steady at 88–95% from 1986 to 1995, but were reduced in the first year following either glyphosate treatment to 40–45%. Cover increased to 75% in the two glyphosate treatments by 1995, but was still significantly lower than cover in the Control (Figure 2-4; Table 2-2).

5.1.3 Target vegetation

Sitka alder Sitka alder was about 100 cm tall at the time of treatment in 1986, and by 1995 had grown to a height of 230 cm in untreated Control plots. Alder height was reduced to 12 cm 1 year following treatment with glyphosate at 6 litres/ha, and 49 cm following treatment with glyphosate at 3 litres/ha. The height of treated alder did not change between 1988 and 1989, but by 1995 it had, on average, recovered to 160 cm (Figure 2-5; Table 2-2).

Sitka alder was reduced to less than 2% cover by both levels of glyphosate, and remained at low cover values from 1987 to 1995 (Figure 2-6; Table 2-2). Alder cover was 18% in the Control at the time of treatment in 1986, and it increased to 27% during the 9 years of the trial.

TABLE 2-2 *Vegetation treatment means and p-values as determined by ANOVA 1986–1995*

	All vegetation		Alder			Fireweed			
	Modal height (cm)	Cover (%)	Height (cm)	Cover (%)	ECW (%)	Height (cm)	Cover (%)	ECW (%)	Competition index
Pre-treatment—1986									
Brushing									
Control	41.56*a	94.56 a	102.83 a	17.70 a		64.94 a	6.58 a		23.40
Glyph-3L/ha	36.38 a†	92.94 a	95.89 a	12.69 a		65.25 a	6.50 a		17.01
Glyph-6L/ha	38.81 a	93.00 a	97.56 a	14.08 a		60.20 a	7.37 a		19.55
p-value	*0.6013*	*0.7586*	*0.6405*	*0.6041*		*0.5882*	*0.9080*		*0.4472*
Grazing									
Ungrazed	37.33 a	93.58 a	92.77 a	14.32 a		58.42 b	7.43 a		18.59
Grazed	40.50 a	93.42 a	104.81 a	15.33 a		68.52 a	6.23 a		21.39
p-value	*0.4647*	*0.7048*	*0.4446*	*0.6183*		*0.0183*	*0.5578*		*0.3446*
1 year post-treatment—1987									
Brushing									
Control	56.53 a	87.78 a	118.94 a	11.28 a	0.00 b	57.70 a	6.81 a	0.00 b	18.32 a
Glyph-3L/ha	27.69 b	45.13 b	48.74 b	2.25 b	93.33 a	40.15 b	3.50 b	81.56 a	3.52 b
Glyph-6L/ha	19.62 b	40.63 b	11.58 c	0.83 b	98.61 a	34.55 b	2.87 b	85.12 a	1.54 b
p-value	*0.0005*	*0.0014*	*0.0003*	*0.0289*	*0.0000*	*0.0112*	*0.0390*	*0.0010*	*0.0086*
Grazing									
Ungrazed	33.13 a	58.63 a	54.31 a	4.42 b	63.29 a	42.18 b	5.54 a	49.28 a	7.74
Grazed	36.26 a	57.31 a	65.19 a	5.15 a	64.00 a	46.50 a	3.22 a	60.68 a	7.84
p-value	*0.7777*	*0.4748*	*0.1024*	*0.0289*	*0.5950*	*0.0726*	*0.1760*	*0.1020*	*0.9011*
2 years post-treatment—1988									
Brushing									
Control	66.78 a	90.62 a	125.19 a	12.16 a	0.00 b	66.68 a	9.18 a	0.00 b	21.25 a
Glyph-3L/ha	43.38 b	67.69 b	22.34 b	0.79 b	94.46 a	59.38 b	5.86 a	57.04 a	4.78 b
Glyph-6L/ha	35.44 b	67.60 b	7.91 b	0.34 b	98.81 a	47.91 c	6.14 a	63.83 a	3.39 b
p-value	*0.0411*	*0.0158*	*0.0006*	*0.0143*	*0.0000*	*0.0034*	*0.2890*	*0.0010*	*0.0019*
Grazing									
Ungrazed	54.75 a	79.06 a	50.17 a	4.68 a	65.38 a	59.27 a	8.14 a	28.83 a	11.14
Grazed	41.47 a	70.91 b	51.31 a	3.88 a	66.22 a	56.47 a	5.87 a	54.00 a	8.47
p-value	*0.2157*	*0.0803*	*0.5647*	*0.7045*	*0.1770*	*0.1415*	*0.3012*	*0.1450*	*0.4067*
3 years post-treatment—1989									
Brushing									
Control	72.24 a	91.55 a	137.18 a	12.87 a	17.90 b	74.61 a	10.36 a	0.00 b	26.23 a
Glyph-3L/ha	49.19 ab	71.06 b	21.90 b	0.79 b	86.28 a	69.43 b	6.42 a	7.03 ab	5.78 b
Glyph-6L/ha	40.63 b	70.38 b	5.17 b	0.25 b	97.33 a	56.54 c	5.56 a	11.28 a	3.86 b
p-value	*0.0482*	*0.0269*	*0.0005*	*0.0078*	*0.0010*	*0.0001*	*0.1012*	*0.0740*	*0.0004*
Grazing									
Ungrazed	61.67 a	81.47 a	56.31 a	5.33 a	68.23 a	68.53 a	8.58 a	5.42 a	14.54
Grazed	45.47 a	73.34 b	52.37 a	3.80 a	67.40 a	65.00 a	6.20 a	6.93 a	9.36
p-value	*0.1823*	*0.0868*	*0.9209*	*0.4877*	*0.6100*	*0.2466*	*0.3955*	*0.5090*	*0.2845*
9 years post-treatment—1995									
Brushing									
Control	155.25 a	89.33 a	232.37	26.82 a		92.03 a	20.91 a		90.70 a
Glyph-3L/ha	44.94 b	72.88 b	171.17	1.53 b		88.30 a	15.23 a		22.53 b
Glyph-6L/ha	52.31 b	78.39 b	154.39	0.91 b		85.09 a	17.47 a		20.31 b
p-value	*0.0010*	*0.0230*	*0.4290*	*0.0230*		*0.4500*	*0.3840*		*0.0320*
Grazing									
Ungrazed	93.24 a	81.58 a	249.77 a	11.74 a		93.79 a	18.82 a		86.53
Grazed	76.17 a	78.78 a	172.13 b	7.99 a		83.12 a	16.87 a		48.13
p-value	*0.4750*	*0.1220*	*0.0830*	*0.6520*		*0.1740*	*0.7550*		*0.6210*

* Mean.
† Means with the same letter (within each column and under each treatment heading) are not significantly different from one another at p > 0.10.

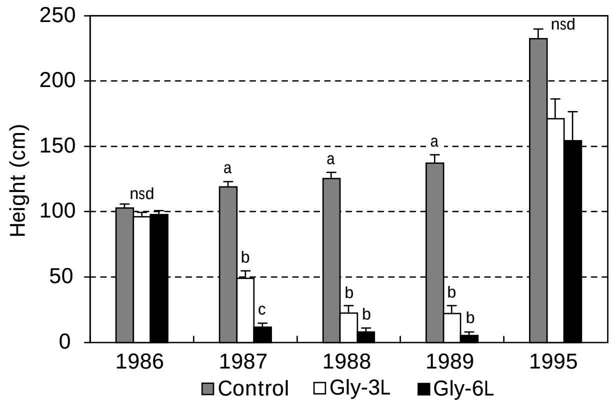

FIGURE 2-5 *Sitka alder height 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq$ 0.10; nsd = no significant difference; histograms are means and error bars are one standard error.*

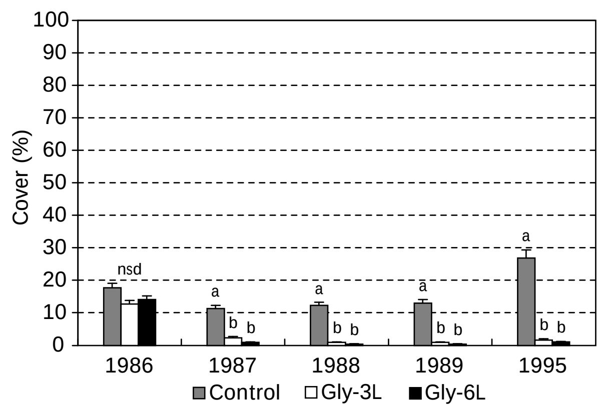

FIGURE 2-6 *Sitka alder cover 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq$ 0.10; nsd = no significant difference; histograms are means and error bars are one standard error.*

Trends in height growth of lodgepole pine seedlings were identical in the Control and the two glyphosate treatments, regardless of the height of neighbouring Sitka alder (Figure 2-7).

Damage to Sitka alder (ECW rating) was over 97% when it was treated with glyphosate at 6 litres/ha, and over 86% when treated with glyphosate at 3 litres/ha between 1987 and 1989. ECW rating did not differ significantly between glyphosate treatments on any measurement date (Table 2-2).

Fireweed In comparison to the Control, fireweed height was significantly reduced by both levels of

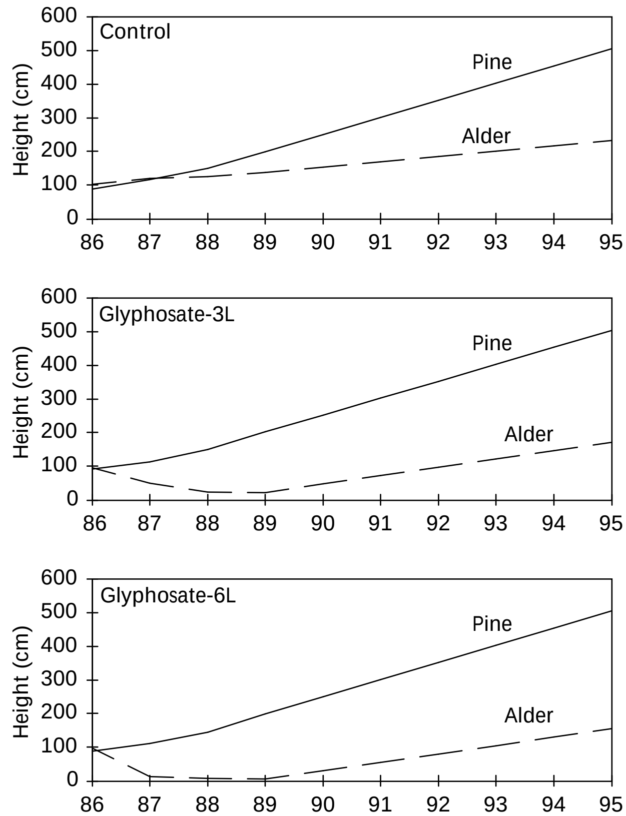

FIGURE 2-7 *Comparison of height growth between lodgepole pine and Sitka alder.*

glyphosate for 3 years. In 1987, 1 year after treatment, the two glyphosate treatments had a similar effect on fireweed height, reducing it by about 33% from the Control value of 58 cm. From 1988 to 1989, however, fireweed treated with glyphosate at 3 litres/ha recovered more quickly than it did in the 6 litres/ha plots (Figure 2-8; Table 2-2). By 1995, there were no longer significant treatment effects on height of fireweed, which had increased in all treatments to 85–92 cm.

Fireweed cover was only about 7% at the time of treatment in 1986, but nevertheless was significantly reduced in comparison to the Control for 1 year following treatment with both levels of glyphosate. From 1988 onwards, however, there were no significant differences in fireweed cover, which increased gradually to 15–20% in 1995 (Figure 2-9; Table 2-2).

Injury to fireweed, as measured with the ECW control rating, did not differ between glyphosate treatments at any time during the 9-year measurement period. Nor did it reflect the measured differences in fireweed height in 1988 and 1989. The ECW control rating averaged 83% 1 year following the

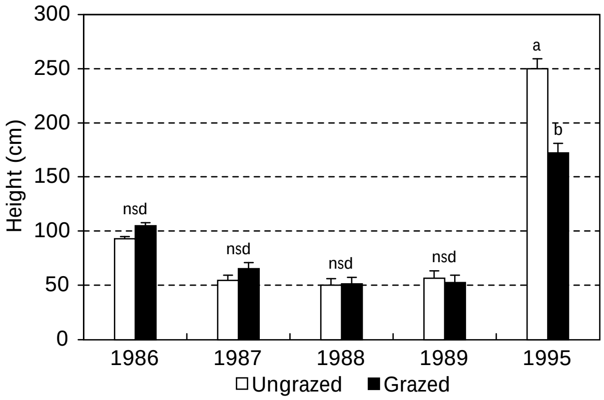

FIGURE 2-11 *Sitka alder height in grazed and ungrazed plots 1986–1995. Grazing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at α ≤ 0.10; nsd = no significant difference; histograms are means and error bars are one standard error.*

5.2 Range Results

5.2.1 Forage production

Native grasses Production of native grasses did not differ between grazed and ungrazed treatments throughout the measurement period (Table 2-3; Figure 2-12). There was a significant interaction (p = 0.072) between grazing and the brushing treatments in 1995 (Table 2-3), but individual pair-wise comparisons failed to show grazing effects on native grass production that year (α = 0.10, Figure 2-13).

Prior to treatment in 1986, there was no difference in native grass production among the Control and two glyphosate treatments (Figure 2-13). In 1987, 1 year following treatment application, production of native grasses was reduced from 115 kg/ha in the Control to 23 kg/ha in the 3 litres glyphosate/ha and 14 kg/ha in the 6 litres glyphosate/ha treatment. After 1987, native grass production in the glyphosate treatments recovered to Control levels for the remainder of the measurement period.

Domestic grasses Production of domestic grasses did not differ between grazed and ungrazed treatments in any year during the measurement period (Table 2-3; Figure 2-12). However, there was a significant interaction (p = 0.078) between grazing and brushing treatments in 1990. In that year, domestic grass production in the grazed Control was significantly higher than in all other grazing/brushing combinations, including the ungrazed Control.

TABLE 2-3 *Results of ANOVAs (p-values) comparing forage production among grazing and brushing treatments 1986–1995*

	1986	1987	1988	1989	1990	1995
Native grass						
Grazing treatments	0.383	0.157	0.952	0.787	0.725	0.165
Brushing treatments	0.606	**0.002**	0.301	0.237	0.129	0.157
Grazing*Brushing	0.791	0.904	0.543	0.280	0.597	**0.072**
Domestic grass						
Grazing treatments	0.456	0.357	0.403	0.389	0.429	0.453
Brushing treatments	0.695	**0.057**	0.264	**0.085**	**0.031**	0.953
Grazing*Brushing	0.398	0.528	0.382	0.303	**0.078**	0.437
Forbs						
Grazing treatments	0.538	**0.090**	**0.051**	**0.047**	0.154	0.535
Brushing treatments	0.337	**0.000**	0.236	0.193	0.288	0.368
Grazing*Brushing	0.712	**0.047**	0.577	0.179	0.403	0.252
Total production						
Grazing treatments	0.524	**0.066**	**0.013**	**0.026**	0.569	0.434
Brushing treatments	0.452	**0.000**	0.106	**0.044**	**0.038**	0.886
Grazing*Brushing	0.710	0.230	0.447	**0.077**	0.146	0.180

NOTE: Bold values are significant at α = 0.10.

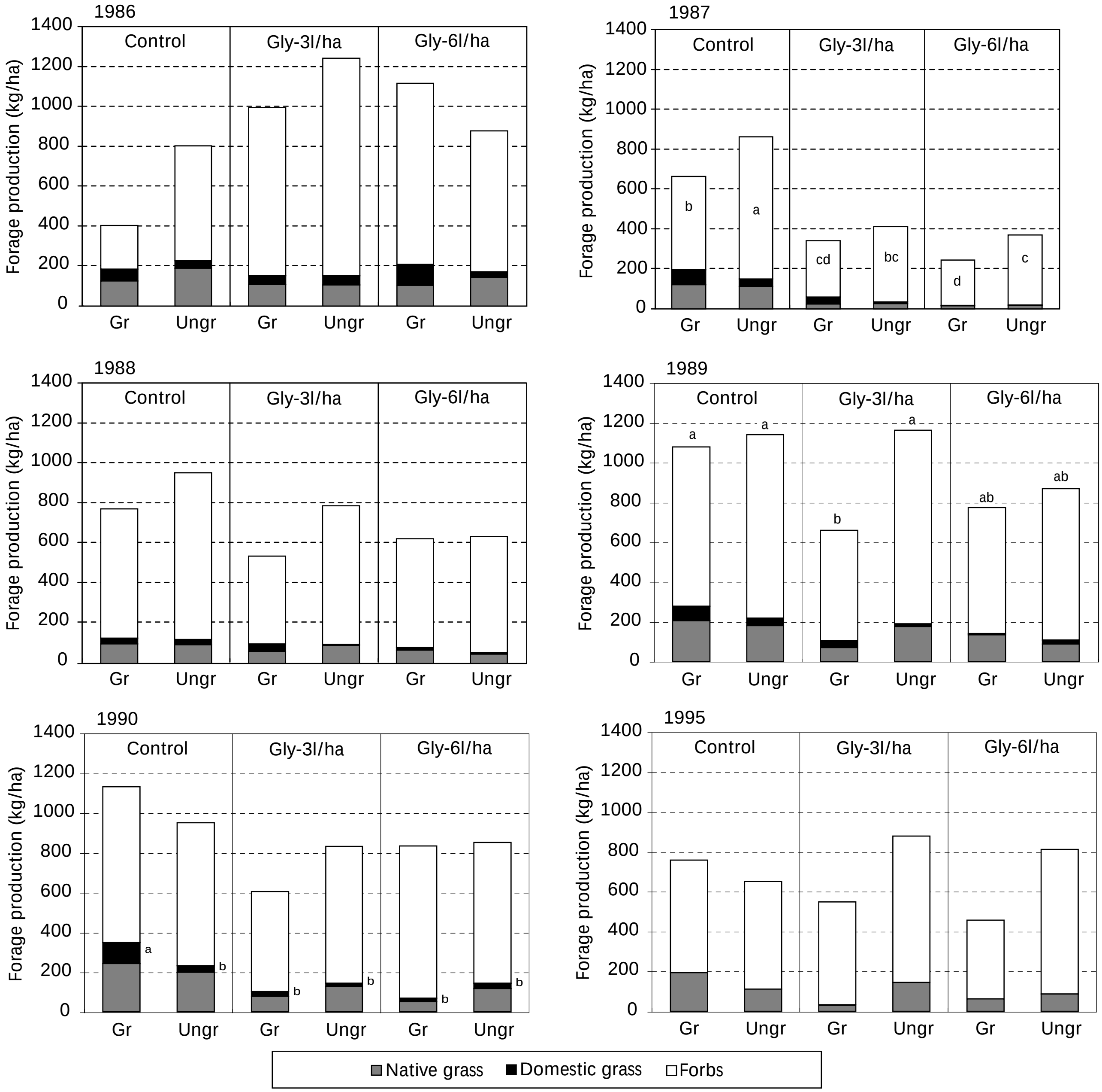

FIGURE 2-12 *Forage production by grazing and brushing treatments 1986–1995. Significant grazing*brushing interactions within a single year were identified using ANOVA (see Table 2-3). Where significant interactions occurred, grazing*brushing treatments with the same letter are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$. Letters indicating significant differences are positioned next to or within the relevent forage component (i.e., forbs in 1987 and domestic grasses in 1990). Letters positioned above the columns indicate significant interactions for total forage. Histograms are means.*

Prior to treatment in 1986, there was no difference in domestic grass production among the Control and two glyphosate treatments (Figure 2-14). In 1987, 1 year following treatment application, production of domestic grasses was reduced from an average of 56 kg/ha in the Control to 22 kg/ha and 2 kg/ha in the 3 litres/ha and 6 litres/ha glyphosate treatments, respectively.

Domestic grasses treated with glyphosate at 3 litres/ha remained at constant production of about 20 kg/ha between 1988 and 1990, but where they were treated with glyphosate at 6 litres/ha,

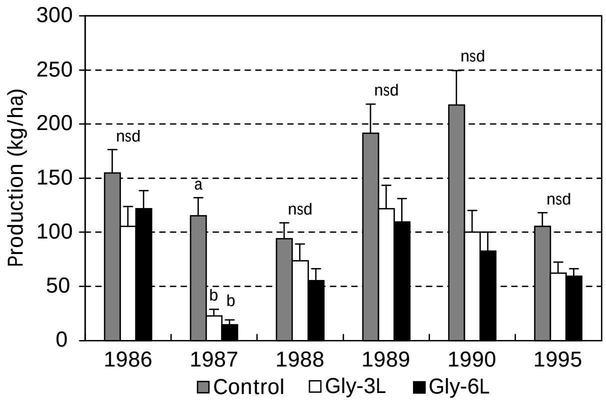

FIGURE 2-13 *Native grass production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

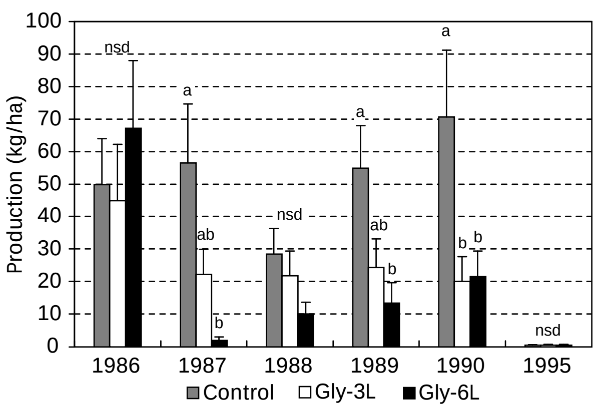

FIGURE 2-14 *Domestic grass production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

production increased gradually from 10 to 22 kg/ha during the same 3-year period. In the Control, domestic grass production was 73 kg/ha in 1990, which was about 3.5 times as high as production in the two glyphosate treatments. By 1995, domestic grass production, which had been the result of seeding in 1979, had declined to less than 1 kg/ha in all three brushing treatments.

Forbs Forb production was considerably higher than either domestic or native grass production both before and after grazing or brushing treatment application. In 1986, prior to treatment, forb production averaged 724 kg/ha, whereas domestic and native grass production only averaged 54 and 127 kg/ha, respectively.

Forb production was significantly reduced in grazed compared to ungrazed plots in 1987, 1988, and 1989 (Table 2-3). The interaction between grazing and brushing treatments was significant in 1987 (Figure 2-12), when forb production in the ungrazed Control and glyphosate at 6 litres/ha treatments was significantly higher than that in the equivalent grazed brushing treatments. Forb production was higher in the ungrazed Control than in any of the other grazing/treatment combinations in that year.

Prior to treatment in 1986, there was no difference in forb production among the Control and two glyphosate treatments (Figure 2-15). One year after treatment, forb production was reduced to 330 kg/ha and 290 kg/ha in the 3 and 6 litres/ha glyphosate treatments, respectively, compared to 590 kg/ha in the Control ($p < 0.001$, Table 2-3). By 1988, however, forbs treated with glyphosate had recovered to the Control production level.

Total forage production As with forbs, total forage production was significantly reduced by grazing in 1987, 1988, and 1989 (Table 2-3). Forbs were the most abundant forage component on this site, and so had the greatest influence on trends in total forage production. The interaction between grazing and brushing was significant in 1989 (Figure 2-12),

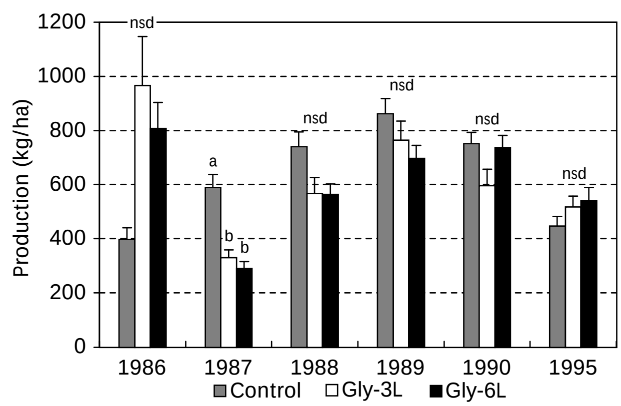

FIGURE 2-15 *Forb production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

TABLE 2-4 *Cumulative (summed) mean species abundance and species richness (number of species) for forbs, grasses, low shrubs, and tall shrubs*

	Forbs		Grasses		Low shrubs		Tall shrubs		Total	
	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.
1986										
Control	15.20	48	5.84	14	6.99	12	0.65	6	**28.68**	**80**
Gly-3 L/ha	12.66	47	4.51	14	5.40	10	0.41	5	**22.98**	**76**
Gly-6 L/ha	15.71	47	4.24	14	6.36	12	0.54	5	**26.85**	**78**
1987										
Control	17.64	52	6.76	17	7.38	11	0.70	6	**32.48**	**86**
Gly-3 L/ha	13.84	46	2.89	16	1.89	11	0.24	4	**48.86**	**77**
Gly-6 L/ha	15.06	45	2.63	16	1.80	11	0.11	3	**19.60**	**75**
1988										
Control	17.76	50	6.86	17	7.31	13	0.65	6	**32.58**	**86**
Gly-3 L/ha	15.93	49	4.39	16	2.34	12	0.25	5	**22.91**	**82**
Gly-6 L/ha	17.93	47	4.01	16	2.44	12	0.18	4	**24.56**	**79**
1989										
Control	18.93	54	6.94	15	7.26	12	0.69	6	**33.82**	**87**
Gly-3 L/ha	16.91	48	5.03	14	2.53	12	0.34	4	**24.81**	**78**
Gly-6 L/ha	17.73	51	4.71	14	2.59	13	0.18	4	**25.21**	**82**
1995										
Control	18.06	53	6.15	14	7.44	11	0.60	4	**32.25**	**82**
Gly-3 L/ha	18.39	53	4.91	16	3.63	12	0.39	5	**27.32**	**86**
Gly-6 L/ha	18.51	50	4.70	16	3.96	12	0.14	4	**27.31**	**82**

when the ungrazed portion of the 3 litres/ha glyphosate treatment had significantly higher total forage production than the grazed portion.

Total forage production was significantly reduced for 4 years (except 1988) following glyphosate treatment, but there were no differences between the two application rates (Figure 2-16). By 1995, total forage production in treated areas had caught up to that in the Control.

5.2.2 Livestock use

Livestock used domestic grasses more heavily than native grasses or forbs between 1986 and 1990. However, glyphosate application had no effect on the use of each forage type (data not shown).

5.2.3 Non-target vegetation abundance and species richness

Treatment with glyphosate resulted in a decrease in the cumulative mean abundance of grasses and low shrubs (Table 2-4). Species richness was generally unaffected by treatment.

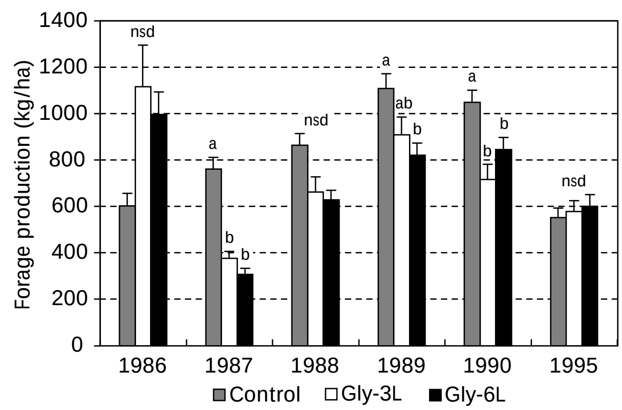

FIGURE 2-16 *Total forage production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at α ≤ 0.10; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

There was very little change in overall species composition as a result of treatment with glyphosate, but several species of both native and domestic grasses were reduced in abundance for up to 9 years (Appendix 1). Bluejoint, Kentucky bluegrass (*Poa pratensis*), and timothy (*Phleum pratense*) were less abundant in the glyphosate treatments than the Control for the entire 9 years of the trial. Similarly, pinegrass and blue wildrye (*Elymus glaucus*) were suppressed for at least 4 years. There was no noticeable effect on orchardgrass (*Dactylis glomerata*), brome (*Bromus* spp.), or fescue (*Festuca* spp.).

Some low shrub species were also reduced in abundance for 9 years following treatment with glyphosate: black twinberry (*Lonicera involucrata*), black gooseberry, thimbleberry (*Rubus parviflorus*), trailing raspberry (*Rubus pubescens*), red raspberry, birch-leaved spirea (*Spiraea betulifolia*), and black huckleberry (*Vaccinium membranaceum*).

6 DISCUSSION

This trial was established to study the effectiveness of glyphosate at 3 litres/ha (1.07 kg ai/ha) and glyphosate at 6 litres/ha (2.14 kg ai/ha) for release of naturally regenerated lodgepole pine seedlings growing in association with the *Dry Alder* Complex. It was also intended to address the concerns of range managers by providing information about the effects of glyphosate on production of livestock forage. Most trials involving vegetation management have focused on the response of seedlings and target vegetation within 3–5 years of treatment, but this trial provides information over a longer term.

Treatment of the *Dry Alder* Complex with glyphosate did not result in any significant improvements in lodgepole pine growth during the 9 years of this trial, in spite of the fact that both levels of herbicide significantly reduced height and cover of Sitka alder and fireweed, as well as modal height and percent cover of the total vegetation community. The research site had been manually brushed in 1984, 2 years prior to installation of this research trial, and it appears that further treatment was not required to release the pine seedlings. At the time the trial was established in 1986, Sitka alder had recovered from the previous brushing treatment to a height of only 1 m, and had less than 20% cover. Lodgepole pine seedlings in the Control were 90 cm tall at the beginning of the trial, and they caught up to Sitka alder in the following year in spite of not receiving further treatment. When the trial was initiated, overtopping ratings indicated that most seedlings were not threatened by the presence of alder and fireweed. Lodgepole pine reached free-growing status in the Control by 1990, 5 years after the trial was initiated and when seedlings were 12 years old, indicating that chemical brushing was not necessary for lodgepole pine on this site to achieve free-growing status within the legislated time period (B.C. Ministry of Forests 1995).

Sitka alder was severely injured by both levels of glyphosate. Alder height was reduced to 14 cm 3 years following either glyphosate treatment (compared to 137 cm in the Control), but had recovered to Control values by 1995. Cover of Sitka alder was even more profoundly affected by glyphosate injury than was height. Alder cover in the Control was 18% in 1986, and it increased to 27% by 1995. In comparison, cover of Sitka alder treated with either level of glyphosate was still less than 2% in 1995. Competition index remained low throughout the study, mainly because of reductions in alder cover. Three years after treatment, ECW ratings indicated 86 and 97% control of alder by glyphosate at 3 and 6 litres/ha, respectively.

Fireweed height was also significantly reduced in comparison to the Control for 3 years following glyphosate treatment in 1986. It was reduced to 35 cm height the year following the 6 litres/ha glyphosate treatment and had recovered to only 57 cm after 3 years (compared to 58 and 75 cm in the Control, 1 and 3 years after treatment, respectively). Cover of fireweed was less affected by treatment, and was reduced for only 1 year. The difference in cover between the glyphosate treatments and the Control was only 3%. ECW ratings indicate that glyphosate had a fairly high impact on fireweed in the first 2 years following treatment; however, actual changes in height and cover do not bear this out. Observations at that time indicate that high ECW ratings were largely a result of changes in fireweed morphology, mainly dwarfing and pincushioning.

It is likely that lodgepole pine seedlings in this trial did not respond to treatment because cover of Sitka alder was too low (18% in 1986) for it to be competitive with pine. Simard (1990) found that pine seedlings appeared to benefit from threshold alder covers ranging between 10 and 35%, where threshold values increased with decreasing site quality. Lodgepole pine seedling growth was negatively affected both above and below the thresholds; above, lodgepole pine seedlings appeared to suffer from light and moisture competition, and below they may have been negatively affected by low nitrogen availability. In support of Simard's (1990) threshold range, Simard and Heineman (1996a) found that lodgepole pine growth increased when alder cover was reduced to 15%, but there were no further benefits to pine when alder cover was reduced below that level.

Intraspecific competition among lodgepole pine seedlings in this trial may partially account for their lack of growth response to the glyphosate treatments. The density of pine appeared to increase dramatically in all treatments between 1986 and 1995. However, density data were not collected so it is impossible to statistically assess this factor.

Range values on this site were negatively affected by glyphosate for at least 4 years. By 1990, total forage production in treated plots had recovered to only 75% of the Control value, and native and domestic grass production were only one-third to one-half Control production. Forbs recovered more quickly, and consequently their contribution to total forage production increased relative to grasses; by 1995, forbs comprised 90% of total forage in treated plots, and native grasses comprised 10%. Domestic grasses essentially disappeared from the Devick Lake site between 1990 and 1995, probably in response to cold winter weather, livestock preference, and shading by the dense stand of lodgepole pine seedlings.

Decreased production of grasses, especially domestic species, would likely reduce the carrying capacity for livestock grazing. In treated plots, forb production increased relative to grasses, and although forbs are generally higher in crude protein than native grasses, they are lower in crude fibre (McLean and Tisdale 1960). However, there is likely an upper limit to the proportion of forbs that cattle will consume in their diet. Quinton (1984) found about 34% forbs in the diets of cattle grazing at elevations of 1200–1300 m, with the proportion increasing to 54% when grass availability declined. Livestock use estimates for the Devick Lake site indicate that domestic grasses were more heavily grazed than forbs or native grasses. We expect that, rather than fully utilizing forage that consists of 90% forbs, cattle will move to other areas, or else increase their impact on the site by searching for preferred species. Cattle prefer a diet of mixed forages, and will select a variety of species and plant parts to meet their nutritional requirements (Gesshe and Walton 1981). On sites with young seedlings, increases in cattle traffic could result in trampling damage. On this site, however, the presence of cattle had no effect on seedling performance.

Although treatment with glyphosate had little effect on species richness among non-crop vegetation, it did reduce the abundance of several low berry-producing shrubs that have value as wildlife forage. The berries of red raspberry, thimbleberry, and black huckleberry provide summer food to bears, ungulates, small mammals, and birds, and black huckleberry is also utilized as winter food by black-tailed deer and Roosevelt elk (Haeussler et al. 1990). If these species were reduced in abundance over several openings across the landscape, there could be negative implications for wildlife.

The results of this trial indicate that while the original manual brushing of the *Dry Alder* Complex in 1984 was beneficial for the release of lodgepole pine seedlings (informal observations in an adjacent unbrushed area showed pine to be severely overtopped by Sitka alder), further glyphosate treatment was unwarranted. The lack of response of pine seedlings to treatment indicates that they were not threatened by competing vegetation. In fact, the presence of alder at low levels was likely benefiting both the present crop of lodgepole pine (Simard 1990; Arnebrant et al. 1993) and the long-term productivity of the site (Crocker and Major 1955; Sachs and Comeau 1992), as well as providing cover for wildlife.

The high impact of chemical brushing treatments on range values for this site must be emphasized, particularly in light of the poor response of lodgepole pine seedlings to treatment. The results illustrate the need to quantify the silvicultural benefits that may be expected from brushing treatments, so that unwarranted reductions in other resource values do not occur. In a case such as this, range managers may have had to shorten the period of livestock use on the site, reduce cattle numbers, or move livestock more often, all of which are costly measures. Where high-impact brushing treatments are unavoidable, communication between forestry and range managers must take place so that alternative grazing areas remain available, and the impact on range values is minimized.

Ellis Creek Study:
Effects of brushing and grazing on lodgepole pine, the *Willow* plant community, and range forage on an MSdm1 site near Penticton, B.C.

ABSTRACT

A research trial was established in 1986 in the southern interior of British Columbia to study the effectiveness of glyphosate applied at 4 litres/ha (1.4 kg ai/ha), hexazinone applied at 10 litres/ha (2.4 kg ai/ha), and manual cutting for releasing planted lodgepole pine seedlings and controlling the *Willow* Complex. Pine seedlings, two target species (willow and timothy), and range forage were assessed for the first 3 years, and again in the 9th year following treatment.

All three brushing treatments resulted in significant increases in height, 1-year height increment, stem diameter, and stem volume of lodgepole pine seedlings from 1989 to 1995. However, only hexazinone and manual cutting significantly reduced height and cover of willow. Although glyphosate did not significantly reduce willow height and cover in comparison to the Control, ECW ratings indicate that it resulted in 35% control of the shrub. These results are interpreted as meaning that 35% control of willow was adequate to release seedlings growing in association with the *Willow* Complex, and that the greater impact of hexazinone and manual cutting (ECW ratings of 65–85%) was not required. In view of heavy winter browsing of willow by ungulates on this site, and in order to maintain the wildlife resource, reductions in willow cover beyond levels required for seedling release are not recommended.

The effects of glyphosate and manual cutting on willow in this trial contradict several other studies in which glyphosate severely injured willow, and manual cutting was ineffective because of the tendency of willow to sprout vigorously. Willow is known to have variable response to treatment, making it difficult to develop operational recommendations.

The height of timothy was reduced for 1 year following treatment with glyphosate and hexazinone, but after that it recovered. In subsequent years, timothy height increased slightly in hexazinone and manual cutting treatments, probably as a result of increased light following removal of the shrub layer.

The effects of brushing treatments on range values were minor and short-lived on this site. Hexazinone reduced forb production from Control levels for 1 year, while manual cutting stimulated total forage production slightly between 1987 and 1990, probably as a result of increased light levels. In chemically treated plots, the proportion of forbs increased relative to grasses between 1986 and 1995, but it decreased slightly in manually cut plots.

1 ABOUT THE ***WILLOW*** COMPLEX

The *Willow* Complex is one of the vegetation communities identified as a competitive threat to conifer plantations in the southern interior of British Columbia (Kimmins and Comeau 1990). It may include a variety of willow (*Salix*) species, and it occurs on moist to wet sites in the Interior Douglas-Fir (IDF), Interior Cedar–Hemlock (ICH), Montane Spruce (MS), and Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zones.

Willow occurs in growth forms that range from dwarf shrubs to low trees, with the greatest diversity of species occurring on nutrient-rich sites that are subhygric or wetter (Haeussler et al. 1990). Of the willows common to the southern interior of British Columbia, it is mainly the juvenile growth of tall shrubs and low trees that competes with conifer seedlings. When mature, willow does not form a dense canopy, but when young it produces large leaves and numerous sprouts, which may limit the amount of light reaching seedlings growing under its canopy (Haeussler et al. 1990).

Reproduction of willow, which occurs from seed as well as from sprouting of damaged roots and stems, is often stimulated by harvesting and site preparation practices. Germination of willow seed is facilitated by the increased light levels (Brinkman

1974) and exposed mineral soil (Haeussler et al. 1990) that occur as a result of harvesting. However, because of initial low densities, it may be several years before conifer regeneration is impeded by shrubs (Eis 1981). Because willow is shade intolerant (Rawson 1974), removal of the canopy also stimulates rapid growth of already-established stems. Damage to willow roots that occurs as a result of mechanical disturbance stimulates sprouting from roots, and incidental cutting of stems during harvesting stimulates sprouting from the stem (Haeussler et al. 1990, citing Porter 1989). The growth rate of sprouts may be more than 2 m/year, far exceeding that of stems produced from seed (Haeussler et al. 1990, citing G. MacKinnon pers. comm., 1985).

Fire also is known to favour reproduction of willow, although in some cases researchers have observed that prescribed burning reduces initial competition from willows in clearcuts (Haeussler et al. 1990, citing C. Delong, W.R. Mitchell, and D. Lloyd, pers. comm., 1989). In the Kamloops Forest Region, fire stimulated both sprouting and height growth of willow (Haeussler et al. 1990, citing J. Wright, pers. comm., 1989). Similarly, following a fire in Montana, Scouler willow (*Salix scouleriana*) was found to have invaded 80% of plots, although increases in cover progressed slowly (Stickney 1981).

Willow may be controlled by summer or early fall applications of glyphosate (Conard and Emmingham 1983; Boateng and Herring 1990; Pollack et al. 1990), although the degree of control has also been observed to be short-lived or incomplete in some cases (Haeussler et al. 1990, citing J. Wright, pers. comm., 1989). Defoliation late in the growing season as a result of insect or fungal infestations is common among willow, and may reduce the efficacy of glyphosate applied at that time (Haeussler et al. 1990, citing J. Wright, pers. comm., 1989).

Manual cutting stimulates sprouting of willow, and is therefore not considered to be an effective method of control (Pollack et al. 1990; Hart and Comeau 1992). Cut stumps of willow sprout regardless of the cutting date, but the effect is more pronounced when cutting takes place during dormancy (Haeussler et al. 1990) rather than in late summer (Hart and Comeau 1992).

Willow is not known to directly benefit conifer seedlings, but it is an extremely important species for wildlife (Rawson 1974), as well as being highly preferred by cattle (Willms et al. 1980). Willow provides year-round browse for moose and deer, and shoots are eaten by many smaller mammals including muskrat, beaver, rabbits, and hares. Birds and ducks feed on the catkins and leaves, and the thicket-forming habit of willow provides cover for a variety of birds and mammals (Rawson 1974).

Timothy (*Phleum pratense*) is one of the more important perennial domestic hay grasses in North America (Pojar and MacKinnon 1994). Quinton (1984) found that timothy, along with orchardgrass and bromegrass, was one of the most important grasses consumed by cattle in seeded clearcuts above 1000 m. Timothy normally occurs in pastures and along roadsides, and does not naturally invade cutblocks to levels where it would compete with conifer seedlings. However, timothy dominated the herb layer on the Ellis Creek site, described herein, because of seeding that had taken place before the trial was established. Grasses may compete with conifer seedlings for both light and soil moisture. Sims and Mueller-Dombois (1968) found that growth of pine seedlings under mesotrophic conditions was inhibited by the presence of a luxuriant grass layer which overtopped seedlings and limited the availability of soil moisture.

Chemical brushing treatments are often prescribed to reduce grass cover for the purpose of ameliorating soil water competition to conifer seedlings. Glyphosate applied from July to September provides good (90–100%) control of perennial grasses (Conard and Emmingham 1984; Boateng and Herring 1990). Hexazinone applied in the spring also causes 60–90% injury to perennial grasses, although results are variable (Conard and Emmingham 1984). Dimock et al. (1983) report 77–97% control of grasses, including timothy and orchardgrass, and forbs when application takes place from mid-May to mid-June.

2 SPECIFIC OBJECTIVES

The specific silviculture objectives for this study were:

1. To study the effects of foliar application of glyphosate (tradename Vision®) at 4 litres/ha, soil application of hexazinone (tradename Velpar®) at 10 litres/ha, and manual cutting on growth of planted lodgepole pine seedlings and abundance of two target species (willow and timothy) over a period of 9 years.

2. To study the effects of grazing (grazing, no grazing) on growth of planted lodgepole pine seedlings and abundance of willow and timothy.
3. To study trends in abundance of other vascular plant species that may have been affected by brushing or grazing treatments.

The specific range objectives were:

1. To determine the effects of glyphosate at 4 litres/ha, hexazinone at 10 litres/ha, and manual cutting on the survival and production of domestic grasses, native grasses, and forbs that are key range species.
2. To contribute to guidelines for accommodating reductions in grazing capacity due to silvicultural activities.

3 STUDY AREA

This study site is located on a single cutblock in the Penticton Forest District, approximately 35 km east of Penticton. The original stagnant lodgepole pine stand (Pl 320-M) was clearcut in the summer of 1980 and broadcast burned in 1982. The site was planted with lodgepole pine (1+0 PSB 211) in 1984 and seeded with domestic grasses in subsequent years. At the time the trial was established, the shrub layer was composed mainly of willow and some Sitka alder (*Alnus viridis* ssp. *sinuata*), and the herb layer was dominated by timothy. Orchardgrass (*Dactylis glomerata*) and clover (*Trifolium repens*) were also common in the herb layer.

The site is at 1400 m elevation in the MSdm1/01 (Okanagan Dry Mild variant of the Montane Spruce zone, site series 01) (Lloyd et al. 1990). The site is situated on a shallow (5–10%) slope with a northeasterly aspect, in mid-slope position. Soil is well drained and is classified as Orthic Dystric Brunisol (Canadian Soil Survey Committee 1978). Texture varies with depth from silt loam at the surface (0–2 cm), to very fine loamy sand (2–20 cm), to sand (> 20 cm). There are very few coarse fragments and no root-restricting layers. Most roots occur in the top 20 cm of mineral soil. The forest floor is a thin (2 cm) Velomoder (Klinka et al. 1981).

The study site occurs within the Carmi Range Unit of the White Lake Stock Range, which provides summer grazing for 100 head of cattle from June 1 to October 31, on both seeded and non-seeded cutblocks.

4 TREATMENTS

The four brushing treatments were (1) control, (2) glyphosate applied at a rate of 4 litres/ha (1.4 kg ia/ha), (3) hexazinone applied at a rate of 10 litres/ha (2.4 kg ai/ha), and (4) manual cutting.

The hexazinone treatment was applied between 0:600 and 09:00 h on July 29 and 30, 1986, under partly cloudy skies with wind speeds up to 12 km/h. Hexazinone was applied to the soil on a 1 × 1 m grid using an exact delivery spot gun; the volume delivered at each spot was 4 mL (2 mL hexazinone plus 2 mL water). The glyphosate treatment was applied between 05:30 and 10:30 h on August 25, 1986, under clear, calm skies. Glyphosate was applied as a low-pressure broadcast spray using hand-pump back-pack sprayers, and was delivered in mixture with water (4 litres glyphosate plus 96 litres water), at a rate of 100 L/ha. Manual cutting was done once on August 24, 1986, using hand-held shears. All woody vegetation, excluding conifers, was cut at the root collar.

5 RESULTS

5.1 Silviculture Results

5.1.1 Lodgepole pine

From 1989 to 1995, lodgepole pine seedlings were significantly taller in all brushing treatments than in the Control; however, these differences were confounded by a pre-treatment height difference between the glyphosate treatment and the Control ($p = 0.08$, Table 3-1). By 1989, however, seedlings in the hexazinone and manual cutting treatments were also significantly taller than seedlings in the Control, and seedlings in the glyphosate treatment had further increased in height in comparison to the Control (Figure 3-1). Seedlings were about 50 cm tall at the time of treatment, and by 1995 were 450–460 cm tall in brushed plots, compared to 360 cm tall in the Control.

In 1987, 1 year after treatment, there were no differences in pine height increment among treatments (Table 3-1), but by 1988 height increment was significantly greater in the glyphosate and manual cutting treatments than in the Control. By 1989, seedlings in all three brushing treatments had greater 1-year height growth than seedlings in the Control, a trend that continued through 1995.

TABLE 3-1 *Lodgepole pine treatment means and p-values as determined by ANOVA 1986–1995*

	Height (cm)	1-year height increment (cm)	Stem diameter (cm)	Stem volume (cm^3)	Relative height growth	Relative diameter growth
Pre-treatment—1986						
Brushing						
Control	47.00*b		0.82 b	9.79 b		
Glyph-4L/ha	56.38 a†		1.03 a	19.42 a		
Hex-10L/ha	52.13 ab		0.95 ab	14.14 ab		
Manual cut	49.29 ab		0.88 ab	11.25 b		
p-value	*0.0837*		*0.0900*	*0.0320*		
Grazing						
Ungrazed	48.84 b		0.88 a	11.37 a		
Grazed	53.56 a		0.97 a	15.93 a		
p-value	*0.0143*		*0.3654*	*0.1420*		
1 year post-treatment—1987						
Brushing						
Control	61.51 b	14.51 a	1.27 b	31.49 b	0.31 a	0.57 b
Glyph-4L/ha	76.65 a	20.28 a	1.76 a	82.19 a	0.36 a	0.70 b
Hex-10L/ha	68.51 ab	16.39 a	1.51 ab	46.03 b	0.33 a	0.59 b
Manual cut	67.26 ab	17.98 a	1.70 a	58.96 ab	0.37 a	0.93 a
p-value	*0.0832*	*0.2190*	*0.0120*	*0.0140*	*0.3950*	*0.0030*
Grazing						
Ungrazed	64.71 b	15.88 a	1.46 a	42.06 a	0.33 a	0.67 a
Grazed	72.26 a	18.70 a	1.66 a	67.34 a	0.35 a	0.73 a
p-value	*0.0657*	*0.1490*	*0.4275*	*0.1550*	*0.2860*	*0.5440*
2 years post-treatment—1988						
Brushing						
Control	84.34 b	22.98 b	1.78 b	87.10 b	0.37 a	0.39 c
Glyph-4L/ha	111.13 a	34.70 a	2.65 a	264.94 a	0.45 a	0.54 b
Hex-10L/ha	100.69 ab	31.00 ab	2.58 a	208.45 a	0.62 a	0.75 a
Manual cut	99.43 ab	32.26 a	2.57 a	198.43 a	0.48 a	0.53 b
p-value	*0.0428*	*0.0280*	*0.0047*	*0.0120*	*0.3310*	*0.0000*
Grazing						
Ungrazed	93.22 a	28.13 a	2.21 a	144.85 a	0.51 a	0.54 a
Grazed	104.57 a	32.34 a	2.58 a	234.61 a	0.45 a	0.57 a
p-value	*0.1293*	*0.3310*	*0.3058*	*0.1430*	*0.6940*	*0.4150*
3 years post-treatment—1989						
Brushing						
Control	117.99 b	34.09 c	2.46 b	233.30 b	0.40 b	0.39 a
Glyph-4L/ha	162.28 a	47.40 ab	3.57 a	672.25 a	0.47 ab	0.37 a
Hex-10L/ha	152.73 a	52.04 a	3.69 a	633.00 a	0.53 a	0.45 a
Manual cut	143.09 a	43.66 b	3.42 a	519.27 a	0.44 ab	0.38 a
p-value	*0.0180*	*0.0030*	*0.0010*	*0.0060*	*0.0280*	*0.1810*
Grazing						
Ungrazed	135.24 a	42.24 a	3.05 a	411.40 a	0.46 a	0.41 a
Grazed	152.80 a	46.36 a	3.52 a	616.16 a	0.47 a	0.38 a
p-value	*0.1957*	*0.1720*	*0.2890*	*0.1450*	*0.6700*	*0.4380*
9 years post-treatment—1995						
Brushing						
Control	360.09 b	46.46 b	6.49 b	4937.91 b	0.35 a	0.28 a
Glyph-4L/ha	465.88 a	51.48 a	8.31 a	9604.47 a	0.33 a	0.24 b
Hex-10L/ha	462.13 a	55.77 a	8.66 a	10031.58 a	0.35 a	0.24 b
Manual cut	451.18 a	51.84 a	8.53 a	9220.20 a	0.37 a	0.24 ab
p-value	*0.0100*	*0.0060*	*0.0020*	*0.0160*	*0.5560*	*0.0670*
Grazing						
Ungrazed	415.79 a	49.87 a	7.55 a	7213.84 a	0.35 a	0.25 a
Grazed	453.55 a	52.87 a	8.44 a	9665.63 a	0.35 a	0.26 a
p-value	*0.1930*	*0.3020*	*0.2830*	*0.1550*	*0.4230*	*0.2000*

* Mean.
† Means with the same letter (within each column and under each treatment heading) are not significantly different from one another at p > 0.10.

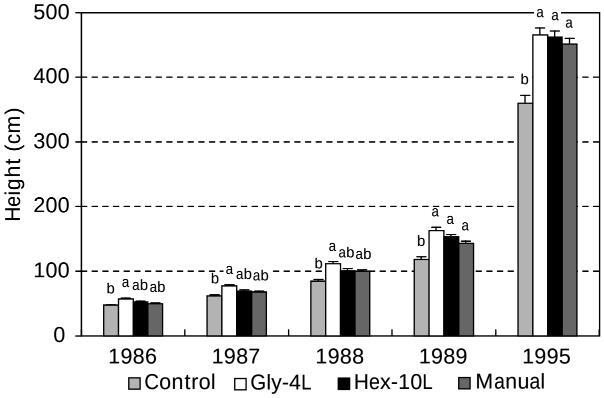

FIGURE 3-1 *Lodgepole pine height 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

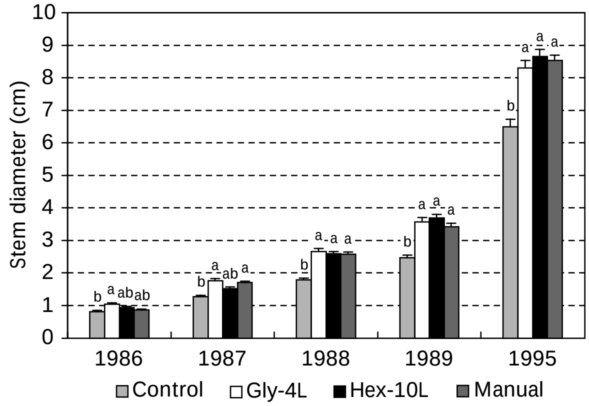

FIGURE 3-2 *Lodgepole pine stem diameter 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

Relative height growth rate of lodgepole pine was not affected by brushing treatments, except in 1989, when it was significantly higher in the hexazinone treatment than in the Control (Table 3-1).

Trends in pine stem diameter were similar to those in height. Again, seedlings initially were slightly larger in glyphosate plots than in the Control (p = 0.09); however, by 1988, seedlings in all brushing treatments had significantly larger stem diameters than seedlings in the Control (Figure 3-2; Table 3-1). Stem diameter of the 2-year-old lodgepole pine seedlings was 0.8 cm in the Control in 1986, and it increased to 6.5 cm by 1995. In comparison, 1995 stem diameter averaged 8.5 cm in the glyphosate, hexazinone, and manual cutting treatments.

There were significant differences in relative diameter growth rate among treatments in 1987, 1988, and 1995, but there was no consistent pattern among years (Table 3-1).

Figure 3-3 compares height growth of lodgepole pine and willow during the 9 years of this trial, and illustrates that increases in the height of lodgepole pine were unrelated to reductions in willow height. Trends in pine height were similar following all three brushing treatments, yet willow height was drastically reduced by both hexazinone and manual cutting and was unaffected by glyphosate.

Although stem volume of lodgepole pine seedlings initially (1986) differed among treatments (p = 0.0320), by 1988 differences between the Control and three brushing treatments were large enough to be attributed to brushing treatment effects (p = 0.0160, Table 3-1). In 1988, stem volume of seedlings treated with glyphosate was 3 times greater than that of seedlings in the Control. In the hexazinone and manual cutting treatments, stem volumes were 2.4 and 2.2 times larger than in the Control. By 1995, stem volume was about twice as large in all three brushing treatments as it was in the Control.

Most pine seedlings were of good vigour through the 9 years of this study. However, a slightly higher proportion of seedlings were of good vigour in the brushing treatments than in the Control (data not shown). More seedlings were taller than neighbouring vegetation in the brushing treatments, particularly the manual cutting treatment, than in the Control between 1987 and 1989. By 1995, many lodgepole pine had grown taller than willow in the Control, and many were free-growing. However, it had taken Control seedlings 2–6 years longer to grow above willow than seedlings in the three brushing treatments. Almost all pine seedlings in manually cut plots had been taller than surrounding vegetation since treatment in 1986.

5.1.2 All vegetation

Prior to treatment in 1986, the dominant shrub was willow, with lesser amounts of Sitka alder, dwarf blueberry (*Vaccinium caespitosum*), and grouseberry (*V. scoparium*). Dominant grasses were orchardgrass and pinegrass (*Calamagrostis rubescens*), and dominant forbs were clover, arctic lupine (*Lupinus*

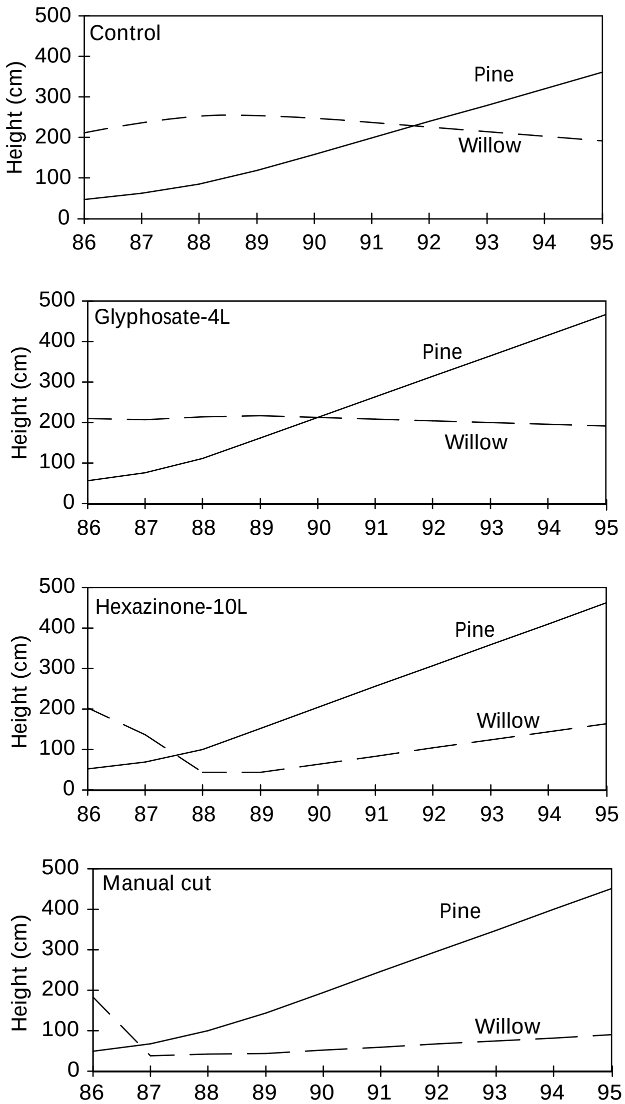

FIGURE 3-3 *Comparison of height growth between lodgepole pine and willow.*

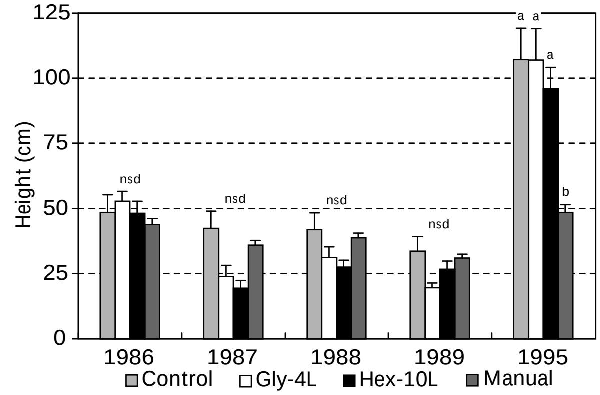

FIGURE 3-4 *Modal height of all vegetation 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error.*

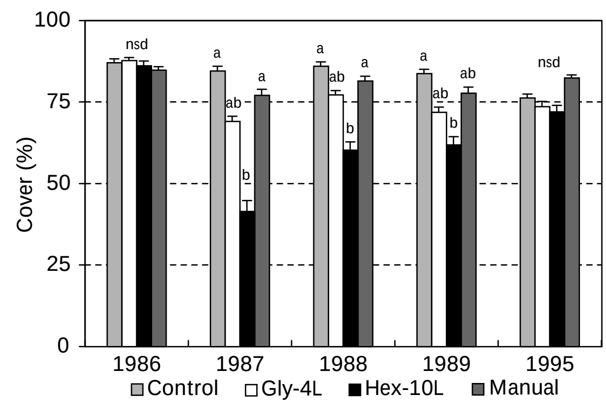

FIGURE 3-5 *Total vegetation cover 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error.*

arcticus), fireweed (*Epilobium angustifolium*), heart-leaved arnica (*Arnica cordifolia*), and bunchberry (*Cornus canadensis*). The abundance of orchard-grass and pinegrass was reduced for 3 or more years following treatment with hexazinone, whereas glyphosate affected pinegrass for 1 year only. Changes in forb abundance were minimal during the 9 years of the trial, but shrub abundance gradually increased.

Modal height of all vegetation did not differ significantly among treatments between 1986 to 1989 (Figure 3-4). By 1995, however, vegetation was more than twice as tall in the Control, glyphosate, and hexazinone treatments as in the manual cutting treatment.

Total vegetation cover was significantly reduced by hexazinone in comparison to the Control from 1987 to 1989 (Figure 3-5). By 1995, total cover no longer differed among any of the treatments.

5.1.3 Target vegetation

Willow At the onset of this trial in 1986, willow in the Control was about 211 cm tall, and it increased to 257 cm by 1989. Between 1989 and 1995, however, the height of willow in the Control declined to 192 cm as a result of winter browsing by moose. One year after treatment, the height of willow was significantly reduced to 136 cm by hexazinone, and to 42 cm by manual cutting (Figure 3-6). In 1988 and 1989, willow height decreased further in the hexazinone treatment so that it was virtually the same (44 cm) as in manually cut plots. By 1995, however, willow treated with hexazinone had recovered to 164 cm, and was no longer significantly different from the Control; in contrast, manually cut willow was only 90 cm tall, and was still significantly shorter than willow in the Control. Willow height was not reduced by glyphosate.

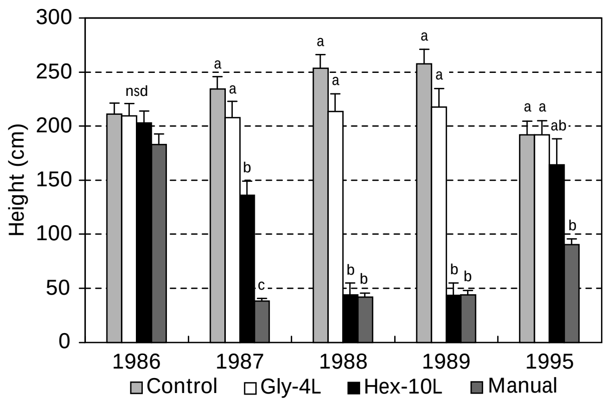

FIGURE 3-6 *Willow height 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

Willow cover in the Control was 26% between 1986 and 1989, and declined to 13% by 1995, probably as a result of moose browsing. Meanwhile, hexazinone and manual cutting both significantly reduced willow cover to less than 5% between 1987 and 1989. By 1995, however, differences between these treatments and the Control were no longer significant (Figure 3-7). In the glyphosate treatment, willow cover was significantly less than in the Control in 1989 only.

ECW control ratings reflect the relative effect of the three treatments on height and cover of willow (Table 3-2). From 1987 to 1989, treatment with hexazinone resulted in better than 80% control of willow, compared to 65–70% control by manual cutting, and 33–38% by treatment with glyphosate. ECW ratings for willow were significantly higher in the hexazinone and manual cutting treatments than in the glyphosate treatment during this period.

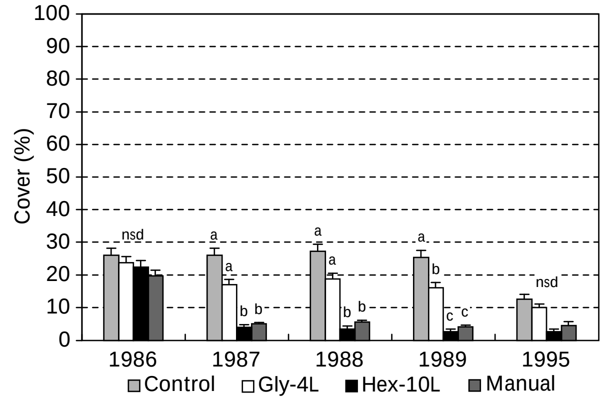

FIGURE 3-7 *Willow cover 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

Timothy None of the three brushing treatments was effective at reducing the height of timothy over the long-term. Glyphosate and hexazinone both significantly reduced its height for 1 year, whereas manual cutting stimulated an increase in height (Figure 3-8), probably in response to increased light levels following removal of the shrub canopy. In 1988, timothy in the manual cutting and hexazinone treatments was significantly taller than in the Control, but by 1995 there were no longer any significant height differences among brushing treatments. Height of timothy in 1995 was about 20 cm less than it had been at the onset of the trial in 1986. Brushing had no significant effect on timothy cover during the 9 years of this study (Figure 3-9).

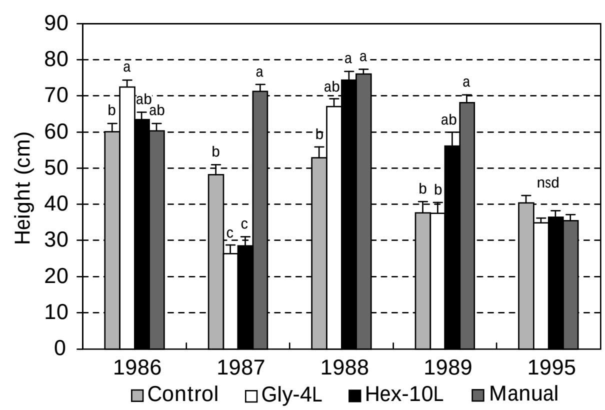

FIGURE 3-8 *Timothy height 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

TABLE 3-2 *Vegetation treatment means and p-values as determined by ANOVA 1986–1995*

	All vegetation		Willow			Timothy			
	Modal height (cm)	Cover (%)	Height (cm)	Cover (%)	ECW (%)	Height (cm)	Cover (%)	ECW (%)	Competition index
Pre-treatment—1986									
Brushing									
Control	48.38*a	87.06 a	210.84 a	26.00 a		60.13 b	11.89 a		73.11 a
Glyph-4L/ha	52.69 a†	87.75 a	209.30 a	23.68 a		72.50 a	18.60 a		72.29 a
Hex-10L/ha	48.06 a	86.14 a	202.88 a	22.35 a		63.45 ab	11.96 a		64.50 a
Manual cut	43.88 a	84.75 a	182.93 a	19.74 a		60.31 ab	23.01 a		54.14 a
p-value	*0.9266*	*0.8375*	*0.7877*	*0.7944*		*0.1050*	*0.3104*		*0.7476*
Grazing									
Ungrazed	43.75 a	86.50 a	197.03 a	21.89 a		64.16 a	16.52 a		64.08 a
Grazed	52.75 a	86.35 a	205.94 a	23.96 a		64.03 a	16.21 a		67.94 a
p-value	*0.6629*	*0.9669*	*0.8432*	*0.6520*		*0.9879*	*0.9604*		*0.8994*
1 year post-treatment—1987									
Brushing									
Control	42.37 a	84.51 a	234.18 a	26.00 a	0.06 c	48.14 b	12.10 a	1.38 b	77.68 a
Glyph-4L/ha	23.75 a	69.06 ab	207.73 a	17.01 a	37.57 b	26.27 c	2.81 a	83.41 a	49.54 ab
Hex-10L/ha	19.27 a	41.41 b	135.95 b	3.95 b	82.33 a	28.50 c	3.48 a	60.65 a	12.08 b
Manual cut	35.95 a	77.03 a	37.83 c	4.93 b	67.68 a	71.25 a	21.94 a	0.00 b	18.28 b
p-value	*0.1595*	*0.0342*	*0.0012*	*0.0043*	*0.0000*	*0.0005*	*0.1392*	*0.0030*	*0.0323*
Grazing									
Ungrazed	29.59 a	74.43 a	159.84 a	13.51 a	43.41 a	46.74 a	11.59 a	41.30 b	40.83 a
Grazed	30.97 a	61.40 a	148.00 a	12.32 a	50.66 a	40.89 a	9.03 a	42.82 a	37.96 a
p-value	*0.9108*	*0.2460*	*0.8373*	*0.8270*	*0.5980*	*0.4418*	*0.6505*	*0.0970*	*0.9199*
2 years post-treatment—1988									
Brushing									
Control	41.81 a	86.01 a	253.62 a	27.23 a	0.00 c	52.81 b	9.68 ab	0.00 c	87.13 a
Glyph-4L/ha	31.13 a	77.13 ab	213.39 a	18.79 a	33.08 b	67.00 ab	3.94 b	73.33 a	56.84 ab
Hex-10L/ha	27.38 a	60.26 b	43.60 b	3.43 b	83.79 a	74.38 a	8.13 ab	36.65 b	15.65 b
Manual cut	38.63 a	81.48 a	41.75 b	5.50 b	65.83 a	76.11 a	23.10 a	0.00 c	21.47 b
p-value	*0.5675*	*0.0572*	*0.0005*	*0.0042*	*0.0000*	*0.0518*	*0.1030*	*0.0020*	*0.0443*
Grazing									
Ungrazed	33.91 a	80.11 a	146.63 a	14.29 a	40.48 a	63.81 a	12.36 a	24.27 a	47.84 a
Grazed	35.56 a	72.33 a	128.77 a	13.20 a	52.23 a	71.34 a	10.06 a	33.05 a	42.70 a
p-value	*0.8527*	*0.1083*	*0.7910*	*0.8653*	*0.4720*	*0.6305*	*0.7419*	*0.5300*	*0.8748*
3 years post-treatment—1989									
Brushing									
Control	33.56 a	83.68 a	257.48 a	25.32 a	0.00 c	37.60 b	9.06 a	0.00 c	82.41 a
Glyph-4L/ha	19.50 a	71.81 ab	217.45 a	16.06 b	35.38 b	37.50 b	3.65 a	59.28 a	53.51 ab
Hex-10L/ha	26.70 a	61.88 b	43.24 b	2.60 c	85.74 a	56.13 ab	8.30 a	37.89 ab	14.98 b
Manual cut	31.00 a	77.75 ab	43.88 b	4.08 c	64.62 a	68.14 a	19.15 a	2.00 bc	17.06 b
p-value	*0.3745*	*0.0881*	*0.0005*	*0.0015*	*0.0000*	*0.0211*	*0.1732*	*0.0110*	*0.0308*
Grazing									
Ungrazed	35.26	77.22 a	150.28 a	12.52 a	41.01 a	61.66 a	11.47 a	14.24 a	45.69 a
Grazed	20.12 a	70.34 a	130.74 a	11.48 a	51.71 a	37.84 a	8.62 a	36.72 a	38.29 a
p-value	*0.4791*	*0.6407*	*0.7693*	*0.8019*	*0.5250*	*0.1007*	*0.5276*	*0.5500*	*0.8147*
9 years post-treatment—1995									
Brushing									
Control	107.23 a	76.18 a	191.91 a	12.58 a		40.43 a	8.87 a		38.57
Glyph-4L/ha	107.03 a	73.56 a	191.73 a	9.92 a		34.79 a	2.89 a		28.83
Hex-10L/ha	96.11 a	71.96 a	164.00 ab	2.57 a		36.38 a	4.99 a		25.14
Manual cut	48.50 b	82.38 a	90.08 b	4.49 a		35.43 a	7.04 a		8.56
p-value	*0.0310*	*0.2290*	*0.0550*	*0.1230*		*0.5700*	*0.3430*		*0.2850*
Grazing									
Ungrazed	90.01 a	77.73 a	152.63 a	9.46 a		37.46 a	5.81 a		31.02
Grazed	89.42 a	74.31 a	172.89 a	5.82 a		35.95 a	6.08 a		22.08
p-value	*0.9870*	*0.5300*	*0.8380*	*0.4300*		*0.9820*	*0.9010*		*0.6190*

* Mean.

† Means with the same letter (within each column and under each treatment heading) are not significantly different from one another at p > 0.10.

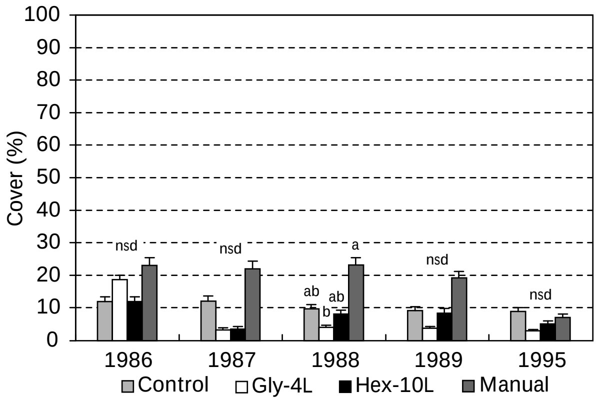

FIGURE 3-9 *Timothy cover 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

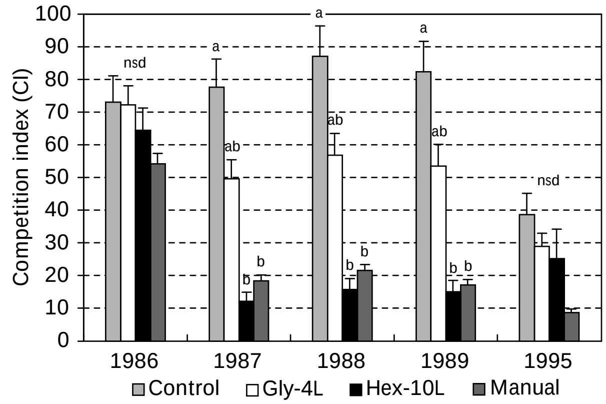

FIGURE 3-10 *Competition index 1986–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error.*

ECW ratings indicate 83% control of timothy in the first year after application of glyphosate, and 61% control in the first year after application of hexazinone. By 1989, control had decreased to 59 and 38% in the glyphosate and hexazinone treatments, respectively. As expected, manual cutting had virtually no effect on timothy (Table 3-2).

5.1.4 Competition index (CI)

In this study, "competition index" was calculated as the sum of (height × cover) of willow and timothy. Competition index was significantly reduced from 1987 to 1989 by hexazinone and manual cutting, largely as a result of the severe impact of both of those treatments on willow height and cover (Figure 3-10). Glyphosate did not reduce the competition index in comparison to the Control.

5.1.5 Effects of cattle grazing on lodgepole pine and vegetation

During the 9 years of this study, cattle grazing had no effect on any measure of lodgepole pine growth, nor did cattle grazing have any effect on overall vegetation height and cover, or willow and timothy height, cover, and ECW ratings (Tables 3-1; 3-2). There were no significant interactions between brushing and grazing treatments for any of the variables measured.

5.2 Range Results

5.2.1 Forage production

Native grasses During the 9 years of this study, there were no differences in native grass production between grazed and ungrazed treatments, nor were there any significant interactions between grazing and the four brushing treatments (Table 3-3).

Native grasses, mainly bluejoint *(Calamagrostis canadensis)* and pinegrass, were less abundant than domestic grasses and forbs on this site (Appendix 1). Prior to treatment in 1986, there were no differences in native grass production among the Control and brushing treatments (Figure 3-11; Table 3-3). In 1987, native grass production was higher following manual cutting than treatment with hexazinone and glyphosate, and it remained higher in manually cut than hexazinone plots through 1990. By 1995, there were no longer any significant differences among treatments, but native grass production overall was about twice as high as it had been in 1986.

Domestic grasses Domestic grass production did not differ between grazed and ungrazed treatments between 1986 and 1995, nor were there any significant interactions between grazing and brushing treatments (Table 3-3).

Manual cutting was the only brushing treatment that had any effect on domestic grass production. In 1988, production was more than twice as great following manual cutting as any other treatment,

TABLE 3-3 *Results of ANOVAs (p-values) comparing forage production among grazing and brushing treatments 1986–1995*

	1986	1987	1988	1989	1990	1995
Native grass						
Grazing treatments	0.441	0.197	0.343	0.392	0.761	0.604
Brushing treatments	0.126	**0.035**	**0.053**	**0.042**	**0.087**	0.115
Grazing*Brushing	0.345	0.286	0.531	0.544	0.564	0.192
Domestic grass						
Grazing treatments	0.969	0.269	0.896	0.313	0.275	0.313
Brushing treatments	0.970	0.182	**0.079**	0.258	0.517	0.416
Grazing*Brushing	0.731	0.989	0.407	0.253	0.371	0.836
Forbs						
Grazing treatments	0.628	0.268	0.536	0.404	0.333	0.887
Brushing treatments	0.560	**0.037**	0.167	0.502	**0.024**	0.494
Grazing*Brushing	0.302	0.118	**0.043**	0.629	**0.048**	0.573
Total production						
Grazing treatments	0.379	0.280	0.329	0.299	0.310	0.703
Brushing treatments	0.643	**0.031**	**0.008**	0.300	**0.076**	**0.041**
Grazing*Brushing	0.686	0.673	0.190	0.463	0.192	0.213

NOTE: Bold values are significant at $\alpha = 0.10$.

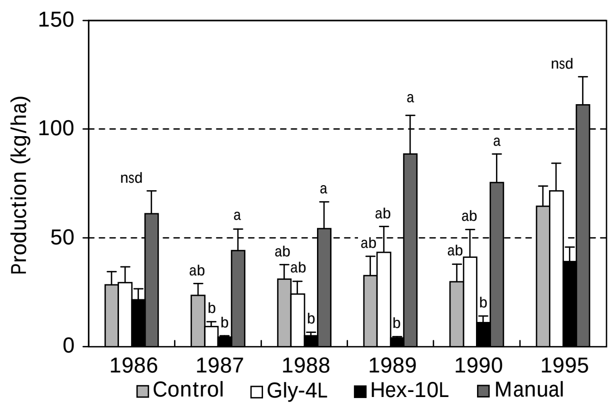

FIGURE 3-11 *Native grass production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

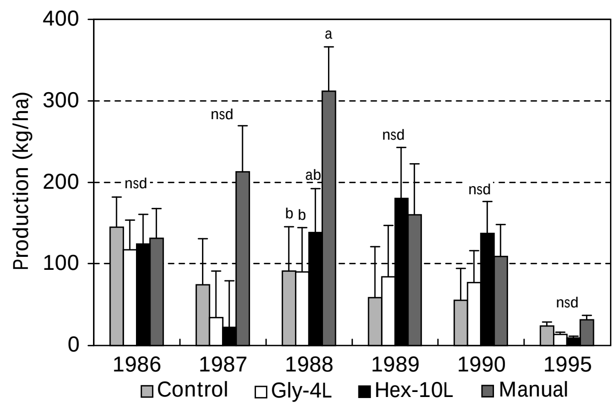

FIGURE 3-12 *Domestic grass production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

including the Control. During 1989 and 1990, domestic grass production declined in manually cut plots, and was no longer significantly different from other treatments. By 1995, domestic grass production was less than 35 kg/ha in all treatments, which was approximately one-third of 1986 levels (Figure 3-12).

Forbs Forb production did not differ between grazed and ungrazed treatments in any measurement year; however, there were significant interactions between the grazing and brushing treatments in 1988 and 1990 (Table 3-3). In those years, forbs in the manual cutting treatment were more abundant in ungrazed than grazed plots (Figure 3-13).

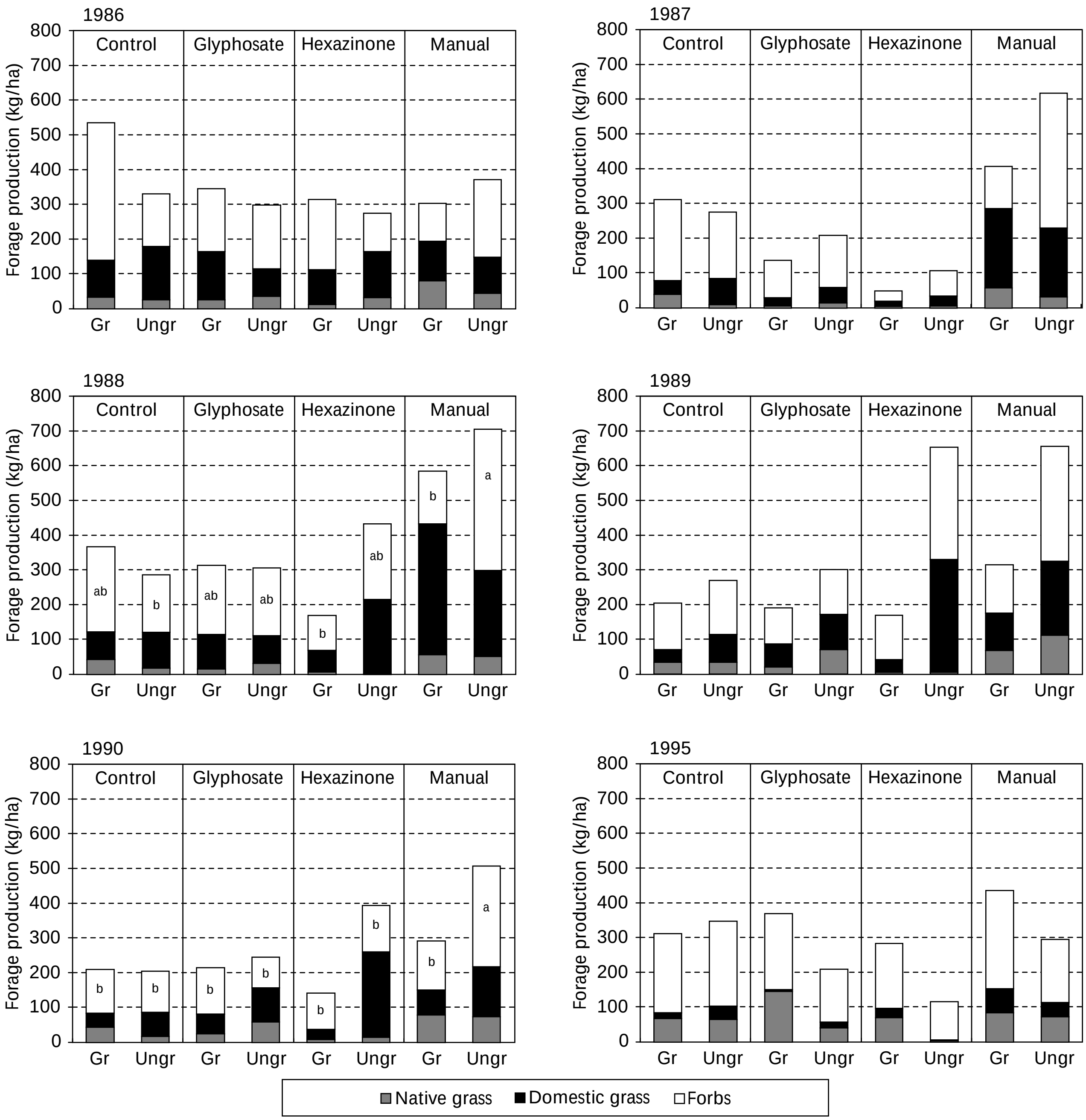

FIGURE 3-13 *Forage production in grazed and ungrazed areas, by brushing treatment. Significant grazing*brushing interactions within a single year were identified using ANOVA (see Table 3-3). Where significant interactions occurred, grazing*brushing treatments with the same letter are not significantly different from one another as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$. Letters indicating significant differences are positioned within the bar for the relevant forage component (i.e., forbs in 1988 and 1990). Histograms are means.*

Forbs were the most abundant forage component on this site, and production was relatively constant from 1986 to 1995. In the first year after treatment with hexazinone, forb production was significantly reduced from the Control value of 213 kg/ha to 52 kg/ha (Figure 3-14). The only other treatment effect occurred in 1990, when forb production in the manual cutting treatment was higher than in chemical treatments or the Control.

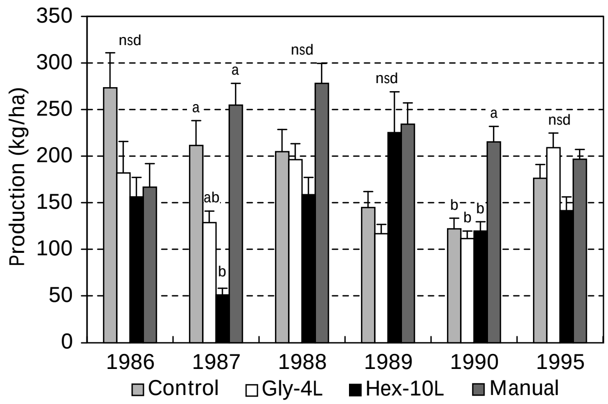

FIGURE 3-14 *Forb production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at α ≤ 0.10; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

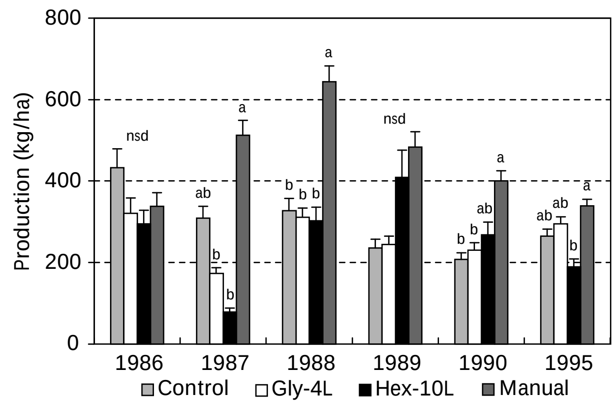

FIGURE 3-15 *Total forage production 1986–1995. Brushing treatments with the same letter within a single year are not significantly different from one another as determined by ANOVA and mean separation tests at α ≤ 0.10; nsd = no significant difference; histograms are means of grazing treatments and error bars are one standard error.*

Total forage There were no differences in total forage production between grazing treatments, nor were there significant interactions between grazing and brushing treatments (Table 3-3).

Trends in total forage production were inconsistent between 1987 and 1995. In 1987, 1 year following treatment, total forage production was significantly higher in the manual cutting treatment (510 kg/ha) than in either herbicide treatment, but did not differ significantly from the Control. By 1988, total forage production in the manual cutting treatment was also significantly higher than in the Control (Figure 3-15). There were no differences in total forage production among treatments in 1989, but in 1990 production was again higher in the manual cutting treatment than in the Control or glyphosate treatment. In 1995, total forage production was significantly greater in the manual cutting than hexazinone treatment.

5.2.2 Livestock use

Livestock used domestic grasses and forbs more heavily than native grasses in 1987, 1989, and 1990. No livestock grazing took place on this block in either 1986 or 1988. In 1987, livestock use of native grasses was lower in plots treated with glyphosate and hexazinone than in Control or manually cut plots (data not shown). Otherwise, brushing treatments had no effect on levels of livestock use for each forage type.

5.2.3 Non-target vegetation abundance and species richness

Hexazinone reduced the cumulative mean abundance of grasses in the first year after treatment, an effect that was noticeable until 1995 (Table 3-4). By 1995, the cumulative abundance of forbs, grasses, and low shrubs was higher in the manual cutting than other treatments, probably because ongoing reduction in willow height and cover increased the availability of light. Species richness was unaffected by treatment (Table 3-4).

There were slight changes in the abundance of a few forbs during the 9 years of this trial (Appendix 2). Leafy aster (*Aster foliaceus*) and wild strawberry (*Fragaria virginiana*) gradually increased in abundance from 1986 to 1995 in all treatments. Abundance of arctic lupine and clover decreased slightly in the first year following treatment with hexazinone, while fireweed increased slightly in all treatments from 1986 to 1987.

Abundance of bluejoint, pinegrass, and orchardgrass was reduced by hexazinone in the first year following application. Abundance of pinegrass was also reduced by glyphosate for 1 year. There were no other major changes in the grass community as a result of treatment, except that hair bentgrass (*Agrostis scabra*) appeared on the site between 1989 and 1995.

Although none of the treatments had a profound effect on shrub species composition, a few shrubs

TABLE 3-4 *Cumulative (summed) mean species abundance and species richness (number of species) for forbs, grasses, low shrubs, and tall shrubs*

	Forbs		Grasses		Low shrubs		Tall shrubs		Total	
	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.
1986										
Control	8.90	33	2.74	6	2.68	8	0.79	3	**15.11**	**50**
Glyphosate	6.58	29	2.75	9	1.60	8	1.28	3	**12.21**	**49**
Hexazinone	5.61	30	2.10	6	2.08	8	1.25	2	**11.04**	**46**
Manual cut	7.93	33	1.66	8	2.46	9	0.89	3	**12.94**	**53**
1987										
Control	10.68	38	2.84	8	3.01	8	0.85	3	**17.38**	**57**
Glyphosate	8.59	32	2.40	7	1.08	8	0.61	3	**12.68**	**50**
Hexazinone	6.09	30	1.00	4	1.99	9	1.04	2	**10.12**	**45**
Manual cut	10.00	33	2.46	9	2.88	9	0.65	3	**15.99**	**54**
1988										
Control	11.86	38	2.79	7	3.10	8	0.95	3	**18.70**	**56**
Glyphosate	10.51	35	2.96	10	1.39	8	0.76	3	**15.62**	**56**
Hexazinone	8.99	35	1.66	7	2.44	9	1.11	4	**14.20**	**55**
Manual cut	11.31	35	3.09	11	3.09	10	0.65	3	**18.14**	**59**
1989										
Control	11.20	38	2.83	7	3.15	8	0.96	3	**18.14**	**56**
Glyphosate	9.86	33	3.24	10	1.59	8	0.83	3	**15.52**	**54**
Hexazinone	9.28	34	1.75	7	2.89	9	1.19	3	**15.11**	**53**
Manual Cut	12.30	36	3.28	11	3.28	10	0.65	3	**19.51**	**60**
1995										
Control	11.23	39	2.89	7	3.63	11	2.04	4	**19.79**	**61**
Glyphosate	13.29	40	3.30	11	2.75	9	2.05	3	**21.39**	**63**
Hexazinone	10.16	36	2.26	10	4.01	10	2.45	4	**18.88**	**60**
Manual cut	17.03	39	4.26	14	5.49	12	1.54	4	**28.32**	**69**

gradually increased in abundance. During the 9 years of the study, kinnikinnick (*Arctostaphylos uva-ursi*), dwarf blueberry, grouseberry, and Sitka alder gradually increased in abundance in all treatments.

6 DISCUSSION

This trial was established to study the effectiveness of glyphosate at 4 litres/ha, hexazinone at 10 litres/ha, and manual cutting for release of 2-year-old lodgepole pine seedlings growing in competition with the *Willow* Complex. It was also intended to address the concerns of range managers by providing information about the impacts of these brushing treatments on production of livestock forage. Most trials involving vegetation management have focused on the response of seedlings and target vegetation within 3–5 years of treatment, but this trial provides information over a longer term.

All three brushing treatments in this trial resulted in significant increases in stem diameter, height, 1-year height increment, and stem volume of lodgepole pine seedlings; however, only hexazinone and manual cutting significantly reduced the competition index of willow and timothy. Unfortunately, seedling response to glyphosate treatment was confounded by pre-treatment differences in height and stem diameter between that treatment and the Control. By 1988–1989, however, the magnitude of these differences had substantially increased, and appeared to result from the brushing treatment. At the onset of the trial, pine seedlings were about 50 cm tall. By 1995 they had grown to 360 cm in the Control, and 450–465 cm in the three brushing treatments.

Both hexazinone and manual cutting treatments dramatically reduced the height and cover of willow; prior to treatment, it was 211 cm tall with 26% cover. Willow height was reduced to less than 45 cm for 3 years following manual cutting, and remained less than 100 cm for 9 years. These results contradict those of numerous other studies, which report that manual cutting of willow was ineffective due to vigorous sprouting (Pollack et al. 1990; Hart and Comeau 1992; Simard and Heineman 1996b). Hexazinone also reduced the height of willow to less than 45 cm within 2 years of treatment, but it recovered to the Control height by 1995 (mean 183 cm). Willow cover was reduced to approximately 5% by both hexazinone and manual cutting for 3 years following treatment, which was significantly less than the Control cover of 26%.

Glyphosate had no effect on willow height, and it reduced willow cover in 1989 only. In a similar study in the ICH, height and cover of willow were even less affected by glyphosate, even though it was applied at the maximum allowable rate of 6 litres/ha (2.14 kg ai/ha) (Simard and Heineman 1996b). The results of these two trials contradict other studies, where glyphosate was effective at controlling willow (Conard and Emmingham 1983; Boateng and Herring 1990; Pollack et al. 1990).

Both glyphosate and hexazinone reduced the height of timothy for 1 year following treatment. In 1988 and 1989, however, timothy grew significantly taller in the hexazinone and manual cutting treatments than in the Control; this was likely a response to increased light following reduction of the shrub canopy.

Lodgepole pine seedlings responded similarly to all three brushing treatments, even though glyphosate reduced willow height, cover, and competition index less than either hexazinone or manual cutting. However, ECW ratings indicate 35% control of willow following treatment with glyphosate, mainly in the form of leaf deformity and reduced vigour. Although glyphosate affected willow less than the other brushing treatments, it appears to have resulted in sufficient increases in resource availability to allow seedlings to respond. These results suggest that the injury to willow caused by hexazinone and manual cutting was much more severe than necessary for the release of pine seedlings.

Timothy is not normally abundant enough to compete with conifers, but because it was seeded onto this site it dominated the herb layer in 1986 (12–23% cover). Considerable amounts of orchardgrass and clover were also present, and all of these species together may have been competing with lodgepole pine seedlings for soil water. However, lodgepole pine responded equally to the herbicide treatments (which reduced overall vegetation cover) and to manual cutting (which did not), indicating that competition was mainly for light rather than soil resources. Manual cutting stimulated height growth of timothy and abundance of grasses and herbs, but this had no effect on growth of lodgepole pine seedlings.

Grazing had no effect on lodgepole pine growth, nor on abundance of Sitka alder and timothy through the 9 years of this study. Conversely, the vegetation management treatments had no negative long-term effects on native grass, domestic grass, forb, or total forage production. Manual cutting stimulated grass and forb production during the first 3 years, likely through increased resource availability, but this effect was short-lived as overstory increased. Cattle are known to vary their diets depending on the availability of forage, particularly on higher-elevation sites, where forbs may constitute 34–54% of the diet (Quinton 1984). On the Ellis Creek site, the proportion of forbs was higher than either native or domestic grasses, and the quick recovery of that forage component helped restrict the impact of chemical brushing to a single season. In summary, range values were not significantly affected by brushing treatments, nor were lodgepole pine or the plant community negatively affected by grazing.

Changes to species composition were minimal on this site. The only noticeable trends occurred following hexazinone treatment, where the abundance of bluejoint, pinegrass, orchardgrass, clover, and lupine was slightly reduced for 1 year.

Heavy winter browsing of willow (78–94%) by moose was recorded in 1995 in all but the hexazinone treatment, where only 24% of willow were browsed. Browsing likely explains the 65 cm reduction in Control willow height between 1989 and 1995. According to Haeussler et al. (1990), willow is an important food for ungulates, small mammals, and birds. Large-scale reductions in willow cover could, therefore, have an adverse effect on wildlife. There were some increases in the abundance of low shrub species such as dwarf blueberry and grouseberry, which occurred across all treatments. None of the three brushing treatments affected species composition for any of the vegetation growth forms.

The equal response of lodgepole pine across all treatments in this trial indicates that no more than 35% control of willow was necessary to produce a significant increase in pine seedling stem diameter and height. Furthermore, free-growing status was achieved in the Control when seedlings were 10 years old, indicating that stocking obligations could have been met without any brushing intervention. Brushing had little effect on range values, but the ongoing reduction of willow height and cover that resulted from manual cutting may have had an unnecessarily severe impact on wildlife values. Further study is required to resolve some of the inconsistencies in treatment response that occur with willow.

Upper McKay Creek Study:
Effects of brushing and grazing on lodgepole pine, the *Pinegrass* plant community, and range forage on an IDFdk1 site near Lillooet, B.C.

ABSTRACT

A research trial was established in 1987 in the southern interior of British Columbia to study the effectiveness of hexazinone at 9 litres/ha (2.2 kg ai/ha), hexazinone at 4.5 litres/ha (1.1 kg ai/ha), and glyphosate at 6 litres/ha (2.1 kg ai/ha) to release planted lodgepole pine seedlings and suppress the *Pinegrass* Complex. Lodgepole pine seedlings and pinegrass were assessed 1, 2, 3, and 8 years following treatment.

All three chemical treatments had a significant effect on height and cover of pinegrass. ECW ratings indicate 95% control of pinegrass for 1 year following treatment with hexazinone at 9 litres/ha, and 84% control after 3 years. Hexazinone at 4.5 litres/ha resulted in 87% control after one year, and 64% after three years. The efficacy of glyphosate was lower than expected, with ECW ratings indicating 73% control after 1 year, and 52% after 2 years.

Abundant pinegrass on this site was thought to be competing with the 35-cm-tall lodgepole pine seedlings for soil water. However, seedlings did not respond to decreases in height and cover of pinegrass, implying that soil water competition was not the major factor limiting growth. Seedling relative height and diameter growth rates, as well as 1-year height increment, differed between the brushing treatments and Control in 1989 and 1990; however, the differences were small and transient, indicating a weak response to treatment. Pine were observed to be performing better on burned windrows than elsewhere, suggesting that low nutrient availability may have been limiting seedling response to increased availability of soil water.

Range values on this site were negatively affected for 3 to 8 years by chemical brushing. Pinegrass was the main forage species as well as the principal brushing target, so silviculture and range objectives were in direct conflict. Hexazinone applied at 9 litres/ha had a more severe effect on pinegrass abundance than hexazinone applied at 4.5 litres/ha or glyphosate at 6 litres/ha.

1 ABOUT THE *PINEGRASS* COMPLEX

The *Pinegrass* Complex, which is dominated by pinegrass (*Calamagrostis rubescens*) and has minor amounts of arctic lupine (*Lupinus arcticus*), is widespread in the Interior Douglas-Fir (IDF) biogeoclimatic zone. It also occurs in the Interior Cedar–Hemlock (ICH), Montane Spruce (MS), Ponderosa Pine (PP), Bunchgrass (BG), Sub-Boreal Spruce (SBS), and Engelmann Spruce–Subalpine Fir (ESSF) zones. It has been recognized as a major competitor to crop trees in the southern interior of British Columbia (Kimmins and Comeau 1990).

Pinegrass occurs on xeric to hygric sites (Angove and Bancroft 1983), and is present across a wide range of nutrient regimes (Haeussler and Coates 1986). Shade tolerance of pinegrass is reported to be variable, but cover and root development often increase dramatically in response to canopy removal (Haeussler et al. 1990). Pinegrass is favoured by light- to moderate-severity fires (Stickney 1986), but may be extensively damaged by fires severe enough to penetrate the duff layer (McLean 1979). However, even severe fires provide only a short-term setback to pinegrass (Haeussler et al. 1990). Pinegrass spreads mainly through its rhizomatous root system and rarely flowers (Angove and Bancroft 1983), but may be stimulated to bloom profusely in the first few years following a severe wildfire (Crane et al. 1983).

The dense, rhizomatous root system of pinegrass makes it an efficient competitor for soil water. According to Petersen and Maxwell (1987), soil water content on a pinegrass-dominated site decreased in direct proportion to increasing vegetation levels. Pinegrass grows quickly in the spring when water is most available, and then begins to die back by the end of June; in contrast, conifer growth peaks in mid-summer when soil water is most limiting. Nicholson (1989) found that this pattern of water competition exacerbated Douglas-fir moisture stress, and contributed to poor seedling performance. Haeussler et al. (1990) suggest that seedlings that establish their root systems prior to pinegrass invasion may experience less soil water competition than those established concurrent with, or later than, pinegrass. The presence of pinegrass may, however, improve the nutrient status of a site by contributing organic material to the soil, and it has also been suggested that pinegrass competition reduces or prevents overstocking by lodgepole pine (Clark 1975, cited by Haeussler et al. 1990).

The abundance of pinegrass in IDF forests makes it valuable for cattle grazing. However, management strategies for the range resource often conflict with those of the timber resource. Canopy removal, thinning, mechanical site preparation, and herbicide application are among silvicultural treatments that affect the abundance of pinegrass, and may therefore have an impact on range values (Haeussler et al. 1990).

Chemical brushing treatments are often prescribed to reduce grass cover, usually with the objective of reducing soil water competition to seedlings. The Expert Committee on Weeds (1987) recommendations for control of grasses are that glyphosate be applied at 2.1 kg ai/ha (5.9 litres/ha) for site preparation and 1.5–2.0 kg ai/ha (4.2–5.6 litres/ha) for conifer release. Conard and Emmingham (1984d) report that perennial grasses sustain 90–100% injury when glyphosate is applied at 1.12 kg ai/ha (1.5 lb/acre) in summer and fall, 60–90% injury after winter application, and 25–60% injury after spring application. Lloyd and Heineman (1994a) found that application of glyphosate at 6 litres/ha (2.1 kg ai/ha) from mid-June to mid-July reduced pinegrass cover by 80–90% for 4 years, and that glyphosate at 4 litres/ha (1.4 kg ai/ha) reduced cover by 75% for 3 years. Spring application of hexazinone reportedly results in 60–90% injury to pinegrass, although results are variable (Conard and Emmingham 1984). Dimock et al. (1983) found that hexazinone applied to various perennial grasses in mid-May to mid-June resulted in about 70% control after 2 years, and about 50% control after 4 years. Movement of hexazinone through the soil may lead to seedling damage, however. Comeau et al. (1996) found significant damage to newly planted Douglas-fir as a result of soil application of 1.5% hexazinone.

Brushing prescriptions that reduce the presence of pinegrass must take into account its importance as forage during the grazing season, particularly on the drier ranges that are common in the IDF zone; dry sites tend to be dominated by pinegrass, whereas moister sites have a greater variety and quantity of forbs (Stout and Quinton 1986). In addition to its importance to cattle, pinegrass provides year-round forage for Rocky Mountain elk (Kufeld 1973), and is an important early spring food for mule deer (Haeussler et al. 1990).

2 SPECIFIC OBJECTIVES

The specific silviculture objectives of this study were:

1. To study the effects of ground foliar applications of hexazinone at 4.5 litres/ha (1.1 kg ai/ha), hexazinone at 9 litres/ha (2.2 kg ai/ha), and glyphosate at 6 litres/ha (2.14 kg ai/ha) on planted lodgepole pine seedlings and pinegrass over a period of 8 years.
2. To study trends in abundance of other vascular plant species that may have been affected by treatment.

Specific range objectives were:

1. To study the effects of hexazinone at 4.5 litres/ha, hexazinone at 9 litres/ha, and glyphosate at 6 litres/ha on the survival and production of native grasses and forbs.
2. To contribute to guidelines for accommodating reductions in grazing capacity due to silvicultural activities.

3 STUDY AREA

This study site is located on Slok Creek Road in the Lillooet Forest District, approximately 54 km northwest of Lillooet. The original lodgepole pine stand (Pl 320-P) was stagnant and infested with mistletoe, and was sanitation clearcut in 1983. The slash was windrowed and burned in 1984. In 1984, lodgepole pine was planted (2+0 bareroot) and also naturally seeded-in to the site. Douglas-fir was planted on the perimeter of the block to serve as a buffer, but survival was very poor. The vegetation complex that developed was composed primarily of pinegrass. The area was not grazed during the study period.

This flat site is at elevation 1300 m, and is classified as IDFdk1/04-01 (Thompson Dry Cool variant of the Interior Douglas-fir zone, site series 04-01) (Lloyd et al. 1990). Soil is moderately well drained and is classified as a Luvisol (Canadian Soil Survey Committee 1978). Texture varies from a volcanic ash veneer to sandy clay loam with depth. Bulk density appears to increase with depth, and there may be root-restricting layers in some places. There are some surface stones, and approximately 35% coarse fragments in the mineral soil. The forest floor is 10 cm thick, and is classified as Orthihemimor (Klinka et al. 1981).

4 TREATMENTS

The following four treatments were applied: (1) control, (2) glyphosate applied at a rate of 6 litres/ha (2.1 kg ai/ha), (3) hexazinone applied at a rate of 9 litres/ha (2.2 kg ai/ha), and (4) hexazinone applied at a rate of 4.5 litres/ha (1.1 kg ai/ha).

Although pre-treatment measurements were made in 1987, chemicals were not applied until 1988. Hexazinone (tradename Velpar®) was applied as a ground foliar spray on June 18, 1988, under clear, calm skies. Glyphosate (tradename Vision®) was applied as a ground foliar spray on August 25–26, 1988. Rain delayed application of glyphosate, which may have reduced its efficacy.

5 RESULTS

5.1 Silviculture Results

5.1.1 Lodgepole pine

There were no significant effects of either rate of hexazinone or glyphosate on the height of lodgepole pine seedlings during the 8 years of this study. Pine seedlings were 33 cm tall at the time of treatment with hexazinone in the spring of 1988, and 49 cm tall when they were treated with glyphosate in the fall of 1988. By 1995, seedlings averaged 247 cm across all four treatments (Figure 4-1).

In 1990, 1-year height increment of pine seedlings was 32–35 cm in the two hexazinone treatments, compared to 23 cm in the Control ($p = 0.0178$, Table 4-1). In 1989–1990, relative height growth rate of lodgepole pine was also significantly greater in plots treated with both levels of hexazinone than it was in the Control ($p < 0.001$, Table 4-1). However, these differences had disappeared by 1995.

Stem diameter of lodgepole pine was unaffected by brushing treatments through the 8 years of this study (Table 4-1; Figure 4-2). Seedlings increased from an average diameter of 0.9 cm in 1987 to 5.1 cm in 1995 across all four treatments. Relative diameter growth rate was significantly higher among seedlings treated with hexazinone at 9 litres/ha than those in the Control in 1989 and 1990, and higher among those treated with hexazinone at 4.5 litres/ha in 1989 (Table 4-1). Again, these differences had disappeared by 1995.

Stem volume was also unaffected by brushing treatments. In 1995, stem volume averaged 2308 cm^3 across all four treatments (Table 4-1). Most seedlings in this trial were of medium vigour. Dominance ratings were low because of the small stature (20–30 cm tall) of neighbouring pinegrass (data not shown).

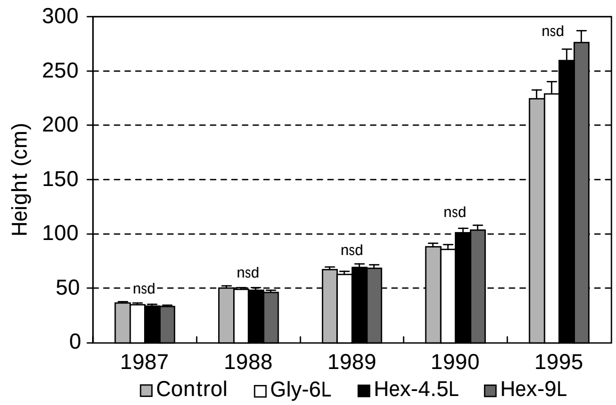

FIGURE 4-1 *Lodgepole pine height 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error.*

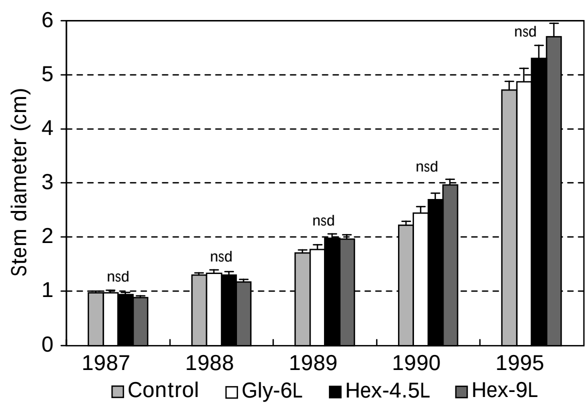

FIGURE 4-2 *Lodgepole pine stem diameter 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error.*

TABLE 4-1 *Lodgepole pine treatment means and p-values as determined by ANOVA 1987–1995*

	Height (cm)	1-year height increment (cm)	Stem diameter (cm)	Stem volume (cm^3)	Relative height growth	Relative diameter growth
Pre-treatment—1987						
Control	36.45*a	9.34 a	0.97 a	10.19 a		
	1.35 †	*0.57*	*0.03*	*0.82*		
Glyph-6L/ha	34.93 a‡	9.10 a	0.97 a	11.83 a		
	1.51	*0.68*	*0.05*	*1.91*		
Hex-4.5L/ha	33.50 a	9.25 a	0.94 a	10.63 a		
	1.66	*0.67*	*0.04*	*1.60*		
Hex-9L/ha	33.00 a	8.42 a	0.88 a	8.29 a		
	1.39	*0.58*	*0.03*	*0.85*		
p-value	*0.8409*	*0.9005*	*0.7325*	*0.7360*		
1 year post-treatment—1988						
Control	50.30 a	13.80 a	1.30 a	25.60 a	0.41 a	0.35 a
	1.76	*0.85*	*0.04*	*2.24*	*0.03*	*0.02*
Glyph-6L/ha	48.72 a	13.98 a	1.33 a	30.20 a	0.42 a	0.38 a
	2.02	*0.87*	*0.06*	*4.52*	*0.03*	*0.03*
Hex-4.5L/ha	48.28 a	14.77 a	1.30 a	28.69 a	0.48 a	0.40 a
	2.22	*0.88*	*0.06*	*3.97*	*0.03*	*0.03*
Hex-9L/ha	45.97 a	12.97 a	1.17 a	21.28 a	0.41 a	0.33 a
	1.95	*0.86*	*0.05*	*2.41*	*0.03*	*0.02*
p-value	*0.8742*	*0.7926*	*0.5950*	*0.6730*	*0.6753*	*0.1535*
2 years post-treatment—1989						
Control	67.01 a	16.72 ab	1.71 a	59.58 a	0.34 b	0.32 c
	2.39	*0.95*	*5.13*	*5.19*	*0.02*	*0.01*
Glyph-6L/ha	62.64 a	14.15 b	1.77 a	73.55 a	0.29 c	0.34 c
	2.92	*1.15*	*0.09*	*10.62*	*0.02*	*0.03*
Hex-4.5L/ha	69.20 a	20.92 ab	1.98 a	93.91 a	0.45 a	0.54 b
	3.15	*1.27*	*0.08*	*12.51*	*0.03*	*0.03*
Hex-9L/ha	68.28 a	22.32 a	1.96 a	89.81 a	0.49 a	0.68 a
	3.13	*1.41*	*0.08*	*10.77*	*0.02*	*0.03*
p-value	*0.8312*	*0.0320*	*0.5195*	*0.5410*	*0.0001*	*0.0010*
3 years post-treatment—1990						
Control	88.28 a	22.97 b	2.22 a	133.88 a	0.32 b	0.30 b
	3.27	*1.12*	*0.07*	*11.64*	*0.01*	*0.01*
Glyph-6L/ha	85.70 a	22.98 b	2.44 a	194.36 a	0.35 b	0.35 b
	4.45	*1.47*	*12.10*	*28.33*	*0.02*	*0.02*
Hex-4.5L/ha	100.93 a	32.20 a	2.69 a	252.90 a	0.47 a	0.36 b
	4.31	*1.53*	*11.79*	*32.28*	*0.02*	*0.02*
Hex-9L/ha	103.53 a	34.86 a	2.96 a	299.92 a	0.53 a	0.53 a
	4.53	*1.47*	*0.11*	*31.83*	*0.02*	*0.03*
p-value	*0.3848*	*0.0178*	*0.1724*	*0.2690*	*0.0003*	*0.0027*
8 years post-treatment—1995						
Control	224.25 a	33.18 a	4.72 a	1568.07 a	0.32 a	0.23 a
	8.39	*1.20*	*0.16*	*157.09*	*0.01*	*0.01*
Glyph-6L/ha	228.65 a	33.38 a	4.87 a	2088.21 a	0.34 a	0.20 a
	11.39	*1.33*	*0.25*	*296.97*	*0.01*	*0.01*
Hex-4.5L/ha	259.70 a	37.48 a	5.30 a	2509.99 a	0.32 a	0.20 a
	10.37	*1.30*	*0.24*	*295.67*	*0.01*	*0.01*
Hex-9L/ha	275.95 a	37.73 a	5.70 a	3066.50 a	0.34 a	0.18 a
	10.98	*1.16*	*0.25*	*360.23*	*0.01*	*0.01*
p-value	*0.3340*	*0.3480*	*0.3920*	*0.3830*	*0.1080*	*0.1420*

* Mean.
† Standard error (italics).
‡ Means with the same letter (within each column and in each year) are not significantly different from one another at $p > 0.10$.

5.1.2 All vegetation

Prior to treatment in 1988, vegetation was dominated by 30–40% cover of pinegrass. The most abundant shrubs on the site were prickly rose (*Rosa acicularis*), kinnikinnick (*Arctostaphylos uva-ursi*), and soopolalie (*Shepherdia canadensis*), and the most abundant herbs were sedges (*Carex* spp.), wild strawberry (*Fragaria virginiana*), and twinflower (*Linnaea borealis*).

Modal height of all vegetation was significantly reduced in comparison to the Control by both levels of hexazinone in 1988, and by all three treatments in 1989 (Figure 4-3). By 1990, however, these treatment effects had disappeared. In 1995, modal height was significantly lower in the glyphosate treatment than either hexazinone treatment, probably because glyphosate had a greater impact on the abundance of shrubs. However, none of the treatments differed in modal height from the Control.

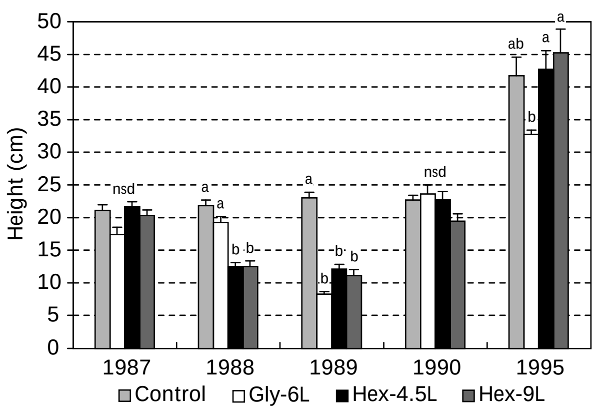

FIGURE 4-3 *Modal height of all vegetation 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so vegetation shows no response to that treatment in the 1988 assessment.*

All three chemical treatments significantly reduced total vegetation cover in the first growing season after application, and this reduction remained significant until 1995 in the glyphosate and 9 litres/ha hexazinone treatments (Figure 4-4). From 1988 to 1990, total vegetation cover in the two hexazinone treatments was reduced to less than 30%, compared to 56–58% in the Control. By 1995, total cover had recovered, on average, to 37% in all three chemical treatments, compared to 50% in the Control.

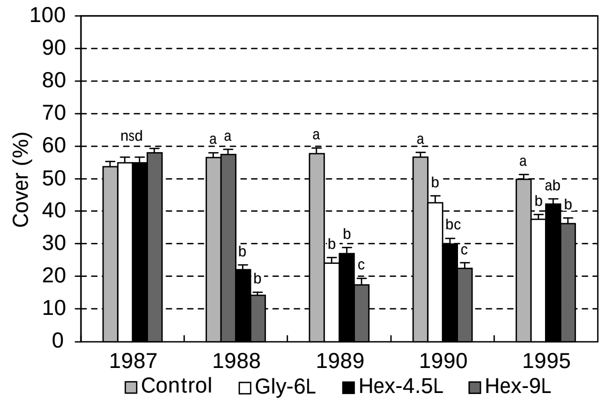

FIGURE 4-4 *Total vegetation cover 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so vegetation shows no response to that treatment in the 1988 assessment.*

5.1.3 Target vegetation

Pinegrass Pinegrass height was significantly reduced by both levels of hexazinone in the 1988 assessment, and by glyphosate in the 1989 assessment (Figure 4-5; Table 4-2). In 1988, treatment with hexazinone at 9 litres/ha had a significantly greater impact on pinegrass height than treatment with 4.5 litres/ha hexazinone; by 1989, however, pinegrass had regained Control heights in both hexazinone treatments. Glyphosate application in

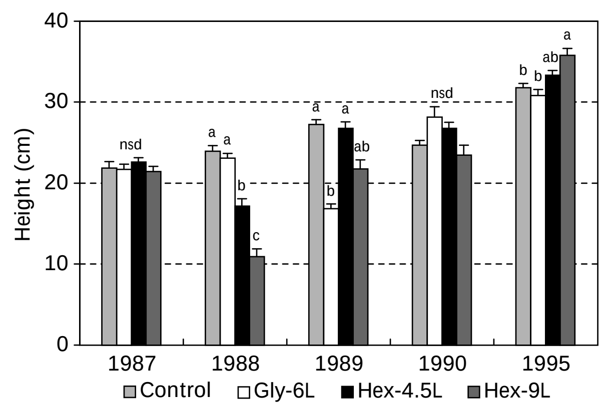

FIGURE 4-5 *Pinegrass height 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at α ≤ 0.10; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so pinegrass shows no response to that treatment in the 1988 assessment.*

TABLE 4-2 *Vegetation treatment means and p-values as determined by ANOVA 1987–1995*

	All vegetation		Pinegrass			
	Modal height (cm)	Cover (%)	Height (cm)	Cover (%)	ECW (%)	Competition index
Pre-treatment—1987						
Control	21.08*a	53.97 a	21.86 a	34.07 a		7.73 a
	0.91 †	*1.59*	*0.77*	*1.50*		*0.53*
Glyph-6L/ha	17.42 a‡	54.92 a	21.67 a	32.27 a		7.28 a
	1.07	*1.74*	*0.65*	*1.92*		*0.60*
Hex-4.5L/ha	21.67 a	54.92 a	22.58 a	33.83 a		7.75 a
	0.78	*1.70*	*0.56*	*1.38*		*0.40*
Hex-9L/ha	20.33 a	58.00 a	21.42 a	38.58 a		8.50 a
	0.82	*1.28*	*0.62*	*1.45*		*0.48*
p-value	*0.3340*	*0.7790*	*0.9252*	*0.6557*		*0.9000*
1 year post-treatment—1988						
Control	21.83 a	56.42 a	23.92 a	35.67 a	0.00 b	8.80 a
	0.87	*1.46*	*0.72*	*1.40*	*0.00*	*0.55*
Glyph-6L/ha	19.25 a	57.42 a	23.08 a	32.85 a	0.00 b	7.84 a
	0.92	*1.65*	*0.56*	*1.88*	*0.00*	*0.59*
Hex-4.5L/ha	12.50 b	22.00 b	17.12 b	7.07 b	87.12 a	1.39 b
	0.62	*1.49*	*0.94*	*0.93*	*2.74*	*0.21*
Hex-9L/ha	12.50 b	14.17 b	10.90 c	2.00 b	94.72 a	0.31 b
	0.89	*0.91*	*0.93*	*0.27*	*0.89*	*0.08*
p-value	*0.0007*	*0.0001*	*0.0030*	*0.0001*	*0.0000*	*0.0011*
2 years post-treatment—1989						
Control	23.00 a	57.67 a	27.25 a	35.17 a	0.00 d	9.78 a
	0.85	*1.70*	*0.58*	*1.52*	*0.00*	*0.54*
Glyph-6L/ha	8.25 b	23.97 bc	16.83 b	9.37 bc	72.66 b	1.70 b
	0.44	*1.85*	*0.58*	*0.99*	*2.53*	*0.21*
Hex-4.5L/ha	12.08 b	26.97 b	26.75 a	11.43 b	64.15 c	3.19 b
	0.78	*1.87*	*0.81*	*0.93*	*2.63*	*0.31*
Hex-9L/ha	11.13 b	17.35 c	21.75 ab	6.52 c	83.08 a	1.77 b
	0.90	1.96	1.11	0.92	2.52	0.29
p-value	*0.0029*	*0.0001*	*0.0106*	*0.0001*	*0.0000*	*0.0001*
3 years post-treatment—1990						
Control	22.67 a	56.58 a	24.67	35.00 a	0.00 c	8.83 a
	0.72	*1.48*	*0.60*	*1.34*	*0.00*	*0.48*
Glyph-6L/ha	23.58 a	42.58 b	28.17	14.27 b	52.43 b	4.29 b
	1.39	*2.10*	*1.28*	*1.51*	*3.69*	*0.61*
Hex-4.5L/ha	22.75 a	29.95 bc	26.75	11.62 b	63.50 ab	3.13 b
	1.28	*1.75*	*0.73*	*0.88*	*3.64*	*0.25*
Hex-9L/ha	19.42 a	22.42 c	23.47	6.23 b	84.32 a	1.58 b
	1.18	*1.75*	*1.21*	*0.72*	*1.96*	*0.19*
p-value	*0.8447*	*0.0031*	*0.3123*	*0.0010*	*0.0000*	*0.0082*
8 years post-treatment—1995						
Control	41.70 ab	49.82 a	31.75 b	24.77 a		7.93
	2.89	*1.45*	*0.55*	*0.92*		*0.35*
Glyph-6L/ha	32.75 b	37.52 b	30.82 b	18.23 ab		5.72
	0.68	1.48	0.72	1.08		0.38
Hex-4.5L/ha	42.75 a	42.18 ab	33.30 ab	20.25 ab		6.73
	2.84	*1.60*	*0.61*	*0.97*		*0.33*
Hex-9L/ha	45.22 a	36.13 b	35.77 a	14.55 b		5.40
	3.63	*1.78*	*0.88*	*1.21*		*0.50*
p-value	*0.0500*	*0.0290*	*0.0090*	*0.0380*		*0.1090*

* Mean.
† Standard error (italics).
‡ Means with the same letter (within each column and in each year) are not significantly different from one another at p > 0.10.

1988 resulted in first-year post-treatment reductions in pinegrass height that were intermediate between the two rates of hexazinone. By 1995, pinegrass in the 9 litres/ha hexazinone treatment had grown significantly taller than in the Control and glyphosate treatment.

In the first year after chemical application, pinegrass cover was significantly reduced from 35% in the Control, to 2, 7, and 9% in the 9 litres/ha hexazinone, 4.5 litres/ha hexazinone, and glyphosate treatments, respectively (Figure 4-6). By 1995, only the higher rate of hexazinone continued to have a significant effect on pinegrass cover.

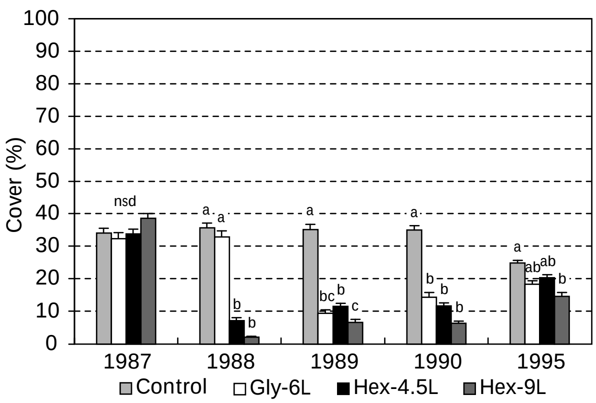

FIGURE 4-6 *Pinegrass cover 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so pinegrass shows no response to that treatment in the 1988 assessment.*

ECW ratings indicate 95% control of pinegrass by hexazinone at 9 litres/ha in the first year after treatment (Table 4-2). In the following 2 years (1989 and 1990), pinegrass recovered slightly, but ECW ratings still indicated about 84% control. ECW ratings for hexazinone at 4.5 litres/ha indicate 87% control of pinegrass in 1988, dropping to 64% in 1989 and 1990. ECW ratings for glyphosate indicate 73 and 52% control in 1989 and 1990, respectively.

5.1.4 Competition index (CI)

Competition index, which is based on the height and cover of pinegrass, was significantly reduced by both levels of hexazinone for 3 years following treatment, and by glyphosate for at least 2 years following treatment (Figure 4-7).

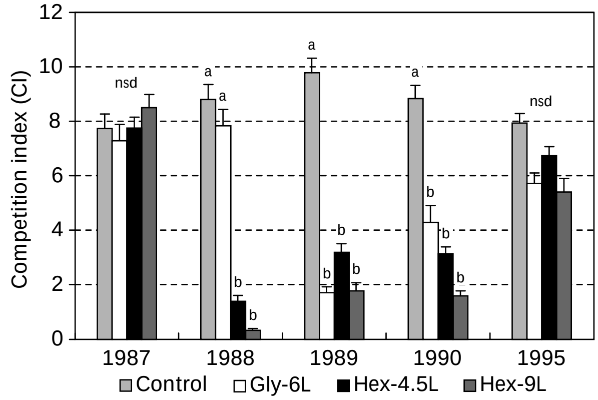

FIGURE 4-7 *Competition index 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so vegetation shows no response to that treatment in the 1988 assessment.*

5.2 Range Results

5.2.1 Forage production

Native grasses Native grass production was significantly lower in the 4.5 and 9 litres/ha hexazinone treatments (61 kg/ha and 27 kg/ha, respectively) than in the Control (243 kg/ha) in 1988, 1 year after application (Figure 4-8). It was also reduced 1 year following glyphosate application (132 kg/ha in the glyphosate treatment compared to 230 kg/ha in the Control in 1989). Production of native grasses in

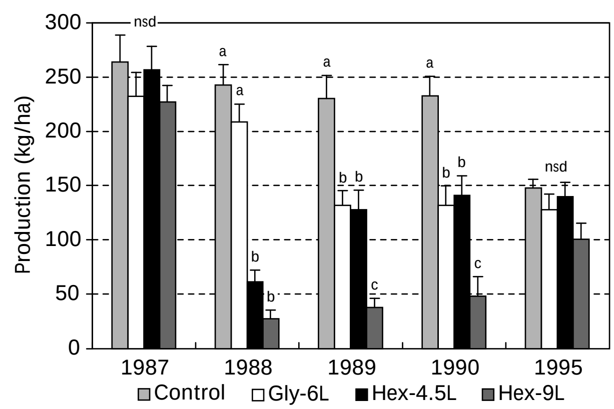

FIGURE 4-8 *Native grass production 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so native grasses show no response to that treatment in the 1988 assessment.*

the glyphosate treatment remained at approximately 130 kg/ha between 1989 and 1995, and was roughly equivalent to production in the 4.5 litres/ha hexazinone treatment. Of the three chemical brushing treatments, hexazinone at 9 litres/ha resulted in the greatest reduction in native grasses. By 1995, however, none of the chemical treatments differed significantly from the Control. Prior to treatment in 1987, native grass production in the Control was about 250 kg/ha, but by 1995, it had dropped to approximately 150 kg/ha.

Forbs Forbs were a less abundant forage component than grasses, and their production was variable (Figure 4-9). Although forb production varied significantly among treatments between 1988 and 1995, differences appeared related more to pre-treatment variability than to brushing effects.

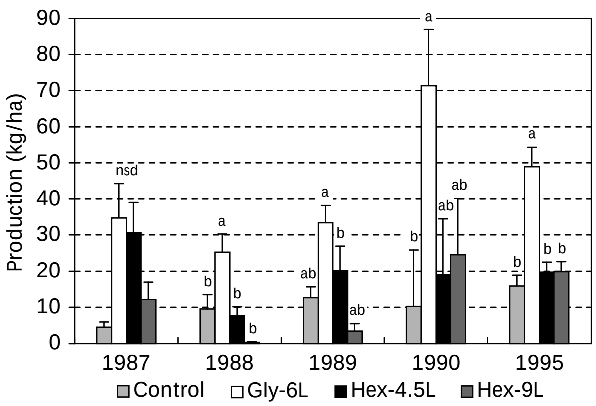

FIGURE 4-9 *Forb production 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error.*

Total forage Total forage production was significantly reduced by 70–89% for at least 3 years following treatment with hexazinone at 9 litres/ha. Hexazinone at 4.5 litres/ha significantly reduced total forage (by 73%) in 1988 only. Glyphosate had no effect on total forage production at any time during the measurement period. By 1995, all treatment effects had disappeared. However, overall production was about 40% less in 1995 than it had been in 1987, mainly because of reductions in grasses rather than forbs.

5.2.2 Non-target vegetation abundance and species richness

The cumulative mean abundance of non-target forbs and grasses immediately decreased following

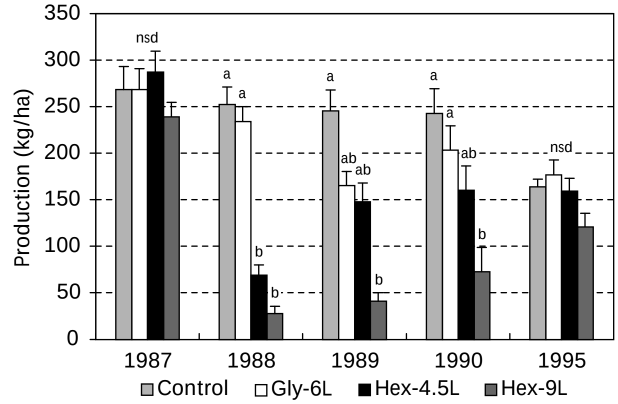

FIGURE 4-10 *Total forage production 1987–1995. nsd = no significant difference between brushing treatment means as determined by ANOVA and mean separation tests at $\alpha \leq 0.10$; histograms are means and error bars are one standard error. Note that glyphosate was not applied until fall of 1988, so forage shows no response to that treatment in the 1988 assessment.*

treatment with both levels of hexazinone, but more so as a result of the higher application rate (Table 4-3). These trends continued through 1990 in the hexazinone at 4.5 litres/ha treatment, and through 1995 in the hexazinone at 9 litres/ha treatment. The cumulative mean abundance of herbs, grasses and low shrubs was reduced for 1 year following treatment with glyphosate, after which the herbs and grasses not only recovered, but increased beyond pre-treatment levels. The cumulative mean abundance of shrubs continued to be slightly depressed in the glyphosate treatment in 1995.

The abundance of most species other than pinegrass was low on this site (Appendix 3). Abundance of sedges (*Carex* spp.) was reduced by both hexazinone and glyphosate for the duration of the trial, but none of the forbs were negatively affected. Between 1987 and 1995, the following forbs increased slightly in abundance in all treatments: yarrow (*Achillea millefolium*), fireweed (*Epilobium angustifolium*), white hawkweed (*Hieraceum albiflorum*), tiger lily (*Lilium columbianum*), twinflower, spikelike goldenrod (*Solidago spathulata*), and dandelion (*Taraxacum officinale*). The following shrubs were common through all treatments and measurement years: kinnickinnick, prickly rose, and soopolallie.

TABLE 4-3 *Cumulative (summed) mean species abundance and species richness (number of species) for forbs, grasses, low shrubs, and tall shrubs*

	Forbs		Grasses		Low shrubs		Tall shrubs		Total	
	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.	Abund.	No. spp.
1987										
Control	3.06	17	0.31	2	4.01	7	0.07	2	**7.45**	**28**
Hex-9L/ha	3.18	14	0.21	2	3.65	6	0.12	2	**7.16**	**24**
Hex-4.5L/ha	3.88	13	0.34	2	3.65	7	0.11	2	**7.98**	**24**
Gly-6L/ha	3.80	18	0.76	4	3.60	6	0.01	1	**8.17**	**29**
1988										
Control	3.41	16	0.31	2	4.06	7	0.07	2	**7.85**	**27**
Hex-9L/ha	1.75	9	0.09	1	3.15	6	0.11	2	**5.10**	**18**
Hex-4.5L/ha	2.61	15	0.21	2	3.53	7	0.11	2	**6.46**	**26**
Gly-6L/ha	4.36	21	0.88	5	3.66	7	0.04	2	**8.94**	**35**
1989										
Control	3.35	19	0.41	3	3.99	7	0.06	2	**7.81**	**31**
Hex-9L/ha	1.03	12	0.06	1	2.95	7	0.08	2	**4.12**	**22**
Hex-4.5L/ha	2.65	16	0.19	1	3.53	7	0.06	2	**6.43**	**26**
Gly-6L/ha	3.10	22	0.45	6	2.01	6	0.00	0	**5.56**	**34**
1990										
Control	3.93	16	0.43	2	4.14	7	0.07	2	**8.57**	**27**
Hex-9L/ha	1.69	14	0.13	2	3.41	7	0.10	2	**5.33**	**25**
Hex-4.5L/ha	2.94	18	0.25	2	4.04	7	0.06	2	**7.29**	**29**
Gly-6L/ha	4.79	24	1.21	7	2.11	6	0.00	0	**8.11**	**37**
1995										
Control	5.01	17	0.51	1	4.63	7	0.08	2	**10.23**	**27**
Hex-9L/ha	3.71	19	0.33	3	4.25	6	0.14	2	**8.43**	**30**
Hex-4.5L/ha	4.74	19	0.36	2	4.81	7	0.07	2	**9.98**	**30**
Gly-6L/ha	6.93	23	0.99	6	2.99	6	0.00	0	**10.91**	**35**

6 DISCUSSION

This trial was established to study the effectiveness of hexazinone at 4.5 litres/ha (1.1 kg ai/ha), hexazinone at 9 litres/ha (2.2 kg ai/ha), and glyphosate at 6 litres/ha (2.1 kg ai/ha) for release of 3-year-old lodgepole pine seedlings growing in competition with the *Pinegrass* Complex. It was also intended to address the concerns of range managers by providing information about the impacts of chemical brushing treatments on production of livestock forage. The responses of seedlings, pinegrass, and the overall vegetation community were measured over a period of 8 years.

There were no increases in lodgepole pine height, stem diameter, or stem volume as a result of treatment of the *Pinegrass* Complex with either level of hexazinone or glyphosate. In 1987, at the onset of the study, seedlings were about 35 cm tall and 1 cm in diameter, and by 1995 they averaged 250 cm tall and 5 cm in diameter. First-year height increment of pine was significantly larger in both hexazinone treatments than in the Control in 1990, and relative height growth rate was greater in the two hexazinone treatments than the Control in both 1989 and 1990. Similarly, relative stem diameter growth rate was significantly higher in both hexazinone treatments than the Control in 1989, and continued to be higher in the 9 litres/ha hexazinone treatment in 1990. However, these results indicate weak and transient responses to treatment, and never amounted to significant differences in seedling height or diameter.

All three chemical treatments reduced height and cover of pinegrass. Hexazinone at 9 litres/ha had a somewhat greater effect than hexazinone at

4.5 litres/ha or glyphosate, but differences between the three treatments were rarely significant. ECW ratings for pinegrass treated with hexazinone are comparable to those reported in the literature, but ECW ratings for pinegrass treated with glyphosate were lower than expected (Conard and Emmingham 1984). The efficacy of glyphosate may have been low in this study because of the late-August application date, and because it rained soon after application of the herbicide. Hexazinone was applied in the spring, when pinegrass was more susceptible to treatment. Nonetheless, the effect of glyphosate lasted at least 2 years, compared to at least 3 years for hexazinone. After 8 years, only the 9 litres/ha hexazinone treatment continued to have a suppressive effect on pinegrass cover.

Pinegrass was abundant (32–39% cover) and dominated the plant community (55% total vegetation cover) in 1987. At that time, the 3-year-old lodgepole pine seedlings were only 35 cm tall. Pinegrass was assumed to be competing with pine for soil water, but the lack of seedling growth response to reductions in pinegrass cover suggests that soil water may not have been the main limiting factor. Modal vegetation height prior to treatment was only about 20 cm, also ruling out competition for light as the reason for poor seedling growth. However, during early assessments it was noticed that seedlings growing on burned windrows were considerably larger than seedlings elsewhere, suggesting that nutrient availability may have been more limiting to pine seedlings than soil water availability. If this were the case, then resolving nutrient deficiencies may have allowed seedlings to respond to increases in soil water availability.

This study strongly illustrates the need to quantify conifer seedling response to brushing, so that range and wildlife values are not unnecessarily affected. Chemical brushing reduced forage production on this site, without resulting in a growth response among lodgepole pine seedlings. Pinegrass is the dominant forage species throughout the IDF zone of the southern interior of British Columbia, and, starting in May or June, it can be grazed for up to 120 days, depending on climatic conditions of the range. Pinegrass is also a valuable forage species for wildlife, particularly Rocky Mountain elk (Kufeld 1973), and large-scale reductions in its cover may have adverse effects on the availability of food throughout the year. On this site, where pinegrass was both the principal brushing target and the dominant forage species, range and silvicultural values were in direct conflict.

OVERALL CONCLUSIONS

All three of the research trials discussed in this report involve sites that were deemed suitable for operational brushing in the Kamloops Forest Region in 1986. However, a significant growth response by pine seedlings occurred only at Ellis Creek, following brushing of the *Willow* Complex. At that site, even the lightest treatment (ECW of 35%), which had no significant effect on height and cover of willow, allowed seedlings to release. The Devick Lake site had been previously brushed in 1984, and by 1986 alder had recovered to a height of 1 metre and 18% cover, which was thought to warrant a second operational brushing. None of the treatments applied in 1986 improved pine growth, however, and it was concluded that the *Dry Alder* Complex had not been sufficiently abundant to pose a competitive threat to seedlings. At Upper McKay Creek, it was concluded that pine seedlings did not respond to reductions in the abundance of pinegrass because competition for soil water had not been the primary factor limiting growth. In these three studies, the only brushing treatment that was operationally justifiable was the 4 litres/ha glyphosate treatment applied to the *Willow* Complex at Ellis Creek. Other treatments were unnecessarily severe or had no effect on seedling performance. Further, none of the treatments applied in these three studies were required for seedlings to reach free-growing. At all sites, seedlings in the untreated Control were well above surrounding vegetation within the legislated time period.

From a range perspective, cattle forage production was negatively affected by chemical brushing for 4 to 8 years at Devick Lake and Upper McKay Creek, even though no silvicultural gains resulted from brushing. The range resource was least affected at Ellis Creek, largely because forage at that site was dominated by forbs, which tended to recover more quickly from chemical brushing than either native or domestic grasses. The lack of silvicultural gain and high cost to range forage production suggest that criteria for prescribing brushing should be carefully evaluated, and that costs and benefits must be quantified.

The effects of brushing treatments on target vegetation were variable. Willow height and cover at Ellis Creek were reduced by hexazinone and manual cutting, but were unaffected by glyphosate. At Devick Lake, glyphosate reduced height and cover of Sitka alder, and at Upper McKay Creek, both hexazinone and glyphosate reduced pinegrass cover. Although brushing did not affect the number or diversity of vascular plant species on any of the sites, a few non-target species were reduced in abundance for varying amounts of time. For example, at Devick Lake the abundance of several low shrub species (black twinberry, black gooseberry, thimbleberry, trailing raspberry, red raspberry, birch-leaved spirea, and black huckleberry) was reduced for nine years following application of glyphosate. Hexazinone tended to have a longer-lasting effect than glyphosate on the abundance of grasses and forbs. Plant communities naturally change over time, but sudden shifts in structure and composition, such as are associated with brushing, may negatively affect the availability of food for wildlife. Both willow and pinegrass are important wildlife forage species, and reductions in their abundance as a result of brushing ought to be justified by quantifiable silvicultural gains.

Results from the Devick Lake and Ellis Creek studies indicate that seedlings are able to tolerate a greater abundance of "competing" vegetation than was previously suspected. Reducing alder cover from 18 to 2% at Devick Lake had no effect on seedling growth, which supports the competition threshold of 10–35% cover for Sitka alder suggested by Simard (1990). In view of the predicted contribution of alder to long-term site productivity, its presence should be reduced by the least possible amount to allow seedlings to release. At Ellis Creek, lodgepole pine seedlings responded equally well to low- and high-impact treatments, suggesting that drastic reductions in the *Willow* Complex were not required to release seedlings. For shrub and hardwood-dominated vegetation complexes, competition index (CI) may be a good measure of whether seedlings will respond to brushing. At Ellis Creek and in two other studies (Simard and Heineman 1996a, 1996c), seedlings responded to brushing when CI, which was dominated by the target shrub and hardwood species, was between 42 and 73 prior to treatment. Seedlings did not respond to treatment at Devick Lake, where CI was only 23 prior to brushing.

APPENDIX I Mean abundance of non-target vascular species in the *Dry Alder* Complex (Devick Lake Study)

	1986			1987			1988			1989			1995		
	Cont*	G3	G6	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6
Forbs															
Achillea millefolium	0	0.03	0	0	0	0	0.01	0.01	0	0.01	0.01	0	0.04	0.01	0.01
Actaea rubra	0.11	0.03	0.15	0.13	0.10	0.14	0.09	0.14	0.06	0.08	0.08	0.13	0.08	0.10	0.16
Anaphalis margaritacea	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0.03	0
Antennaria neglecta	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0
Antennaria racemosa	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0
Aquilegia formosa	0.13	0.04	0.14	0.13	0.03	0.04	0.16	0.03	0.05	0.16	0.03	0.05	0.26	0.11	0.31
Arnica cordifolia	0.54	0.39	0.35	0.59	1.04	0.73	0.78	1.14	0.93	0.78	1.13	0.93	0.90	1.28	0.91
Aster ciliolatus	0	0	0	0.01	0.01	0	0.01	0.01	0	0.01	0	0.01	0.09	0.05	0.04
Aster conspicuus	0.33	0.81	0.54	0.46	0.66	0.30	0.46	0.75	0.36	0.44	0.76	0.30	0.45	0.94	0.50
Aster foliaceus	0	0	0	0	0	0	0	0	0	0	0	0	0.64	0.75	0.66
Athyrium felix-femina	0.11	0.04	0	0.06	0.01	0	0.05	0	0	0.06	0	0	0.04	0.01	0
Botrychium lunare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03
Campanula rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01
Carex spp.	0.19	0.13	0.34	0.36	0.08	0.10	0.41	0.11	0.13	0.40	0.08	0.13	0.20	0.09	0.08
Carex concinna	0	0	0	0	0.01	0	0	0.01	0	0	0.01	0	0	0.01	0
Carex rossii	0.01	0	0.01	0	0	0.01	0	0	0.03	0	0	0.04	0	0	0
Cerastium arvense	0.18	0	0.11	0.24	0.15	0.26	0.24	0.38	0.53	0.25	0.36	0.51	0.19	0.09	0.15
Chimaphila umbellata	0	0.03	0.03	0.01	0.03	0	0.01	0.01	0	0.01	0.01	0	0.01	0.01	0
Cirsium spp.	0	0	0.01	0	0	0.03	0	0	0.06	0	0	0.06	0	0	0.04
Cirsium arvense	0.13	0.01	0.05	0.15	0.01	0.08	0.13	0.14	0.24	0.09	0.18	0.30	0	0.04	0.05
Clintonia uniflora	0.25	0.08	0.09	0.20	0.04	0.03	0.20	0.06	0.04	0.18	0.04	0.03	0.28	0.09	0.10
Cornus canadensis	1.48	1.65	1.61	1.58	1.88	1.81	1.55	1.89	1.84	1.54	2.10	1.40	1.78	2.23	2.14
Disporum hookeri	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01	0.01	0
Dryopteris assimilis	0.18	0.03	0.03	0.15	0	0	0.14	0	0	0.13	0	0	0.05	0	0.01
Epilobium glandulosum	0	0.03	0	0.03	0.25	0.59	0.01	0.38	0.84	0.04	0.35	0.85	0.06	0.09	0.13
Equisetum arvense	0.86	0.56	0.93	0.96	0.94	1.23	1.00	0.70	1.26	1.01	1.00	1.33	0.65	0.68	0.68
Erigeron speciosus	1.78	1.09	2.01	1.83	0.76	1.15	1.81	0.93	1.30	1.79	0.98	1.28	0.85	0.41	0.64
Erodium cicutarium	0.01	0	0	0	0	0.01	0	0.03	0.05	0	0	0.03	0	0	0
Fragaria virginiana	1.95	0.93	1.48	2.10	0.93	1.06	2.13	1.15	1.25	2.01	1.15	1.24	1.88	1.40	1.58
Galium boreale	0.05	0.01	0.03	0.01	0	0.03	0.01	0	0.03	0.01	0	0.03	0	0	0.01
Galium triflorum	0.38	0.29	0.49	0.60	0.59	0.63	0.65	0.71	0.84	0.69	0.71	0.86	0.81	0.69	0.71
Gentian spp.	0.03	0.01	0	0.03	0.01	0.01	0	0.01	0.01	0	0.01	0.01	0.01	0.01	0
Gentianella amarella	0	0	0	0	0	0	0	0.03	0	0	0.04	0.04	0.03	0.06	0.09
Geum macrophyllum	0.26	0.13	0.11	0.16	0.03	0.06	0.19	0.20	0.30	0.14	0.19	0.38	0.20	0.23	0.38
Geum triflorum	0.04	0	0	0	0	0	0	0	0	0.03	0	0	0.01	0.01	0
Goodyera oblongifolia	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.03	0.03
Gymnocarpium dryopteris	0.04	0.05	0	0.08	0.01	0	0.09	0.03	0	0.08	0.03	0	0.05	0.05	0
Heracleum sphondylium	0	0	0	0	0	0.05	0	0.01	0.10	0	0	0.01	0	0	0.10
Hieracium spp.	0.16	0.35	0.33	0.28	0.34	0.45	0.33	0.41	0.45	0.31	0.44	0.51	0	0	0
Hieracium albiflorum	0.09	0.51	0.18	0.30	0.53	0.23	0.31	0.64	0.28	0.31	0.61	0.28	0.65	1.01	0.71
Hieracium canadense	0	0	0.01	0	0	0	0	0	0.01	0	0	0.01	0	0	0
Lathyrus nevadensis	0	0	0	0.03	0	0	0.05	0	0	0.05	0	0	0.01	0	0
Lathyrus ochroleucus	0	0	0	0.08	0.03	0	0.03	0.03	0	0.04	0.03	0	0.03	0.01	0
Lilium columbianum	0.08	0.34	0.16	0.11	0.49	0.19	0.10	0.44	0.20	0.09	0.43	0.18	0.04	0.04	0.05
Linnaea borealis	0.25	0.94	0.73	0.30	0.90	0.70	0.33	1.00	0.88	0.33	0.99	0.84	0.46	1.44	1.35
Lupinus arcticus	1.00	1.75	1.90	1.14	1.03	0.93	1.10	1.09	0.96	1.10	1.15	0.95	0.85	1.46	1.40
Luzula parviflorus	0.28	0.14	0.21	0.40	0.04	0.05	0.43	0.04	0.06	0.46	0.09	0.11	0.33	0.13	0.08
Lycopodium annotinum	0.06	0.08	0.13	0.05	0.10	0.13	0.04	0.10	0.11	0.06	0.10	0.11	0.06	0.06	0.09
Melilotus spp.	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
Mimulus spp.	0	0.01	0	0	0	0	0	0	0	0	0	0.01	0	0	0
Mitella spp.	0	0.01	0.03	0.11	0	0.05	0.10	0	0.05	0.10	0	0.05	0.14	0.01	0.13
Mitella nuda	0	0	0.03	0	0	0	0	0	0	0.01	0	0	0.14	0	0.09
Montia spp.	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0

	1986			1987			1988			1989			1995		
	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6
Forbs (continued)															
Orthilia secunda	0.04	0.08	0.06	0.05	0.16	0.13	0.10	0.19	0.15	0.11	0.26	0.23	0.35	0.44	0.36
Orthilia spp.	0	0	0	0.01	0	0	0	0	0	0.01	0	0	0	0	0
Osmorhiza chilensis	0.29	0.21	0.13	0.41	0.35	0.45	0.45	0.53	0.56	1.08	0.63	0.69	0.70	0.80	0.73
Parnassia fimbriata	0.03	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
Pedicularis bracteosa	0	0.01	0.01	0.01	0	0	0.03	0	0	0.03	0	0	0.01	0.01	0
Petasites palmatus	1.14	0.76	1.50	1.16	0.88	1.26	1.18	0.85	1.29	1.53	0.84	1.24	0.95	0.84	1.04
Pyrola spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0
Pyrola asarifolia	0.04	0.03	0.01	0.05	0.03	0.01	0.05	0.03	0.01	0.06	0.03	0.01	0.10	0.03	0.03
Ranunculus uncinatus	0	0.01	0.03	0.01	0.14	0.35	0.01	0.19	0.63	0.01	0.19	0.38	0.13	0.18	0.21
Rhinanthus crista-galli	0	0	0	0	0	0	0.01	0	0	0.04	0	0	0	0	0
Rubus pedatus	0.31	0.19	0.49	0.36	0.06	0.23	0.35	0.14	0.23	0.35	0.18	0.24	0.41	0.33	0.41
Senecio pseudaureus	0.93	0.16	0.58	1.01	0.15	0.38	1.11	0.21	0.55	1.10	0.28	0.66	1.10	0.31	0.84
Smilacina racemosa	0.04	0.05	0.08	0.06	0.14	0.16	0.05	0.15	0.13	0.11	0.18	0.16	0.14	0.26	0.11
Smilacina stellata	0.08	0.01	0.04	0.14	0.03	0.03	0.04	0	0	0.05	0.01	0	0.04	0	0
Streptopus amplexifolius	0.34	0.16	0.23	0.33	0.20	0.23	0.15	0.15	0.20	0.28	0.19	0.23	0.10	0.11	0.13
Streptopus roseus	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0
Taraxacum officinale	0.33	0.20	0.09	0.44	0.43	0.48	0.46	0.49	0.56	0.49	0.51	0.50	0.50	0.46	0.49
Thalictrum occidentale	0.33	0.16	0.20	0.34	0.14	0.21	0.33	0.21	0.26	0.33	0.25	0.31	0.46	0.36	0.35
Tiarella unifoliata	0.20	0.11	0.05	0.30	0.10	0.03	0.29	0.14	0.03	0.31	0.16	0.01	0.43	0.31	0.09
Tragopogon dubius	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0
Trifolium spp.	0	0	0	0.01	0.01	0	0	0.01	0	0.03	0.04	0	0.05	0.01	0.03
Trifolium arvense	0.10	0.03	0.03	0.23	0.03	0.05	0.16	0.04	0.04	0.18	0.04	0.04	0.05	0.04	0.01
Urtica dioica	0	0	0	0.01	0.01	0	0	0.01	0.01	0	0.06	0.01	0	0.04	0
Valeriana sitchensis	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Veratrum viride	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Veronica spp.	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Vicea americana	0.05	0	0.01	0.04	0	0.03	0.04	0	0.03	0.04	0	0.03	0.01	0	0.04
Viola spp.	0.04	0	0	0.03	0	0.03	0.04	0	0.03	0.04	0	0.01	0.28	0.18	0.25
Grasses															
Agrostis spp.	0.59	0.48	0.53	0.70	0.29	0.21	0.48	0.36	0.28	0.50	0.41	0.33	0.26	0.18	0.15
Agrostis crispa	0	0	0	0.01	0	0	0.01	0	0	0	0	0	0	0	0
Agrostis scabra	0	0.03	0	0.01	0	0	0.01	0	0	0	0	0	0	0	0
Bromus spp.	0.03	0.11	0.21	0.08	0.05	0.09	0.06	0.10	0.16	0.04	0.05	0.26	0	0.04	0.23
Bromus inermis	0.20	0.01	0.05	0.28	0.03	0.04	0.25	0.03	0.04	0.23	0.10	0.08	0.28	0.30	0.05
Bromus vulgaris	0.41	0.35	0.20	0.48	0.25	0.14	0.45	0.35	0.24	0.54	0.34	0.25	0.53	0.35	0.43
Calamagrostis canadensis	1.31	0.56	0.55	1.38	0.36	0.41	1.26	0.49	0.53	1.38	0.61	0.53	1.51	0.86	0.89
Calamagrostis rubescens	0.71	0.79	0.83	0.48	0.25	0.29	0.48	0.18	0.26	0.28	0.18	0.26	0.38	0.35	0.40
Cinna latifolia	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0.15	0.20
Dactylis glomerata	0.33	0.53	0.45	0.41	0.48	0.34	0.40	0.53	0.40	0.36	0.51	0.44	0.39	0.33	0.26
Elymus glaucus	0.33	0.16	0.28	0.43	0.08	0.09	0.56	0.23	0.29	0.61	0.33	0.36	0.34	0.40	0.44
Festuca spp.	0.04	0	0.01	0.04	0	0	0.01	0	0	0.01	0	0	0.05	0.05	0.03
Festuca idahoensis	0.03	0.05	0	0.09	0.16	0.04	0.10	0.23	0.05	0.10	0.28	0.06	0.10	0.14	0.01
Festuca occidentalis	0.65	0.48	0.58	0.85	0.54	0.55	0.75	0.64	0.59	0.76	0.65	0.64	0.81	0.86	0.74
Festuca ovina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca saximontana	0	0	0	0.01	0.08	0.11	0.04	0.20	0.19	0.05	0.20	0.21	0.01	0.15	0.13
Grass spp.	0	0	0	0	0.04	0.01	0	0.01	0.03	0	0	0	0	0	0
Koeleria macrantha	0	0	0	0	0.03	0.01	0	0.06	0.08	0	0	0	0	0	0
Phleum pratense	0.73	0.68	0.40	0.94	0.15	0.28	0.96	0.50	0.33	0.91	0.54	0.33	0.78	0.49	0.29
Poa spp.	0	0.13	0	0	0	0	0	0	0	0	0	0	0	0	0
Poa pratensis	0.40	0.18	0.11	0.41	0.11	0.01	0.48	0.04	0.03	0.51	0.08	0.09	0.36	0.04	0.10
Schizachne purpurascens	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Trisetum spicatum	0.10	0	0	0.19	0.01	0.01	0.56	0.46	0.55	0.66	0.76	0.89	0.36	0.24	0.38

APPENDIX I *Concluded.*

	1986			1987			1988			1989			1995		
	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6	Cont	G3	G6
Low shrubs															
Amelanchier alnifolia	0.01	0	0	0.01	0	0	0.01	0	0	0	0	0	0	0	0
Arctostaphylos uva-ursi	0	0	0	0.01	0	0	0.01	0	0	0.01	0	0	0	0	0
Lonicera involucrata	0.80	0.80	0.98	0.74	0.11	0.03	0.75	0.14	0.05	0.78	0.13	0.05	1.18	0.35	0.48
Ribes lacustre	1.74	1.33	1.51	1.75	0.61	0.50	1.70	0.64	0.56	1.63	0.65	0.63	1.74	0.89	0.93
Rosa spp.	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0
Rosa acicularis	0.15	0.09	0.14	0.19	0.05	0.08	0.19	0.05	0.10	0.19	0.04	0.13	0.18	0.09	0.23
Rosa nutkana	0	0	0.04	0	0	0	0	0	0	0	0.03	0	0	0.06	0
Rubus idaeus	1.41	1.05	1.26	1.40	0.38	0.20	1.34	0.49	0.26	1.30	0.53	0.26	0.83	0.54	0.43
Rubus parviflorus	0.55	0.19	0.56	0.61	0.06	0.20	0.61	0.06	0.29	0.59	0.06	0.30	0.55	0.20	0.29
Rubus pubescens	0.86	0.21	0.40	1.01	0.14	0.56	1.03	0.30	0.83	1.01	0.36	0.84	1.15	0.54	0.91
Shepherdia canadensis	0.05	0.09	0.08	0.05	0.06	0.01	0.04	0.06	0.01	0.04	0.06	0.01	0.01	0.08	0.01
Spiraea betulifolia	0.90	1.08	0.69	1.01	0.10	0.05	1.05	0.16	0.10	1.05	0.20	0.11	1.15	0.39	0.29
Vaccinium caespitosum	0.10	0	0.04	0.11	0.04	0.01	0.10	0.01	0.01	0.13	0.01	0.03	0.06	0.03	0.05
Vaccinium membranaceum	0.38	0.53	0.60	0.45	0.33	0.14	0.46	0.40	0.18	0.50	0.45	0.18	0.54	0.41	0.28
Vaccinium myrtilloides	0	0	0	0	0.01	0	0	0.01	0.01	0	0	0.01	0	0	0
Vaccinium scoparium	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0.01
Viburnum edule	0.04	0.05	0.08	0.03	0	0.03	0.03	0	0.04	0.05	0.01	0.04	0.06	0.06	0.08
Tall shrubs															
Populus balsamifera	0.05	0.08	0.05	0.04	0.06	0	0.04	0.05	0	0.03	0.04	0	0	0.04	0
Populus tremuloides	0.08	0.04	0.18	0.10	0.03	0.01	0.09	0	0.01	0.08	0	0.01	0.05	0.01	0.01
Salix spp.	0.19	0.08	0.18	0.21	0.06	0.04	0.25	0.04	0.04	0.24	0.06	0.04	0.14	0.05	0.03
Sambucus racemosa	0.24	0.19	0.09	0.25	0.09	0.06	0.21	0.15	0.10	0.26	0.23	0.11	0.20	0.25	0.08
Sorbus scopulina	0.05	0	0	0.06	0	0	0.03	0	0	0.03	0	0	0	0	0
Sorbus sitchensis	0.05	0.04	0.05	0.04	0	0	0.04	0.01	0.03	0.06	0.01	0.01	0.21	0.04	0.03
Conifers															
Abies lasiocarpa	0.45	0.68	0.71	0.49	0.78	0.69	0.49	0.79	0.71	0.48	0.84	0.66	0.79	1.33	0.89
Picea engelmannii	0.31	0.38	0.38	0.38	0.40	0.40	0.40	0.44	0.44	0.41	0.45	0.43	0.81	0.74	0.66
Pseudotsuga menziesii	0	0.03	0.01	0	0.04	0.03	0	0.04	0.01	0	0.04	0.01	0	0.04	0

* Cont = control, G3 = Glyphosate applied at 3L/ha, G6 = Glyphosate applied at 6L/ha.

APPENDIX 2 Mean abundance of non-target vascular species in the *Willow* Complex (Ellis Creek Study)

	1986				1987				1988				1989				1995			
	Cont*	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut
Forbs																				
Achillea millefolium	0.04	0.03	0.03	0.08	0.06	0.1	0.04	0.18	0.08	0.16	0.09	0.34	0.09	0.19	0.11	0.39	0.14	0.46	0.28	0.68
Adenocaulon bicolor	0	0.01	0.01	0	0	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
Anaphalis margaritacea	0.13	0.15	0.1	0.1	0.19	0.09	0.03	0.11	0.21	0.23	0.1	0.19	0.21	0.28	0.19	0.21	0.25	0.55	0.44	0.75
Antennaria spp.	0	0	0	0	0.01	0.01	0.01	0	0.01	0.01	0.03	0.01	0.03	0.01	0.04	0.01	0.28	0.64	0.39	0.31
Antennaria microphylla	0	0	0	0.01	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0.03	0.1	0.06	0.15
Antennaria umbrinella	0.03	0.05	0.01	0.04	0.08	0.08	0.01	0.03	0.1	0.16	0.04	0.04	0.1	0.28	0.05	0.06	0.08	0.21	0.04	0.2
Aquilegia formosa	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0
Arabis spp.	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
Arenaria serpyllifolia	0.01	0	0.01	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0	0
Arnica cordifolia	0.64	0.26	0.34	0.48	0.6	0.24	0.16	0.46	1.11	0.25	0.28	0.5	0.6	0.23	0.31	0.45	0.34	0.29	0.26	0.59
Aster conspicuus	0.26	0.03	0.03	0.09	0.25	0.01	0	0.09	0.28	0.01	0	0.11	0.21	0.01	0	0.11	0.24	0.09	0.03	0.08
Aster foliaceus	0.33	0.03	0.05	0.39	0.39	0.09	0.15	0.59	0.39	0.79	0.23	0.39	0.43	0.29	0.26	0.79	0.94	1.16	0.73	1.31
Carex spp.	0.54	0.21	0.16	0.25	0.59	0.18	0.1	0.31	0.59	0.16	0.13	0.35	0.63	0.24	0.14	0.35	0.48	0.19	0.2	0.51
Carex concinna	0	0.05	0.01	0.24	0	0.03	0.05	0.28	0	0.03	0.05	0.3	0	0.03	0.05	0.33	0	0.04	0.05	0.36
Castilleja miniata	0.24	0.08	0.08	0.01	0.4	0.08	0.09	0.13	0.74	0.34	0.16	0.29	0.9	0.4	0.2	0.39	1.53	1.44	0.83	0.98
Chimaphila umbellata	0.06	0	0	0	0.03	0	0	0	0.03	0	0	0	0.03	0	0	0	0.01	0	0	0.01
Cirsium spp.	0.01	0	0.01	0	0.05	0.04	0.03	0.2	0.05	0.09	0.1	0.26	0.06	0.08	0.13	0.26	0.03	0	0	0.01
Cirsium arvense	0.11	0.3	0.09	0.01	0.13	0.19	0.06	0.03	0.1	0.2	0.08	0.03	0.1	0.23	0.1	0.04	0.03	0	0.03	0
Cornus canadensis	0.56	0.5	0.54	0.73	0.78	0.95	1.08	0.9	0.8	0.99	1.14	0.93	0.85	0.89	1.13	0.9	0.93	1.13	1.28	1.23
Epilobium angustifolium	0.76	0.91	0.7	0.96	0.93	1	0.98	1.08	0.95	1	0.95	1.16	0.95	0.96	1.14	1.16	0.63	0.91	0.85	0.99
Epilobium glandulosum	0	0	0	0	0.04	0.45	0.25	0.01	0.04	0.38	0.89	0	0.03	0.06	0.63	0.03	0	0.01	0.25	0.03
Equisetum arvense	0.3	0.4	0.18	0.01	0.3	0.35	0.05	0.01	0.29	0.35	0.21	0.01	0.26	0.3	0.19	0.01	0.04	0.18	0.1	0.01
Equisetum sylvaticum	0.26	0	0	0.61	0.23	0	0	0.6	0.24	0	0	0.6	0.2	0	0	0.58	0.18	0.01	0.01	0.58
Erigeron spp.	0.04	0.04	0	0.01	0.16	0.03	0.04	0.05	0.16	0.06	0.06	0.06	0.1	0.06	0.06	0.08	0.04	0	0	0
Erigeron speciosus	0.14	0.14	0	0.03	0.16	0.2	0.03	0.06	0.2	0.26	0.03	0.06	0.25	0.25	0.04	0.08	0	0	0	0
Erodium cicutarium	0	0	0	0	0.05	0.56	0.33	0.08	0.06	0.43	0.59	0.09	0.01	0.04	0.28	0	0	0.03	0.01	0
Fragaria virginiana	0.2	0.11	0.13	0.3	0.28	0.23	0.11	0.46	0.3	0.38	0.16	0.58	0.35	0.49	0.23	0.73	0.96	1.33	1.03	2.08
Galium trifidum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0.01	0	0
Galium triflorum	0.11	0	0.01	0	0.09	0	0	0	0.06	0.01	0.01	0	0.08	0.01	0.01	0	0.03	0.01	0.04	0
Gentian spp.	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0
Geum macrophyllum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01
Haplopappus lyallii	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hieracium spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01
Hieracium albiflorum	0.15	0.19	0.19	0.13	0.23	0.39	0.19	0.31	0.35	0.55	0.54	0.46	0.36	0.73	0.66	0.61	0.65	0.89	1.01	0.84
Hieracium canadense	0.08	0.13	0.05	0.08	0.06	0.03	0	0.04	0.04	0	0.01	0	0.03	0	0	0	0.03	0.01	0	0.01
Juncus spp.	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0.04
Lilium columbianum	0.08	0.03	0.11	0.03	0.04	0.03	0.01	0.05	0.1	0.01	0.01	0.06	0.06	0.01	0.01	0.03	0.06	0.01	0.03	0.13

APPENDIX 2 *Continued*

	1986				1987				1988				1989				1995			
	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut
Forbs (continued)																				
Linnaea borealis	0.23	0.15	0.13	0.3	0.31	0.2	0.15	0.33	0.33	0.23	0.15	0.39	0.33	0.25	0.19	0.41	0.28	0.36	0.16	0.59
Lupinus arcticus	0.95	0.36	0.48	0.71	1.41	0.31	0.3	0.95	1.39	0.39	0.58	1.11	1.35	0.45	0.75	1.26	0.83	0.31	0.46	1.13
Melampyron lineare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.48	0.26	0.6
Orthilia spp.	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0
Orthilia secunda	0.15	0.04	0.05	0.04	0.15	0.09	0.04	0.05	0.19	0.14	0.04	0.06	0.25	0.19	0.04	0.06	0.54	0.43	0.19	0.21
Osmorhiza chilensis	0.04	0	0	0	0.01	0	0	0	0.13	0	0	0	0.01	0	0	0	0.01	0	0	0
Pedicularis spp.	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petasites palmatus	0	0	0.03	0.1	0.01	0	0.04	0.03	0.01	0.06	0.03	0.05	0.03	0.09	0.03	0.08	0.11	0.2	0.06	0.28
Platanthera dilata	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0.09	0.09	0.04	0.04
Pyrola asarifolia	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0	0.05	0.03	0	0.03
Pyrola minor	0	0	0	0	0.01	0.03	0	0	0.01	0.03	0	0	0.01	0.04	0	0	0	0.15	0.01	0
Ranunculus spp.	0	0.01	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0.01	0	0
Rumex acetosella	0.05	0.04	0.03	0.03	0	0	0	0	0	0	0.03	0	0	0	0.03	0	0	0	0	0
Senecio spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0.03	0.01	0.43
Senecio pseudaureus	0.11	0	0	0.14	0.13	0	0	0.18	0.13	0.01	0	0.21	0.1	0.01	0.01	0.25	0	0	0	0
Senecio triangularis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0.01	0.03
Sibbaldia procumbens	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0
Spiranthes romanzoffiana	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0
Stellaria calycantha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
Taraxacum officinale	0.2	0.14	0.15	0.29	0.3	0.41	0.44	0.49	0.31	0.5	0.63	0.58	0.35	0.56	0.63	0.63	0.19	0.56	0.39	0.63
Tragopogon dubius	0	0	0	0.04	0	0	0	0.04	0	0	0	0.04	0	0	0	0.01	0	0	0	0
Trifolium spp.	0.04	0	0	0	0.13	0.14	0.06	0.06	0.15	0.14	0.1	0.1	0.1	0.13	0.11	0.11	0.04	0.06	0.05	0.08
Trifolium arvense	0	0	0.28	0.03	0.01	0	0.05	0.03	0.01	0	0.16	0.03	0	0	0.29	0.06	0.01	0	0.15	0.03
Trifolium repens	2.06	2.16	1.65	1.68	2.09	2.08	1.23	1.83	1.93	2.15	1.39	1.9	1.74	2.1	1.25	1.8	0.93	0.85	0.44	1.1
Viola spp.	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vulpia octoflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0
Grasses																				
Agrostis scabra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.21	0.31	0.28
Aira spp.	0.13	0.09	0.04	0.03	0.25	0.18	0.03	0.21	0.38	0.63	0.33	0.61	0.46	0.73	0.39	0.65	0.24	0.36	0.3	0.46
Bromus spp.	0	0.04	0.01	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
Calamagrostis canadensis	0.04	0.08	0.2	0.06	0.06	0.04	0.03	0.05	0.06	0.04	0.05	0.04	0.08	0.05	0.05	0.04	0.18	0.06	0.29	0.15
Calamagrostis purpurascens	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calamagrostis rubescens	0.91	1.03	0.64	1.03	0.88	0.64	0.13	1.09	0.98	0.75	0.23	1.11	0.88	0.81	0.23	1.11	0.99	1.41	0.46	1.83
Dactylis glomerata	1.55	1.41	1.2	0.48	1.51	1.46	0.83	0.94	1.28	1.38	0.95	1.1	1.31	1.46	0.99	1.23	1.13	1.05	0.74	1.16
Elymus glaucus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.03
Festuca spp.	0	0.05	0	0	0.03	0.01	0	0.01	0.01	0.03	0	0.01	0.04	0.03	0	0.01	0.1	0.04	0.06	0.06
Festuca idahoensis	0	0.03	0	0.01	0.01	0.06	0	0.03	0	0.09	0	0.04	0	0.09	0	0.05	0	0.06	0	0.09

APPENDIX 2 *Concluded.*

	1986				1987				1988				1989				1995			
	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut	Cont	Gly	Hex	Cut
Grasses (continued)																				
Festuca ovina	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01
Festuca rubra	0	0	0	0	0	0	0	0	0	0.01	0	0.01	0	0	0	0.01	0	0	0	0.01
Festuca saximontana	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0.01	0.03	0	0	0	0.01	0
Grass spp.	0.09	0.03	0.01	0.04	0.09	0.01	0	0.05	0.08	0.03	0.09	0.05	0.05	0.04	0.06	0.05	0.1	0.06	0.06	0.09
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01
Poa spp.	0	0	0	0	0.01	0	0	0.08	0.01	0	0	0.09	0.01	0	0	0.08	0	0	0	0.08
Trisetum spp.	0.03	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01	0	0	0	0	0	0
Trisetum spicatum	0	0	0	0.01	0	0	0	0	0	0	0.01	0	0	0.01	0.01	0.04	0	0.01	0.01	0.01
Low shrubs																				
Arctostaphylos uva-ursi	0.04	0.04	0.1	0.01	0.05	0.05	0.08	0.15	0.08	0.08	0.14	0.19	0.09	0.08	0.14	0.28	0.33	0.35	0.28	0.79
Juniperus communis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03
Ledum glandulosum	0.08	0.23	0.39	0.39	0.08	0.2	0.35	0.4	0.08	0.19	0.36	0.4	0.08	0.19	0.48	0.4	0.13	0.41	0.6	0.91
Ledum groenlandicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01
Rosa acicularis	0.3	0.09	0.11	0.24	0.31	0.11	0.1	0.26	0.35	0.11	0.09	0.26	0.35	0.09	0.09	0.28	0.33	0.14	0.09	0.31
Rubus idaeus	0	0	0	0.01	0	0	0.01	0.01	0	0	0.01	0.01	0	0	0.01	0.01	0.01	0	0	0.01
Rubus parviflorus	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0
Shepherdia canadensis	0.46	0.01	0.03	0.14	0.49	0.01	0.03	0.16	0.49	0.01	0.03	0.18	0.45	0.01	0.04	0.18	0.28	0.01	0.03	0.16
Spiraea betulifolia	0.05	0.2	0.08	0.23	0.04	0.03	0.01	0.21	0.04	0.04	0.01	0.21	0.04	0.06	0.01	0.2	0.05	0.09	0.01	0.26
Symphoricarpos albus	0.09	0.06	0.19	0.11	0.11	0.03	0.08	0.15	0.1	0.06	0.08	0.14	0.09	0.06	0.09	0.14	0.09	0.06	0.11	0.19
Vaccinium caespitosum	0.9	0.48	0.49	0.74	1.1	0.38	0.61	0.93	1.1	0.5	0.79	0.99	1.14	0.63	0.88	1.01	1.26	0.96	1.26	1.69
Vaccinium membranaceum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0
Vaccinium myrtilloides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0.1	0.05
Vaccinium ovalifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0
Vaccinium scoparium	0.76	0.5	0.7	0.6	0.84	0.28	0.73	0.6	0.88	0.4	0.94	0.7	0.93	0.48	1.16	0.78	1.1	0.71	1.5	1.08
Tall shrubs																				
Alnus incana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0
Alnus viride	0.76	1.08	1.06	0.8	0.78	0.58	1.01	0.55	0.83	0.73	1.05	0.46	0.81	0.76	1.15	0.45	1.91	1.98	2.38	1.29
Betula papyrifera	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0.01	0	0.01	0.04
Populus balsamifera	0.01	0.18	0.19	0.03	0.06	0.01	0	0.05	0.11	0.01	0.03	0.13	0.14	0.01	0	0.14	0.1	0.01	0	0.14
Populus tremuloides	0.01	0.03	0	0.06	0.01	0.03	0.03	0.05	0.01	0.03	0.03	0.06	0.01	0.05	0.03	0.06	0	0.03	0.05	0.08
Prunus vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0
Salix spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0
Conifers																				
Abies lasiocarpa	0	0.03	0	0	0	0.03	0.01	0	0	0.03	0.03	0	0	0.03	0.04	0	0.03	0.06	0.05	0.01
Larix occidentalis	0	0.01	0.03	0	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0	0.04	0.04	0.01
Picea engelmannii	0.01	0	0	0	0.01	0.01	0.03	0	0.03	0.03	0.03	0	0.04	0.05	0.04	0.01	0.14	0.19	0.24	0.15
Picea glauca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03	0	0.01

* Cont = Control, Gly = Glyphosate applied at 4L/ha, Hex = Hexazinone applied at 10L/ha, Cut = manual cutting.

APPENDIX 3 Mean abundance of non-target vascular species in the *Pinegrass* Complex (Upper McKay Creek Study)

	1987				1988				1989				1990				1995			
	Cont*	HH	HL	Gly	Cont*	HH	HL	Gly	Cont	HH	HL	Gly	Cont	HH	HL	Gly	Cont	HH	HL	Gly
Forbs																				
Achillea millefolium	0.03	0.03	0.20	0.09	0.04	0	0.10	0.10	0.01	0	0.10	0.25	0.05	0.03	0.14	0.51	0.30	0.28	0.35	0.59
Agoseris glauca	0	0	0	0.01	0	0	0	0.03	0	0	0	0.03	0	0	0.04	0.03	0.01	0	0.05	0.04
Anaphalis margaritacea	0.03	0	0.09	0.05	0.03	0	0.03	0.08	0.01	0	0.08	0.09	0.03	0	0.08	0.08	0	0	0	0
Antennaria spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0.10	0.21
Antennaria microphylla	0.01	0	0	0.01	0.01	0	0	0.01	0.01	0	0	0	0.01	0	0	0.04	0.14	0.01	0.04	0.39
Antennaria neglecta	0.09	0.10	0.16	0.24	0.09	0.03	0.05	0.24	0.09	0.01	0.13	0.18	0.09	0.01	0.09	0.23	0.15	0.05	0.11	0.25
Antennaria umbrinella	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0.01	0	0	0	0
Arabis spp.	0	0	0	0.03	0	0	0	0.03	0	0	0	0.08	0	0.01	0.01	0.16	0	0.01	0	0.15
Arnica spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.01	0.03
Arnica cordifolia	0	0.01	0	0	0	0	0.01	0.01	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0.03	0.05	0.18	0.13
Arnica mollis	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0.05	0	0	0.03	0	0	0	0.01	0
Aster conspicuus	0.21	0.30	0.39	0.19	0.26	0.28	0.41	0.20	0.21	0.16	0.36	0.05	0.26	0.31	0.48	0.15	0.23	0.30	0.48	0.21
Astragalus miser	0	0	0	0.14	0	0	0	0.15	0	0	0	0.11	0	0	0	0.16	0	0	0	0.11
Carex spp.	1.24	1.29	1.24	1.33	1.24	0.63	0.73	1.34	1.29	0.16	0.46	0.26	1.24	0.14	0.24	0.09	1.01	0.43	0.39	0.33
Cirsium spp.	0.04	0.01	0	0.03	0.03	0	0	0.03	0.01	0	0	0.01	0.01	0	0	0.09	0	0	0	0
Cirsium arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0	0	0
Epilobium angustifolium	0.04	0.08	0.03	0.06	0.06	0.09	0.03	0.09	0.04	0.04	0.05	0.06	0.06	0.11	0.08	0.21	0.06	0.21	0.14	0.38
Epilobium glandulosum	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0
Fragaria virginiana	0.39	0.46	0.53	0.53	0.45	0.14	0.33	0.60	0.40	0.11	0.29	0.36	0.49	0.11	0.29	0.50	0.53	0.16	0.35	0.65
Gentianella amarella	0.08	0.11	0.05	0.09	0.06	0	0	0.11	0.16	0.09	0.03	0.08	0.24	0.08	0.05	0.38	0.20	0.08	0.10	0.34
Hieracium albiflorum	0.06	0.10	0.20	0.29	0.09	0.06	0.10	0.34	0.10	0.03	0.06	0.23	0.19	0.06	0.08	0.29	0.29	0.40	0.40	0.41
Hieracium canadense	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
Lilium columbianum	0.03	0.01	0	0	0.11	0	0.01	0.05	0.09	0.06	0.11	0.16	0.24	0.25	0.29	0.23	0.29	0.29	0.39	0.35
Linnaea borealis	0.61	0.43	0.48	0.33	0.66	0.29	0.35	0.36	0.61	0.19	0.48	0.40	0.68	0.28	0.41	0.60	1.09	0.63	0.93	1.03
Orthilia secunda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
Polemonium spp.	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0.01	0	0	0	0
Polemonium micranthum	0	0	0	0.04	0	0	0	0.04	0	0	0	0.03	0	0	0	0.03	0	0	0	0.05
Potentilla spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
Pyrola chlorantha	0.01	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.01	0.04	0	0
Sedum lanceolatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
Solidago spathulata	0.11	0.19	0.40	0.26	0.16	0.13	0.34	0.39	0.18	0.08	0.34	0.24	0.24	0.13	0.39	0.46	0.54	0.41	0.50	0.79
Sonchus arvensis	0.01	0	0	0	0.03	0	0	0	0.01	0	0	0	0.03	0	0	0	0	0	0	0
Taraxacum officinale	0.09	0.06	0.11	0.11	0.10	0.13	0.11	0.18	0.09	0.09	0.13	0.41	0.09	0.16	0.20	0.49	0.14	0.24	0.16	0.48
Tragopogon dubius	0	0	0	0	0	0	0	0	0.01	0	0.03	0	0	0	0.06	0.01	0.01	0.04	0.06	0
Grasses																				
Agrostis scabra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.19	0	0.03	0	0.13
Aira spp.	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0
Elymus glaucus	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.01	0	0	0	0.01

APPENDIX 3 *Concluded.*

	1987				1988				1989				1990				1995			
	Cont	HH	HL	Gly	Cont	HH	HL	Gly	Cont	HH	HL	Gly	Cont	HH	HL	Gly	Cont	HH	HL	Gly
Grasses (continued)																				
Festuca spp.	0.01	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0	0	0.01	0	0	0	0
Grass spp.	0	0	0.01	0.09	0	0	0	0.10	0	0	0	0.08	0	0	0	0.26	0	0	0	0.05
Koeleria macrantha	0	0.04	0	0.16	0.01	0	0.01	0.23	0	0	0	0.04	0	0	0	0	0	0.10	0.03	0.09
Oryzopsis asperifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0
Oryzopsis exigua	0.30	0.18	0.33	0.49	0.30	0.09	0.20	0.53	0.39	0.06	0.19	0.29	0.39	0.10	0.24	0.39	0.51	0.20	0.34	0.61
Poa spp.	0	0	0	0.03	0	0	0	0.01	0	0	0	0.03	0	0	0	0.01	0	0	0	0
Trisetum spicatum	0	0	0	0	0	0	0	0	0.01	0	0	0	0.04	0.03	0	0.34	0	0	0	0.10
Low shrubs																				
Amelanchier alnifolia	0.03	0	0.04	0	0.01	0	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0.06	0	0.03	0	0.08	0
Arctostaphylos uva-ursi	1.60	1.70	1.55	1.59	1.60	1.25	1.45	1.61	1.61	1.18	1.45	1.50	1.63	1.26	1.49	1.38	1.56	1.39	1.48	1.39
Juniperus communis	0.09	0.05	0.04	0.10	0.09	0.05	0.04	0.10	0.10	0.04	0.06	0.10	0	0	0	0.03	0.21	0.21	0.23	0.31
Rosa acicularis	1.35	1.24	1.21	1.15	1.35	1.21	1.20	1.09	1.31	1.14	1.14	0.15	1.36	1.28	1.25	0.40	1.33	1.41	1.31	0.65
Shepherdia canadensis	0.49	0.45	0.51	0.41	0.49	0.44	0.51	0.43	0.50	0.36	0.53	0.18	0.50	0.44	0.56	0.18	0.83	0.76	0.85	0.25
Spiraea betulifolia	0.15	0.11	0.14	0.15	0.18	0.14	0.21	0.20	0.13	0.08	0.16	0.03	0.19	0.15	0.26	0.03	0.19	0.13	0.30	0.05
Vaccinium caespitosum	0.31	0.10	0.16	0.20	0.35	0.06	0.10	0.23	0.33	0.15	0.18	0.06	0.45	0.28	0.41	0.11	0.49	0.35	0.58	0.34
Tall shrubs																				
Populus tremuloides	0.04	0.03	0.03	0.01	0.04	0.01	0.03	0.01	0.03	0.03	0.01	0	0.04	0.01	0.01	0	0.04	0.01	0.01	0
Salix spp.	0.03	0.09	0.08	0	0.03	0.10	0.08	0.03	0.03	0.05	0.05	0	0.03	0.09	0.05	0	0.04	0.13	0.06	0
Conifers																				
Picea engelmannii	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0	0.01	0	0	0.01	0.01	0	0	0
Pseudotsuga menziesii	0	0	0.03	0	0	0	0.03	0	0	0	0.03	0	0	0	0.01	0	0	0	0.03	0.01

* Cont = Control, HH = Hexazinone applied at 9L/ha, HL = Hexazinone applied at 4.5L/ha, Gly = Glyphosate applied at 6L/ha.

Angove, K. and B. Bancroft. 1983. A guide to some common plants of the southern interior of British Columbia. B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 7.

Arnebrant, K, H. Ek, R.D. Finlay, and B. Söderström. 1993. Nitrogen translocation between *Alnus glutinosa* (L.) Gaertn. seedlings inoculated with *Frankia* sp. and *Pinus contorta* Doug. ex Loud seedlings connected by a common ectomycorrhizal mycelium. New Phytologist 130: 231–242.

Bancroft, B., S. Simard, and D. Sachs. 1991. Stand release trials in the Kamloops Forest Region — Technical Report, Kamloops Forest Region (draft).

Binkley, D. 1981. Nodule biomass and acetylene reduction rates of red alder and Sitka alder on Vancouver Island, B.C. Can. J. For. Res. 11: 281–286.

———. 1982. Nitrogen fixation and net primary production in a young Sitka alder stand. Can. J. Bot. 60: 281–284.

Biring, B.S., P.G. Comeau, and J. Boateng. 1993. Effectiveness of forest vegetation control methods in British Columbia (draft). B.C. Min. For., Victoria, B.C.

Boateng, J.O. and L. Herring. 1990. Site Preparation: Chemical. *In* Regenerating British Columbia's Forests. D.P. Lavender, R. Parish, C.A. Johnson, G. Montgomery, A. Vyse, and R. Willis (editors). UBC Press, Vancouver, B.C. pp. 164–178.

Brinkman, K.A. 1974. Willow. *In* Seeds of woody plants of the United States. U.S. Dep. Agric. For. Serv., Agric. Handb. 450.

British Columbia Ministry of Forests. 1995. Forest Practices Code of British Columbia: Establishment to free-growing guidebook. Victoria, B.C.

Canadian Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification. Ottawa, Ont. Can. Dep. Agric. Publ. 1646.

Clark, M.B. 1975. Grass – conifer compatibility: a problem analysis. B.C. Min. For., Kamloops, B.C. (unpublished report).

Comeau, P., G. Harper, B. Biring, and B. D'Anjou. 1996. A comparison of mulch mat and herbicide treatments for reducing grass competition in the IDFww. B.C. Min. For., Res. Br., E.P. 1135.03, Establishment and first year report (unpublished).

Comeau, P.G., S.B. Watts, C.L. Caza, J. Karakatsoulis, S.M. Thompson, and A.B. McGee. 1989. Autecology, biology, competitive status and response to treatment of seven southern interior weed species. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 93.

Conard, S.G. and W.H. Emmingham. 1983. Herbicides for shrub control on forest sites in northeastern Oregon and northern Idaho. Oreg. State Univ., For. Res. Lab. Corvallis, Oreg. Special Publ. 5.

———. 1984. Herbicides for grass and herbaceous weed control in Oregon and Washington. Oreg. State Univ., For. Res. Lab. Corvallis, Oreg. Special Publ. 7.

Crane, M.F., J.R. Habeck, and W.S. Fischer. 1983. Early postfire revegetation in western Montana Douglas-fir forests. U.S. Dep. Agric., For. Serv. Res. Pap. INT-319.

Crocker, R.L. and J. Major. 1955. Soil development in relation to vegetation and surface age of Glacier Bay, Alaska. J. Ecol. 43: 427–448.

Dimock, E.J. II., T.F. Beebe, and E. B. Collard. 1983. Planting-site preparation with herbicides to aid conifer reforestation. Weed Sci. 31: 215–221.

Eis, S. 1981. Effect of vegetative competition on regeneration of white spruce. Can. J. For. Res. 11: 1–8.

Expert Committee on Weeds. 1983. Instructions for the preparation of research abstracts. Misc. Mimeo. (unpublished) (as cited by Herring and Pollack 1985)

———. 1984. Research Report. Western Canada Section Meeting, December 3–6, 1984, Winnipeg, Man.

———. 1985. Research Report. Western Canada Section Meeting, December 3–5, 1985, Edmonton, Alta.

———. 1987. Research Report. Western Canada Section Meeting, December 1–3, 1987, Victoria, B.C.

Gesshe, R.H. and P.D. Walton. 1981. Grazing animal preferences for cultivated forages in Canada. J. of Range Manage. 34 (1): 42–45.

Haeussler, S. and D. Coates. 1986. Autecological characteristics of selected species that compete with conifers in British Columbia: a literature review. B.C. Min. For., Victoria, B.C. Land Manage. Rep. No. 33.

Haeussler, S., D. Coates, and J. Mather. 1990. Autecology of common plants in British Columbia: a literature review. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 158.

Hart, D. and P.G. Comeau. 1992. Manual brushing for forest vegetation management in British Columbia: a review of current knowledge and information needs. B.C. Min. For., Victoria, B.C., Land Manage. Rep. No. 77.

Herring, L.J. and J.C. Pollack. 1985. Experimental design protocol for forest vegetation management research: Level B trials (first approximation). B.C. Min. For. Internal Report (unpublished).

Kimmins, J.P. and P.G. Comeau. 1990. Forest vegetation management research strategy for the southern interior, British Columbia. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 132.

Klinka, K. and A.M. Scagel. 1984. Selected ecological characteristics of some tree and shrub species in British Columbia: genera Juniperus, Taxus, Populus, Alnus, Betula, Quercus, Prunus, Rhamnus, Acer, Cornus, and Arbutus. Can. Cartographics Ltd. Coquitlam, B.C.

Klinka, K., R.N. Green, R.L. Trowbridge, and L.E. Lowe. 1981. Taxonomic classification of humus forms in ecosystems of British Columbia. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 8.

Kufeld, R. 1973. Foods eaten by Rocky Mountain elk. J. Range Manage. 26: 106–112.

Lindeburgh, S. 1995. Effects of fireweed and associated vegetation on conifer survival and growth in the southern interior — fifth year results. B.C. Min. For. and For. Can., Victoria B.C. FRDA Research Memo No. 226.

Lloyd, D., K. Angove, G. Hope, and C. Thompson. 1990. A guide to site indentification and interpretation for the Kamloops Forest Region. B.C.Min For., Victoria, B.C., Land Management Handbook No. 23.

Lloyd, D. and J. Heineman. 1994a. Control of pinegrass (*Calamagrostis rubescens* Buckl.) with glyphosate applied at various rates and on different growing season dates, FRDA 3.41, B.C. Min. For. and For. Can. (unpublished report).

Lloyd, D. and J. Heineman. 1994b. Treatment of Sitka alder (*Alnus viridis* ssp. *sinuata*) in the southern interior of British Columbia by 3 methods: aerial glyphosate, manual cutting, and glyphosate applied to cut stumps. FRDA project 3.41, unpublished report, B.C. Min. For. and For. Can., Victoria B.C.

———. 1994c. The use of 3 rates of glyphosate to treat fireweed (*Epilobium angustifolium* L.) on various growing season dates. FRDA project 3.41, unpublished report, B.C. Min. For. and For. Can., Victoria B.C.

McLean, A. 1979. Range plant communities. *In* Range management handbook for British Columbia. A. McLean (editor). Agric. Can. Res. Stn., Kamloops, B.C., pp. 37–53.

McLean, A. and E.W. Tisdale. 1960. Chemical compositions of native forage plants in British Columbia in relation to grazing practices. Can. J. Plant Sci. 40: 405–423.

Nicholson, A. 1989. Water relations, survival and growth of Douglas-fir seedlings at a pinegrass dominated site in south-central British Columbia — FRDA Memo (FRDA 3.1), B.C. Min. For., Victoria, B.C.

Petersen, T.D. and B.D. Maxwell. 1987. Water stress of *Pinus ponderosa* in relation to foliage density of neighbouring plants. Can. J. For. Res. 17: 1620–1622.

Pojar, J. and A. MacKinnon. 1994. Plants of Coastal British Columbia. Lone Pine Publishing, Vancouver, B.C.

Pollack, J.C., P. LePage, and F. van Thienen. 1990. Some effects of different forest herbicides on upland *Salix* spp. Can. J. For. Res. 20: 1271–1276.

Porter, G.L. 1990. Willow species of disturbed sites in the sub-boreal spruce zone in north-central British Columbia. B.C. Min. For., Res. Br., Victoria, B.C. FRDA Handb. No. 004.

Quinton, D.A. 1984. Cattle diets on seeded clearcut areas in central interior British Columbia. J. Range Manage. 37(4): 349–352.

Rawson, J.W. 1974. Willows. *In* Shrubs and vines for northeastern wildlife. J.D. Gill and W.M. Healy (compilers) U.S. Dep. Agric. For. Serv., Gen. Tech. Rep., NE-9, pp. 147–149.

Rowe, J.S. 1983. Concepts of fire effects on plant individuals and species. *In* The role of fire in northern circumpolar ecosystems. R.W. Wein and D.A. MacLean (editors), John Wiley and Sons, Ltd., London, U.K.

Sachs, D. and P.G. Comeau. 1991. Determination of nitrogen fixation by Sitka alder at two sites in the southern interior of British Columbia. Final Contract Report, Project CO_3, B.C. Min. For., Res. Br., Victoria, B.C. (unpublished report).

———. 1992. Calibration and initial testing of FORECAST for stands of lodgepole pine and Sitka alder in the interior of British Columbia. Final Contract Report, B.C. Min. For., Res. Br., Victoria, B.C. (unpublished report).

SAS Institute Inc. 1985. SAS® User's Guide: Statistics, Version 5 Ed. Cary, N.C.

Simard, S. 1990. Competition between Sitka alder and lodgepole pine in the Montane Spruce zone in the southern interior of British Columbia. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 150.

Simard, S.W. and J. Heineman 1996a. Nine-year response of lodgepole pine and the *Dry Alder* Complex to chemical and manual release treatments on an ICHmk1 site near Kelowna. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 259.

———. 1996b. Nine-year response of Engelmann spruce and the *Willow* Complex to chemical and manual release treatments on an ICHmw2 site near Vernon. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 258.

———. 1996c. Nine-year response of Douglas-fir and the *Mixed Hardwood-Shrub* Complex to chemical and manual release treatments on an ICHmw2 site near Salmon Arm. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. No. 257.

Sims, H.P. and D. Mueller-Dombois. 1968. Effect of grass competition and depth to water table on height growth of coniferous tree seedlings. Ecology 49: 597–603.

Sit, V. 1995. Analysing ANOVA designs. Biom. Info. Handb. 5 Res. Br., B.C. Min. For., Victoria, B.C. Work Pap. 07/1995.

Stickney, P.F. 1981. Vegetative recovery and development. *In* Clearcutting and fire in the larch–Douglas-fir forests of western Montana. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. INT-99, pp. 33–40.

———. 1986. First decade plant succession following the Sundance forest fire, Northern Idaho. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. INT-197.

Stout, D.G. and D.A. Quinton. 1986. Pinegrass: an important forage in Interior B.C., Res. Br., Agric. Can., Kamloops, B.C.

Sullivan, T.P. 1985. Small mammal damage agents which affect the intensive silviculture of lodgepole pine. *In* Lodgepole pine: the species and its management. Symp. Proc., May 14–16, 1984. D.M. Baumgartner, R.G. Krebill, J.T. Arnott, and G.F. Weetman (editors). Vancouver, B.C.

SYSTAT, Inc. 1992. SYSTAT for Windows: Statistics, Version 5 Ed. Evanston, Ill.

Walstad, R.D. and J.D. Wagner. 1982. CRAFTS experimental design manual for B-level studies: Release of young conifers from uniformly distributed brush competition. Dept. of For. Sci., School of Forestry. Oreg. State Univ. (unpublished manuscript) (as cited by Herring and Pollack 1985).

Willms, W., A. McLean, R. Tucker, and R. Ritchey. 1980. Deer and cattle diets on summer range in British Columbia. J. of Range Manage. 33 (1): 55–59.