Partial Cutting and Controlled Fire to Restore Old-growth Forest Conditions in the East Kootenay Trench

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INTRODUCTION

Research shows that before European settlement (i.e., before 1900) the structure of the old-growth forests in the drier Douglas-fir and ponderosa pine forest types of the Rocky Mountain Trench were quite different than they are today. In pre-settlement times, light ground fires swept through these areas every 10–20 years, resulting in open park-like forests characterized by large, old trees and little regeneration (Covington and Moore 1994; Arno et al. 1995). The predominant tree species were ponderosa pine and Douglas-fir, as well as western larch on moister sites. The open structure of these forests and the associated plant communities supported numerous wildlife species.

In the absence of fire, Douglas-fir has regenerated abundantly on these sites and stocking is much higher. The consequences include changed wildlife habitat, reduced forage production, increased susceptibility of trees to insect attack and disease, and increased risk of catastrophic fire because of greater fuel loading and increased fuel laddering.

In 1993, the East Kootenay Trench Ecoregion in the Cranbrook Forest District was identified as having several biogeoclimatic subzones with less than 5% old growth (i.e., trees older than 140 years). This is considerably less than the 10% recommended by the Protected Area Strategy (PAS) as the minimum level required to maintain biodiversity, and the plant and animal species that depend on old-growth forests.

To protect the remaining old-growth areas, a deferral was placed on harvesting old growth in the East Kootenay Trench Ecoregion. However, simply deferring or preserving old stands will not ensure the maintenance of true old-growth conditions.

In 1995, recognizing that management to reduce stocking and re-introduce fire was essential, the Silvicultural Systems Research program in the Nelson Forest Region requested that two stands of old-growth forest in the Interior Douglas-fir Dry Mild (IDFdm2) Biogeoclimatic Subzone within the Trench be released from the harvest deferral. In 1996, the Region implemented a trial and case study to examine the operational, economic, and ecological feasibility of old-growth restoration. The objective of the trial was to modify the stocking levels, species composition, and the forest floor to approximate pre-settlement stand conditions. This will be accomplished by replacing wildfire with a combination of harvesting and prescribed fire on a regular 20-year cycle.

This research summary describes the prescription development, the harvesting operation, and the controlled fire for one of the stands.

SITE DESCRIPTION

The study block is located in the southern part of the Cranbrook Forest District, near the town of Newgate, on a mesic site in the IDFdm2 (Figure 1). The 30-ha stand is within Crestbrook Forest Industries' operating area.

Forest cover ranged from patches of large old ponderosa pine with little understorey, to areas of Douglas-fir and ponderosa pine overstorey with dense fir understories, to areas of predominantly smaller stems of Douglas-fir and some larch. Overall, species composition was approximately 75% Douglas-fir, 20% ponderosa pine, and 5% larch.

Large snags were found throughout most of the stand, and these showed a high degree of wildlife use. Pockets of *Armillaria ostoyae* are present throughout the stand (Figure 2).

STUDY METHODS

Prescription Development

Because the site had been harvested at least twice over the last 100 years, a stump survey was completed to learn more about pre-settlement species composition (Table 1). Together with the results of the stump survey, current research was consulted to develop a description of the target stand for the prescription (Table 1).

Recent research indicates that before 1900 this type of stand probably had about 9–15 m^2 of basal area (75 stems per hectare at an average 50 cm diameter) (Covington and Moore 1994; Arno et al. 1995; Quesnel 1996).

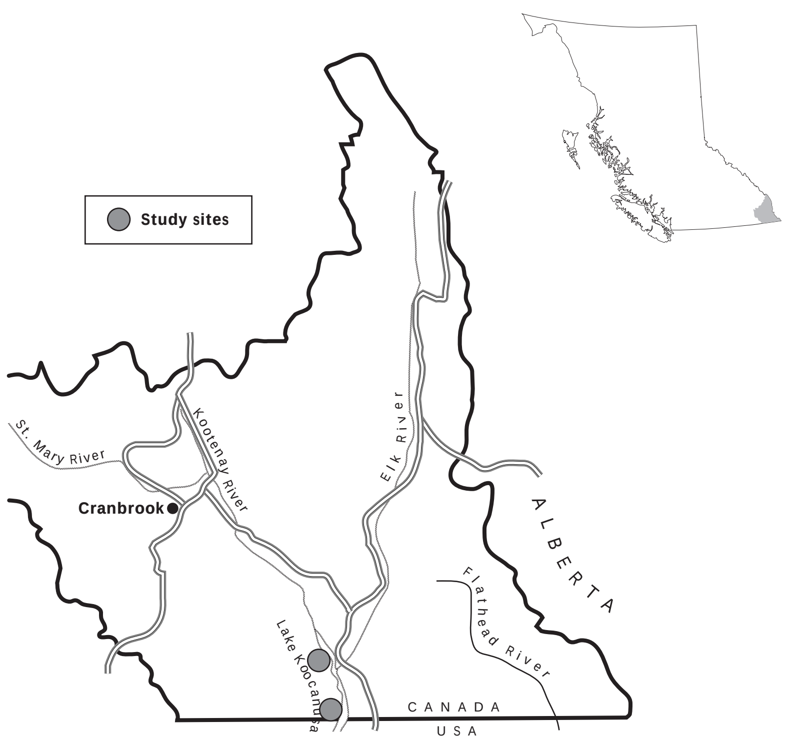

FIGURE 1 *Location of study sites.*

FIGURE 2 *Pre-harvest stand.*

In addition, small thickets of regeneration would be present in areas skipped by fire. It is likely that these thickets would have covered about 5% of the area.

Using the stand and stock tables provided in the cruise compilation, cutting specifications were developed that would remove most of the excess smaller-diameter Douglas-fir stems from the stand. All the ponderosa pine, Douglas-fir greater than 35 cm dbh, and larch greater than 17.5 cm dbh were retained. Smaller larch were removed because of consistently poor form and vigour. To achieve and maintain the target stand structure for the site, it is necessary to reduce current stocking levels and ensure that some form of stocking control occurs in the future. With this in mind, a prescription was developed that included slashing of submerchantable stems to provide ground fuels and understorey burning on a regular cycle.

TABLE 1 *Stand descriptions (stems greater than 17.5 cm dbh)*

	Pre-harvest stand	**Target residual stand**	**Actual residual stand**
Species composition[a]	Fdi (75%) Py (20%) Lw (5%)	Py (40%) Fdi (40%) Lw (20%)	Fdi (60%) Py (30%) Lw (10%)
Stems per hectare	786	75 + some thickets of unmerch. stems	123 + some thickets of unmerch. stems
Basal area/ha (m^2)	27	9-15	16
Average diameter (cm)	20	50	41
Volume (m^3/ha)	185	N/A	128

a Species codes: Fdi = Douglas-fir; Py = ponderosa pine; Lw = western larch.

In areas where the number of larger stems was insufficient to achieve the desired stand structure, some smaller stems were retained to avoid substantial gaps and to allow the desired characteristics to develop over time. Some thickets of regeneration were retained within wildlife tree patches. Slashing and burning of the understorey were to be carried out following logging. To keep the stocking levels down, burning, and possibly harvesting, will be required on a regular 20-year cycle.

In addition to residual trees, 10 wildlife tree patches were identified and marked as no-work zones within the cutblock (Figure 3). Some of these patches include several large snags surrounded by a thicket of understorey Douglas-fir regeneration. About 35% of all snags were protected in 10% of the block area. Snags could be protected without substantial reductions to available timber because few if any merchantable stems existed within these patches.

Harvesting

Harvesting started mid-February 1996 and was completed within 7 days. A total of 1600 m^3 of sawlogs were removed as well as 68 m^3 of pulpwood. The block was harvested with a Caterpillar D4, a 518 Caterpillar skidder, and a John Deere 640 skidder (Figure 4).

This type of operation is best done in winter on frozen ground to reduce costs and to minimize soil disturbance. A key requirement of this initial logging pass was to build up a carpet of ground fuels by topping and delimbing stems where they fell, rather than removing tops and branches at the landing. In frozen conditions, many of the branches were broken on impact and it

FIGURE 3 *Distribution of wildlife tree patches (WTPs) within the block.*

FIGURE 4 *Harvesting operation.*

was quite easy for the skidder to run over each stem to remove any remaining branches before hooking. The frozen ground eliminated any potential site disturbance this extra maneuvering might have otherwise created.

Residual stems incurred very little damage and site disturbance was low. Following logging, a slashing crew felled any remaining submerchantable stems so they would contribute to ground fuels.

Crestbrook Forest Industries' harvesting superintendent felt that the open nature of the stand resulted in logging costs that were no higher than if the site had been clearcut. His only concern was the relatively small size of the block, noting that a larger area would reduce some of the equipment moving costs. A total of $17 630 in stumpage was paid to the Province of British Columbia.

Residual Stand

The resulting stand is substantially more open than its pre-harvest state. It consists of mainly large-diameter stems distributed singly and in clumps (Figure 5). The residual stand's basal area of 16 m^2/ha was close to the target of 9–15 m^2/ha. However, the stand is still excessively stocked, containing about 48 stems per hectare above the standard (Table 1). This is because the average residual stem is still smaller than ultimately desired (41 vs. 50 cm dbh).

More stems than are required were left to ensure that the residual basal area did not drop below 15 m^2. At the next scheduled entry (in 2016), the average diameter will have increased and more stems can be taken out without dropping the residual basal area below 15 m^2. The next entry can also be used to approach the target species composition by further reducing the amount of Douglas-fir. With the improved visibility and the greatly reduced stocking

FIGURE 5 *Residual stand.*

numbers, future harvesting can be done relatively easily on a tree-by-tree basis using a mark-to-cut system.

Burning

Following harvesting and snowmelt, a reconnaissance of the cutblock determined suitability for understorey burning. The burn was scheduled for 1 year after harvest in the spring of 1997, to allow coniferous fuels time to cure. It was thought that by waiting the additional time, the grasses would grow up around the coniferous fuels to supplement the fuels and provide continuity between patches of slash.

This burn was completed on April 25, 1997 by a crew of 10 carrying drip torches (Figure 6). The conditions at the time of the burn are summarized in Table 2.

Approximately 60% of the area was burned at an Impact Rank of 1 (Figure 7). This burn coverage was slightly lower than originally desired, but was adequate given the low amounts of fine carrying fuels such as grass. This type of opening probably attracts both wild and domestic grazing animals, which reduced the amount of grass. As more open forest is created, this graz-

TABLE 2 *Conditons at time of burning*

Temperature	14°C
Relative humidity	62%
Wind	South @5 kph
Drought code	< 200
Duff moisture code	< 30

FIGURE 6 *Ignition with drip torches.*

FIGURE 7 *One week after burning (note spotty coverage).*

ing effect should decline and more grass will become available, achieving a better low-intensity fire coverage. Total cost of planning, ignition, and mop-up was $6984.

Subsequent burning treatments are expected to kill most of any new regeneration that establishes in the next 20-year period. However, enough regeneration is expected to survive the burn to ensure future stand replacement (S. Arno, U.S. Department of Agriculture Forest Service, Missoula, Montana, pers. comm., 1995).

SUMMARY

Initial indications are that partial cutting and controlled burning for old-growth restoration in the IDF biogeoclimatic zone is feasible. By harvesting and burning in this way, key structural elements are retained, forage production should be increased, and a plan is set in motion for the long-term maintenance of these stands. Potential also exists to gain wood volume from areas that are currently considered old-growth reserves and unavailable for harvest, without compromising the original objective of an old-growth reserve. In landscape units where old growth is under-represented, this treatment could also be used to accelerate old-growth recruitment from younger stands. Yet another benefit of the treatments is long-term fuel reduction, which substantially reduces the risk of catastrophic fire.

The economics of a restoration program will be site specific, but for the more marginal sites (i.e., those with smaller stems) the strength of the pulp market will likely be a key factor. While larger block sizes would improve economics, this site contained enough small sawlog material that the harvesting operation was profitable in spite of low pulp prices.

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Stocking Standards for Uneven-aged Interior Douglas-fir

KEN DAY

INTRODUCTION

Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) is a wide-ranging species with a very broad ecological amplitude. In the dry parts of its range, it grows in an uneven-aged fire-dominated subclimax. Historical fire frequency at Knife Creek in the Interior Douglas-fir Dry Cool (IDFdk3) biogeoclimatic zone is between 16 and 18 years (Daniels et al. 1995), and these frequent fires dominated the development of the natural stands. On the basis of this natural condition, the species is well suited to an uneven-aged management regime.

Large timber and proximity to highways and manufacturing plants make the Douglas-fir forests of the IDF highly desirable for timber harvesting. Their low elevation and limited snowpack makes the forests important winter habitat for mule deer (Armleder et al. 1986), and the forests are also used for cattle grazing. Their proximity to population centres makes dry-belt Douglas-fir forests important for public recreation. Such multiple demands on the land base impose complex forest management objectives, which in turn direct prescriptions for forest management.

Interior Douglas-fir tends to regenerate naturally in very dense thickets that establish in canopy gaps after disturbance. Thickets at very high densities tend to stagnate. The physiology of stagnation is poorly documented, but one possible explanation is that competition for soil moisture limits the trees' ability to take up water. Trees shed needles in response to the moisture stress, which in turn increases the light available in the stand. Relatively few trees die in this state, but net productivity is very low (J.P. Kimmins, University of British Columbia, Faculty of Forestry, pers. comm., 1996). Tree and stand vigour is reduced, growth declines, and risk of insect or disease attack increases. Management of stand density is therefore a critical activity in uneven-aged Douglas-fir forests.

Little guidance is available to silviculturists in the selection of appropriate residual stand density in this forest type. Complex stand structures influence carrying capacity, and effective ways to allocate growing space to structural components occupy much of the current literature (Hann and Bare 1979; Guldin 1991; Fiedler 1995; O'Hara and Valappil 1995). Few authors, however, provide detailed guidance on setting residual growing stock. The relationships between growth and density are poorly described for interior Douglas-fir. Functional linkages exist between stand density, diameter growth, and basal area growth, which can be observed with relative ease through retrospective analysis of growth. Understanding these functional relationships is critical to setting appropriate stocking levels. Silviculturists are making decisions on stocking levels daily without knowledge of appropriate stocking, and simple tools for decision making are urgently needed.

This paper describes a retrospective case study of basal area growth and density relationships from four stands in the Knife Creek block of the University of British Columbia's Alex Fraser Research Forest. The objectives of the case study were to examine the functional relationships affecting growth, and to describe appropriate stocking levels for uneven-aged Douglas-fir forests for Knife Creek. A simple tool to assess stocking is calibrated and tested.

Stocking versus Density

To avoid confusion, it is necessary to distinguish between stocking and density. Density is the quantitative measure of the occupation of a site by trees, expressed either as an absolute measure (number of stems, basal area, or volume per unit area) or an expression of the number of trees and their size (Curtis relative density, stand density indices, or crown competition factor) (Ernst and Knapp 1985; Davis and Johnson 1987). Density is a fact that can be attributed to a stand (Davis and Johnson 1987).

Stocking is defined as the density of the subject stand relative to the density of a reference stand (Davis and Johnson 1987), or relative to the optimum condition (Ernst and Knapp 1985; Davis and Johnson 1987; Nyland 1996). Stocking is the description of a stand related to its management objectives.

Problem Statement

Selection management requires explicit description of the stand structural objectives. Although alternative approaches are available, this paper discusses stand structure regulation by BDq (Basal area, maximum Diameter, and diminution quotient) (Guldin 1991; Matthews 1991; Fiedler 1995).

The arrangement of stocking by diameter class (D and q) is essentially a design process that describes the physical qualities of the stand required to meet management objectives. The level to which the stand is stocked is, however, a biological or ecological interpretation. Regulating stand structure and controlling stocking ensures that stand growth is maintained and management objectives are met (Hann and Bare 1979).

Dry Douglas-fir forests of the Interior of British Columbia have had a history of high-grading. Harvesting did not seek to regulate stand structure; instead, harvesting simply removed timber. This high-grading was made possible by the abundance of advanced regeneration that allowed heavy cutting to leave a regenerated stand. High-grading entries are dysgenic (Howe 1995), and leave an inappropriate stand structure composed of low-vigour trees, which are susceptible to insect and disease attack. Such stands are not capable of growing at a rate that maximizes site productivity. Appropriate stand structure targets and stocking control ensure that harvesting will meet management objectives and maximize growth, and rigorous attention to stocking control is critical.

Failure to adequately address residual stocking puts management objectives at risk. Carrying too little stocking means lost timber production and reduced wood quality. Carrying too much stocking also means lost timber productivity because of stagnation and mortality. More importantly, stands grown under intense competition have reduced vigour and are therefore more susceptible to insect or disease attack (Boyce 1961; Furniss and Carolin 1980; Larsson et al. 1983; Carlson et al. 1985; Entry et al. 1991; McDonald 1991; Dolph et al. 1995). In addition, trees grown closely together are slender with small crowns, and are at high risk of loss because of wind or heavy snow (Herman and Lavender 1990).

The maximum size/density relationship represents the absolute limit of density; it is a function of species, site quality, and stand structure (Sterba and Monserud 1993). Stand growth is maximized when a stand is fully stocked, but below the level where suppression and mortality commence. A range of stocking produces the maximum stand growth (Daniel et al. 1979; Lotan et al. 1988); optimum stocking is conveniently stated as a proportion of maximum carrying capacity. Growing a stand at the lowest stocking that still captures all the growing space (B-level Stocking) maximizes both stand growth and individual tree growth (Daniel et al. 1979; B.C. Ministry of Forests 1992). In the absence of good information, stocking guidance usually takes the form of "rules-of-thumb" (Marquis 1976; B.C. Ministry of Forests 1992).

Very broad-based rules do not provide sufficient guidance for the silviculturist who seeks to set residual stocking goals. Silviculturists need:

- an understanding of functional relationships that govern growth;
- stocking standards for timber management in uneven-aged Douglas-fir stands that reflect the biogeoclimatic conditions and species composition of the target stands; and
- simple tools by which stocking can be assessed and cutting plans developed.

METHODS

Four separate stands were sampled on the Knife Creek block of the UBC/Alex Fraser Research Forest near Williams Lake, B.C. The stands selected were relatively flat mesic areas in the IDFdk3. Two of the stands had been cut by diameter-limit methods more than 20 years before measurement, and two stands had no known harvest history. None of the stands have had any forest management disturbance in the past 20 years, except some salvage of bark beetle–caused mortality. The sites were selected for their topographic uniformity and treatment history, and were chosen to represent the range of conditions encountered on mesic sites within the IDFdk3 in the Knife Creek Block.

The stands were sampled systematically by fixed-area plots. Ten plots were established at 100 m intervals on a rectangular transect through each stand. One plot was discarded because it contained a large stump from a tree salvaged after bark beetle mortality.

Layer 1 (dbh ≥ 12.5 cm) and layer 2 (dbh 7.5–12.4 cm) trees were measured on a plot of 7.98 m radius (200 m^2). Each tree in layer 1 and 2 had dbh recorded to the nearest millimetre, 10-year radial increment recorded to the nearest half millimetre, and vigour class (good, medium, or poor) assessed by external criteria. Radial increment was measured by one increment core, taken from the north side of the tree at breast height. Relatively few plots were measured on each stand, and their size was relatively small because of the labour required for measuring radial increments on many trees. In total, 794 trees were measured on 39 plots. Field work was completed in November. The short days and dark conditions required that radial increments were tallied using flashlights and hand lenses.

Although layer 3 (height ≥ 1.3 m, dbh < 7.5 cm) and 4 (height < 1.3 m) trees were measured, they have been excluded from these analyses because large numbers of small trees have great influence on stem count but not basal area. Discussions of relative density, quadratic mean diameter, and basal area therefore require stipulation of minimum diameter. All analyses, results, and discussion in this report are limited to trees exceeding 7.4 cm dbh.

Growth was measured by the radial increment of trees alive on the plots in November 1996. Dead trees were not measured, and all discussion of growth therefore excludes mortality.

The small sample size and limited replication necessitate caution in interpreting the results of this retrospective case study. The results of the analyses should therefore not be extrapolated outside the Knife Creek Block without careful validation.

Data from the tally sheets were entered into a purpose-built spreadsheet (MS Excel 5.0) that calculated diameter classes, basal area, basal area increment, and other required data. All subsequent data analyses were carried out using the Excel spreadsheet program and its functions.

EXAMINING FUNCTIONAL RELATIONSHIPS

Understanding the links between stand density and growth is a core issue in determining appropriate stocking levels. It is widely accepted that stand density affects the diameter growth of a given tree, and therefore the basal area growth of the stand. The relationships between density and diameter growth must vary by species and site productivity.

Stand Structure

The four stands chosen for sampling exemplified two distinctly different stand structures. Although all four stands display the "inverse-j" diameter distribution, two of the stands had been harvested by diameter-limit cutting; all of their density is concentrated between the 10- and 35-cm classes. The other two stands have not had any harvesting disturbance. Stand tables for the four sites are presented graphically in Figure 1.

When radial growth was compared for all trees, it was apparent that stand structure has a significant effect on increment. Figure 2 shows the average radial increment of sampled trees by 1-cm diameter classes, for each of the four blocks sampled. The function for radial growth in the unlogged stands (BM + WR and Jones Creek on the legend) follows the form suggested by Schütz (1975) and Saraçoglu (1988)—generally increasing growth with increasing diameter. The two stands that have been logged show a much different functional form, with rapid rise and then decline in growth rates as diameter increases. This is probably attributed to the extreme crowding that the trees experience as diameter increases (i.e., approaching the maximum size/density relationship), but may also be related to dysgenic tree selection. The model "Prognosis" employs a functional form for diameter increment that is the same as that shown for the logged stands (H. Temesgen, University of British Columbia, Faculty of Forestry, pers. comm., May 1997).

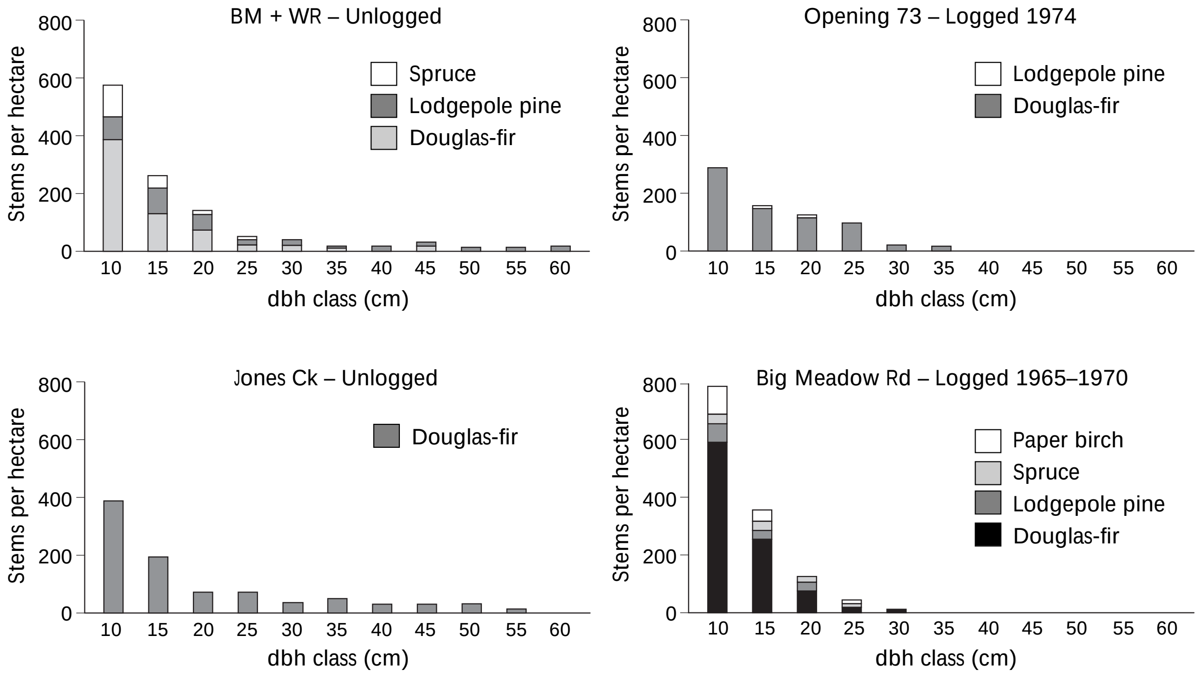

FIGURE 1 *Stand density (stems per hectare) by species and dbh (stems > 7.4 cm dbh only).*

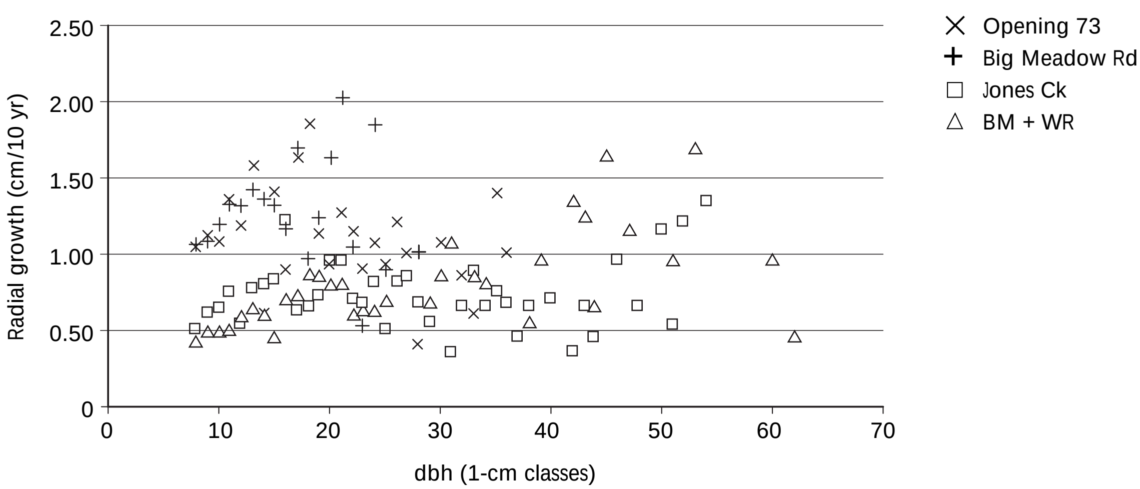

FIGURE 2 *Radial growth as a function of diameter and stand structure.*

Functional Relationships of Basal Area Growth

Tree diameter growth, and hence basal area growth, is a function of density and site quality. Determining the functional relationships that control basal area growth was a prime objective of this project. The data were summarized to examine growth as a function of density, quadratic mean diameter (Dq), and Curtis relative density (RD). Regression equations were attempted, but abandoned because of apparent autocorrelation. The ability to forecast basal area growth is critical to establishing appropriate re-entry periods for a given harvesting prescription. Descriptive statistics were compiled for basal area growth from the data, and are presented below in Table 1.

Empirical evidence indicates that growth will be higher after disturbance than the undisturbed stands examined; how much higher is unknown at this

TABLE 1 *Descriptive statistics for blocks surveyed (all statistics include only stems > 7.4 cm dbh)*

	Unlogged		Diameter-limit cut		Total
Site data	**BM+WR**	**JonesCk**	**BMRd**	**Open73**	
Average of stems per hectare	1138.56	874.75	1309.62	734.79	1011.25
StdDev of stems per hectare	560.96	517.99	560.00	310.87	528.43
Average of m^2/ha > 7.4	31.22	31.89	17.52	18.13	24.53
StdDev of m^2/ha > 7.4	6.58	10.64	6.58	8.62	10.60
Average of 10 yr growth m^2/ha > 7.4	3.82	3.50	5.63	3.80	4.20
StdDev of 10 yr growth m^2/ha > 7.4	1.08	1.55	1.90	1.24	1.67
Quadratic mean diameter	18.68	21.54	13.05	17.72	
Curtis relative density	7.22	6.87	4.84	4.30	

time. An estimate of growth based on the average of all stands examined should be a conservative estimate of periodic basal area increment, and will be useful until more precise estimates are available.

Relationship of Growth to Density

Within limits, height growth is a function of site quality, and diameter growth is a function of stand density. A range of appropriate density exists across which stand growth is maximized—this range of density is the management zone. Using basal area increment as a measure of growth, the relationship between density and growth was examined to describe Langsaeter's relationship as discussed by Lotan (1988).

Langsaeter's Curve

Langsaeter's curve describes the relationship of current or periodic increment to total standing stock. The data acquired from the 39 plots in Knife Creek suggest a curve of a form similar to Langsaeter's. Using multiple linear regression techniques, Langsaeter's curve was estimated for the Knife Creek Block (Figure 3). Although the fit of the curve is poor (R^2 = 0.113, significance P=0.115), the functional form is appropriate. The logarithmic curve employed to describe the function does not provide a point of inflec-

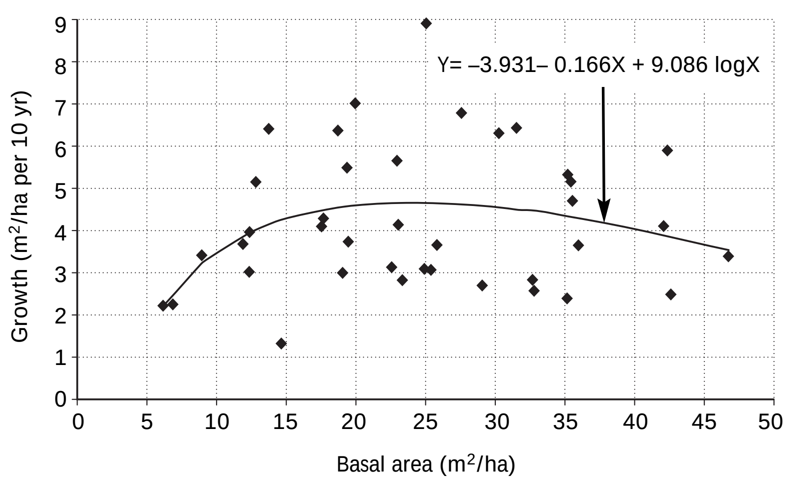

FIGURE 3 *Langsaeter's curve for the IDFdk3 at Knife Creek (multiple R^2 = 0.113).*

tion, so B-level stocking (the lowest density that fully occupies a site) could not be calculated based on the regression curve.

To estimate B-level stocking for Knife Creek, the data were partitioned on the independent axis, and linear regressions performed on each part of the data (Figure 4). Moving the partition through the data, recalculating the regressions, and observing the residual sum of squares yielded the two regression equations with the lowest aggregate residual sum of squares. The point where these two equations intersect is used as an estimate of the point of inflection of Langsaeter's curve. By this method, B-level stocking was estimated as 17.5 m^2/ha.

CONSTRUCTION OF A GINGRICH STOCKING CHART

Stocking guides represent the biological potential of a site to support stand density. When the maximum density is shown, stocking can be described relative to that maximum value. A stocking chart developed by Ginrich [sic][1] (1967) displays stand basal area and stems per hectare, and includes maximum density and suggested stocking levels. Ernst and Knapp (1985) set out a sequence of steps to develop a Gingrich chart, and those steps follow below.

Developing a Reference Level

Reference levels are "the absolute stand density that we would normally expect . . . under some standard condition . . ." and are either a standard of maximum competition, or no competition (Ernst and Knapp 1985). It is with this reference level that relative density and residual stocking targets are described. Ernst and Knapp (1985) recommend that a standard of maximum competition is most useful.

The data collected at Knife Creek provided some very high densities across a wide range of quadratic mean diameters. When size/density data from the Knife Creek block were plotted on natural log axes, a reasonable re-

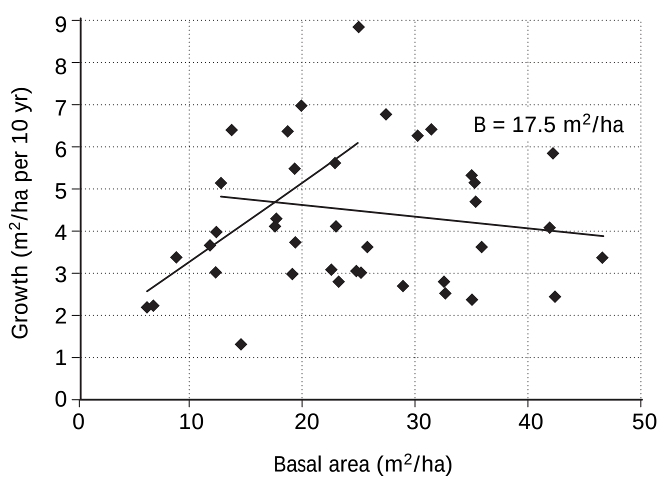

FIGURE 4 *Calculation of B-level stocking by partitioned linear regressions.*

1 This first reference and the citation under "References" contain the unfortunate misspelling of Gingrich's name in his article from 1967. All other references to this author contain the correct spelling of his name.

lationship of maximum size/density appeared to be present. The self-thinning rule (Long 1985) was employed because the slope of the self-thinning line (-3/2) seemed to fit the data well. A limiting size/density function was determined by:

- transforming the quadratic mean diameter (*Dq*) and density to natural logarithms;
- assuming the slope of the function to be -3/2; and
- moving the y-axis intercept until the function equalled the highest data point.

The simple function that results is the maximum size/density relationship for the Knife Creek Block, and is shown in Figure 5. The function was transformed to natural antilogs and manipulated to calculate the limit of density for a given quadratic mean diameter, according to Equation 1.

Using the values for stems per hectare that resulted from Equation 1, the basal area implied for each maximum density/*Dq* combination was calculated according to Equation 2. The resulting data points were charted to create the reference level equivalent to the limiting size/density relationship for the stands sampled.

$$\text{Stems per hectare} = e^{11.718} \times Dq^{-1.5} \qquad (1)$$

where: $Dq = 12 \rightarrow 30$ (increment = 2)

$$\text{Basal area per hectare} = \frac{\left(\frac{Dq}{2}\right)^2 \times \pi}{10\,000} \times \text{stems per hectare} \qquad (2)$$

where: $Dq = 12 \rightarrow 30$ (increment = 2)

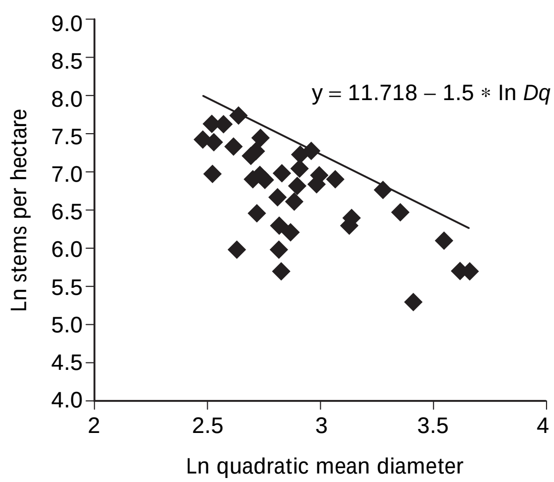

FIGURE 5 *Maximum size/density relationship from the -3/2 power law for Knife Creek plots.*

Stocking Levels

Stocking levels are a function of site quality, species, and management objectives, defined for an "ideal" stand (Gingrich 1967; Ernst and Knapp 1985; Davis and Johnson 1987; Purri et al. 1988; Nyland 1996). Stocking levels are shown on the stocking chart to depict a range of acceptable stocking—maximum and minimum stocking levels that delimit the management zone for a given objective. For a timber management objective, the lower limit should be the lowest stocking that represents full site occupancy, and the upper limit should equal the onset of competition-induced mortality.

Ernst and Knapp (1985) suggest that stocking limits should be based on experience and research in growth response to various levels of residual basal area. Other authors (Drew and Flewelling 1979; Long 1985; Lotan et al. 1988) suggest a different method of establishing stocking levels, in which proportional decreases of the reference level are used.

The stocking levels suggested by these authors are based on even-aged stands—I have assumed that the theory will extend to stocking levels for uneven-aged stands. On that basis, the stocking levels suggested by Long (1985) were used with the upper limit set at 60% and the lower limit set at 35%. The limits were drawn on the chart by proportionately reducing the maximum size/density line.

Creating a Gingrich Chart for Knife Creek

The background of the chart shows the isolines of quadratic mean diameter (*Dq*) that were calculated according to the formula shown at Equation 2 above.

1. Stems per hectare were varied between 100 and 3000 in increments of 10.
2. Basal area was calculated for each quadratic mean diameter and density.
3. Functions were graphed.
4. Maximum size/density function (Equation 1) was added to the chart.
5. Stocking levels were calculated for each *Dq* (as a percentage of the maximum size/density value) and added to the chart.

The Gingrich chart developed from the data collected at Knife Creek is shown at Figure 6.

Gingrich Chart Validation

The Gingrich chart was tested by observing the basal area growth for each plot, when classified by the stocking limits drawn on the chart as understocked, stocked, or overstocked (Figure 7). The mean volume growth for

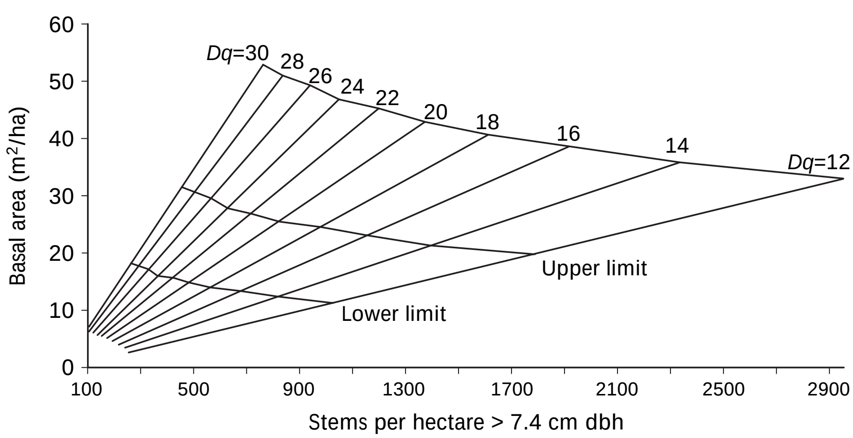

FIGURE 6 *A Gingrich stocking chart for Knife Creek.*

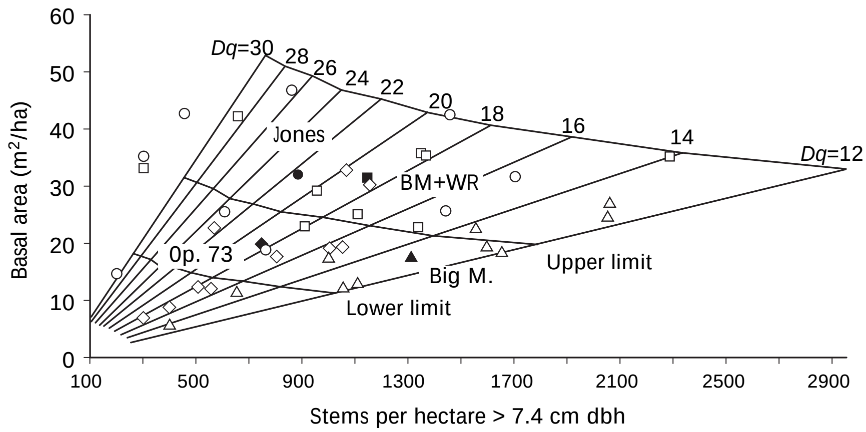

FIGURE 7 *Plots (open symbols) and blocks (closed symbols) sampled at Knife Creek.*

each stocking class was tested for differences by analysis of variance and least significant differences. These tests indicated that a significant difference ($p = 0.05$) existed between the understocked and the other conditions, but not between the stocked and overstocked conditions.

The data were compiled by blocks that were classified by stocking status (Figure 7) and the mean growth for each block was tested by analysis of variance and least significant difference. These tests showed that basal area at Big Meadow Road (stocked) grew significantly faster ($p = 0.05$) than all others. No significant differences could be clearly attributed to stocking status of the blocks because of the unexplained lack of significant difference in growth between Opening 73 (stocked) and the two undisturbed blocks (overstocked).

The stocking status of six permanent sample plots of Knife Creek (Marshall and Wang 1996) was classified by the Gingrich chart and ranked in order of basal area growth. Apparently the three plots that appear to be most appropriately stocked show the best basal area growth. It is also important to note that all plots suffered some mortality during the remeasurement period, which indicates overstocking.

Data collected from 18 permanent sample plots at Knife Creek (Marshall 1996) were used to examine the changes in stocking status after three different pre-commercial thinning treatments. The treatment that leaves the lowest density appears to leave the stands appropriately stocked, while the other two treatments frequently leave the stand overstocked. Remeasurements are currently under way to determine periodic increment for each of the treatments. The results of these remeasurements will yield information to further validate the chart. Anecdotal comments from the field crew indicate that, on average, individual stem growth in the lowest-density treatment is better than diameter growth in the other two treatments.

Basal Area Growth

Basal area growth strongly depends on stand density. Therefore, the development of good relationships was expected, which could forecast growth based on the easily measured parameters of relative density, quadratic mean diameter, and density. The diameter growth and basal area growth relationships that were expected in the data were, however, obscured by plot variability. The stands studied are extremely heterogeneous, and the 10 relatively small plots did not characterize each stand precisely; that is, the area outside the plots influenced the measured values for growth within the plots to such an extent that relationships were not clear.

The data clearly show that diameter growth is a function of diameter. Further, the functional form of the relationship appears to vary by stand structure. This indicates that stand structure is important to maintain maximum basal area growth, and appropriate stand structures will enhance basal area growth.

Basal area growth does not equate to volume growth. Stands of low mean diameter may have very high basal area growth, but low volume growth because the basal area is distributed among many short stems. Conversely, stands with a large mean diameter may have low basal area growth, but high volume growth because the growth is accumulated on a few large trees with good height. This supports the general conclusion that uneven-aged stand structures should maintain most of the stocking in large-diameter classes.

On average, the stands studied grew at a rate of 4.2 m^2/ha per decade. This average increment is useful as a preliminary guide to set re-entry periods, and allows a silviculturist to estimate that basal area harvested will be replaced at a rate of 0.42 m^2/ha per year in the IDFdk3. This estimate is conservative because many of the plots are not stocked appropriately. Stocking control on all plots would presumably increase mean increment.

The lack of data on mortality is a concern. Including mortality in the growth projections would decrease the estimated increment. Marshall (1996) found mortality ranging between 0.08 and 0.59 m^2/ha over a 4-year period (0.2–1.48 m^2/ha per decade). However, appropriate timber marking will foresee mortality and harvest some of the trees that will not survive until the next re-entry (Day 1996).

Langsaeter's Curve

One method of determining an appropriate residual stocking level is to identify B-level stocking on Langsaeter's curve—the level of stocking below which current annual increment (CAI) is reduced, and above which CAI is maintained. This classical approach fails to recognize that B-level stocking should vary depending on mean diameter. To impose a uniform level of stocking to all cohorts regardless of their mean diameter will result in the overstocking of small-diameter cohorts and the understocking of large-diameter cohorts.

Using partitioned regressions, B-level stocking was estimated at 17.5 m^2/ha for Langsaeter's curve. This stocking level falls into the lower limit of stocking developed with the Gingrich chart, for a quadratic mean diameter of approximately 26 cm. For any other mean diameter, however, this B-level stocking is not ideal.

Maximum Size/Density

Maximum size/density relationships are described by the widely accepted self-thinning rule (Yoda et al. 1963, referenced in Long 1985) and the stand density indices derived from that rule (Long 1985). This concept implies that, at the upper limit of stocking, some trees must die to provide space for others to grow. The relationship is very predictable (Long 1985), and is also referred to as the "-3/2 power law" (Drew and Flewelling 1979). Some authors (Curtis 1982; Ziede 1987) suggest that the slope of the self-thinning function is variable, and depends on species (Curtis 1982) or stand structure and age (Ziede 1987).

In most cases, stand density indices that are derived from the -3/2 power law are used to describe even-aged stands (Drew and Flewelling 1979; Curtis 1982; Long 1985). Sterba and Monserud (1993), however, state that the concept of self-thinning applies to uneven-aged stands, although the slope of the self-thinning line is flatter in complex stand structures. Figure 5 clearly shows, however, that a slope of -3/2 fits the Knife Creek data well.

Gingrich Stocking Chart for Knife Creek

Gingrich stocking charts are a simple tool to describe the density of a stand by its basal area and numbers of stems. Although Gingrich (1967) intended the charts for use with even-aged hardwood stands, he states that ". . . stand structure has little effect on stocking percent . . ." and suggests that the charts could be used for "irregular" stands. Ernst and Knapp (1985) seem ambiguous—while stating that Gingrich charts can be developed and used for any tree species and forest type, they specify that reference stocking levels must be developed from even-aged stands. Purri et al. (1988) and Nyland (1996) discuss Gingrich charts for even-aged stocking only. Marquis (1976) states that Gingrich charts are equally useful for uneven-aged stands, and advocates their use.

Gingrich charts generally show maximum density and describe a management zone within which stand management objectives can be met. In the Knife Creek chart (Figure 6), the management zone is delimited with the proportion of maximum density taken from the literature. A minimum basal area for a given mean diameter is shown. For a given cohort in a multi-aged stand, this could be developed into residual density recommendations. In this way, adjustments to the residual basal area within the stand would recognize the mean diameter at the given location. This approach will help to avoid overstocking of small-diameter cohorts and understocking of large-diameter cohorts during stand marking.

Validation tests of the Gingrich chart are not conclusive because of the small plot area and the variable nature of the stands sampled. The tests showed, however, that a significant difference exists in basal area growth between understocked plots (according to the chart) and appropriately stocked or overstocked plots. When all plots were summarized by block, a significantly better basal area growth was evident on the appropriately stocked block compared to the other three blocks.

In comparing the chart to external data:

- the permanent sample plots with the best basal area growth rate were closest to appropriately stocking levels; and
- the spaced plots, with the best growth (anecdotal) were appropriately stocked according to the stocking chart.

There is, therefore, reason to cautiously employ the stocking chart on the Knife Creek block of the research forest, and to further investigate the applicability of the chart. Stocking limits should be revised as additional information becomes available.

Silviculturists should set uneven-aged stand structure goals on the basis of management objectives and site productivity. One of the most critical factors for silviculturists to control is stand density because the allocation of growing space is critical to attain stand structural goals. Little guidance on residual growing stock has been available, and silviculturists have, by necessity, used "rules-of-thumb."

This paper discusses the functional relationships between stand density, stocking, and stand growth, but does not describe mathematical relationships between growth and density. A periodic basal area growth rate of 4.2 m^2/ha per decade was calculated as an average for Knife Creek. This is considered a conservative estimate of potential growth given active management.

The use of Gingrich charts is proposed as a simple tool to guide decisions for residual growing stock. While it is not conclusive whether the chart drawn for Knife Creek has predictive value, it holds out some potential, and further validation work is required. Gingrich charts are easy to use, simple to calibrate, and can be used to describe the intended progression towards the stand structural goal.

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Site Preparation on Dry Grassy Sites in the Cariboo Forest Region

TERESA NEWSOME

INTRODUCTION

Poor seedling performance on dry grassy sites in the Sub-boreal Spruce (SBSdw) and Interior Douglas-fir (IDFdk) subzones resulted in establishment of a number of different trials in the Cariboo Forest Region. This paper is intended to be an operational summary of three trials. Table 1 provides details of the individual trial papers summarized here, the authors of the papers, the trial numbers, the subzones where the trials occurred, and the number of sites in each subzone.

Operational problems faced on these sites included cold injury, drought, vegetation competition, and cattle damage. In the older trials, stock quality may also have been a problem, especially for Douglas-fir, but stock quality has improved over the last 10 years. Cold injury has been observed on these sites as a result of growing-season frosts and through winter desiccation. Spittlehouse and Stathers (1990) found that growing-season frosts could occur every month during the growing season in these subzones. As well, low snowpack can result in desiccation of exposed portions of the seedling. If the air temperature warms to above freezing during the winter months, the frozen roots can not supply water to the respiring needles, which causes desiccation in the exposed portion of the tree (Lavender et al. 1990). Precipitation is low on these subzones, ranging from 300 to 750 mm per year, with approximately one-half falling during the growing season (Hope et al. 1991). These droughty conditions are compounded by grass competing with seedlings for moisture. Grass can also increase the frost problems by restricting air movement within the zone of standing grass (Stathers 1989).

Mechanical site preparation can alleviate some of these problems. A number of methods were tested in these three trials, including hand scarification,

TABLE 1 *A summary of the three trials*

Authors	Trial no.	Subzone	No. sites per subzone
Daintith and Newsome (1995)	EP 841.07	IDFdk4	1
		SBSdw2	1
Daintith et al. (1995)	SX 84503	SBSdw2	1
Konowalyk (1995)	EP 841.06	IDFdk3	2
		SBSdw1	1
		SBSdw2	1

TABLE 2 *Summary of site preparation treatments used in the three trials*

Site preparation treatment	Trials		
	EP 841.07	EP 841.06	SX 84503
No treatment		X	X
Hand scarification	X	X	X
Leno patch scarifier		X	
Disc trencher (passive)		X	
Ripper-tooth[a]	X	X	
Ripper plow		X	
V-plow (1 m)[b]	X		
V-plow (3 m)[c]		X	X
V-plow (1 m) and ripper-tooth[d]	X		

a The ripper-tooth used on EP 841.07 was winged.
b Creates 1 m wide continuous screef.
c Creates 3 m wide continuous screef and only used in the SBSdw subzone.
d The winged ripper-tooth was run down the middle of the path made by the 1-m V-plow.

mechanical patch scarification, and various forms of ripping, trenching, and plowing. A summary is provided in Table 2.

All of these site preparation treatments expose mineral soil in varying amounts. The 3-m V-plow exposes the most and the ripper-tooth, especially without a wing, exposes the least. By exposing mineral soil, the grass competition directly around the seedling is reduced, and the insulating vegetative layer—both the standing grass and duff layers—at the soil surface is eliminated. The result is an increase in moisture for the seedling and reduced temperature extremes at the surface. Removing the duff layer allows heat to be conducted from the surface into the soil, which cools the seedling during the day. At night the process is reversed: the soil re-radiates heat absorbed during the day, which warms the seedling. Removing the standing grass layer also reduces the risk of frost damage by increasing air exchange with the overlying air mass near the soil surface.

The other major effect from some of the treatments is to provide a trench into which the seedling is planted. This allows shading of the seedling/soil interface. It also provides a catchment area for any precipitation and allows the seedling roots to extend further into the soil profile where more moisture may be available. Both the ripper plow and the V-plow and ripper-tooth combination provided the most mineral soil exposure and also the benefits of trenching.

Microclimate data were collected for trial number EP 841.07 at the IDFdk4 site. Soil surface temperature, 15 cm air temperature, and 15 cm soil temperature were recorded on one block. The results show that soil surface temperatures were lowest on the ripping treatments and highest on the control. Soil temperatures taken at 15 cm soil depth were highest on the V-plow treatments and lowest on the control (Daintith and Newsome 1995).

A variety of stock types were used in the different trials (Table 3). Because it is more resistant to the climatic extremes, lodgepole pine generally has superior survival and growth compared to Douglas-fir in large openings in the IDFdk3 and IDFdk4 subzones. With appropriate stock and site preparation, Douglas-fir seedlings may achieve acceptable performance. Two different stock types were tested in two trials. The container stock, although smaller than the bareroot, is easier to handle, especially on dry sites. Interior spruce

TABLE 3 *Summary of stock types tested in the three trials*

Stock type	Trial		
	EP 841.07	EP 841.06	SX 84503
Douglas-fir (Fd)			
Bareroot 2+0 (BBR)	X		X
PSB 313[a] 1+0 (313)	X	X	X
Lodgepole pine (Pl)			
Bareroot 2+0	X		X
PSB 211 1+0 (211)	X	X	X
Interior spruce			
PSB 313 1+0		X	

a PSB 313 refers to plug styroblock with 3-cm top and 13-cm depth; the 211 refers to 2-cm top and 11-cm plug depth.

was only planted on the SBSdw sites in one trial. It is not a species usually planted on dry, grassy sites, and the data are not included in this paper.

Trial number EP 841.07 also tested the differences between cattle grazing and no cattle grazing by comparing all the treatments inside and outside a fenced area on both sites. The sites for the other trials received a varying amount of cattle grazing and in trial number EP 841.06 two blocks at one site were fenced.

RESULTS

Only survival and height results are given in this paper, as these are the most critical for operational staff. Each trial is summarized by species/stock type and by subzone, either SBSdw or IDFdk. For trial number EP 841.07, fencing and grazing results are included. Fifth-year data are presented for trial number EP 841.07 and tenth-year data for trial numbers EP 841.06 and SX 84503.

Lodgepole Pine

SBSdw Subzone Generally, seedling survival for pine container stock in the SBSdw subzone was good (Table 4). The no site preparation treatment for trial numbers EP 841.06 and SX 84503 produced the lowest survival results for the container stock, suggesting that some form of site preparation did improve survival. Bareroot stock survival was lower than container stock and treatments involving ripping improved survival rates.

Significant seedling height differences were found on the older trials, EP 841.06 and SX 84503 (Table 5). On these trials, most mechanical site preparation treatments increased seedling height. Except for the Pl 211 stock type on the ripped treatment, data from EP 841.07 showed the same trends as the older trials, although the results were not significantly different. The Pl 211 seedlings on the grazing treatment were generally smaller than those on the fenced section, except on the ripper-tooth treatment. Conversely, the larger bareroot stock did not appear adversely affected.

TABLE 4 *Percent survival of pine seedlings in the SBSdw subzone in three trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)	SX 84503 (10th yr)	
	Fenced		Grazed				
Site preparation	Pl 211	Pl BBR	Pl 211	Pl BBR	Pl 211	Pl 211	Pl BBR
No treatment					70	70	59
Hand screef	97	63	95	72	85	78	73
Leno					87		
Disc trench					84		
Ripper-tooth	99	82	96	84	86		
Ripper plow					87		
V-plow (1 m)	100	62	91	71			
V-plow (3 m)					90	88	58
V-plow (1 m) and ripper-tooth	99	85	93	86			

TABLE 5 *Height of pine seedlings in the SBSdw subzone in three trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)	SX 84503 (10th yr)	
	Fenced		Grazed				
Site preparation	Pl 211	Pl BBR	Pl 211	Pl BBR	Pl 211	Pl 211	Pl BBR
No treatment					276a[a]	321a	275a
Hand screef	90a	106a	77a	104a	270a	314a	285a
Leno					324b		
Disc trench					306ab		
Ripper-tooth	83a	121a	99a	119a	328b		
Ripper plow					322b		
V-plow (1 m)	107a	116a	96a	126a			
V-plow (3 m)					343b	406b	378b
V-plow (1 m) and ripper-tooth	106a	122a	95a	124a			

a Observations followed by the same letter in the same column are not significantly different ($p < 0.05$).

IDFdk Subzone Seedling survival in the 10-year-old trial, EP 841.06, was improved by any kind of site preparation, but was improved the most by some form of trenching (Table 6). For the 5-year-old trial, trends were not so clear. Survival was over 90% for the Pl 211 stock except for the V-plow treatment in the grazed section, suggesting that possible cattle damage resulted in mortality. The bareroot survival was more variable, with the hand-screef and V-plow treatments having lower survival than the two ripping treatments.

Seedling height differences were also more clearly defined on the older trial (Table 7). The two ripper treatments significantly increased seedling height compared to screefing or no treatment, and mechanical screefing (Leno) was better than hand screefing. In the 5-year-old trial, no statistical differences were found between site preparation treatments on the fenced areas. However, site preparation, especially the ripper and V-plow treatment, resulted in taller bareroot seedlings. On the grazed treatment, the results were similar to those of trial number EP 841.06. Seedlings were significantly taller on the two ripped treatments compared to the hand screefing, and Pl 211 stock was taller on the V-plow treatments. Strong trends were found when comparing seedling height between grazed and fenced treatments on

TABLE 6 *Percent survival of pine seedlings in the IDFdk subzone in two trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)
	Fenced		Grazed		
Site preparation	**Pl 211**	**Pl BBR**	**Pl 211**	**Pl BBR**	**Pl 211**
No treatment					51
Hand screef	98	73	95	72	70
Leno					73
Disc trench					80
Ripper-tooth	100	90	93	84	87
Ripper plow					82
V-plow (1-m)	97	75	78	69	
V-plow (1-m) and ripper-tooth	99	89	95	78	

the same site preparation treatment. On the grazed areas, hand screefing resulted in smaller seedlings; conversely, both treatments involving ripping produced taller seedlings. The two ripping treatments may have discouraged cattle activity in the rips, and reduced grazing around the rips improved seedling height. The cattle may have damaged the seedlings outside a rip, which caused reductions in height.

Douglas-fir

Subzone SBSdw Survival varied by stock type and trial (Table 8). In trial number EP 841.07, seedling survival was high for all treatments and stock types except for Fd 313 on the grazed V-plow treatment. Overall, 10-year survival was poor in trial number EP 841.06; however, the best survival was found on the Leno, ripper-plow, and 3-m V-plow treatments. Survival in the SX 84503 trial was also the highest on the 3-m V-plow treatment. The results of the older trials indicate that site preparation treatments that reduce vegetation competition may produce the best results in this subzone. Conversely, the results from EP 841.07 suggest that site preparation may not affect survival in most cases.

Clear, significant differences in seedling growth occurred only in the SX 84503 trial. The seedlings on the 3-m V-plow treatment were significantly taller for both stock types (Table 9). Also, Pl 211 stock was taller compared to

TABLE 7 *Height (cm) of pine seedlings in the IDFdk subzone in two trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)
	Fenced		Grazed		
Site preparation	**Pl 211**	**Pl BBR**	**Pl 211**	**Pl BBR**	**Pl 211**
No treatment					130c[a]
Hand screef	60a	68a	50d	66c	151c
Leno					181b
Disc trench					209ab
Ripper-tooth	60a	75a	70b	87ab	245a
Ripper plow					233a
V-plow (1 m)	64a	80a	62c	79bc	
V-plow (1 m) and ripper-tooth	64a	92a	83a	97a	

a Observations followed by the same letter in the same column are not significantly different ($p < 0.05$).

TABLE 8 *Percent survival of Douglas-fir seedlings in the SBSdw subzone in three trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)	SX 84503 (10th yr)	
	Fenced		Grazed				
Site preparation	Fd 313	Fd BBR	Fd 313	Fd BBR	Fd 313	Fd 313	Fd BBR
No treatment					20	79	35
Hand screef	93	93	80	91	29	78	38
Leno					54		
Disc trench					46		
Ripper-tooth	91	95	89	87	39		
Ripper plow					61		
V-plow (1 m)	97	93	65	82			
V-plow (3 m)					59	88	69
V-plow (1 m) and ripper-tooth	91	79	76	83			

TABLE 9 *Height (cm) of Douglas-fir seedlings in the SBSdw subzone in three trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)	SX 84503 (10th yr)	
	Fenced		Grazed				
Site preparation	Fd 313	Fd BBR	Fd 313	Fd BBR	Fd 313	Fd 313	Fd BBR
No treatment					87ab[a]	152a	137a
Hand screef	41a	59a	39a	62a	85ab	157a	100a
Leno					101ab		
Disc trench					89ab		
Ripper-tooth	43a	64a	46a	54a	78b		
Ripper plow					78b		
V-plow (1 m)	52a	53a	35a	56a			
V-plow (3 m)					109a	173b	162b
V-plow (1 m) and ripper-tooth	46a	61a	42a	60a			

a Observations followed by the same letter in the same column are not significantly different ($p < 0.05$).

the bareroot stock, even though the bareroot stock was taller at time of planting. Seedling height results for the EP 841.06 trial were probably influenced by poor survival. Treatments with higher survival may be carrying more poor seedlings, which results in a lower mean height compared to treatments where the poorer seedlings have already died. If both the survival and total seedling height results are considered, the Leno and 3-m V-plow treatment produced the tallest seedlings combined with the highest survival. The EP 841.07 trial produced no significant differences between site preparation methods, although Fd 313 on the grazed 1-m V-plow treatment has the shortest seedlings and the poorest survival.

IDFdk subzone Extreme climate conditions on the IDFdk sites often result in poor performance of Douglas-fir. In the EP 841.06 trial, the only seedlings surviving in large enough quantities to monitor were in the fenced section of the Em Fire. Results given in Table 10 are for two of the six blocks established. Trenching improved survival compared to scarification on these two blocks. Conversely, Douglas-fir survival in the EP 841.07 trial was very good

TABLE 10 *Percent survival of Douglas-fir seedlings in the IDFdk subzone in two trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)
	Fenced		Grazed		
Site preparation	**Fd 313**	**Fd BBR**	**Fd 313**	**Fd BBR**	**Fd 313[a]**
No treatment					6
Hand screef	71	95	47	83	16
Leno					8
Disc trench					45
Ripper-tooth	79	99	68	97	46
Ripper plow					56
V-plow (1 m)	71	99	32	61	
V-plow (1 m) and ripper-tooth	89	96	72	95	

a Only two blocks in the fenced portion of the Em Fire were reported because Douglas-fir survival was very low on any grazed block, including the Axe Lake site.

except for the grazed sections on the 1-m V-plow treatment for both stock types and the hand screefing treatment for Fd 313 stock. Stock quality and/or planting techniques probably contributed to the differences in results between the two trials.

Site preparation treatments produced differences in seedling height for both trials (Table 11). The trenching treatment produced taller seedlings in the EP 841.06 trial, but the data were not analyzed because of low survival. Significant growth differences were found in the EP 841.07 trial for the bareroot stock only. Within the fenced treatment, all site preparation methods improved seedling height, while in the grazed areas only the two ripping treatments increased height compared to hand screefing. Although not significant, the same trends were observed for the smaller Fd 313 stock type. Frost-damaged seedlings were evident in both trials, which would have inhibited height growth. In some cases, the frost damage was so extreme that site preparation benefits would have been minimized.

TABLE 11 *Height (cm) of Douglas-fir seedlings in the IDFdk subzone in two trials*

	EP 841.07 (5th yr)				EP 841.06 (10th yr)
	Fenced		Grazed		
Site preparation	**Fd 313**	**Fd BBR**	**Fd 313**	**Fd BBR**	**Fd 313[a]**
No treatment					73
Hand screef	26a[b]	31b	26a	36b	57
Leno					62
Disc trench					109
Ripper-tooth	33a	42a	34a	48a	115
Ripper plow					130
V-plow (1 m)	32a	43a	27a	33b	
V-plow (1 m) and ripper-tooth	34a	48a	36a	52a	

a PSB 313 refers to plug styroblock with 3-cm top and 13-cm depth; the 211 refers to 2-cm top and 11-cm plug depth.

b Observations followed by the same letter in the same column are not significantly different ($p < 0.05$).

Species

Pine in both subzones was taller and in superior condition compared to Douglas-fir. This difference was greater in the IDFdk because of the very poor condition of most Douglas-fir seedlings in this subzone.

Stock Type

Pine container-stock survival was superior in both subzones. Bareroot stock was taller at time of planting and this height advantage was maintained in the EP 841.07 trial, but not in the SX 84503.

Stock type differences for Douglas-fir were very inconclusive. In the SBSdw EP 841.07 trial, survival was high and fairly consistent across all stock types, and the bareroot stock maintained its height advantage. In the SX 84503 trial, the container stock showed greater height and survival than the bareroot stock. In the EP 841.06 trial, container stock survival and growth was very poor. For some stock types, the seedling performance was quite uniform across all site preparation and fencing treatments. The different results between stock types might be attributed to stock quality and/or handling.

In the IDFdk, Douglas-fir bareroot stock was superior to the container stock, both in height and survival. Larger stock may perform better in this extreme climate.

Although bareroot stock generally has produced taller seedlings and in some cases superior survival, it is not a recommended stock type because of handling difficulties. More stock type choices now exist that are easier to handle and plant. The trial results emphasize that in some cases larger stock, especially for Douglas-fir, may improve plantation growth and survival.

Grazing (only for EP 841.07)

In the IDFdk, Douglas-fir seedling survival was reduced by grazing on the V-plow and hand-screef treatments. The effects on pine survival were not as strong, but seedling height was improved by grazing on the two ripping treatments and was lower on the grazed, hand-screef treatment. Therefore, grazing can cause positive or negative effects, depending on other management techniques.

In the SBSdw, grazing did not produce the differences that were found in the IDFdk, except for Douglas-fir container stock. This stock type had the smallest seedlings with the poorest survival on the grazed V-plow treatment.

The SBSdw has more moisture and perhaps a lower grazing pressure, which resulted in the differences between the two subzones.

Site Preparation

On grazed areas in the IDFdk, the disc trencher, ripper-tooth, ripper-tooth and V-plow, and the ripper plow all improved seedling height and/or survival compared to the other site preparation treatments for both species. On fenced treatments, trends in most of the data indicated that any continuous linear site preparation treatment will increase seedling height and, in one case, seedling survival.

In the SBSdw, ripping or trenching treatments sometimes improved and consistently produced high pine survival. Any kind of mechanical site preparation improved pine height, although differences for the EP 841.07 trial's fifth-year data were not significant.

Site preparation options in the SBSdw were not as clear for Douglas-fir. Except for the SX 84503 trial, where the 3-m V-plow significantly improved seedling height and survival, the poor performance of Douglas-fir makes recommendations for site preparation methods difficult.

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Regeneration of a Dry, Grassy Site in the Interior Douglas-fir Zone

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INTRODUCTION

Douglas-fir and lodgepole pine forests in the dry belt of the Interior Douglas-fir (IDF) biogeoclimatic zone are intensively used for many reasons, including timber production, cattle production, wildlife habitat, and recreation activities. Because of easy access, most of these stands have been at least partially cut. Douglas-fir–dominated forests have been harvested using various silviculture systems, including clearcutting, diameter-limit cutting, faller's selection, or some modification of shelterwood (Vyse et al. 1991). Lodgepole pine–dominated forests, in contrast, have been harvested almost exclusively using the clearcut method. Conifer establishment following harvest, especially clearcutting, has been difficult on these sites. Some of the factors contributing to regeneration failure include inadequate seed supply, poor planting stock, winter temperature extremes, summer drought, summer frost, and competition with pinegrass (*Calamagrostis rubsecens*) for resources, particularly soil water (Newsome et al. 1991). According to the history records, planting of large stock (PSB 415 versus the smaller PSB 313) over the past 10 years has greatly improved survival of both Douglas-fir (91% survival for PSB 415 versus 67% for PSB 313) and lodgepole pine (91% versus 80%). Survival of lodgepole pine and Douglas-fir exceeds 75% in the IDFdk1, IDFdk2, and IDFdm1 subzones, but averages only 40% for Douglas-fir and 62% for lodgepole pine in the harsher IDFxh subzone.

Pinegrass, the dominant understorey species on circum-mesic IDF and dry Montane Spruce (MS) zone sites (Lloyd et al. 1990), has a strong influence on the severity of summer drought and frost in forest openings (Nicholson 1989; Stathers 1989). Pinegrass usually increases dramatically in cover on sites where large openings (i.e., more than 1 tree length) have been created by harvest. It develops an extensive system of roots and rhizomes which penetrate throughout the soil profile and forms a thick sod in the upper 10 cm. Rapid growth of the root system early in the growing season and the ability to transpire under high drought stress gives pinegrass a competitive advantage over conifer seedlings for exploiting scarce soil water (Nicholson 1989). The low, dense canopy of pinegrass also increases the risk of frost damage to seedlings. The grass reduces heat stored in the soil during the day and creates a stagnant, cold, frost-prone air layer at night (Stathers 1989). The ability of pinegrass to compete strongly with conifers for water and to increase the risk of frost damage has widely contributed to poor plantation performance in the drier subzones of the IDF and MS (Mather 1985; Newsome et al. 1990).

In several studies, the removal of pinegrass by either chemical or mechanical methods resulted in significant increases in conifer seedling survival and growth (Haeussler et al. 1990). On a flat, pinegrass-dominated clearcut in the IDFdk subzone near Williams Lake, B.C., for example, Nicholson (1989) found that removal of pinegrass using glyphosate increased soil temperatures, increased soil water availability, and reduced frost damage to seedlings. Removal of pinegrass around a seedling to a radius of 1.25 m was most beneficial for improving seedling condition and survival. In another study, Black et al. (1991) compared mechanical and chemical treatments on three flat, pinegrass-dominated sites in the IDFdk, MSxk, and Engelmann Spruce–Subalpine Fir (ESSFxc) subzones near Kamloops, B.C. They found that scalping, ripping, and herbicide treatments conserved soil water, but that only scalping and ripping, which removed the forest floor, increased soil temperature and reduced frost damage. Black et al. (1991) determined that the primary cause of mortality was repeated frost damage during the growing season and the primary factor contributing to poor growth was low soil water availability. They recommended that the forest floor be scalped to at least 1 m around a seedling to maximize water availability and to 2–3 m to minimize frost damage. Mechanical treatments that are relatively severe, such as those tested by Black et al. (1991), remove pinegrass roots and surface organic layers and can retard re-invasion for 3–4 years. Light mechanical disturbance, in contrast, results in re-invasion of pinegrass within one season (Haeussler et al. 1990).

Removal of the forest floor during mechanical site preparation can have severe effects on soil nutrient capital. On the same sites used by Black et al. (1991), Hope (1991) demonstrated that scalping reduced total nitrogen by 40–60%, extractable phosphorus by 50%, and extractable sulphur by 20–30% in the forest floor and mineral soil. After 3 years, reductions of most foliar nutrients, particularly boron, were evident (Hope 1991), and after 5 years the imposed nutrient deficiencies resulted in a decline in seedling growth (Black et al., unpublished data). Other long-term studies and modelling efforts have demonstrated that forest floor removal can have important effects on productivity in the long term (Skinner et al. 1988; Kimmins et al. 1990).

Removal of the forest floor reduces not only soil nutrient capital, but can also affect soil structure and the community of soil organisms (Harvey et al. 1980; Amaranthus et al. 1990). Organic matter plays a critical role in forming and maintaining soil structure. The forest floor and mineral soil are home to various micro-organisms, including ectomycorrhizae, rhizobacteria, protozoa, amoebae, nematodes, and micro-arthropods, which play critical roles in maintaining the health of the plant/soil system (Perry et al. 1989). Protecting rhizosphere micro-organisms is particularly critical in dry, cold environments, such as the dry-belt IDF, where resources are in short supply. These micro-organisms play an important role in improving resource availability through gathering and fixing nitrogen, and maintaining soil structure (Amaranthus and Perry 1987). The presence of vegetation on a site can either stimulate or inhibit ectomycorrhizae colonization of conifer seedlings after harvesting. Some grass species, in particular, can inhibit ectomycorrhizal formation (Amaranthus and Perry 1987; Timbal et al. 1990).

The usual site preparation tools used on flat, pinegrass sites, such as disc trenchers, ripper plows, and V-plows (Newsome et al. 1990), cannot be used on slopes steeper than 35%. Such extreme treatments may not be necessary on steep sites, however, since frost is likely less frequent and severe than on flat ground because cold air is rapidly drained to lower ground (Stathers

1989). As a result, site preparation tools on steep, grassy slopes include the much less destructive array of hand screefers, power screefers, excavators, mulch mats, and ground foliar chemical application. Applying ground foliar chemicals has resulted in good control of pinegrass, and can effectively improve conifer performance, even on sites where frost risk is high (Nicholson 1989). Broadcast applications of glyphosate at a rate of 2.14 kg ai/ha have resulted in good control (Heineman and Simard 1996), particularly when applied during the period of most active growth (May and June) (Lloyd and Stathers 1992). Hexazinone also effectively controls pinegrass (Heineman and Simard 1996), but its use is limited by steep slopes and coarse-textured soils (Otchere-Boateng and Herring 1990).

Here we report on an experiment established 6 years ago on a steep, dry, grassy site in the IDFdk1 variant. The experiment provides an opportunity to examine the effects of different severities of site preparation on seedling productivity, and associated microclimate and soil biology. The specific objectives of the study were to determine the effects of pinegrass removal, with and without forest floor removal, on:

1. performance of planted lodgepole pine seedlings;
2. levels of environmental resources and conditions; and
3. richness and diversity of ectomycorrhizal fungi.

METHODS

Site Description

The experiment is located in two openings in the Murray Creek drainage, approximately 20 km northwest of Spences Bridge. The two openings, one on the west side and one on the east side of Murray Creek, occur at 1250–1300 m elevation and occupy steep (40–55%), middle slopes of uniform topography. The sites are submesic to mesic and classified as IDFdk1/04–01 (Lloyd et al. 1990). The dominant landform is morainal blanket and the lithology is granodiorite. The soils are generally deep and well drained, and soil texture is loam to silt loam. Soils are classified as Dystric Brunisol (Canadian Soil Survey Committee 1978). The humus layer ranges in depth from 1 to 10 cm, and is classified as an Orthihemimor (Klinka et al. 1981). The climate of the site is characterized by warm, dry summers, a relatively long growing season, and cool winters with low to moderate snowfall. Substantial moisture deficits occur throughout the growing season. Lloyd et al. (1990) estimate a mean annual precipitation of 438 mm for the IDFdk1, with mean snowfall of 155 cm, mean annual temperature of 3.4° C, mean growing season temperature of 11.1° C, and frost-free period of 86 days.

Before harvesting in the summer of 1990, the stands were dominated by Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and lodgepole pine (*Pinus contorta* var. *latifolia*). The harvesting system used was clearcutting with single-tree or patch reserves. When the experiment was initiated in 1991 neither of the two openings had been site prepared or planted, and a cover of pinegrass was developing.

Experimental Design and Treatments

Two aspect treatments were assigned to whole plots and five site preparation treatments assigned to subplots in a split-plot treatment structure. The site preparation treatments were replicated three times on each aspect in a randomized complete-block design. The blocks were selected based on slope position, slope, soil texture, and the presence or absence of nitrogen-fixing shrubs (*Alnus viridis* ssp. *sinuata* and *Shepherdia canadensis*). Within blocks, site preparation treatments were randomly assigned to 30 × 30 m treatment units (plots). The site preparation treatments included a control, and two patch sizes (75 × 75 cm and 150 × 150 cm) where pinegrass was removed, with or without forest floor removal. An excavator was used to create patch treatments where both pinegrass and forest floor were removed, and spot ground foliar glyphosate (2.14 kg ai/ha) was used where only pinegrass was removed. The treatments are summarized below:

- Whole plots (aspect):
  - W = west
  - E = east
- Subplots (site preparation):
  - E_0H_0 = No pinegrass removal (control)
  - E_1 = Pinegrass and forest floor removed in a 75 × 75 cm patch using an excavator.
  - E_2 = Pinegrass and forest floor removed in 150 × 150 cm patch using an excavator.
  - H_1= Pinegrass removed in a 75 × 75 cm patch using ground foliar glyphosate.
  - H_2= Pinegrass removed in a 150 × 150 cm patch using ground foliar glyphosate.

Lodgepole pine seedlings were planted into the patches in the spring of 1992. Each treatment unit was planted with 121 seedlings, arranged in an 11 × 11 grid at 2.5 m square spacing.

Seedling Measurements

Survival and vigour were assessed for all planted seedlings at the end of each growing season between 1992 and 1995. Seedling size (height, stem diameter, crown diameter) was measured on the inner 81 seedlings in each treatment plot, and stem volume and height:diameter ratio were calculated.

Survival and vigour were compared among treatments using frequency tables and chi-square tests of independence. Growth variables were compared among treatments using repeated measures analysis, where multivariate analysis (MANOVA) was first performed to test treatment effects over time, and yearly treatment effects were then tested using univariate analysis (ANOVA) (Meredith and Stehman 1991). The growth variables were not transformed because their distributions met the assumptions of nonparametric statistics and repeated measures analysis. For ANOVAs, means were separated using Bonferroni's multiple comparison test ($\alpha = 0.05$). Planned contrasts were performed to determine whether patch size, pinegrass removal, or forest floor removal were the most important determinants of growth differences. The planned contrasts tested were:

1. Is no pinegrass removal different from any pinegrass removal, with or without forest floor removal?
   Control (E_0H_0) versus any treatment (E_1, E_2, H_1, H_2)
2. Is pinegrass removal without forest floor removal different from pinegrass with forest floor removal?
   Treatment H_1, H_2 versus E_1, E_2
3. Is large patch size different from small patch size?
   Treatment E_2, H_2 versus E_1, H_1

Environment Measurements

Environmental conditions were recorded in one block on each of the east and west aspects using CR10 dataloggers and multiplexers (Campbell Scientific). The variables measured at each central location were rainfall, air temperature, and solar irradiance. Rainfall was collected in a tipping bucket rain-gauge (Model TE525 Texas, Campbell Scientific). Air temperature and relative humidity were monitored at 1.5 m height in a Stevenson Screen using a Model 207 Temperature and RH Probe (Campbell Scientific). Solar irradiance was monitored at 1.5 m height on top of the Stevenson Screen using a Model LI-200SA Pyranometer (LI-COR Inc.).

Soil and air temperatures were monitored in one replication of each treatment. Temperature was monitored using thermistors (Model 107, Soilcon Laboratories Ltd.) attached to the dataloggers. Thermistors were installed in each treatment plot, and thermocouples buried at 0.05 and 0.20 m depths in the soil and one at 0.15 m height above the ground surface. Soil water was measured using gypsum soil moisture blocks (Soilcon Laboratories Ltd.) attached to the dataloggers. The moisture blocks were buried 0.20 m beneath the surface in the mineral soil.

Soil Nutrients

A baseline analysis of mineral soil and forest floor nutrients was conducted in the fall of 1991 before treatment. A second analysis was done in the fall of 1997 to determine the effects of pinegrass and forest floor removal on nutrient capital and availability. In September 1991, mineral soil was collected to 15 cm deep using a standard oakfield core. In each treatment unit, samples were collected at 25 points and then combined to form five composite samples. In addition, five forest floor samples (LFH composite) were collected from each treatment unit using a 20 × 20 cm template. The mineral soil samples were cleaned of large stones and woody material, and sieved to obtain the < 2-mm fraction. Forest floor samples were ground with a Wiley Mill. All samples were analyzed at the Forest Research Laboratory in Victoria. Nutrient analyses performed included pH (H_2O and $CaCl_2$), total nitrogen (semimicro-Kjeldahl), mineralizable nitrogen (following anaerobic incubation), total carbon (Leco induction), and total sulphur (Leco induction).

Mineral soil bulk density was sampled at five locations on each aspect. Soil, including all roots and coarse fragments, was excavated from a 10-cm square to a depth of 30 cm. The hole was lined with a plastic bag and filled with water to determine volume (V_{tot}). The sample was ovendried at 105° C and weighed (M_{tot}). Roots and other organic debris (M_r), and coarse fragments (> 2 mm) (M_{cf}) were removed, dried, and weighed. The bulk density of the fine (< 2 mm) fraction (D_f) was calculated as $[(M_{tot} - M_{cf} - M_r)/V_{tot}]$ (after Macadam 1987). Bulk density and soil nutrient concentrations were used to determine soil nutrient capital. Soil nutrient capital, mineralizable N, C:N ratio, and pH were compared among aspects and treatments using two-way ANOVA.

Ectomycorrhizal Diversity

Ectomycorrhizal diversity was measured in the control and large excavator- and herbicide-treated patches on the east aspect over a 3-year period beginning at plantation establishment. Ten seedlings were randomly selected from border areas of each treatment plot in September of 1992, 1993, and 1994. In 1992, the entire seedling was removed, and in 1993 and 1994, major lateral roots totalling approximately 50 cm in length were removed from each seedling. The side branches were removed from the major lateral roots and cut into 2-cm fragments. All of the live mycorrhizal root tips from randomly selected 2-cm root fragments were sampled until 200 (1992 and 1993) or 100

(1994) tips had been examined from each seedling. The mycorrhizal root tips were examined under a dissecting microscope and a compound microscope with a 40× oil immersion objective. The ectomycorrhizae were then categorized into types and identified to the smallest taxon possible. Ectomycorrhizal fungal diversity were calculated using the Shannon-Weaver diversity index. Ectomcyorrhizal richness and diversity were compared among treatments using one-way ANOVA.

RESULTS AND DISCUSSION

Seedling Survival and Growth

Most seedling mortality occurred during the first two growing seasons following planting, and was greatest in the control (18%) and small herbicide patches (19%) (Figure 1). Mortality was predominantly associated with planting error, frost, and drought. Mortality during the initial 2 years was very low (< 1%) in the large patches where pinegrass was removed either alone (herbicide), or along with the forest floor (excavator). After 2 years, survival continued to be greater in most patch treatments compared to the untreated control: it was greater than 97% in large herbicide and mechanically prepared patches, compared with only 78% in the control. Likewise, seedling vigour was best among the large herbicide-treated patches and poorest among those in the control. Survival tended to be greater on the west aspect than the east aspect, probably because of greater soil water availability.

Site preparation treatments affected all lodgepole pine growth variables over the 4-year measurement period; in contrast, no aspect effect (manova $p < 0.05$, test results not shown) was evident. Any kind of site preparation treatment improved seedling growth compared with the control (Table 1). However, the greatest improvements occurred in the large herbicide patch treatment, where seedling height, stem diameter, crown diameter, and stem volume were larger than in any other treatment by the end of the second growing season. Seedling diameter and volume increases in the excavator-

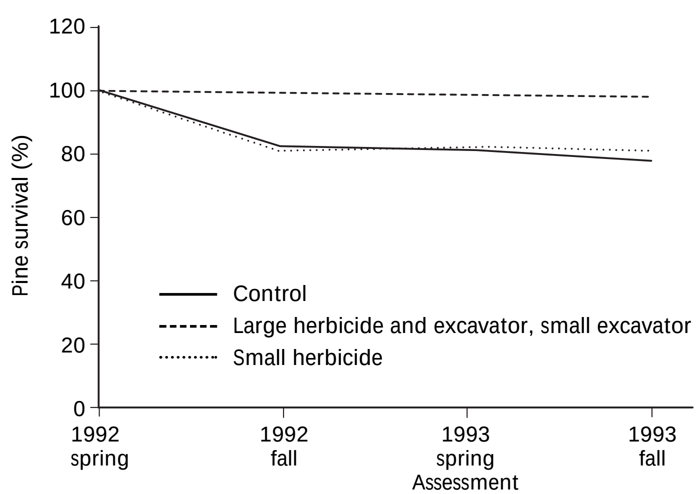

FIGURE 1 *Comparison of mean seedling survival among site preparation treatments between the spring of 1992 (immediately following planting) and the fall 1993 (first 2 years following planting).*

TABLE 1 *Comparison of mean height, stem diameter, height:diameter (H:D) ratio, crown diameter, and stem volume among site preparation treatments for each measurement year. Means within a year followed by different letters indicate a significant difference at* $\alpha = 0.05$ *in a one-way ANOVA (n = 6).*

Year	Control	Small excavator	Large excavator	Small herbicide	Large herbicide	*p*-value	Standard error[c]
Height (cm)							
1992	13.89	14.90	14.94	14.63	15.18	0.2527	0.39
1993	32.09	31.10	32.21	33.37	35.19	0.0385	0.89
1994	44.60 a	46.36 a	49.99 a	47.82 a	55.68 b	0.0006	1.37
1995	55.15 a	58.08 a	59.06 a	61.00 a	73.08 b	0.0027	2.23
Stem diameter (mm)							
1992	2.82	2.74	2.91	2.86	2.85	0.3951	0.06
1993	5.64 a	6.25 ab	6.38 abc	6.67 bc	7.17 c	0.0016	0.35
1994	7.75 a	9.17 b	9.56 b	9.50 b	11.08 c	int[a]	0.25
1995	9.85 a	12.30 b	12.95 b	12.37 b	14.76 c	0.0001	0.47
H:D ratio							
1992	5.00	5.54	5.19	5.21	5.37	0.2747	0.16
1993	5.79 a	5.07 b	5.15 ab	5.09 b	5.02 b	0.0130	0.13
1994	5.80 a	5.10 b	5.29 b	5.15 b	5.10 b	0.0028	0.07
1995	5.72 a	4.79 b	4.70 b	5.00 ab	5.03 ab	0.0051	0.17
Crown diameter (cm)							
1992	5.16	6.52	6.00	5.78	5.80	0.4600	0.49
1993	11.39 a	14.71 ab	15.83 ab	14.61 ab	16.54 b	0.0323	0.98
1994	17.06 a	23.12 b	25.16 b	23.48 b	29.63 c	int[a]	0.82
1995	24.70 a	35.86 b	40.55 b	38.44 b	48.82 c	int[a]	1.77
Stem volume (cm^3)[b]							
1992	0.46	0.46	0.51	0.48	0.50	0.4249	0.02
1993	4.36 a	5.36 ab	5.78 abc	6.57 bc	7.67 c	0.0039	0.77
1994	12.22 a	17.95 ab	20.90 b	20.68 b	31.35 c	0.0001	1.67
1995	25.42 a	42.10 ab	46.69 b	46.68 b	70.48 c	0.0003	4.79

a int = interaction term (aspect × site preparation treatment) was signficant.
b stem volume = (height/2) × π (stem diameter/2)^2.
c standard error applies to all treatment means.

treated patches lagged behind those in the herbicide-treated patches by 1 year (occurred in the second versus first year following treatment), and seedling height increases had occurred only in the large herbicide-treated patches by the end of the measurement period.

The planned contrasts showed that patch size and pinegrass removal were the most important determinants of lodgepole pine growth differences (Table 2). The following conclusions were reached about pine stem diameter response:

1. any site preparation treatment was better than no treatment;
2. large patches were better than small patches; and
3. herbicide treatments (where pinegrass alone was removed) were better than excavator treatments (where pinegrass, as well as forest floor, were removed).

TABLE 2 *Planned contrasts for mean height, stem diameter, height:diameter ratio, crown diameter, and stem volume using one-way ANOVA for each year. Data for 1992 (pre-treatment) not shown because no significant treatment effects existed that year.*

	Height (cm)	Stem diameter (cm)	Height:diameter ratio	Crown diameter (cm)	Stem volume (cm^3)
Contrast: Is any pinegrass removal different from no pinegrass removal? (E_1, E_2, H_1, H_2 versus E_0H_0)					
1993 means	33.1 vs 31.9	6.65 vs 5.72	5.1 vs 5.7	15.5 vs 11.8	6.4 vs 4.5
p-value	*NS*[a]	*0.0007*	*0.0011*	*0.0046*	*0.0028*
1994 means	50.0 vs 44.6	9.82 vs 7.75	5.2 vs 5.8	25.3 vs 17.1	22.7 vs 12.2
p-value	*0.0017*	*0.0001*	*0.0002*	*0.0001*	*0.0001*
1995 means	62.8 vs 55.1	13.10 vs 9.88	4.9 vs 5.7	40.9 vs 24.7	51.6 vs 25.6
p-value	*0.0115*	*0.0001*	*0.0006*	*0.0001*	*0.0002*
Contrast: Is pinegrass removal with forest floor removal different from pinegrass without forest floor removal? (E_1, E_2 versus H_1, H_2)					
1993 means	31.7 vs 34.5	6.32 vs 6.98	5.1 vs 5.0	15.3 vs 15.8	5.6 vs 7.3
p-value	*0.0071*	*0.0028*	*NS*	*NS*	*0.0031*
1994 means	48.2 vs 51.7	9.36 vs 10.28	5.2 vs 5.1	24.1 vs 26.6	19.4 vs 26.0
p-value	*0.0090*	*0.0038*	*NS*	*0.0192*	*0.0012*
1995 means	58.6 vs 67.1	12.68 vs 13.58	4.7 vs 5.0	38.2 vs 43.6	44.4 vs 58.9
p-value	*0.0039*	*0.0235*	*NS*	*0.0054*	*0.0034*
Contrast: Is large patch size different from small patch size? (E_2, H_2 versus E_1, H_1)					
1993 means	33.7 vs 32.5	6.78 vs 6.53	5.1 vs 5.1	16.2 vs 14.8	6.7 vs 6.1
p-value	*NS*	*NS*	*NS*	*NS*	*NS*
1994 means	52.8 vs 47.1	10.32 vs 9.33	5.2 vs 5.1	27.4 vs 23.3	26.1 vs 19.3
p-value	*0.0006*	*0.0026*	*NS*	*0.0011*	*0.0010*
1995 means	66.1 vs 59.6	13.85 vs 12.35	4.9 vs 5.0	44.7 vs 37.1	58.5 vs 44.8
p-value	*0.0162*	*0.0022*	*NS*	*0.0008*	*0.0046*

a NS = not significant at $\alpha = 0.05$.

Seedling Microenvironment

The Murray Creek site was climatically harsh, with hot days, cold nights, and frosts that were potentially damaging to seedlings (< -4° C) throughout the growing season. In addition, relative humidity was low during the daytime (20–50%) and rain-free periods of 3–4 weeks were common during the summer months (data not shown). During those periods, soil-water potentials would commonly fall to levels stressful to seedlings (< -15 MPa). These conditions were suitable to induce stomatal closure, reduce net photosynthesis, and possibly affect growth. Precipitation was lower on the east aspect than the west aspect, which corresponded with lower soil water potentials.

Removal of pinegrass, either with or without forest floor removal, increased the minimum air temperature at seedling height (data not shown). As a result, fewer nights fell below -4° C where pinegrass was removed than in the control, reducing risk of frost damage to seedlings (Figure 2). The occurrence of night-time frost was lowest in the large patches, but no further improvements occurred when forest floor was removed along with the pinegrass. In addition to decreasing night-time frost incidence, pinegrass and forest floor removal in large patches also increased average soil temperature (5 cm) above control values (Figure 3), thereby improving conditions for

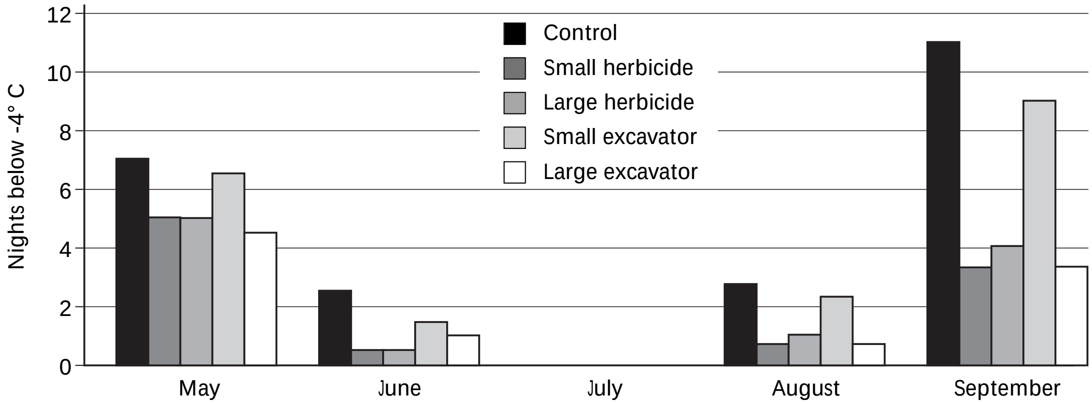

FIGURE 2 *Comparison of number of nights where air temperature (15 cm) fell below -4°C among site preparation treatments during the 1994 growing season.*

water uptake, soil biological activity, net photosynthesis, and growth. In contrast to frost incidence, there was added benefit to soil temperature by removing forest-floor material along with the pinegrass. Soil-water potentials were commonly higher in herbicide- and excavator-treated patches than in the control (Figure 4), but this varied from month to month and year to year. In summary, removal of pinegrass in large patches increased minimum air temperatures, decreased incidence of frost, increased soil temperature, and decreased soil water stress. Removal of forest floor along with the pinegrass further improved soil temperatures, but did not consistently improve the other microclimatic conditions.

Soil Nutrients

The baseline soil nutrient analysis showed that no differences in soil nutrient concentration or capital existed among the site preparation treatments. This result will help to detect treatment effects 5 years after treatment. However, concentration and capital did differ between aspects for all nutrients tested (Table 3). Total C, N, and S, and the C:N ratio were higher, whereas mineralizable N and pH were lower on the western than the eastern aspect. The western aspect also is higher in elevation, receives more precipitation, has lower soil temperatures, has higher soil-water potential, and had a

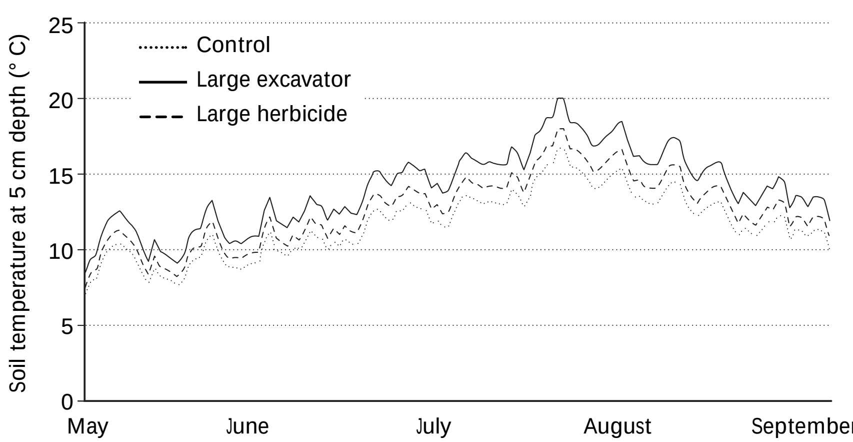

FIGURE 3 *Comparison of average soil temperature (5 cm) among site preparation treatments during the 1994 growing season.*

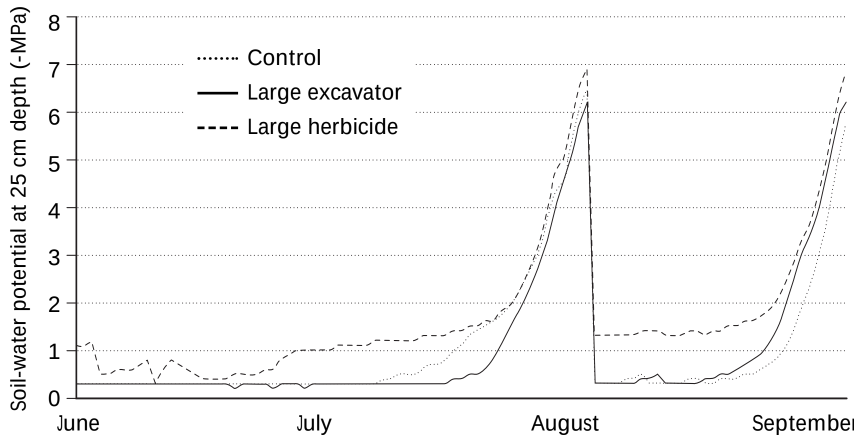

FIGURE 4 *Comparison of average soil-water potential (25 cm) among site preparation treatments during the 1994 growing season.*

TABLE 3 *Comparison of mineral soil and forest floor nutrient concentrations, as well as mineral soil nutrient capital, between aspects prior to treatment in 1991. Aspects were compared using using* t*-test.*

	East aspect		West aspect			
	Mean	**Standard error**	**Mean**	**Standard error**	***df***	***p*-value**
Mineral soil nutrient concentration						
Total C (%)	1.782	0.053	2.166	0.053	147	0.0000
Total N (%)	0.090	0.002	0.104	0.003	147	0.0000
C:N ratio	19.431	0.387	20.416	0.365	146	0.0659
Mineralizable N (ppm)	32.623	1.146	26.803	1.194	146	0.0006
Total S (%)	0.003	0.0003	0.004	0.0003	147	0.0043
pH (H_20)	5.554	0.025	5.368	0.025	145	0.0000
pH ($CaCl_2$)	5.015	0.027	4.835	0.028	147	0.0000
Forest floor nutrient concentration						
Total C (%)	21.913	0.748	33.606	0.639	148	0.0000
Total N (%)	0.753	0.026	1.029	0.020	148	0.0000
C:N ratio	29.227	0.438	33.018	0.565	148	0.0000
Mineralizable N (ppm)	351.956	15.227	449.615	16.213	148	0.0000
Total S (%)	0.064	0.003	0.102	0.002	148	0.0000
pH (H_20)	5.140	0.028	4.890	0.032	148	0.0000
pH ($CaCl_2$)	4.644	0.029	4.464	0.034	148	0.0001
Mineral soil nutrient capital						
Total C (kg/ha)	16873.40	503.40	21049.63	4476.40	147	0.0000
Total N (kg/ha)	848.15	20.80	1005.70	208.04	147	0.0000
Mineral N (kg/ha)	30.88	1.09	26.05	1.16	146	0.0028
Total S (kg/ha)	28.16	2.42	39.59	2.72	147	0.0021

considerably higher component of lodgepole pine in the harvested stand than did the eastern aspect. Greater precipitation and soil water availability on the western versus eastern aspect may partly explain its greater soil nutrient capital, whereas lower soil temperatures and greater lodgepole pine litter inputs may help explain lower N mineralization rates and pH.

Ectomycorrhizal Diversity

Richness and diversity of ectomycorrhizae associated with 2-year-old lodgepole pine seedlings (seedling level) or of ectomycorrhizal fungi available to inoculate seedlings (plot level) were lowest in the control and intermediate excavator-treated patches, where both pinegrass and forest floor were removed (Figure 5) (Jones et al. 1996). In contrast, the greatest ectomycorrhizal richness and diversity at the seedling and plot levels occurred in the herbicide-treated patches, where forest floor was not removed. Richness and diversity in these treatments were positively correlated with seedling growth. Seedling-level richness and diversity are important when seedlings become established on a site because they result in physiological diversity during variable environmental conditions. Plot-level diversity and richness, however, indicate the number of fungi that are potentially available to colonize a tree over time. In addition to reducing ectomycorrhizal richness and diversity, forest floor removal using the excavator also resulted in a shift in composition of the ectomycorrhizal community, to one with a greater dominance of fungi common to disturbed soils. That the mechanical treatment reduced ectomycorrhizal diversity and changed community composition was not surprising—the forest floor, which was removed by this treatment, is where ectomycorrhizal inoculum is typically found. Removal of the floor would have removed ectomycorrhizal spores and fungi attached to roots remaining in the soil. In addition, fungi that colonized seedling roots from the nursery would have been inhibited from spreading because of the shortage of suitable habitat (i.e., decomposing plant litter). The higher diversity of fungi associated with seedlings in the herbicide-treated patches has several benefits for those seedlings: it provides them with physiological diversity under stressful and variable conditions, as well as greater resource-gathering ability.

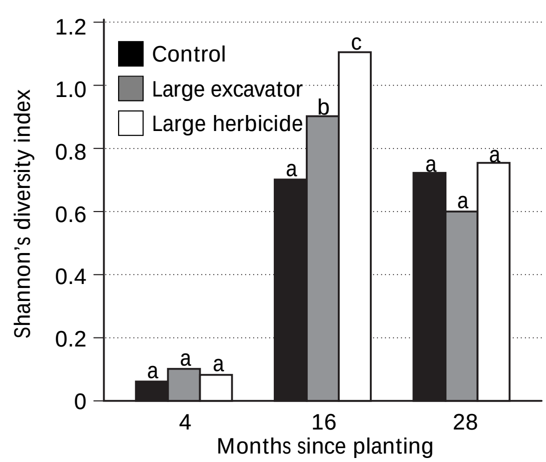

FIGURE 5 *Comparison of mean ectomycorrhizal diversity per seedling among site preparation treatments during the first 28 months following planting. Different letters at the top of the bars indicate a significant difference at $\alpha = 0.05$ in a one-way ANOVA (n = 3). Similar results were found for richness per seedling as well as richness and diversity per plot (see Jones et al. 1996).*

Low ectomycorrhizal richness and diversity associated with seedlings in the control may have occurred because seedlings were smaller and less vigorous than in the site preparation treatments. Some ectomycorrhizal fungi associate only with more vigorous, photosynthetically active seedlings because of high fungal carbon demands. Consequently, control seedlings may have been able to support only those ectomycorrhizae with low carbon demands. The pinegrass itself may also have inhibited formation of ectomycorrhizae on pine seedlings. Pinegrass forms only vesicular-arbuscular mycorrhizae, and other studies show that plant communities dominated by this mycorrhizae can suppress the formation of ectomycorrhizae (Amaranthus and Perry 1987; Timbal et al. 1990).

SUMMARY AND RECOMMENDATIONS

Any kind of patch site preparation treatment improved seedling survival, but the best survival occurred where pinegrass was removed in large patches (97% survival in large patches versus 78% in the control). Where large patches were created, it was not necessary to remove forest floor along with pinegrass for survival improvements. Small patches created with herbicide were not large enough to greatly affect seedling survival (even though they improved seedling growth); where small patches were used, it was necessary to remove forest floor in addition to pinegrass to improve survival. The improvements in seedling survival in the large patch treatments were attributed to reduced occurrence of summer frost and increases in soil-water potential during the first 2 years following planting.

Any kind of patch site preparation treatment improved seedling growth, but the best growth occurred where pinegrass alone was removed in large patches using herbicide. Compared with seedlings in the untreated control, stem diameter was 50% larger in the large herbicide patch and only 27% larger in the large excavator-treated or small patches 4 years after planting. Seedling height was 32% greater in the large herbicide-treated patch than the untreated control after 4 years, but none of the other treatments had yet affected height growth.

Summer frost, low relative humidity, low soil-water potential, and low soil temperatures all contributed to poor seedling growth potential at Murray Creek. Removal of pinegrass in large patches increased minimum air temperatures, decreased frost incidence, increased soil temperature, and decreased soil-water stress. Pinegrass removal also corresponded with increased seedling survival and growth. Removal of forest floor along with the pinegrass further improved soil temperatures, but did not consistently improve the other microclimatic conditions. In addition, it resulted in lower growth rates than where pinegrass alone was removed.

Ectomycorrhizal richness and diversity were greater in the large herbicide-treated patches than in those treated by excavator. This corresponded with greater seedling growth and suggests that the more diverse ectomycorrhizae community in the herbicide-treated patches played a role in enhanced seedling nutrient and/or water uptake. Conversely, the excavator treatment reduced ectomycorrhizal richness and diversity, shifted the community to one dominated by "weedy" types, and may have imposed nutrient limitations by removal of the forest floor. Ectomycorrhizal diversity of control seedlings was also high in the final year of ectomycorrhizae sampling, but by that time survival and growth of seedlings were already limited.

In addition to ectomycorrhizal diversity, other factors important to seedling performance were also likely affected by forest floor removal. The effect of the treatments on nutrient availability, seedling nutrition, seedling physiology, and soil structure will be examined following measurement of foliar and soil nutrients, net photosynthetic rates, soil porosity, hydraulic conductivity, and particle aggregation in the fall of 1997.

Based on these interim results, we recommend preparing high-elevation, steep, dry, grassy sites in the IDFdk1 by removing pinegrass in 150 × 150 patches using ground foliar application of glyphosate. Care must be taken not to remove forest floor material because of negative effects on the ectomycorrhizae community, and possibly nutrient availability. Broadcast herbicide treatments do not appear necessary for improved survival or growth, and may have negative implications for range and wildlife values (Heineman and Simard 1996).

ACKNOWLEDGEMENTS

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Effects of Cattle Trampling and Browsing on Lodgepole Pine Plantations

REG NEWMAN, GEORGE POWELL, KEVIN CAMERON, AND CRAIG DEMAERE

INTRODUCTION

This project was established to determine the effects of cattle grazing on regenerating lodgepole pine. A second objective was to examine how the seeding of domestic forage species would influence tree growth and interact with the effects of grazing. The study was repeated on three sites so that results could be applied over a wide area. Two sites are located on the Guichon Creek Road above Tunkwa Lake in the Kamloops Forest District. The third site is near Helmer Lake off the Coquihalla Highway in the Merritt Forest District.

The Tunkwa Lake sites were harvested in November 1986 and were windrowed, burned, and drag-scarified during November 1987. The majority of the Helmer Lake site was harvested in 1985 with an additional 10-ha harvest in October 1987. The Helmer site was rough-piled and track-and-blade-scarified, and the piles were burnt after the first snowfall.

All sites were aerially seeded in May 1988 to a forage seed mix of 35% orchardgrass, 5% timothy, 40% alsike clover, and 20% white Dutch clover. Seed was applied at rates of 3 and 12 kg/ha and equal areas were left unseeded. One-year-old container-grown lodgepole pine seedlings were then planted at a density of 1400 stems per hectare. The sites were fenced into 5-ha pastures.

Grazing was initiated in 1989, the year following planting, and has continued for 8 years. Grazing is applied at 50 and 80% forage use with an ungrazed control. The grazing period is kept constant at about 30 days. Cattle numbers are modified to achieve the different levels of forage use. For example, a 50% use area may be stocked with six cow/calf pairs for 30 days, while an 80% use area may be stocked with 10 cow/calf pairs for the same period, depending on forage availability.

RESULTS

Browsing

Browsing damage was minimal. On average, only about 2% of the lodgepole pine seedlings were browsed (Figure 1). Cattle rarely browse lodgepole pine intentionally. However, high levels of browsing damage can occur if forage plants become scarce. When available forage was reduced to less than 100 kg/ha at moderate cattle stocking, browsing damage increased dramatically. Therefore, if evidence of extensive browsing exists in a lodgepole pine plantation, poor grazing management practices should be suspected.

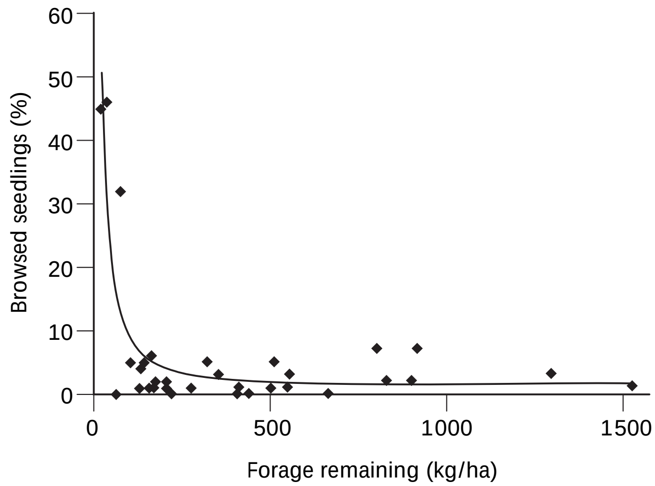

FIGURE 1 *Cattle browsing of lodgepole pine relative to remaining forage.*

Trampling

Unlike browsing damage, trampling damage was common. The number of trees trampled varied depending on the number of cattle in the area and the size of the tree. Trampling damage was highest in the first 2–3 years after planting (Figure 2). Trampling damage dropped well below 10% by the fourth year after planting. The decrease in damage as trees age was attributed to the greater visibility of larger trees. Cattle will seldom step on trees if the trees are large enough to be a physical hindrance.

Increased forage production resulted when cutblocks were seeded to domestic forage species. Trampling damage increased because increased amounts of palatable forage can sustain greater numbers of cattle. Trampling damage on seeded cutblocks can be expected to be 20–30% greater in the first 2 years after planting, compared to damage on unseeded cutblocks grazed at the same level of use (Figure 3).

The more cattle in an area, the greater the probability that trees will be trampled (Figure 4). It also follows that the longer cattle remain in a cutblock, the greater the chance that a tree will be stepped on.

Operationally prescribed cattle stocking rates resulted in moderate trampling damage in the first few years after planting. Damage can reach as high as 60% of trees if cattle are allowed to concentrate. Improper distribution, not prescribed stocking rate, is the usual cause of excessive trampling damage.

Not all trampled seedlings die. About 27% of 2-year-old tree seedlings that were trampled subsequently died. By age 6, only 5% of trampled trees died. In cases of continued high cattle concentrations over several years, however, mortality can accumulate. To date, five of the 18 grazed areas in the study are considered not satisfactorily restocked (NSR). Moderate grazing, however, results in adequate tree stocking.

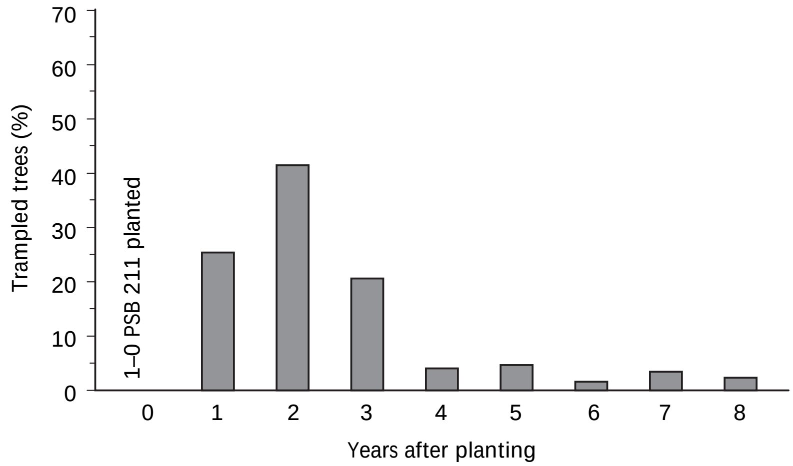

FIGURE 2 *Lodgepole pine trampled by livestock in unseeded cutblock.*

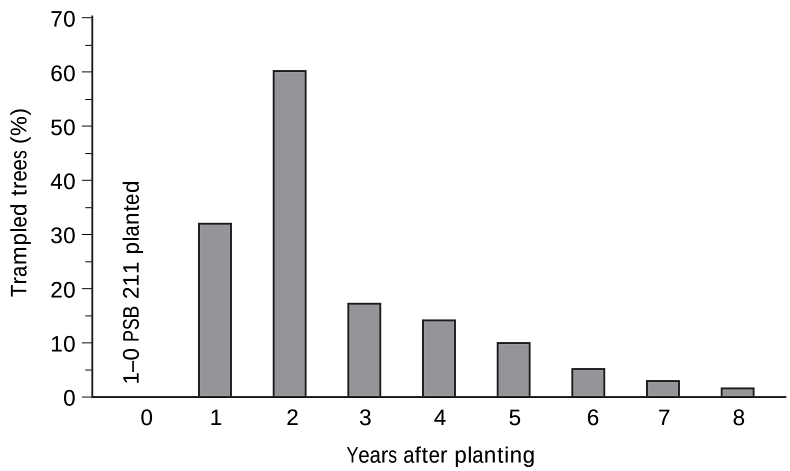

FIGURE 3 *Lodgepole pine trampled by livestock in seeded cutblock.*

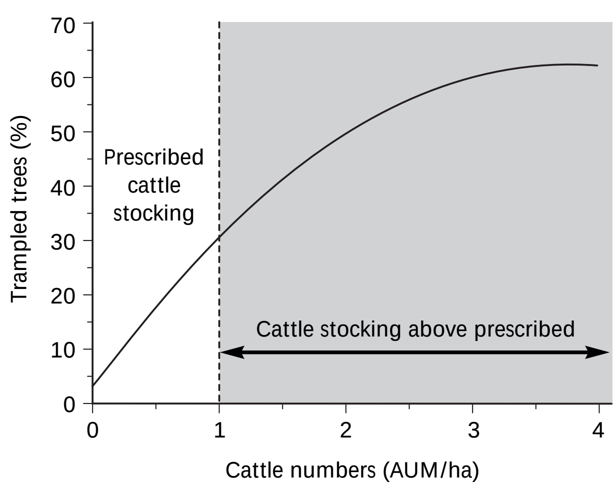

FIGURE 4 *Lodgepole pine trampled by cattle in the first 2 years after planting.*

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Relationship of Wildlife Habitat Diversity to the Seed-tree Silvicultural System in Mixed Douglas-fir–Lodgepole Pine Forests

TOM SULLIVAN

INTRODUCTION

In mixed stands of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and lodgepole pine (*Pinus contorta* var. *latifolia*) in the Southern Interior of British Columbia (Montane Spruce and Interior Douglas-fir biogeoclimatic zones), pine is often harvested by clearcutting and the Douglas-fir are left as residual standing trees. These "seed trees" serve as a source of Douglas-fir regeneration to provide a secondary species to lodgepole pine, which regenerates naturally from abundant cone slash. This is a relatively widespread practice that has been in place since the early to mid-1970s when lodgepole pine became an important commercial timber species.

The seed-tree silvicultural system is essentially a method of even-aged management whereby a few windfirm seed trees are left standing singly, or in groups, to furnish seed to naturally regenerate the cleared area (Smith 1986). After a new crop is established, these seed trees may be removed in a second harvest or left indefinitely. The major distinction from shelterwood cutting is that the crown cover on standing trees is not sufficient to make the cleared area different in microclimate compared to an open clearcut area (Smith 1986). Compared with the clearcutting silvicultural system, the seed sources are retained within the harvested area rather than near the perimeter of a given block.

The seed-tree and shelterwood systems are not necessarily distinguished on the basis of some arbitrary number of reserved trees per hectare. Amount of residual crown cover to provide a significant degree of shade to shelter new seedlings is likely the best distinction (Smith 1986). The seed-tree method is a "concept" of leaving just enough trees to provide seed to regenerate a stand.

In the Southern Interior of British Columbia, observations suggest that residual Douglas-fir left after harvesting of lodgepole pine form mixed stands which range from a few trees per hectare up to 100 or more. In most cases, the number of trees left depends on the original composition of the harvested stand (J. Hatch, Gorman Brothers, pers. comm.). The silvicultural goal is to maintain, and perhaps increase, the proportion of Douglas-fir in the regenerated forest (G. Desnoyers, B.C. Ministry of Forests, Penticton, pers. comm.).

Because of the availability of lodgepole pine seed from cone slash after harvest (Vyse and Navratil 1985), pine tends to dominate young stands in these particular seed-tree systems. Young stands of pine with some overstorey Douglas-fir provide a degree of "green-tree retention" from one forest ecosystem to another through time. The residual Douglas-fir will eventually become durable snags in the second-growth forest of pine, which provides an additional desirable attribute of diverse stand structure. These mature trees will provide habitat for cavity-using birds and mammals through time (Schmidt et al. 1983; Guy and Manning 1995).

Thus, from the perspective of wildlife habitat diversity, these seed-tree stands may be comparable to mixed Douglas-fir–pine residual stands in some aspects of stand structure. A major question is: what role do these seed-tree stands play in managing the forest landscape for biodiversity objectives? These stands represent a silvicultural system that produces a potentially unique stand structure. This system may mimic a natural disturbance regime whereby some residual old-growth Douglas-fir survive amidst fire-regenerated stands of lodgepole pine.

Objectives

The two objectives of this study were:

1. to compare the stand structure (understorey vegetation and deciduous/coniferous components of tree layers) of mixed Douglas-fir–pine (seed-tree harvest), mixed Douglas-fir–pine residual, and young lodgepole pine (clearcut harvested) stands; and
2. to relate stand structure (habitat) attributes of these stands to small mammal communities as a measure of wildlife habitat diversity.

This paper is a second-year progress report on a 3-year project.

STUDY AREA AND EXPERIMENTAL DESIGN

This study is located in the Bald Range, 25 km west of Summerland (Penticton District, Kamloops Region), within the Montane Spruce (MSdm) biogeoclimatic zone (Meidinger and Pojar 1991). The study area has a cool, continental climate with cold winters and moderately short, warm summers. Mean annual temperature is 0.5–4.7°C and precipitation ranges from 380 to 900 mm. The landscape has extensive young and maturing seral stages of lodgepole pine, which have regenerated after wildfire. Hybrid interior spruce (*Picea glauca* x *P. engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the dominant shade-tolerant climax trees. Douglas-fir is an important seral species in zonal ecosystems and is a climax species on warm south-facing slopes in the driest ecosystems. Trembling aspen (*Populus tremuloides*) is a common seral species and black cottonwood (*Populus trichocarpa*) occurs on some moist sites (Meidinger and Pojar 1991).

Three replicates occur with a total of nine experimental units (stands) in the following randomized block design:

	Blocks		
	1	**2**	**3**
Young pine clearcut harvest	K	L	M
Mixed Douglas-fir–pine seed-tree harvest	N	O	P
Mixed Douglas-fir–pine residual	Q	R	S

Treatment history and characteristics of these stands are listed in Table 1. Stands on harvested sites range in area from 10 to 20 ha.

TABLE 1 *Stand histories and characteristics for seed-tree and wildlife habitat study.*[a]

Treatment and stand	Tree species composition	Age (yr)	Site class	Height class (m)	Crown closure	Year harvested	Year thinned
Residual (uncut)							
Q	Pl	101–140	M	19.5–28.4	66–75	-	-
	F	141–251+					
R	Pl	101–140	M	19.5–28.4	56–65	-	-
	F	141–251+					
S	Pl	101–140	M	19.5–28.4	66–75	-	-
	F	141–251+					
Seed tree							
N	Pl	18	G	-	-	1977	1987
	F	141–251+					
O	Pl	17	M	-	-	1978	1987
	F	141–251+					
P	Pl	17	M	-	-	1978	1985
	F	141–251+					
Clearcut							
K	Pl	17	M	-	-	1978	1985
L	Pl	17	M	-	-	1978	1985
M	Pl	17	M	-	-	1978	1985

a Abbreviations used in this table: Pl = lodgepole pine; F = Douglas-fir; G = good; M = medium.

METHODOLOGY

Stand Structure

Trees and snags The stand structure attributes were measured in five 20 × 20 m plots randomly located within each stand. Five plots were installed in each stand. Each plot was divided into four 10 × 10 m subplots for ease of sampling. For each tree and snag within a subplot, the following parameters were recorded:

- species
- dbh (cm)
- height class
  R = regeneration (< 1.3 m)
  S = subcanopy (1.3–5 m)
  M = main canopy (5–20 m)
  V = veteran (> 20 m)
- profile 1–9 (wildlife tree classification system)
- hardness (five decay classes)
  1 = intact
  2 = intact to partially soft
  3 = hard large pieces
  4 = small soft blocky pieces
  5 = soft and powdery or hollow
- cavities (nesting, feeding, or both)
  0 = none
  1 = roosting/nesting
  2 = feeding holes
  3 = both

The subcanopy and main canopy categories vary according to stand structure in the different experimental units.

Understorey vegetation Within each 10 × 10 m subplot, two sizes of nested subplots were established: a 3 × 3 m subplot for sampling shrubs, and a 1 × 1 m subplot for sampling herbs, mosses, and lichens. These nested subplots were located 2 m in from the quadrat perimeter. Shrub and herb layers were subdivided into height classes (Table 2). For each species height-class combination within the appropriate nested subplot, the percentage cover of the ground was visually estimated. Total percentage cover for each layer was also estimated. These data were summarized as percent occurrence (presence) and absolute crown volume (m^3/0.01 ha) for each plant species (Stickney 1980, 1985) when the habitat sampling was completed. The product of percent cover and representative height gives the volume of a cylindroid that represents the space occupied by the plant in the community. Volume values were averaged by species for each plot size and converted to 0.01-ha base to produce a tabular value given for each species and life-form group. Sampling was done in September 1995 and in July–August 1996. Plant species were identified in accordance with Hitchcock and Cronquist (1973).

Species richness, species diversity, foliage height diversity, and an index of similarity will be calculated for these habitat data.

TABLE 2 *Height class categories and corresponding layer classes (adapted from Walmsley et al. 1980).*

Vegetation layer	Tree class	Tree height class	Shrub and herb height class
A0 trees	Veteran		
A1 trees	Dominant	30 m	
A2 trees	Main canopy	20–30 m	
A3 trees	Suppressed	10–20 m	
B1 trees		5–10 m	
		3–5 m	
B2 trees and shrubs			>3 m
		2–3 m	2–3 m
		1–2 m	1–2 m
		0.5–1 m	0.5–1 m
		0.25–0.5 m	0.25–0.5 m
		<0.25 m	<0.25 m
C herbs			>3 m
			2–3 m
			1–2 m
			0.5–1 m
			0.25–0.5 m
			<0.25 m

Downed wood Downed wood was recorded along two transect lines of 20 m each on the perimeter of the plot. The following attributes were recorded for each piece encountered:

- species
- diameter (cm) where line crosses wood
- height off ground (cm), measured at upper surface of piece
- approximate length (m)
- hardness (five decay classes)

Physical characteristics The physical characteristics of each plot were recorded, including aspect, slope, site position, and other ecologically relevant features.

Small Mammal Communities

Small mammal populations were sampled at 4-week intervals from May to October each year starting in 1995 in all stands. Trapping grids (1 ha) have 49 (7 × 7) trap stations at 14.29-m intervals with one Longworth live-trap at each station (Ritchie and Sullivan 1989). Traps were supplied with oats and cotton as bedding. Traps were set on the afternoon of day 1, checked on the morning and afternoon of day 2 and morning of day 3, and then locked open between trapping periods. All animals were ear-tagged, their reproductive condition noted, and weight and point of capture recorded.

Small mammal species sampled by this procedure included the deer mouse (*Peromyscus maniculatus*), northwestern chipmunk (*Tamias amoenus*), meadow vole (*Microtus pennsylvanicus*), long-tailed vole (*Microtus longicaudus*), red-backed vole (*Clethrionomys gapperi*), heather vole (*Phenacomys intermedius*), western jumping mouse (*Zapus princeps*), dusky shrew (*Sorex monticolus*), wandering shrew (*Sorex vagrans*), common shrew (*Sorex cinereus*), and short-tailed weasel (*Mustela erminea*).

PRELIMINARY RESULTS

Stand Structure

Stand structure attributes will be summarized and analyzed in detail during 1997. Five plots were sampled in each of the nine stands.

Small Mammal Communities

In 1995 and 1996, populations of small mammals were recorded for replicate stands in the young pine clearcut harvest (Figure 1), mixed Douglas-fir–pine seed-tree harvest (Figure 2), and mixed Douglas-fir–pine residual (Figure 3). The following groups were observed: meadow and long-tailed voles, seed eaters, shrews and weasels, and heather and red-backed voles.

The seed-eaters (deer mice and chipmunks) were common in all stands except the residual old growth, where the former species was dominant. Red-backed voles occurred primarily in old-growth stands, with lower numbers in the seed-tree and young pine stands. Heather voles were absent from old growth, but occurred at low numbers (fewer than five per hectare) in the other stands. Meadow and long-tailed voles were at low numbers in all stands. Shrews and weasels were relatively more common in young pine and seed-tree stands than in old growth.

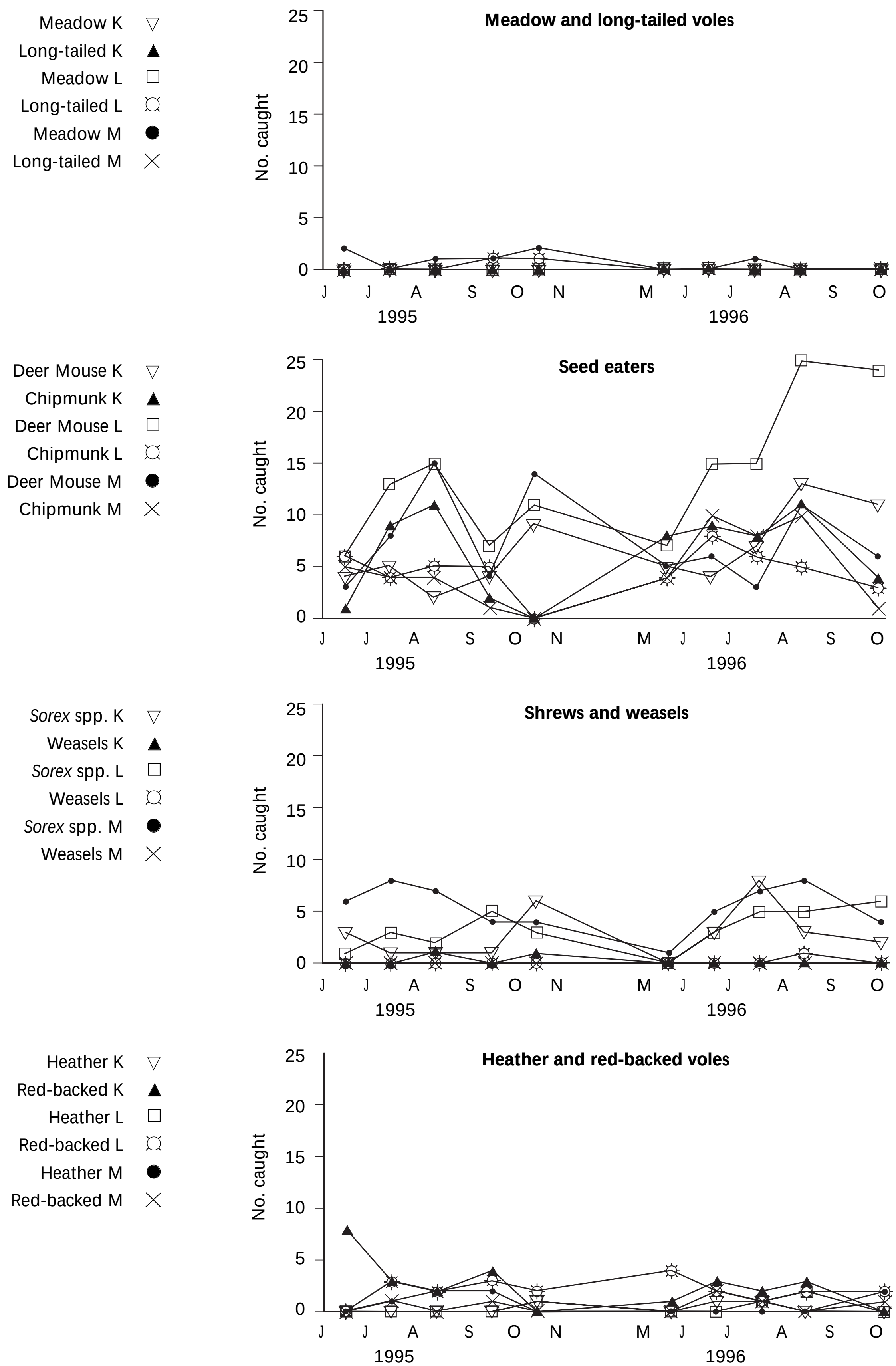

FIGURE 1 *Populations of small mammals in replicate stands of young pine clearcut harvest during 1995 and 1996.*

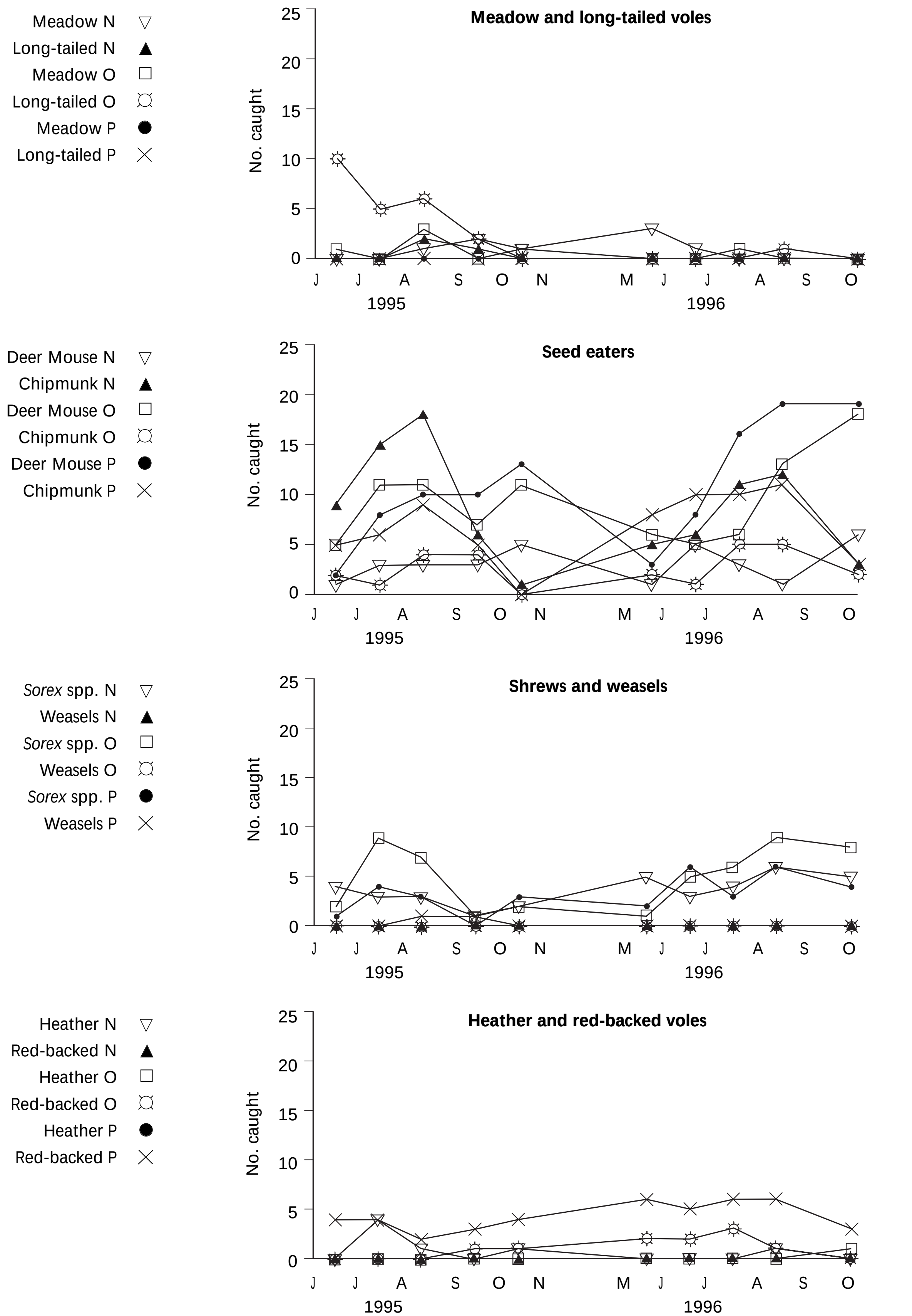

FIGURE 2 *Populations of small mammals in replicate stands of mixed Douglas-fir–pine seed-tree harvest during 1995 and 1996.*

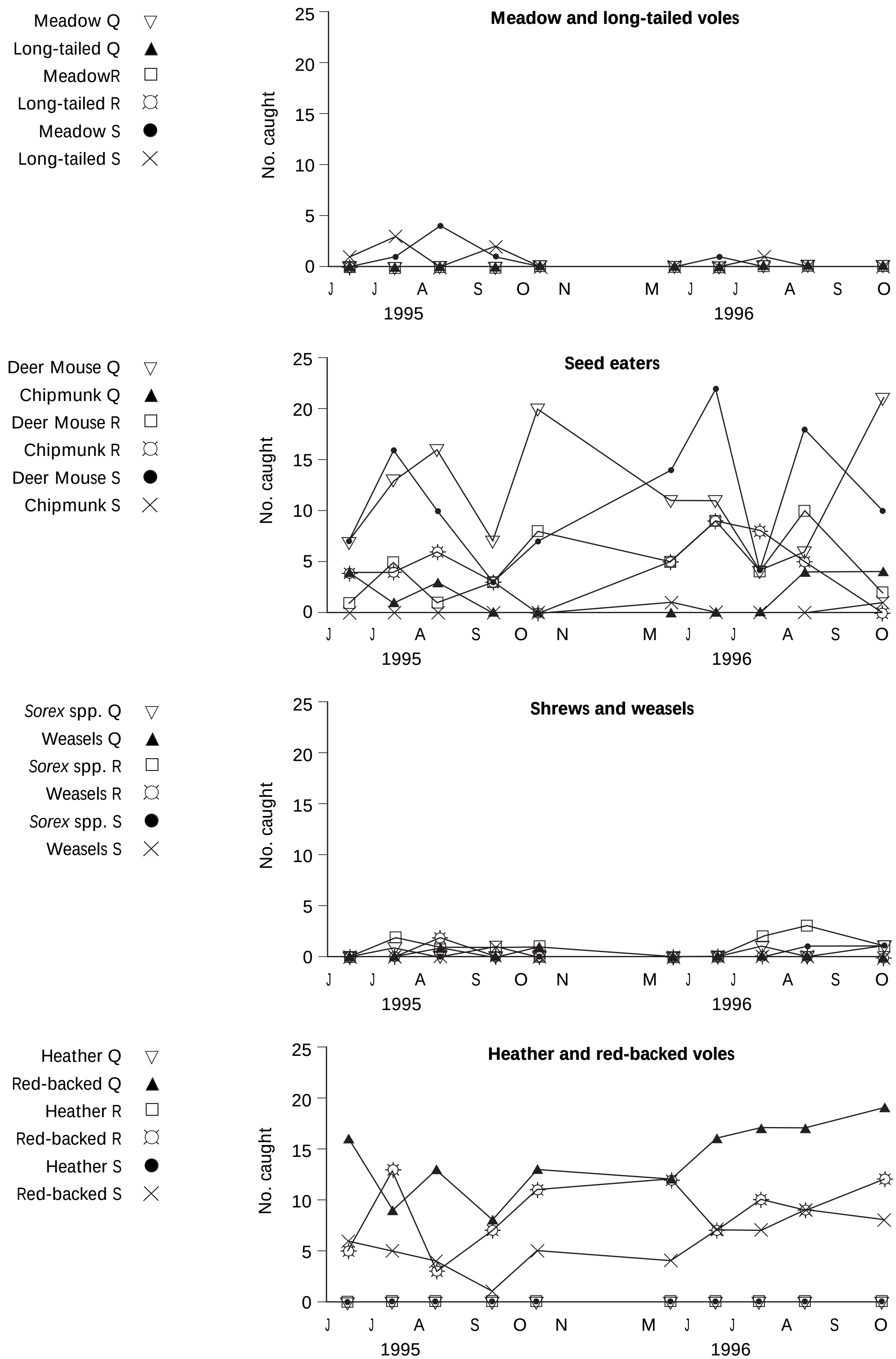

FIGURE 3 *Populations of small mammals in replicate stands of mixed Douglas-fir–pine residual (old growth) during 1995 and 1996.*

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