3. MONITORING MECHANICAL RESTORATION EFFECTIVENESS IN MONTANE FORESTS OF THE EAST KOOTENAY

3.1 Introduction

Prior to 1900 (pre-settlement) ponderosa pine (*Pinus ponderosa* Douglas ex Lawson & Lawson var. *ponderosa*) and interior Douglas fir [*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco] forests characterized montane forests of the inland northwest. These forests were maintained largely by fire and other disturbances (insect outbreaks etc.) (Everett et al. 2000). In areas where fire-resistant ponderosa pine and Douglas fir were seral, low intensity surface fires limited shade-tolerant competitors such as lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. *ex*. S. Wats.) and young interior Douglas fir from establishing in the understory (Arno et al. 1995). In summarizing the literature on historic fire regimes in ponderosa pine/Douglas-fir types in Western Montana, Arno et al. (1995) concluded that prior to 1900 most stands had recurring surface fires at intervals of 26-50 years at high elevation sites (1500-1800m), and approximately 13 years at low elevations (800m-1500m).

In the late 1800's, selective logging preferentially removed most large ponderosa pine and Douglas fir. The simultaneous introduction of fire suppression policies in the early 1900's allowed for enhanced understory conifer regeneration in fire-maintained forests across North America (Kaye et al. 1999). This in combination with the absence of widespread native American burning, and unregulated grazing early in the 20th century resulted in a marked change in forest stand structure from relatively open, older-aged forests to closed, young forests (Veblen et al. 2001).

These changes also occurred in British Columbia (BC). With the establishment of the Forest Service in 1912. Regulations concerning fire management on forested land were greatly expanded (Dorey 1979). Policy was instituted that called for the suppression of fires in all areas to prevent the loss of valuable timber (Parminter 1978). Active suppression increased coincided with an increase in the fire return interval by as much as 60 years, accelerating forest ingrowth and encroachment within dry forest zones (Bai 2000), including those within the East Kootenay Trench of southeastern BC. Dry forest zones that historically experienced frequent, low intensity fires (5 – 50 years) that limited encroachment by woody species, are classified as Natural Disturbance Type 4 (NDT4) systems (Province of British Columbia 1995). There are approximately 250 000 ha of NDT4 in the Rocky Mountain Trench of BC. Gayton (1997) estimated that nearly 1% or 3000 ha of open NDT4 forest are lost each year in the Trench to ingrowth and encroachment, an estimate similar to those made in other parts of the province (Bai et al. 2001).

Within ingrown forests of North America, changes in forest structure and the associated understory have received considerable attention in the past because of reductions in forage availability for livestock and wildlife (Pase 1958, Cooper 1960, Ffolliott and Clary 1982, Bojorquez et al. 1990). In addition to forage declines, shading caused by the invasion of conifer species has favoured the invasion of mesophytic shrubs and herbs into historically dry stands (Lunan and Habeck 1973), resulting in species composition changes. For example, pinegrass (*Calamagrostis rubescens* Buckl.), a rhizomatous perennial that remains abundant under shade, is prevalent under dense fir canopies (Steele and Geier-Hayes 1993). Lack of light and increased competition from pinegrass may limit the existence and distribution of more desirable plant species including native bunchgrasses [e.g., rough fescue (*Festuca campestris* Rydb.), Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), Richardson's needlegrass (*Stipa richardsonii* Link.), needle-and-thread grass (*Stipa comata* Trin.&Rupr.) and stiff needlegrass (*Stipa occidentalis* Thurb. ex S. Wats. var. *pubescens* Maze, Tayor and MacBryde]. The loss of bunchgrass communities is significant within the Rocky Mountain Trench, as native ungulates and livestock exhibit a high degree of preference for these species (Clark et al. 1998, Ross 2001). Given that ungulate numbers (including livestock) tend to remain relatively constant in an area over time, the gradual loss of bunchgrasses can lead to overgrazing of remaining vegetation, causing further undesirable changes in species composition (Gayton 1997).

As land administrations shift away from management at the forest stand or single species level and towards ecosystem management, the effect of conifer encroachment on understory species composition and diversity is receiving increased attention (Thomas et al. 1999). The goal of ecosystem management is the maintenance of ecosystem integrity, including species composition (Naumberg and DeWald 1999). Therefore, an understanding of overstory-understory relationships is increasingly guiding efforts to mitigate negative impacts caused by ingrowth and encroachment through the use of ecosystem restoration (Fiedler and Carlson 1992, Covington et al. 1997, Kaye et al. 1999, Ritchie and Harksen 1999).

Although dry forest restoration treatments have been used in several areas of North America, including Arizona, Colorado, Montana and British Columbia, most research has examined a narrow set of treatment effects. Furthermore, while prescribed burning has been studied extensively, less attention has been given to the ecological impacts of the thinning treatments necessary to restore a more natural stand structure prior to the re-introduction of fire (Smith and Arno 1999). Restoration of dense stands begins with selective thinning to remove excess understory and weak overstory trees that cannot be safely killed in a prescribed fire (Arno et al. 2000).

Every phase of restoration should be monitored in isolation to ensure the goals and objectives of ecosystem restoration are being met, as well as obtain information that will guide future restoration efforts (Ritchie and Harksen 1999). This research project was designed to monitor thinning treatments conducted by the BC Ministry of Forests as part of their ecosystem restoration operations. Prescriptions were based on land use guidelines set by the Kootenay Boundary Land Use Plan (KBLUP) (Province of British Columbia 1997). The plan stipulates that existing grassland and open forest must be maintained in the region, and ingrown NDT4 forests restored to historical open forest (Province of British Columbia 1998) (Table 3.1). In response to the KBLUP, the Cranbrook and Invermere Forest Districts initiated a large-scale NDT4 restoration program. The Rocky Mountain Trench Restoration Program is the largest, longest-running terrestrial restoration initiative underway in the province (Machmer et al. 2002). According to current projections, an estimated 135 000 ha of land will be converted to grassland or open forest by the year 2030 (Rocky Mountain Trench Ecosystem Restoration Steering Committee 2000). This research project monitored the first of a three-phase rotational block prescription designed to restore ingrown forests in the Rocky Mountain Trench. In the first phase, ingrown forest stands were thinned to 20% - 70% of the original basal area.

Pre-treatment (i.e. pre-thinning) overstory-understory relationships were initially examined using a retrospective assessment at 2 sites in the dry forest zone of the Rocky Mountain Trench of British Columbia. This was followed by an examination of the initial 2-year understory response to tree thinning. Specific objectives were to (1) quantify various overstory-understory synecological relationships within NDT4 forests, and (2) determine the initial effect of forest thinning on changes in understory species composition, diversity and production. This project was also designed to represent the first step of an ongoing monitoring program implemented to evaluate the ongoing success of restoring ingrown ponderosa pine and Douglas fir forests in southeastern BC.

The following null hypotheses were tested:

?? There is no significant pre-treatment relationship between forest overstory characteristics [canopy closure (understory light, timber volume (m^3/ha), or merchantable stem density (stems/ha)] and the understory plant community, including species richness and diversity, species cover, and forage production.

?? ? reduction of forest overstory will not significantly increase the density of important forage and browse species.

3.2 Methods

3.2.1 Study Area

This research was conducted in the southeastern corner of British Columbia in the Rocky Mountain Trench, within the Invermere Forest District (Fig. 3.1), an area more commonly known as the East Kootenay Valley. This region is strongly influenced by maritime polar air masses that are drier after being lifted over the Coast, Monashee, and Selkirk Mountains. The southern valley has an upland continental climate with well-defined seasons. Summers are characterized as warm and dry while winters are typically cold with deep valley inversions (Marsh 1986), which often causes warmer temperatures at low elevation sites (McLean and Holland 1957). Mean monthly air temperatures vary from –8.3? to 18.2?C (Table 3.2). Average annual precipitation is 384.5mm, with May and June being the wettest months (Table 3.2). There is an average of 147.9cm of snow during the winter months. This project was initiated in 1999 when precipitation and temperatures were near average. However, 2000 and 2001 were dry with approximately 45% and 35% of average precipitation during the growing season (May-September), respectively (Table 3.2).

Two blocks (i.e. treatment areas) were selected for this project, and included the Sheep Creek North Range Unit (RU5041) and the Wolf/Sheep Creek (also known as Premier Ridge) Range Unit (RU5015). Both sites were approximately 75km south of Invermere and 20km apart (49?58'N 115?43'W) (Fig. 3.1). These areas will hereafter be referred to as the Sheep Creek and Wolf Creek areas, respectively. Both Sheep Creek and Wolf Creek were highlighted in the Kootenay Boundary Land Use Plan (Province of British Columbia 1997) as "important ungulate winter range". In addition, Wolf Creek is a zoned as a Special Resource Management Zone (SRMZ), largely due to a high concentration of regionally significant and sensitive resource values, including critical wildlife habitat (e.g. Hudson et al. 1976).

Current commercial uses of these areas include cattle grazing. The earliest recorded grazing at Sheep Creek was 1937 and at Wolf Creek, 1941. Large ponderosa pine and Douglas fir were likely selectively logged in these areas during the 1930's, as many forest stands were 'unofficially' logged to support railway tie production (Phil Burke, Range Officer, Invermere Forest District, per comm., 2002). Decomposing, large Douglas-fir and ponderosa pine stumps were observed in both stands.

Both blocks were situated within NDT4 forests. The Sheep Creek block is situated in the IDFdm2 (Kootenay dry mild interior Douglas-fir variant) vegetation zone, while Wolf Creek is located in the PPdh2 (Kootenay dry hot ponderosa pine variant) vegetation zone (Braumandl and Curran 1992). Zonal PPdh2 sites have open stands of Douglas fir and ponderosa pine with an understory of predominantly bluebunch wheatgrass. Zonal IDFdm2 sites have climax stands of Douglas fir with an understory dominated by pinegrass and shrubs such as birch-leaved spiraea (*Spiraea betulifolia* Pall. ssp. *lucida* (Dougl. ex Greene) Taylor & MacBryde), common juniper (*Juniperus communis* L.), soopolallie (*Shepherdia canadensis* (L.) Nutt.), Saskatoon (*Amelanchier alnifolia* Nutt.), and common snowberry (*Symphoricarpos albus* (L.) Blake) (Braumandl and Curran 1992). Site specific characteristics for each block are contained in Appendix 1.

Soils at Sheep and Wolf Creek are classified as Orthic Eutric Brunisols (Lacelle 1990). Eutric Brunisols are characterized as strongly calcareous and low in organic matter (National Research Council of Canada 1998). The dominant soil association at both sites is Fishertown, a gravelly, sandy loam derived from fluvioglacial parent material (Lacelle 1990). The soil is rapidly drained and located on moderately to strongly rolling sites (Lacelle 1990). A less common soil association found at both sites is the Wycliffe association, consisting of Brunisolic soils derived from morainal parent material containing limestone (Lacelle 1990). There are minor occurrences of the Elko soil association at Wolf Creek, an Orthic Eutric Brunisol on glaciofluvial parent material. These soils are not as gravelly as the Wycliffe and Fishertown associations, but are still relatively well-drained (Lacelle 1990).

3.2.2 Experimental Design

An identical experimental design was used at each block. To facilitate objective and representative data collection across blocks, sampling was superimposed on existing timber cruise plots, from which comprehensive overstory information had previously been collected by Invermere Forest District staff. An added benefit of this approach was that cruise plots were systematically distributed (on a 100m*100m grid) throughout each block and were therefore representative of a wide range of initial forest structure conditions. Prior to sampling, however, plots were stratified by biogeoclimatic zone using methods outlined in Braumandl and Curran (1992) and slope. All timber cruise plots identified as being in the IDFdm2 and PPdh2 and having a slope less than 5% were selected for subsequent monitoring. Slopes greater than 5%

were excluded to remove strong moisture gradients as a confounding factor in the analysis. Final plot numbers in the Sheep Creek and Wolf Creek blocks were 15 and 18, respectively.

Within each sampled timber cruise plot, three parallel 10 m transects were established oriented south to north. The 2 outer transects were equidistant off the centre of the plot (4m in either direction), while the middle transect intersected the plot centre (Fig. 3.2). Transect ends and plot centres were permanently marked with rebar pins to facilitate relocation, and all plots located using a GPS. Sampling occurred for three consecutive years beginning in 1999, the year thinning activities were initiated.

Pre-thinning sampling for understory herb and shrub cover, as well as understory light and duff were completed in 1999 at both bocks. However, forage production data were collected in 1999 at Wolf Creek only because Sheep Creek was thinned later that summer (i.e. June 1999). Thinning of Wolf Creek occurred a year later during June-July 2000. Timber cruise data were made available by the Invermere Forest District and summarized by plot.

In 2000, all first-year post-thinning sampling was completed at Sheep Creek. At Wolf Creek, only forage production was sampled in 2000 due to the timing of harvest relative to plant growth. A year later, comprehensive second-year post-harvest sampling was completed at both blocks in 2001. All thinning treatments were consistent with the KBLUP (Province of British Columbia 1998) (Table 3.1) and were intended to promote winter forage availability and create the open forest habitat required for many threatened or endangered species (e.g., badger, Lewis woodpecker, and sharp-tailed grouse).

3.2.3 Vegetation Sampling

Vegetation sampling was modified from the methods provided in the document, 'Monitoring Restoration of Fire-Maintained Ecosystems in the Invermere Forest District' (Powell et al. 1998). Within each plot, the 2 outer 10 m transects were sampled for vegetation cover by species (Daubenmire 1959) and key species density. Percent canopy cover by plant species was estimated in $0.1m^2$ quadrats positioned every metre (n=20). In addition, the density of key native bunchgrasses (rough fescue, Idaho fescue, bluebunch wheatgrass, Richardson's needlegrass, needle-and-thread grass and stiff needlegrass) were counted in $10m^2$ (1m * 10m) belted transects established along the interior of each outside transect. Density was averaged across the 2 transects (x/m^2). Density counts were restricted to those bunchgrass species historically common within NDT4 plant communities, and were also considered important forage species for wildlife.

Species richness was determined by counting the total number of species found in all quadrats ($x/2m^2$). Species diversity was determined using the Shannon-Weiner diversity index ($H=-P_i\log[P_I]$) (Bonham 1983).

Ocular estimates of shrub canopy cover (Daubenmire 1959) were obtained within 20, $2m^2$ (1m * 2m) quadrats nested overtop the $0.1\ m^2$ quadrats at each metre mark of the outside transects. Shrub quadrats were contiguous along the outer transects, oriented with the narrow side on the transect (Fig. 3.2). The density of key shrubs and tree saplings (<1.5m tall) was assessed in 2, $20m^2$ (2m * 10m) belted transects, each centred on the outside line transects. Key shrubs included common browse species [Saskatoon, antelope-brush (*Purshia tridentata*

(Pursh) DC.)] and woody species considered to be 'encroaching' (e.g. Douglas fir and lodgepole pine). Density was averaged across the 2 transects (x/m^2). Depth of the Ah horizon was also assessed at each plot to assess the effect of conifer ingrowth and encroachment on soil organic matter.

Forage production was quantified within 4, 0.5 m^2 quadrats (0.5m*1m) systematically located on the centre transect. Quadrats were located, *a-priori*, at different locations in each of the 3 years of the study (Fig. 3.2) to avoid confounding effects of sampling during subsequent years. Current annual production in all quadrats was clipped to ground level in early September after peak growth was reached. All samples were sorted by descriptive group for analysis and included bunchgrasses, pinegrass, other grass, sedges (*Carex* spp.), forbs and shrubs. Kinnikinnick (*Arctostaphylos uva-ursi* (L.) Spreng.) was not clipped as it was not a species of direct interest for monitoring habitat changes, as it is not a desirable forage species for domestic and wild ungulates. Descriptive groups were assessed instead of individual species due to suspected difficulty in detecting statistically significant changes at the species level. To assess the practical importance of ungulate (wild and domestic) herbivory in each block, two (1.5m)^2 range cages were randomly situated in each of 5 randomly selected plots per block. In each cage, vegetation was sampled the same as the adjacent production quadrats within the plot, with caged-uncaged comparisons (i.e. the paired-plot method) used to quantify the level of herbivory (Bonham 1983). All vegetation samples were stored in a paper bag and air-dried, and subsequently oven-dried at 60 ?C to constant mass and weighed.

Understory light is a direct measurement of the overstory influence on understory growing conditions. The amount of diffuse non-interceptence light (or understory light) was measured using a LI-COR®LAI-2000 Plant Canopy Analyzer (Welles and Norman 1991). This value is the ratio of diffuse light measured at the top of each 0.1 m^2 Daubenmire frame (i.e. 30cm high) used for plant canopy cover measurement, as a proportion of the diffuse light measurement simultaneously taken from a vantage point with an unobstructed sky view. Light measurements could only be taken on days when the sky was uniformly overcast. BC Ministry of Forests staff took all light measurements.

Tree volume (m3/ha), and tree stem density (stems/ha) pre-thinning values were obtained from Ministry of Forests timber cruise data. Standard cruising methodology was used using variable plot methods (Province of British Columbia 2002). Variable plot sampling , also known as prism sampling, was used since the probability of tree selection was proportional to basal area, therefore, the large diameter trees are sampled with the same intensity as the small diameter trees (Province of British Columbia 2002). Post-thinning measurements were taken by Ministry of Forests Staff. Post-thinning values were obtained by subtracting the basal area and volume of trees present in the pre-thinning plots that were not present in the post-thinning plots. The problem with this method is that not all trees were accounted in the pre-thinning variable plot sampling (e.g. some smaller trees may be excluded from the variable plot), therefore it is not a precise measurement of the amount of material removed. Post-thinning measurements can be viewed more as a measure of the intensity of thinning that occurred at each plot.

3.2.4 Statistical Analyses

In the investigation of pre-thinning plant synecological relationships, treatments were considered to be the varying levels of forest ingrowth (overstory characteristics) among plots. Differences between the 2 blocks were initially assessed using an analysis of variance (ANOVA) for a completely random design with subsampling. Preliminary analysis indicated there were no significant block by treatment effects ($p>0.1$). However, between plot variance was also high within each block (Table 3.3) and may have prevented the identification of significant interactions. Additionally, most pre-thinning descriptive group canopy cover values were significantly different ($p<0.05$) between blocks, as was understory light and timber volume ($p<0.05$) (Table 3.3). Due to the noted abiotic and biotic differences between blocks, they were examined separately in all subsequent analysis.

Pre-thinning relationships of understory light, merchantable stem density and overstory tree volume with the understory characteristics were examined using regression techniques (Steel et al. 1997). Within a block, treatment averages of each response variable were calculated for each plot and regressed against the independent variables, with each plot forming one point in the regression. All regressions were checked for non-linear relationships, there were none found. It is possible that non-linear relationships would be detected at higher sample sizes.

All data were checked for normality prior to analysis. Non-normal data were transformed using a square root (tree volume, tree density, and pinegrass, bunchgrass shrub, sedge, and forb production, as well as bunchgrass, sedge and bryophyte canopy cover) or a log+1 (Saskatoon canopy cover and density) transformation. Where transformations were necessary, negative values were made positive by adding the lowest value in the data set to each observation. Additionally, data were always uniformly transformed within a response variable across both blocks and years. All differences were considered significant at $p<0.10$, unless indicated otherwise.

To evaluate changes in vegetation following thinning, understory canopy cover and density values within a descriptive group in the pre-thinning year were subtracted from values in years 1 and 2 post-thinning (i.e. 2000-1999, 2001-2000 and 2001-1999). Changes in independent variables by plot were also quantified during the same time periods. Responses to thinning were then determined by regressing the change in independent variables against the change in canopy cover, density and production of each descriptive group.

3.3 Results

3.3.1 Pre-Thinning Relationships

Understory light at Sheep Creek displayed a significant ($p<0.10$) positive association to 3 understory variables (Table 3.4) including Saskatoon canopy cover (Fig. 3.3) and density, as well as total live herb canopy cover (Fig 3.4). Several other variables also approached significance ($p<0.20$) (Table 3.4), displaying weak positive relationships. Only spiraea canopy cover was significantly ($p<0.05$) associated with overstory tree density, also displaying a positive relationship.

At Wolf Creek, understory light was positively ($p<0.10$) related to 9 understory variables (Table 3.4), including species diversity (Fig. 3.5) and richness along with shrub, forb, sedge, and bunchgrass canopy cover (Fig 3.6), but was negatively ($p<0.01$) related to sedge production (Table 3.4). Similar to the other block, Saskatoon canopy cover (Fig. 3.3) and density were positively related to light at Wolf Creek.

At both blocks, depth of the Ah layer had too little variance between plots to analyze (1-2cm), although it was observed that the thicker Ah layers were found under relatively open canopies.

3.3.2 Overstory Changes With Thinning

At Sheep Creek, thinning removed an average of 68m^3/ha of timber, leaving 59m^3/ha. Tree stem density decreased by 261, leaving 243 stems/ha. In contrast, understory light increased ($p<0.001$) an average of 27% across all plots following thinning.

Thinning treatments at Wolf Creek removed an average of 48 m^3/ha, leaving 27 m^3/ha. Stem density decreased by 513, leaving 192 stems/ha. Understory light subsequently increased ($p<0.001$) by 30% following thinning.

3.3.3 Post-Thinning Relationships

3.3.3.1 Sheep Creek

Over the two years of the study, the overall canopy cover of pinegrass, birch-leaved spiraea, total shrubs and bryophytes all declined significantly ($p<0.05$) at Sheep Creek (Table 3.5). The only understory characteristic that increased ($p<0.10$) over that period was bunchgrass density (Table 3.5). Note that changes in production could not be assessed due to the lack of data from 1999 prior to thinning.

Following thinning, there were several positive responses in the understory of plots at Sheep Creek that were associated with overstory changes (Table 3.6). A total of 8 understory variables responded positively ($p<0.10$) at increased levels of thinning, 8 between 2000-2001 and 1 between 1999-2001 (Table 3.6). In general, positive changes in the understory were more closely associated to changes in overstory tree density (5 relationships) rather than timber volume (2 relationships) or understory light (1 relationship) (Table 3.6). Understory characteristics demonstrating positive responses included species richness (Fig. 3.7) and diversity, as well as forb and bryophyte canopy cover.

There were also 3 negative ($p<0.10$) associated with increased thinning intensity within the understory (Table 3.6). Changes in Saskatoon density varied inversely with greater reductions in tree density and timber volume in the first year after harvest (Table 3.6). Notably, bunchgrass density demonstrated a negative response with understory light increases following thinning over the period from 1999 to 2001 (Table 3.6, Fig. 3.8). This was despite an overall increase in bunchgrass density during the study (Table 3.5).

3.3.3.2 Wolf Creek

Thinning treatments at Wolf Creek were not completed until June 2000. As a result, changes recorded in August 2001 were equivalent to 1 full year of recovery. Thinning reduced ($p<0.10$) the canopy cover of pinegrass, sedge, and total live canopy cover, as well as bunchgrass and forb production (Table 3.5).

There were several negative associations found between the amount of overstory thinning and the understory at Wolf Creek (Table 3.7). Of the 10 significant ($p<0.10$) relationships found, 9 indicated the understory responded negatively at greater levels of thinning. Of these, 8 occurred between 1999-2001 while only 1 occurred between 2000-2001 (Table 3.7). Although forage production was negatively affected between 2000 and 2001 (Fig. 3.10), this same relationship did not materialize over the longer three year period from 1999 to 2001. Other negatively affected characteristics included species richness (Fig. 3.9) and the canopy cover of pinegrass (Fig. 3.11), bryophytes, and total live canopy cover, which were all associated with changes in both understory light and timber volume (Table 3.7). The single positive understory response was in shrub production (Table 3.7).

3.4 Discussion

3.4.1. Pre-Thinning Overstory-Understory Relationships

Initial differences in understory plant communities between blocks were likely the result of varied overstory and/or ecosite conditions. Wolf Creek is located in the PPdh2 biogeoclimatic zone and Sheep Creek in the IDFdm2. Ponderosa pine sites are historically more open, drier and thus, better suited to support shade intolerant bunchgrass communities. In contrast, Douglas fir sites are relatively closed, moister and therefore capable of supporting more shrubs adapted to mesic conditions, such as, Saskatoon and birch-leaved spiraea. Given that the outcome of thinning will depend on initial plant community structure and composition (Thomas et al. 1999), differences between the 2 sites, as determined by landscape-scale variation, likely accounts for much of the differential responses to thinning.

Among the overstory variables examined in the pre-thinning data, understory light levels clearly was most closely associated with understory plant characteristics at both blocks. Tree density was associated with only a single understory characteristic, while basal area had no significant association. Studies documenting overstory effects on the understory have found that understory light is significantly associated with species presence and abundance as measured by density and canopy cover (Lieffers and Stadt 1993, Naumberg and DeWald 1999), while overstory tree characteristics (e.g. stem density , stand volume) are more closely associated with understory biomass (Riegel et al. 1995, Naumberg and DeWald 1999). Neither tree density nor timber volume are thought to relate well to the spatial distribution of trees (i.e. clumped vs. uniformly dispersed) in a stand or the influence of crown cover on the understory (DeMaere, Range Research Technician, BC Ministry of Forests, per. comm. 2002), which may explain why understory light is generally the best predictor of pre-thinning understory plant characteristics, particularly species canopy cover and presence. Furthermore, light measurements are a direct indication of the above-ground competitive influences within ingrown

NDT4 stands, as it is the only measurement that directly accounts for the overstory influence of trees and shrubs because it is taken 30cm off the ground.

The adverse impact of declining understory light levels is apparent at both blocks but is better expressed at Wolf Creek, possibly due to the larger sample size at this site. Declining diversity (Fig. 3.5) and species richness at low light levels has implications for the health of a plant community. Less diverse plant communities are less 'resilient' and less likely to recover from disturbances such as grazing or fire (Schulz and Mooney 1993, Tilman and Downing 1994**,** Naumberg and DeWald 1999). This finding is consistent with other studies completed in North American fire-maintained ecosystems (Covington et al. 1997, Uresk and Severson 1998).

Additionally, results at Wolf and Sheep Creek reflect the association between the bunchgrass and the palatable shrub community (e.g., Saskatoon) to increased tree crown cover or decreased light levels (Fig. 3.3 and 3.6). As light declines over time the more productive and light demanding species disappear and create room for the establishment and growth of other species better suited to the changing conditions (Knowles et al. 1999). There was no significant relationship, positive or negative, found between pinegrass canopy cover and light reinforcing the notion that this species is tolerant of the loss of light (Lunan and Habeck 1973, Steele and Geier-Hayes 1993). Furthermore, birch-leaved spiraea cover was positively associated with increasing tree density (Table 3.4). Replacement of desirable forage species with less palatable species may have implications for grazing management at both locations.

The general lack of significant pre-thinning relationships between the overstory and forage production at Wolf Creek is contrary to several studies that documented a strong negative relationship between forage production and crown closure (Pase 1958, Cooper 1960, Moir 1966, Ffolliott and Clary 1982, Borjoquez et al. 1989, Knowles et al. 1999). The only significant relationship found was a negative association between sedge production and light (Table 3.4), which was somewhat unusual as there was a positive relationship between sedge canopy cover and light (Table 3.4). These seemingly contradictory patterns may be attributed to a greater number of sedge plants at increased light levels, the size and biomass of which may be limited by intense competition from other graminoids under these conditions, leading to lower production. In any case, sedge production contributed relatively little to total production (7%), and thus, has limited implications for ungulate management. Pre-thinning forage production versus light relationships may also need to be examined in more detail due to the small sample sizes employed here and the fact that only one year of pre-thinning data was collected at the Wolf Creek site only.

3.4.2. Post-Thinning Overstory-Understory Relationships

The thinning treatments resulted in significant negative changes in the understory at both locations. This finding was likely due, at least in part, to the disturbance associated with thinning (i.e. selective logging) itself and its direct impact on the understory such as the destruction of Saskatoon shrubs at Sheep Creek (Table 3.6). The greater number of trees removed at Wolf Creek, and the fact that thinning occurred during the growing season (i.e. July), also suggests the overwhelmingly negative understory responses at this location are due to physical disturbance. Results of this research indicate that at low thinning intensities, physical site disturbance may outweigh any benefits to plants provided by increased resources such as light, particularly in the short-term. This has been found in other thinning projects as well (Thomas et al. 1999, Thysell and Carey 2001). The observed absence of an increase in herb canopy cover (Table 3.5) is consistent with other studies that have found plant canopy cover by life form failed to increase 2 years post-thinning (Riegel et al. 1995, Ross 2001). Ross (2001) observed that forage production in the East Kootenay did not increase significantly until 2 years after restoration treatments were initiated.

The results found here should also be tempered by the unusually dry conditions of 2000 and 2001 (Table 3.2), which may be one of the leading cause in the reduction of plant canopy cover and production after thinning. Severe drought accompanying thinning would have limited the potential for plant regrowth, and may have further amplified the impact of mechanical disturbance associated with logging**.** In addition, significant grazing effects ($p<0.10$), particularly at Sheep Creek (Table 3.8), may have placed further stress on the understory, leading to poor plant community responses over a 1 or 2 year period. The return of average precipitation, coupled with continued recovery of vegetation, will likely result in greater recovery of the herbaceous understory. Monitoring the duration it takes a plant community to positively respond is important as the ability of the understory to recover from mechanical operations is critical for maintaining a stable forage supply for wild ungulates and livestock (Riegel et al. 1992), as well as preventing the over utilization of NDT4 rangelands.

Despite severe summer drought, the presence of grazing and mechanical disturbance, bunchgrass density did increase at Sheep Creek over the 3 years of monitoring. This change coincided with a general reduction in species such as pinegrass. Relative to other grasses, bunchgrasses are less limited by water and are adapted to low-nutrient environments (Herron et al. 2001), which likely gives these species a competitive advantage at the sites examined, especially shallow-rooted pinegrass. It should also be noted, however, that the observed increase in bunchgrass density may not be due to actual recruitment over the limited time period examined here. Rather, the change could be due to an increase in the size of heavily suppressed (and thus, undetected) bunchgrasses during pre-thinning sampling. Regardless of the mechanism, the observed increase suggests that this key understory component is poised to recover following the return of average growing conditions. Although bunchgrass density generally increased, there was a negative relationship between the change in bunchgrass density and light transmittance (Table 3.6, Fig. 3.8), likely an artifact of their susceptibility to mechanical disturbance, similar to that of other species.

Despite the short-term negative effects of thinning, it appears that in the second year of recovery, more positive changes were evident at greater thinning intensities within the plant communities examined at Sheep Creek (Table 3.6). These results are consistent with other studies that have found higher levels of plant canopy cover and species richness at greater levels of thinning (Uresk and Severson 1998, Thomas et al. 1999). This same trend did not materialize at Wolf Creek (Table 3.7), in part due to the shorter elapsed response time of that block following thinning (i.e. only 1 year of recovery).

Unlike the pre-thinning relationships, positive changes in the understory at Sheep Creek were often related to stem density and stand volume rather than light (Table 3.6). This trend suggests the plant communities examined may be associated with changes in belowground resource availability such as nutrients and water rather than light itself. Studies have shown that thinning increases soil moisture (Della-Bianca and Dils 1960, Riegel et al. 1992, Feeney et al. 1998, Kaye and Hart 1998b). In Northeastern Oregon, Riegel et al. (1992) reported that increased soil water (in response to thinning) added two months to the growing season, leading to significantly greater understory biomass. Studies documenting the effects of thinning on available plant nutrients have also found increases in mineralizable nitrogen (Riegel et al. 1992, Kaye and Hart 1998a).

Negative relationships between key shrub density (Table 3.6) and overstory thinning intensity at Sheep Creek were likely due to the mechanical disturbance caused by thinning operations. Shrubs maintain aboveground biomass and are therefore susceptible to damage and may account for other studies indicating that shrub production (i.e. current annual growth) does not respond significantly to thinning (McConnell and Smith 1965, Riegel et al. 1992, Thomas et al. 1999). This finding, however, contrasts with the positive change in shrub production observed in relation to changes in tree volume at Wolf Creek (Table 3.7), and is somewhat surprising given the high level of disturbance at the latter block (512 stems/ha removed). A potential explanation involves the initial abundance of shrubs at each location, as Wolf Creek had a less extensive shrub community compared to Sheep Creek (Table 3.3). This would both reduce the potential for a negative impact from the physical disturbance of thinning at Wolf

Creek, as well as minimize competition among recovering shrubs in the post-thinned environment, facilitating their growth. This is reinforced by the observation that shrub cover was not significantly impacted at Wolf Creek by thinning as is was at Sheep Creek (Table 3.5).

A consideration when using thinning as a restoration tool is that opening of the overstory may favor early-successional species and possibly, exotic species (Thomas et al. 1999, Thysell and Carey 2001). Early germination, rapid growth, and allocation of resources to aboveground biomass enable weeds to preempt resource use by their competitors (Sheley et al. 1993, Herron et al. 2001). Although there were no noxious weeds found in the pre-thinning plant communities, 2 plots had Canada thistle (*Cirsium arvense* (L.) Scop. var. *horridium* Wimm. & Grab.) at the Sheep Creek site in 2001, a noxious weed in the East Kootenay (B.C. MoF/MoAFF Noxious/Nuisance Weed List). Occurrences were located on highly compacted soils, and did not appear to be restricting the range or growth of native species. Thysell and Carey (2001) observed a 280% initial increase in exotic species but recorded a decline in the first year post-thinning to the third. The initial increase in exotic species may be temporary as weed species may have 'transient occupancy' (Thysell and Carey 2001) at Sheep Creek.

3.5 Conclusions and Recommendations

It is apparent that increased tree ingrowth within the NDT4 stands investigated is associated with negative changes in the understory plant community (cover, production and diversity) at both Sheep and Wolf Creek, indicating that restoration activities were warranted.

Although initial short-term changes in the thinned communities examined here appear to be negative, this seems to be largely due to mechanical disturbance and drought, potentially compounded by grazing. Greater thinning intensities were associated with larger positive changes in the understory in species richness and diversity. There was also some evidence for the recovery of the bunchgrass community. However, these results were not consistent across both study locations. It is therefore evident that individual blocks slated for restoration will need to be monitored in the future to see if recovery occurs and/or continues in each. Additionally, blocks should be monitored for the longevity of damage due to thinning activities (e.g. weed invasion, soil compaction leading to poor herb re-establishment or forage production).

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Table 3.1 Restoration targets[1] for various habitat components on crown land in the East Kootenay Trench of BC at the end of 30 years (2030).

Habitat component	Current distribution (% of Trench)	Final distribution target (% and ha of Trench)	Tree density target (stems/ha)
Shrubland	5 %	5 % (12,500 ha)	0
Grassland	10 %	23 % (57,500 ha)	? 75
Open forest	Open & managed forest is 85 % combined	31 % (77,500 ha)	76 – 400
Managed forest		41 % (102,500 ha)	400 – 5,000

[1] Targets are achieved within the Crown NDT4 land base at the forest district level (Machmer et al. 2001).

Table 3.2 Temperature and precipitation at Johnson Lake weather station, 1999-2001[1] compared to the long-term averages recorded at the Cranbrook[2] airport (1968 - 1990).

	1999		2000		2001		Long-Term Avg.	
	Temp. (?C)	Ppt. (mm)	Temp. (?C)	Ppt. (mm)	Temp. (?C)	Ppt. (mm)	Temp. (?C)	Ppt. (mm)
May	10.1	22.6	10.6	22	12.8	7.7	11.2	43.6
June	14	50.1	14.8	16.9	14.3	29.2	14.9	50.5
July	16.5	44.1	19.5	13.8	19.4	16	18.3	31.6
Aug	18.4	47.5	18.2	12.1	20.6	4.2	17.8	34.4
Sept	12	6.5	11	21.9	14.1	13.8	12.4	32.6

[1] 49?55'N 115?44'W, Elev.-853m.

[2] 49?37'N 115?47'W, Elev.-939m.

Table 3.3 Comparison of overstory and understory (i.e. canopy cover) characteristics between the Sheep and Wolf Creek blocks, as sampled prior to thinning (1999).

		Sheep Creek (IDF)		**Wolf Creek (PP)**		
Strata	**Variable**	**Mean**	**StDev**	**Mean**	**StDev**	**p-value**
Understory						
	Bunchgrass canopy cover[1,2] (%)	1.62	1.62	7.22	1.42	**<0.001**
	Pinegrass canopy cover (%)	9.93	5.57	16.67	11.61	**0.05**
	Shrub canopy cover (%)	14.69	5.12	7.07	3.04	**<0.001**
	Carex canopy cover[2] (%)	0.61	0.18	4.9	5.06	**<0.001**
	Forb canopy cover (%)	8.38	5.75	8.72	5.34	0.86
Overstory						
	Volume (m^3/ha)[2]	126.77	63.5	75.25	44.39	**0.008**
	Density (stems/ha)[2]	503.62	367.36	705.28	457.50	0.23
	Understory light (%)	27.3	7	33.5	10	**0.05**

[1] Native bunchgrasses considered historically common as listed on pp.51.

[2] p-values are reported based on analysis using transformed data. Means and standard deviations of original data are presented.

Table 3.4 Summary of pre-thinning regressions of the understory variables on understory light and overstory tree density. Only regressions with $p<0.20$ are reported.

Block	**Independent variable**	**Dependent variable**	**r^2 value**	**Root MSE**	**P-value**	**Regression equation**
Sheep Creek (n=15) [4]						
	Light (% of full)	Species richness (x/2m^2)	0.18	5.65	0.11	y=8.42+34.80x
		Species diversity	0.18	0.17	0.13	y=0.57+0.97x
		Bunchgrass density^{1,2} (x/10m^2)	0.16	1.13	0.13	y=0.26+6.48x
		Shrub canopy cover(%)	0.14	5.02	0.17	y=7.95+0.31x
		Saskatoon canopy cover(%)^2	0.22	0.31	**0.08**	y=-0.16+2.41x
		Saskatoon density (x/20m^2)^2	0.30	0.45	**0.03**	y=-0.14+3.88x
		Total herb canopy cover (%)	0.32	12.37	**0.03**	y=1.99+110.61x
	Tree density (stems/ha)	Spiraea canopy cover (%)	0.30	5.48	**0.04**	y=-3.49+0.48x
Wolf Creek (n=18)						
	Light (% of full)	Species richness (x/80m^2)	0.18	6.01	**0.07**	y=10.81+25.92x
		Species diversity	0.26	0.19	**0.03**	y=0.47+0.97x
		Bunchgrass canopy cover (%)^{1,2}	0.29	8.9	**0.02**	y=6.68+0.11x
		Forb canopy cover (%)	0.67	4.80	**<0.001**	y=-4.39+39.93x
		Total canopy cover (%)	0.44	17.65	**0.002**	y=17.76+144.71x
		Shrub canopy cover (%)	0.20	2.96	**0.06**	y=2.37+13.60x
		Saskatoon canopy cover (%)^2	0.33	0.21	**0.01**	y=0.20+1.39x
		Saskatoon density (x/20m^2)^2	0.49	0.27	**0.02**	y=0.74+2.33x
		Sedge canopy cover (%)^2	0.35	0.92	**0.008**	y=-0.14+6.25x
		Sedge production (kg/ha)^{2,3}	0.63	0.31	**0.006**	y=1.95-0.5x

[1] Native bunchgrasses considered historically common as listed on pp.51.

[2] p-values are reported based on analysis using transformed data. Means and standard deviations of original data are presented.

[3] These data only use 10 plots as production data was not collected at all 18 plots in 1999.

[4] No production available from Sheep Creek in 1999.

Table 3.5 Understory variables undergoing significant ($p<0.1$) changes during 3 consecutive years of sampling from 1999-2001 at each block.

Block	**Time**	**Response Variable**	**? mean**	**SD$_{? x}$**	**Pr<F**
Sheep	2000 – 2001	? Pinegrass canopy cover (%)^1	-3.15	3.66	0.03
	1999 – 2001	? Bunchgrass density (x/10m^2)^1	6.1	7.30	0.07
		? Spiraea canopy cover (%)	-4.03	1.09	0.02
		? Shrub canopy cover (%)^1	-6.37	6.25	0.002
		? Bryophyte canopy cover (%)^1	-6.75	8.31	0.02
Wolf	1999 – 2001	? Pinegrass canopy cover (%)	-7.36	8.24	0.03
		? Sedge canopy cover (%)	-2.46	3.61	0.09
		? Total herb canopy cover (%)	-28.68	17.41	<0.001
		? Bunchgrass production (kg/ha)^{1,2}	-21.7	36.4	0.03
		? Forb Production (kg/ha)^{1,2}	-25.2	33.9	0.03

[1] p-values are reported based on analysis using transformed data. Means and standard deviations of original data are reported.

[2] These data only use 10 plots as production data were not collected at all 18 plots in 1999.

Table 3.6 Relationship of changes in the tree overstory following thinning to subsequent understory changes from 1999-2001 at Sheep Creek (Interior Douglas Fir zone). Only regressions with p<0.1 are reported (n=15).

Time Period	Independent Variable	Dependent Variable	r^2 Value	Root MSE	Pr<F	Regression Equation
1999-2000						
	? Tree density (stems/ha)	? Saskatoon density (x/20m^2)^1	0.43	3.45	0.07	y=3.78-0.27x
	? Volume (m^3/ha)	? Saskatoon density (x/20m^2)^1	0.36	3.82	0.07	y=3.39-0.50x
2000-2001						
	? Tree density (stems/ha)	? Species diversity	0.25	0.11	0.07	y=-0.08+0.01x
		? Species richness (x/80m^2)	0.43	2.84	0.01	y=-5.59+0.25x
		? Total cover (%)	0.33	9.44	0.03	y=-14.36+0.68x
		? Forb cover (%)	0.22	4.51	0.09	y=-4.87+0.25x
		? Bryophyte cover (%)^1	0.29	4.40	0.05	y=-6.43+0.29x
	? Volume (m^3/ha)	? Species richness (#spp/80m^2)	0.44	2.72	0.01	y=-5.25+0.49x
		? Bryophyte cover (%)^1	0.42	3.62	0.02	y=-7.52+0.61x
	? Light (%)	? Bryophyte cover (%)^1	0.27	5.29	0.05	y=-5.72+25.1x
1999-2001						
	? Light (%)	? Bunchgrass density (x/10m^2)^1	0.22	0.68	0.08	y=5.09-2.83x

[1] p-values are reported based on analysis using transformed data. Means and standard deviations of original data are reported.

Table 3.7 Relationship of changes in the tree overstory following thinning to subsequent understory changes at Wolf Creek from 1999-2001 (Ponderosa Pine zone). Only regressions with $p<0.1$ are reported ($n=18$).

Time Period	Independent Variable	Dependent Variable	r^2 Value	Root MSE	Pr<F	Regression Equation
1999-2000						
	? Volume (m^3/ha)	? Shrub Production (kg/ha)	0.45	0.50	0.07	$y=-0.14+0.12x$
2000-2001						
	? Light (%)	? Total Production (kg/ha)	0.22	3.72	0.06	$y=3.08-11.3x$
1999-2001						
	? Light (%)	? Species Richness (#spp/80m^2)	0.17	4.29	0.09	$y=2.15-10.5x$
		? Total Cover (%)	0.16	16.61	0.1	$y=39.7-15.6x$
		? Pinegrass Cover (%)	0.30	6.92	0.02	$y=0.33-24.9x$
		? Bryophyte Cover	0.25	1.54	0.05	$y=1.14-3.87x$
	? Tree Density (stems/ha)	? Pinegrass Cover (%)	0.30	7.10	0.02	$y=-0.92-0.34x$
		? Bryophyte Cover	0.20	1.38	0.1	$y=0.93-0.05x$
	? Volume (m^3/ha)	? Pinegrass Cover (%)	0.24	7.40	0.04	$y=-1.17-1.08x$
		? Bryophyte Cover	0.20	2.34	0.09	$y=0.95-0.17x$

Table 3.8 Comparison of forage removed for all significant ($p<0.10$) variables, as determined by caged and uncaged production (kg/ha) data at both blocks in 2000 and 2001.

			Caged		Uncaged		Pr<F
Location	**Time Period**	**Functional Group**	**Mean**	**StDev**	**Mean**	**StDev**	
Sheep	2000	Shrubs[1]	27.3	11.3	7.7	7.4	0.01
		Total	131.4	53.3	45.7	34.6	0.02
	2001	Pinegrass	44.2	18.9	9.3	8.7	0.01
		Shrubs[1]	50.5	33.7	4.0	3.2	0.02
		Total	124.5	20.4	37.9	38.1	0.002
Wolf	2001	Forbs	38.9	25.0	13.0	9.1	0.06

[1] p-values are reported based on analysis using transformed data. Means and standard deviations of original data are presented.

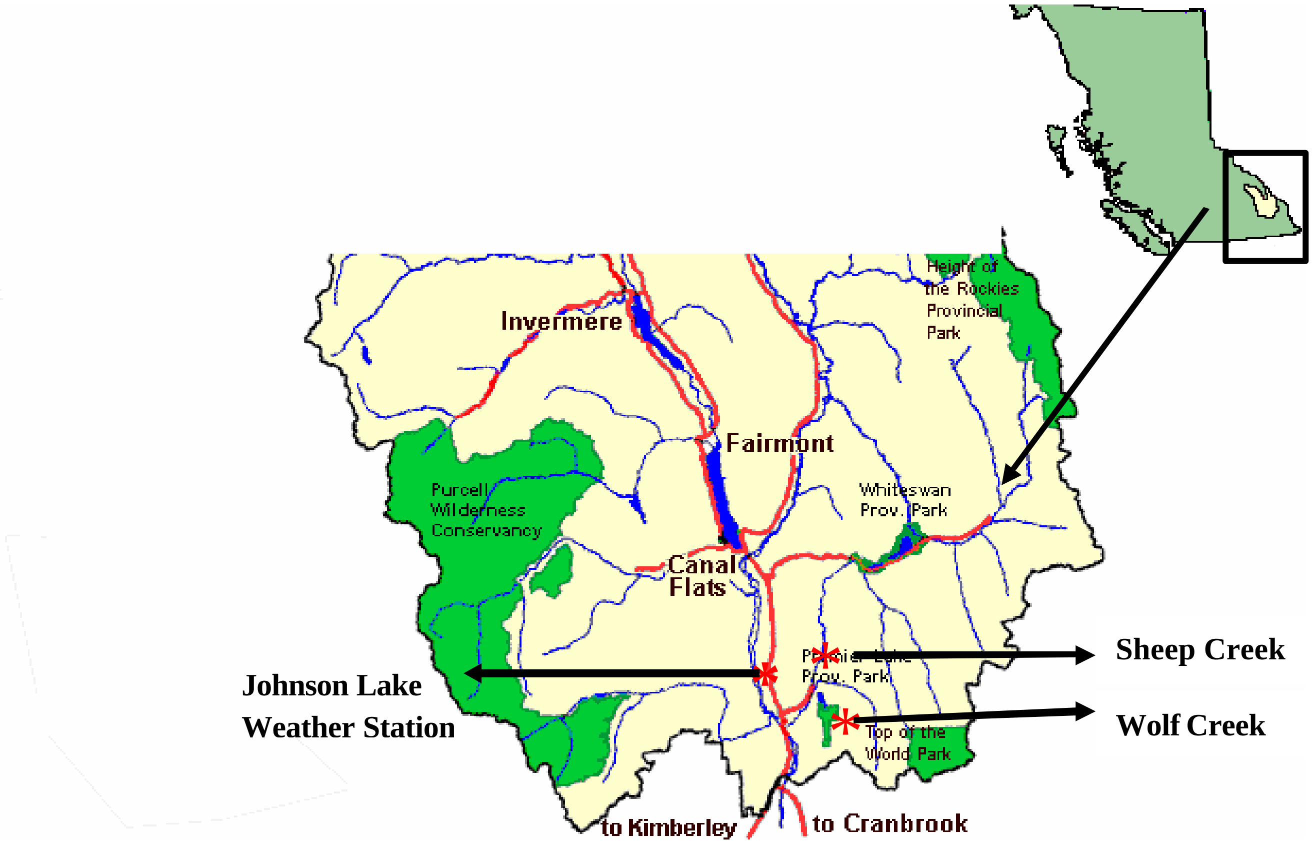

Fig. 3.1. Invermere Forest District. An (*) indicates the location of the two monitoring blocks (Sheep and Wolf Creek).

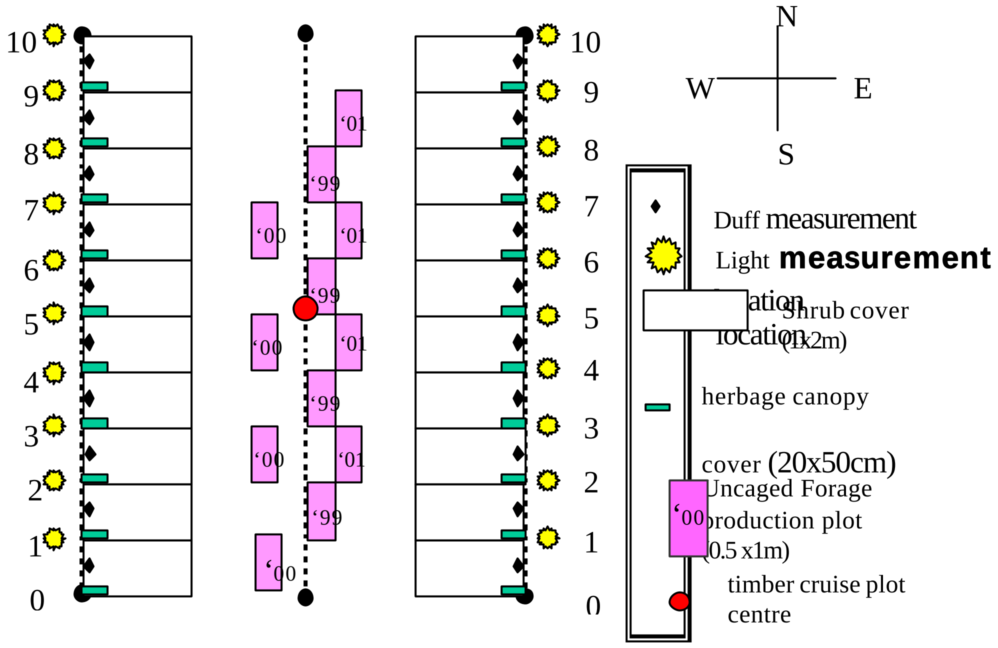

Fig. 3.2. Example of a plot used for sampling the understory (DeMaere 2001). Adapted from Powell et al. (1998).

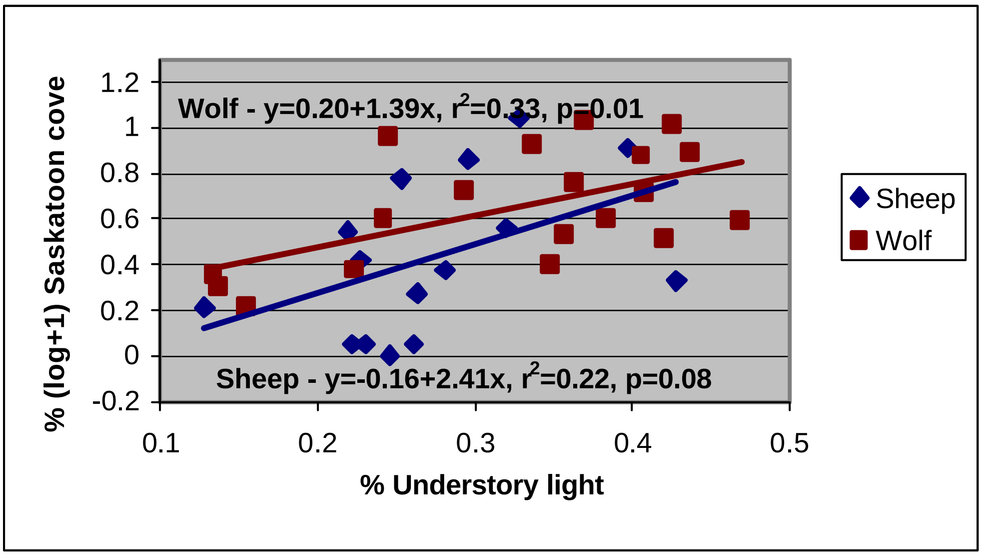

Fig. 3.3. Pre-thinning Saskatoon cover (%) regressed against understory light for both blocks in 1999.

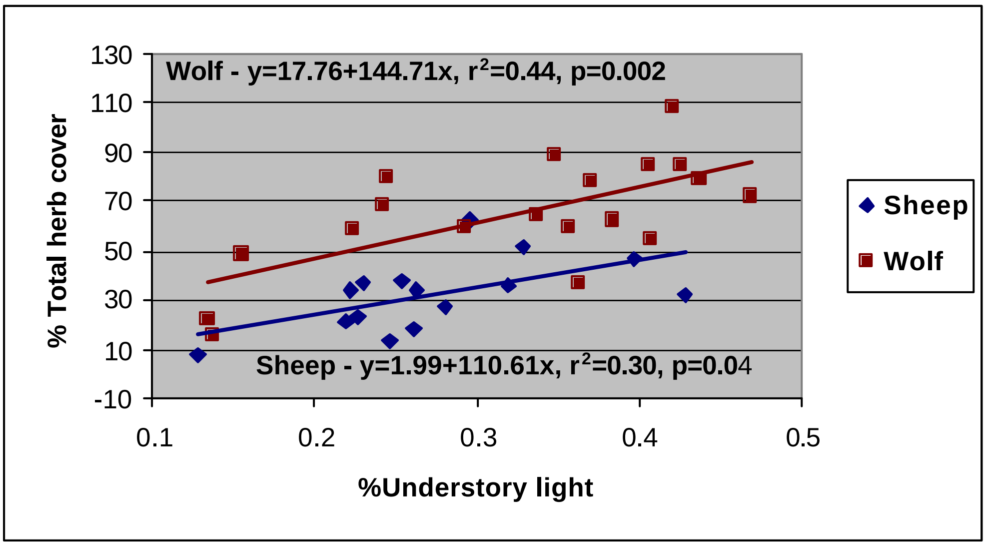

Fig. 3.4. Pre-thinning total herb cover (%) regressed against understory light for both blocks in 1999.

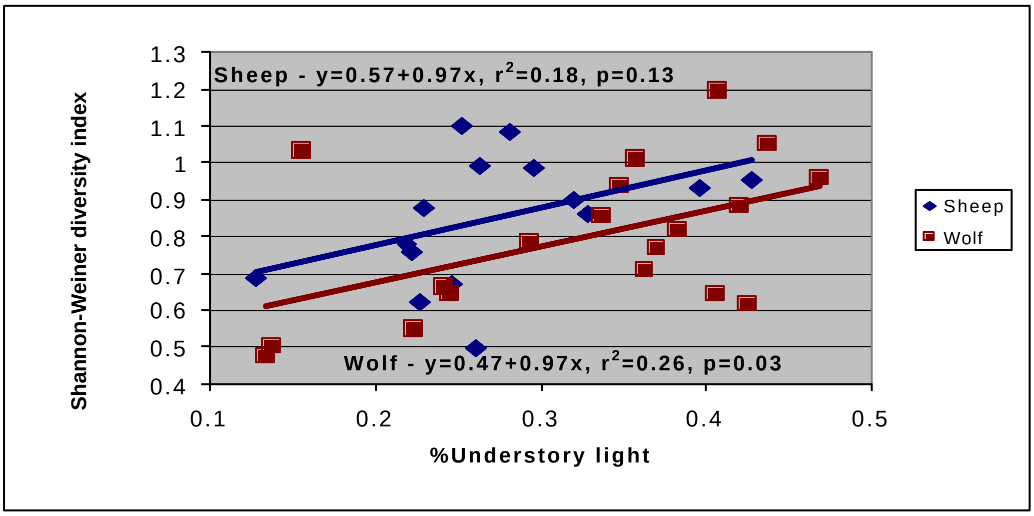

Fig. 3.5. Pre-thinning species diversity (Shannon-Weiner index) regressed against understory light for both blocks in 1999.

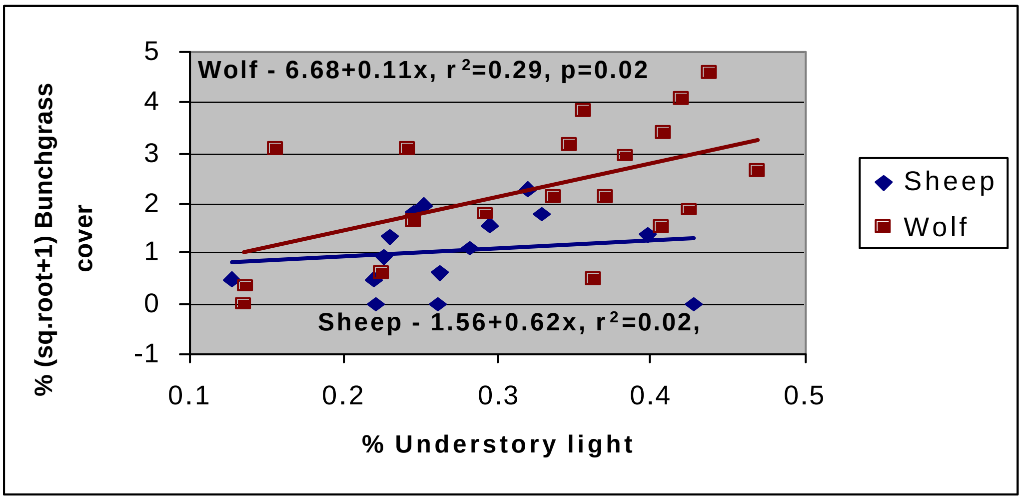

Fig. 3.6. Pre-thinning bunchgrass cover regressed against understory light for both blocks in 1999.

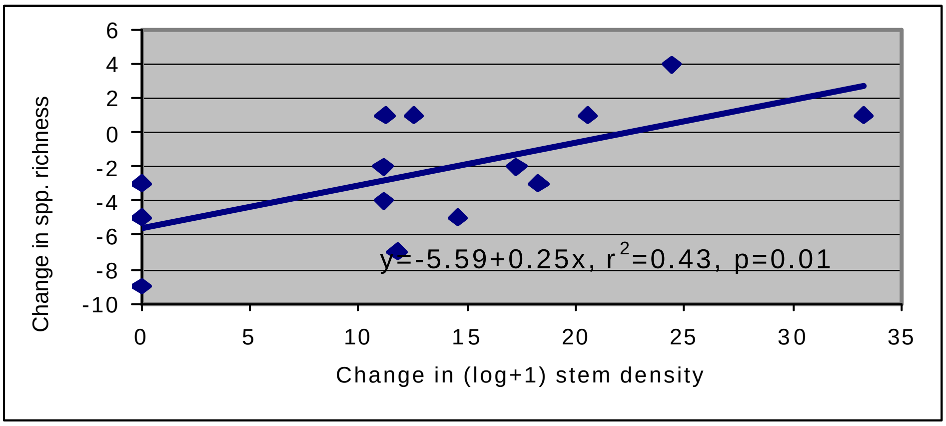

Fig. 3.7. Change in (?) species richness regressed against ? stem density (log+1 transformation) at Sheep Creek between 2000 and 2001.

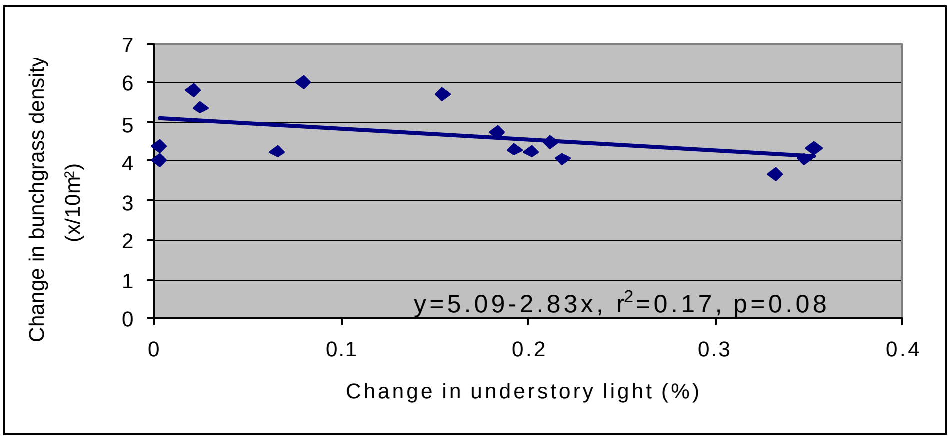

Fig. 3.8. Change in (?) bunchgrass density (x/10m^2) regressed against ? understory light at Sheep Creek between 1999 and 2001.

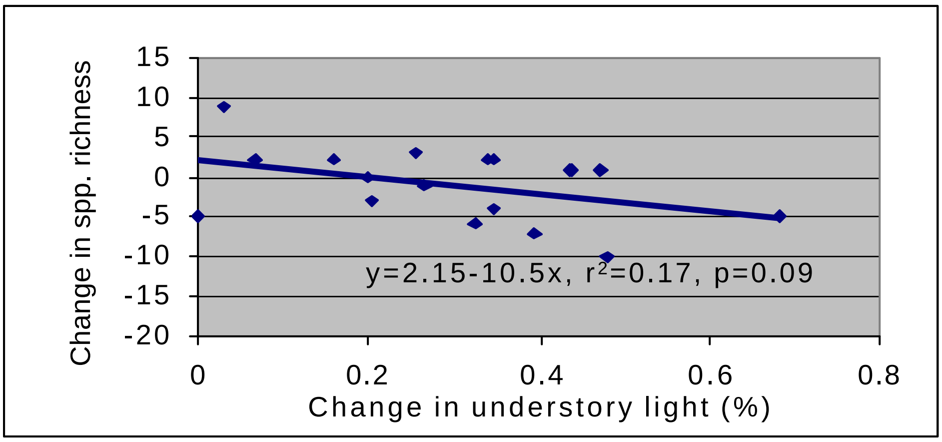

Fig. 3.9. Change in (?) species richness regressed against ? understory light at Wolf Creek between 1999 and 2001.

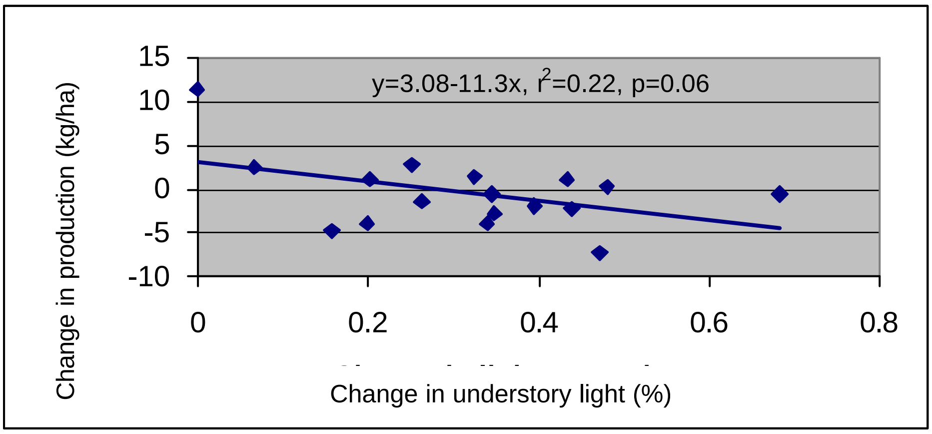

Fig. 3.10. Change in (?) production (kg/ha) regressed against ? understory light at Wolf Creek between 2000 and 2001.

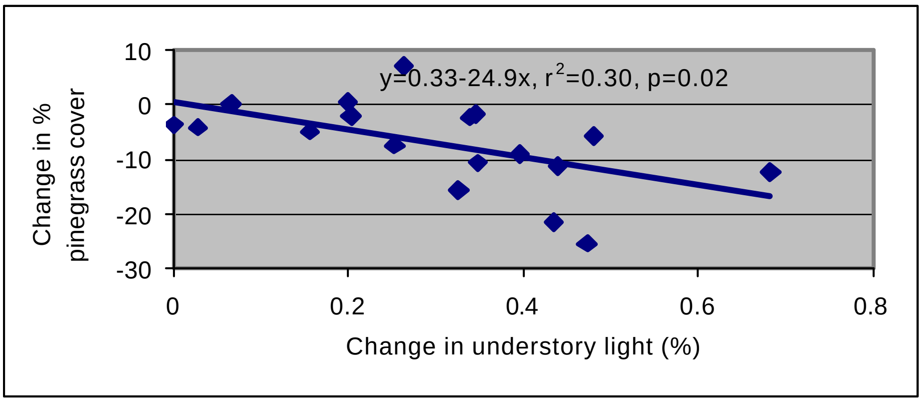

Fig. 3.11. Change in (?) pinegrass cover regressed against ? understory light at Wolf Creek between 1999 and 2001.