# RESPONSE OF UNDERSTORY VEGETATION TO SOIL DISTURBANCE IN THE INTERIOR DOUGLAS-FIR ZONE OF SOUTHEASTERN BRITISH COLUMBIA

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A thesis in partial fulfillment of the requirements for the degree:
MASTER OF SCIENCE
in
ENVIRONMENT AND MANAGEMENT

We accept this thesis as conforming to the required standard

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February 2007

# Abstract

This research studies soil disturbance effects on understory vegetation and the application of remotely sensed data in three replicated Long-Term Soils Productivity sites in southeastern British Columbia. Forest floor removal reduced total cover of vegetation. The combined effects of forest floor removal and compaction significantly reduced cover of kinnikinnick, total forbs, and rough fescue. Species richness and diversity increased after harvesting. Grass diversity increased under forest floor retention and decreased under forest floor removal and heavy compaction. Forb diversity increased with forest floor removal. Soil rehabilitation reduced vegetation cover and organic matter amelioration did not affect vegetation cover greatly. Remotely sensed vegetation cover data detected trends in cover classes and was moderately correlated to ground data. This study indicates that vegetation cover is a suitable indicator of severe soil disturbance and may be useful as a visual classification system in adaptive forest management.

## Acknowledgements

I would like to thank Dr. Robert Magai and Dr. Mike Curran for their guidance and supervision of this research project. Dr. Margaret Magai provided invaluable assistance in field data collection and review of this thesis. Peter Ott, biometrician with the Ministry of Forests and Range, provided invaluable assistance with statistical analysis models. The Forest Investment Account (FIA) provided funding for the remote sensing and data analysis portions of this project. The support of the School of Renewable Resources at Selkirk College in providing time to complete this thesis was of great assistance. As well, the Selkirk College Faculty Association provided needed funds to offset University expenses while attending residencies. Most importantly, the support of my parents, wife and children was a constant source of strength during this project and university course work.

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# 1.0 Background

## 1.1 Introduction

Understory vegetation in Douglas-fir forests of southeastern British Columbia provides critical habitat and forage for wildlife species, grazing land for domestic livestock, and performs critical ecosystem services such as controlling microclimate extremes on sites. Monitoring changes in understory vegetation as a result of site disturbance can be labour-intensive and can benefit from innovative methods such as high resolution remote sensing that is capable of monitoring large areas of land in short time periods. While some studies have been conducted in similar ecosystems (Hope, 2006; Newman and Wurtz, 2004) little is known regarding the response of understory species to varying levels of soil disturbance on calcareous (high pH) soils in southeastern British Columbia. In addition, no studies have been conducted using digital analysis of remote sensing to monitor changes in vegetation that may occur with soil disturbance in these ecosystems.

This thesis will focus on the response of understory vegetation to differing levels of soil disturbance in southeastern British Columbia, and the applicability of airborne remote sensing to detect the changes in vegetation structure in response to predetermined levels of soil disturbance. The research is conducted on Long-term Soils Productivity (LTSP) replicated research installations in the east Kootenay region near Canal Flats, British Columbia. The LTSP network is an international research collaboration that studies the effects of differing levels of soil compaction and organic matter removal on long-term site productivity. In addition to forest productivity and soil conservation, results from this research have broad applications for habitat management of rare species, ecological restoration, range planning for domestic livestock, and applying operational remote sensing technology for ecosystem monitoring.

## 1.2 Sustainable soil management

Sustainable forest management is a key objective outlined by the 1992 United Nations Conference on Environment and Development through Agenda 21 and the Statement of Forest Principles (United Nations Department of Economic and Social Affairs, 2006). Based on the principles outlined in Agenda 21, soils have been identified as critical indicators of sustainable forest management in temperate and boreal ecosystems through The Montreal Process (1995) and by the Canadian Council of Forest Ministers (CCFM, 2003). Changes in soil chemistry and physical qualities that result from loss of surface organic matter and soil compaction are specific criteria cited for sustainable forest management identified by the Montreal Process and the CCFM.

Proper management of forest soil resources is critical in order to maintain the delivery of ecosystem goods and services (Cline et al., 2006). Vegetation can serve as integrators of all environmental conditions, such as underlying soil properties (Gray and Azuma, 2004), such that changes in soil properties may influence vegetation composition and, hence, alter habitat and food for wildlife (Kabzems, 2000). Forest understory vegetation provides habitat and food resources for a wide variety of other wildlife. With attention currently focused on adaptive management and sustainable practices for forestry (Curran et al., 2005b), vegetation may be suitable as one criterion in a visual classification system to provide qualitative soil inspections.

## 1.3 Vegetation responses to soil disturbance

### 1.3.1 Soil Compaction

Soil compaction is a function of soil texture and the forces applied to the soil by harvesting equipment, typically resulting in increased bulk density, decreased soil porosity, and increased soil strength (Greacen and Sands, 1980; Koslowski, 1999). Soil compaction can influence primary productivity by affecting water infiltration, gas exchange, root penetration, and microbial activity (Powers, Sanchez, Scott, and Page-Dumroese, 2004). Vegetation response to soil compaction depends on the soil textures that dominate a site. On coarse textured soils at LTSP sites around North America, a positive response of vegetation on compacted sites was considered to be due to an increase in water holding capacity on the site (Gomez, Powers, Singer, and Horvath, 2002; Powers et al., 2004; Holcomb, 1996). Compaction on sandy loam soils in California was found to increase stem volume ($dm^3 tree^{-1}$) by 173%; whereas, compaction of clay soils reduced stem volume by 45% (Gomez et al., 2002). In southern California, non-compacted medium-textured soils were found to have 55% higher biomass than compacted soils but productivity was higher on compacted sandy loam soils due to increased soil water holding capacity on the coarse-textured soils (Powers et al. 2004). Initial seedling growth response on the silt-loam textured Mud creek LTSP site studied in this thesis indicates that both lodgepole pine (*Pinus contorta*) and Douglas-fir (*Pseudotsuga menziesii*) stem diameter and height did not change on compacted treatments (Kamaluddin, Chang, Curran and Zwiazek, 2005). Rehabilitated treatments (decompacted), had dramatically higher diameter growth response for lodgepole pine (+51%) which was attributed to better nutrient availability and reduced resistance for root penetration. On the same site, foliar Nitrogen (N) levels for lodgepole pine and Douglas-fir were higher in rehabilitated treatments and tended to increase with increasing disturbance such as forest floor removal but not with compaction (Choi et al., 2005). This was attributed to greater availability of N when organic matter becomes incorporated into the mineral soil and exposed to decomposing bacteria following rehabilitation.

In compaction studies with barley on silty-clay soils, total biomass was reduced after experimental compaction due to higher bulk densities and increased root resistance (Arvidsson, 1999). Although plants may be able to meet water and nutrient demands in the short-term, increased soil strength decreases the ability of roots to exploit new portions of the soil (Greacen and Sands, 1980). Decreased water availability often results in increased levels of abscissic acid production in plants followed by stomatal closure and hence lower photosynthetic rates (Kozlowski, 1999). On the other hand, seedling growth has been found to improve under compacted soil conditions on medium-textured soils with intact forest floors (Brais, 2001; Fleming et al. 2006) due to reduced competition from other vegetation on severely compacted sites. Additionally, compaction has been reported to increase root-soil contact and enhance ion uptake by mass flow (Arvidsson, 1999) and led to increased soil temperatures favourable to plants (Powers et al., 2004).

Compaction can result in decreased plant cover because of physical damage to reproductive structures from machinery traffic (Kranabetter, 1999) including basal meristems and changes in the availability of seed sources (Powers et al., 2004). However in some cases, herbaceous plant cover increases to the detriment of other species. Kabzems (2000) reported that bluejoint (*Calamagrostis canadensis*) cover in boreal LTSP sites increased in cover with increasing compaction. Heavy compaction increased bluejoint cover up to 30% while on non-compacted sites, cover increased by about 20%. Strongly rhizomatous species such as bluejoint are capable of surviving compaction by sprouting from dormant buds or broken root fragments buried in the soil (Haeussler, Coates, and Mather, 1990). Although increasing the amount of ground cover can be beneficial for moisture and nutrient retention, any positive benefits will be offset by increased levels of moisture competition with other woody plants. Pinegrass (*Calamagrostis rubescens*), a highly competitive species for moisture in the Interior Douglas-fir zone, maintains high ground cover despite increasing soil compaction levels in British Columbia LTSP sites (Hope, 2006). This species is also strongly rhizomatous and is able to survive damage to above ground structures by reproducing from buried meristems. Few studies have focused on the impact of soil compaction on forage species such as rough fescue (*Festuca campestris*) and bluebunch wheatgrass (*Pseudoroegneria spicata*). Bunchgrasses have been found to suffer damage to above ground structures during restoration harvesting (Page, Bork and Newman, 2005). Damage would also likely occur during machine traffic or log dragging during forest harvesting and this would lead to reduced cover of these species. Idaho fescue (*Festuca idahoensis*) has been found to survive on disturbed sites due to a genotypic adaptation to water stress tolerance and not necessarily from an ability to out compete other vegetation (Goodwin, Doescher, Eddleman, and Zobel, 1999). Soil compaction could lead to water stress in bunchgrasses; however, theses grasses may have adaptations to persist under this type of disturbance.

Soil compaction has been reported to increase species richness and diversity on LTSP sites in boreal forests two years after treatment (Kranabetter, 1999). Most of the increase in richness occurred in the forb layer, where heavy compaction tended to result in higher numbers of species than non-compacted sites (30 and 25 species, respectively). Increases in species richness in boreal forests have been linked to a persistent seed bank of species or effective wind dispersal mechanisms for seeds (Pykala, 2004). Higher richness and diversity has largely been attributed to increases in numbers of weedy annual species in boreal sites (Haeussler, Bedford, Leduc, Bergeron and Kranabetter, 2002; Kranabetter, 1999) such as common dandelion (*Taraxacum officinale*), hawkweed (*Hieracium* spp.), fireweed (*Epilobium* spp.), and pearly everlasting (*Anaphalis margaritaceae*) (Haeussler et al., 2002). On heavily compacted sites, Kranabetter (1999) reported that approximately 10% of the species richness was due to newly dispersed seed compared with less than 5% on non-compacted sites. Compaction decreased the amount of residual sprouting species, and rhizome regeneration. No studies to date have examined the effect of soil compaction on understory species richness and diversity in southern Douglas-fir forests of British Columbia.

Increased soil fauna activity (Koslowski, 1999) and increased root activity (Page-Dumroese et al., 2006) following canopy removal has been found to aid in compaction recovery in some soils. In North American studies, data from primarily non-glaciated forest soils compacted by heavy machinery have had partial recovery 10 years after soil compaction (Page-Dumroese et al., 2006). Soil compaction was evident to depths of 30 cm in the soil which is average rooting depth for many plants. Bulk density (g $cm^{-3}$) recovery on medium to coarse textured soils was higher in the upper 10 cm of the soil profile than at depths exceeding 10 cm. Fine textured soils did not show much recovery five years after treatment and coarse-textured soils were found to recover more quickly than fine textured soils. Some sites are able to recover from soil compaction depending on the level and depth of compaction, percent clay content, and freeze/thaw cycles (Tiarks et al., 1997). However in soil compaction studies in Quebec, Brais (2001) found that penetration resistance on compacted soils was still higher than uncompacted soils six years following timber harvesting. Similar results have been found on sites in southern British Columbia 16 years after compaction (M.P. Curran, personal communication, February 11, 2007).

### 1.3.2 Organic matter removal

In many coniferous forests the forest floor is often a major component of site organic matter and nutrient capital. These forest floor layers develop as a result of litter fall from vegetation, microbial activity in the soil and fungal decomposition. The effects of surface organic removal may not impact ecosystems until the nutrient storage in the upper mineral layers is depleted. However, short-term impacts such as water evaporation and soil erosion may occur without this protective surface organic layer.

Most perennial forest understory species have life history strategies that allow for regeneration after moderate disturbances to the forest floor. These adaptations include bud-banking, seed-banking, horizontal extension of rhizomes, and root-suckering (Roberts, 2004). The ability of vegetation to reproduce by these strategies is dependent on the level of disturbance that occurs in an ecosystem. In severe disturbances, removal of vegetative reproductive structures and the associated seed bank result in decreased perennial vegetation on a site. Pinegrass cover on Douglas-fir dominated LTSP sites with acidic soils did not change after surface organic matter removal and soil compaction (Hope, 2006). This was attributed to the abundant rhizome system of pinegrass in the upper mineral horizons that allows for regeneration following disturbance. In addition, Newman and Wurtz (2004) found that pinegrass cover was only reduced by removal of the upper mineral soil horizons in combinations with the surface organic layer in the Interior Douglas-fir dry-belt of British Columbia. On less severe disturbances, pinegrass tiller density had recovered after only one growing season. Scalping of the forest floor on boreal LTSP sites reduced overall herb cover and provided suitable conditions for a shift in species composition from perennial native species to weedy annuals (Kabzems 2000). Scalping resulted in an increase of seven new “weedy” herbaceous species compared with pre-treatment conditions. All shrub species except prickly rose (*Rosa acicularis*) were reduced by scalping. Prickly rose maintained covers of 2-11% across all treatments irregardless of the level of soil disturbance. Moss cover increases were associated with a decrease in diversity of species and dominance of early pioneer species such as fire moss (*Ceratadon purpureus*) and juniper haircap moss (*Polytrichum juniperinum*) (Kabzems, 2000; Kranabetter, 1999).

Many studies indicate that removal of the surface organic layers will result in an increase in soil temperature (Fleming et al. 2006; Frey et al., 2003; Sanchez, et al., 2006). In cool climates, this increase may be beneficial to the ecosystem because of increased root and soil fauna activity. Organic matter removal on United States LTSP sites has been found to increase early season growing conditions by increasing soil temperatures yet may reduce late season growth due to evaporative loss of soil moisture (Fleming et al., 2006). Stem diameter for seedlings was found to increase on scalped sites where vegetation control (brushing) was used but decreased slightly where no vegetation control was used. Presumably, this effect would dissipate as forest floor began to accumulate organic matter over time. In dry climates, any benefits of increased soil temperature may be offset by a prolonged summer drought condition as a result of the decrease moisture holding capacity of the surface organic layer. For instance, the Emily creek site for this study is dominated by coarse-textured fine sandy loam soils which may have less available soil water during late summer months.

### 1.4 Applications of remote sensing to ecosystem monitoring

Remote sensing with satellite imagery has been limited by the relative coarse spatial resolution of the input data. Lefsky, Cohen, and Spies (2001), reviewed the abilities of different space-borne technologies (Airborne Data Acquisition and Registration-ADAR; Landsat Thematic mapper; and Light detecting and ranging-Lidar). The major disadvantage of space-borne technology is the course spatial resolution (10-30m) of the digital imagery. While this is beneficial for mapping vegetation at sub-regional to regional levels, it has little application in mapping specific responses to soil disturbances at the site level. Airborne digital remote sensing with spatial resolution of less than 30cm has the capability to map vegetation at large scales. Although this type of data requires specialized flights, it may be possible to combine efforts and use one data set for a variety of analyses.

Images are classified based on the spectral reflectance of land cover features. Vegetation absorbs light strongly in the visible portion of the electromagnetic spectrum, particularly in the blue (0.4-0.5 µm) and red (0.6-0.7 µm) portion. Peak reflectance of vegetation occurs in the green portion (0.5-0.6 µm) and in the near and middle infrared (> 0.7 µm) of the spectrum (Campbell, 2002). Colour photography is limited to detecting vegetation responses in the visible portion of the spectrum (mostly green). Alternatively, near-infrared photography can be used to detect vegetation responses in the non-visible portion of the spectrum. The latter is advantageous since the spectral reflectance in the infrared is much greater than the green portion of the spectrum and subtle differences in vegetation may be detectable.

The degree of reflectance and absorption depends on the structure of the leaf, vegetation condition (stress response), and phenology. Chlorophyll is responsible for the absorption of light energy in the red and blue portions of the spectrum. There is a greater abundance of chloroplasts in the upper cells of the leaf (palisade parenchyma) and so greater amounts of light absorption also takes place in this region (Raven, 1987). The amount of chlorophyll found in this tissue affects the reflectance and absorption features on the image. For instance, cool and warm season grasses have been found to differ in their spectral response due to greater chlorophyll content in their leaf tissue in the early spring (Xulin, Price, and Stiles, 2000). For example, chlorophyll content was used to map green and senescent vegetation in New Mexico with high resolution aerial photography using eCognition™ (now Definiens ™) analysis software (Laliberte, Rango, and Fredrickson, 2006).

Images are classified based on the spectral response of individual pixels. Supervised classification of individual pixels has been a common approach; however, difficulties arise when more than one feature occupies a particular pixel. This is a common issue in coarse spatial resolution data derived from satellite technology. Also, Tuominen and Pekkarinen (2005) note that the spectral reflectance in individual pixels is variable with respect to the location in the image. One solution to this problem is to use a “neighbor” classification in which pixels are classified based on their location within larger pixels clusters. Increases in accuracy were found using a neighbor classification in mapping Mediterranean vegetation from scanned colour aerial photographs (Yohay and Ronen, 1998).

There have been many different attempts to map regional vegetation cover using relatively coarse spatial resolution satellite imagery with varied success. Arctic dwarf shrub communities were mapped with 81% accuracy at 20m resolution (Beck, 2005). Toyra and Piettroniro (2005) applied 10 and 30m resolution images to map wetland vegetation and found accuracies of up to 85%. One major advantage of satellite imagery is that it is relatively easy to obtain and there is coverage across most areas of land. However, coarse spatial resolution does not allow for detailed analysis of heterogeneous vegetation communities or complexes of communities.

Although there has been limited current research involving high resolution aerial remote sensing of vegetation and site disturbance effects in British Columbia, some research has been conducted in a variety of ecosystems in differing regions. Remote sensing for rangeland management in the United States is thought to have wide applications for providing quantitative, repeatable and low-cost approach to measure ecosystem health (Hunt et al., 2003). In the Smoky Mountains of the United States, accuracies of up to 80% were also found when mapping vegetation from 1:12,000 scale photographs scanned to 40cm resolution (Welch, Madden, and Jordan, 2002). Mapping of conifer crown density in a boreal forest 5 years following harvesting resulted in detection of individual trees with 70% accuracy using 6cm pixel resolution photographs (Pouloitt, King, and Pitt, 2005). Lang (2004) used automated Definiens ™ software to map sagebrush communities in central Washington state. The author found a high correlation of ground measured data when compared with the image acquired data for sagebrush. The automated object-oriented software was considered superior to traditional pixel-based analysis because of its ability to include context and shape during the classification step. In Europe, Yohay and Ronen (1998) conducted relevant research in a time sequence using digital aerial photography in the Mediterranean region. In that study, approximately 80% classification accuracy was found using 30cm pixel panchromatic aerial photographs. No researchers have attempted to use higher resolution digital imagery for mapping vegetation response to controlled soil disturbance.

Definiens™ software is an object-orientated classification system that detects patterns in digital image data based on tone, shape, texture, area, and context (Definiens, 2006). Images are classed based on predetermined sample objects (nearest neighbor) or according to membership or rule-based algorithm descriptions and the software can potentially increase productivity of analysis of geospatial data. Definiens ™ has been used to classify 1mm resolution colour photographs in New Mexico (Laliberte, Rango, and Fredrickson, 2006). High correlation coefficients (0.88-0.95) were found between remote sensing data and ground sample data for separating green vegetation, senescent vegetation, bare soil, and shadows. Although the photographs used in their research were collected using tripods situated about six meters above the ground, the research provides promising results for applying Definiens ™ in an operational setting for vegetation cover estimation using digital aerial photography.

## 1.5 The Long-term Soils Productivity Network

### 1.5.1 History

The Long-term Soils Productivity (LTSP) network is one of the largest internationally coordinated research projects studying pulse disturbances in sustained forest productivity (Powers, 2006). Currently there are over 62 installations between Canada and the United States (Powers, 2006). In British Columbia, several replicated research installations have been established in boreal and southern Douglas-fir ecosystems over the past 15 years. The LTSP concept was initiated in response to increasing demands in the United States to monitor significant changes in productivity on the land base (Powers, 2006). Organic matter removal and soil compaction are two major anthropogenic processes that are thought to influence forest productivity (Powers, 2006). Organic matter removal occurs during forest harvesting operations when tree boles are removed from the site for processing. In some instances, branches and other slash are also removed from the site to enable better access for future silvicultural interventions. The long-term effect of organic matter removal on ecosystems is not well known, particularly with respect to individual responses of differing ecosystems. Likewise, industrial activities such as forest harvesting result in compaction of soil through machine traffic on skid trails and during the felling operations. Both of these activities are particularly pronounced during road and landing construction where the organic matter is completely removed from the site and severe soil compaction occurs.

There are four null hypotheses that are being addressed by the LTSP research (Powers 2006):

1. Pulse changes in site organic matter and soil porosity do not affect the sustained productive potential of a site,
2. If impacts on productivity occur from changes in organic matter removal and porosity, the changes are universal,
3. If impacts occur they are irreversible, and
4. Plant diversity has no impact on the productive potential of a site.

### 1.5.2 Study area location

The study sites are located in the east Kootenay region of southeastern British Columbia (Figure 1). Emily creek study site is located on the west side of the Kootenay river approximately 10 km from Canal Flats, B.C. Kootenay east and Mud creek sites are located on the east side of the Kootenay river approximately 10 km from Canal Flats B.C.

### 1.5.3 Research design and implementation

Research design and implementation preceded the start of this thesis, consequently, information is presented in this section rather than the Methods section. Each LTSP experimental site is a 3 x 3 factorial design of soil compaction (C0, C1, C2) and organic matter removal (OM1, OM2, OM3) replicated 3 times for a total of nine treatment levels (Figure 2). The initial design concept recognized the desire to have ameliorative treatments. Each southeastern British Columbia LTSP sites installation included a Rehabilitated treatment in which soils were treated as for OM3C2 but then tilled with an excavator bucket to rehabilitate the soils following disturbance. On each Rehabilitated treatment, organic matter was replaced on half of the treatment unit to study the influence of humus enrichment in a heavily disturbed soil. Organic matter was replaced on the north half of Treatment Unit #5, west half of Treatment Unit #11, and the south half of Treatment Unit #30.

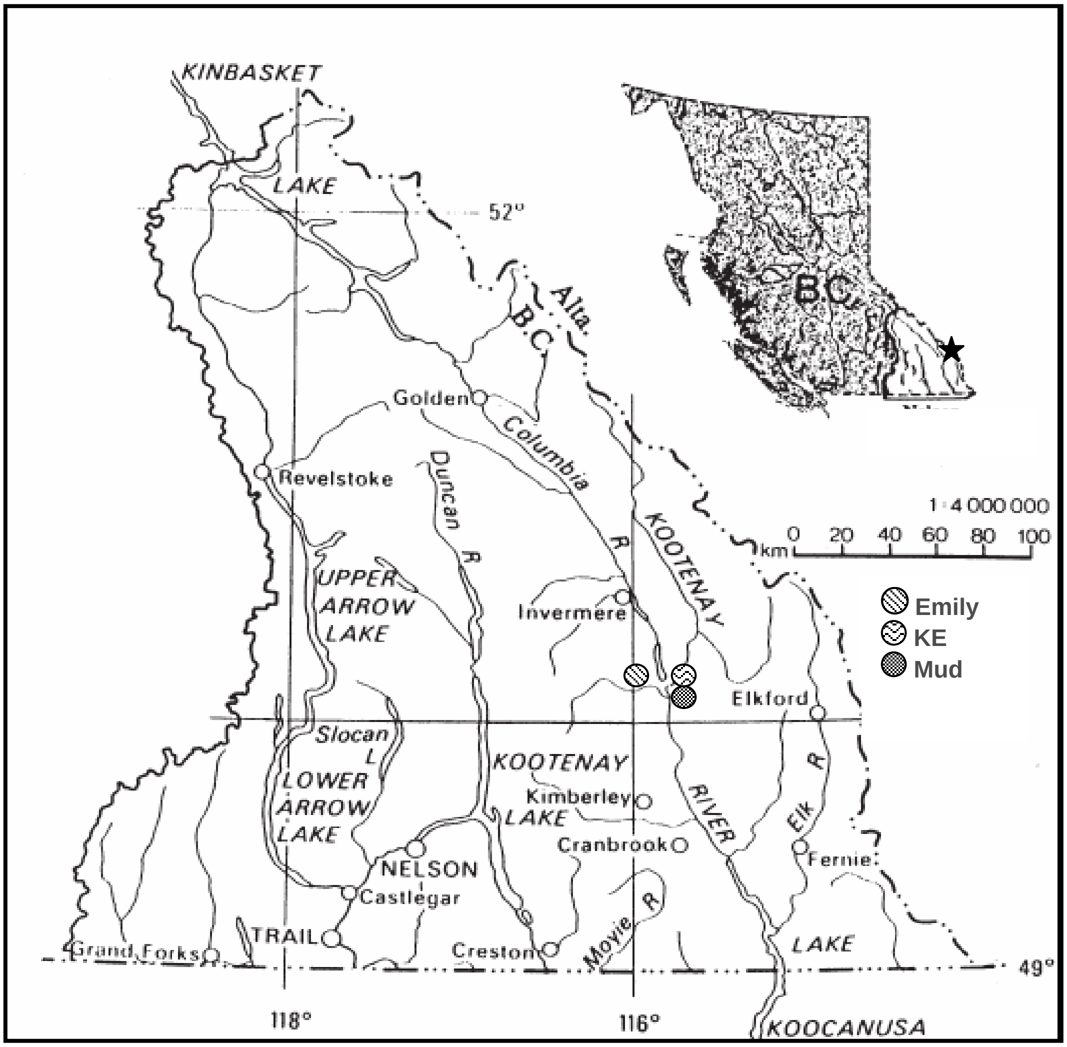

**Figure 1: Study area location.**

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| **Treatment** | **C0**<br>no compaction | **C1**<br>moderate compaction | **C2**<br>heavy compaction |
|---|---|---|---|
| **OM1**[1]<br>boles removed | OM1C0 | OM1C1 | OM1C2, |
| **OM2**<br>Boles and branches removed | OM2C0 | OM2C1 | OM2C2 |
| **OM3**<br>Boles, branches, and forest floor removed | OM3C0 | OM3C1 | OM3C2 |
| | | | Rehabilitated[2] |

**Figure 2: Long-Term Soil Productivity treatment matrix.**

[1] In British Columbia installations, the unharvested control serves as the OM0 treatment level.

[2] Rehabilitated treatments were treated as OM3C2 followed by soil ripping and organic matter amelioration on one half of treatment.

The three replicates used in this study are located at Mud creek (Figure 3), Emily creek (Figure 4) and Kootenay east (KE) (Figure 5) LTSP installations. Mud creek was harvested and treated in 1999 and planted in 2000, Emily creek was harvested and treated in 2000 and planted in 2001, and Kootenay east was harvested and treated in 2001 and planted in 2002. Each treatment unit is a 40m x 70m area permanently marked with metal conduit at each corner and labeled with a yellow sign indicating the treatment level. Treatments were directionally hand–felled under a moderate snow pack to minimize site disturbance due to tree removal. This technique allowed harvesting equipment to reach into the treatment and remove stems without changing the soil properties. After harvesting, treatments were applied using an excavator to uniformly compact the soil with a vibrating plate or to remove the organic matter with a bucket. On scalped treatments, the forest floor was placed along the perimeter of the treatment unit.

Pre-treatment vegetation cover data were collected on the three replicate LTSP research installations. In each treatment type, four 50m$^2$ (3.99m radius) plots were permanently established to monitor vegetation cover. Plot centres were established at a distance of 15m and an angle of 45$^{o}$ from treatment unit boundaries (Figure 6). Plot centers are marked with painted pins driven into the mineral soil. In each plot, percent ocular cover of individual species of trees, shrubs, herbs, grasses, and mosses/lichens were tallied. Species were recorded using the seven letter Latin code (first 4 letters of genus and first 3 letters of species) and followed the naming system found in BC Flora (2004).

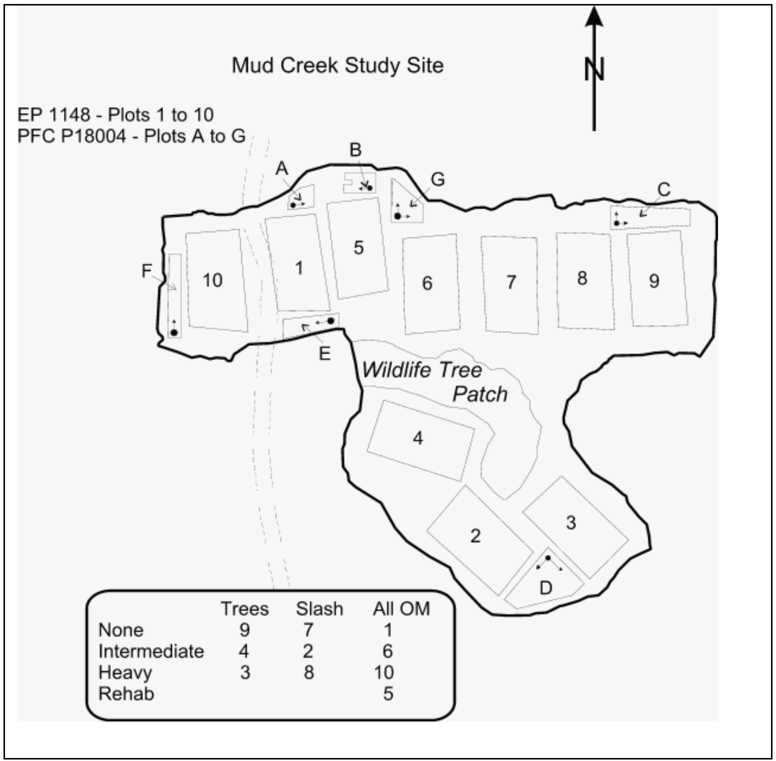
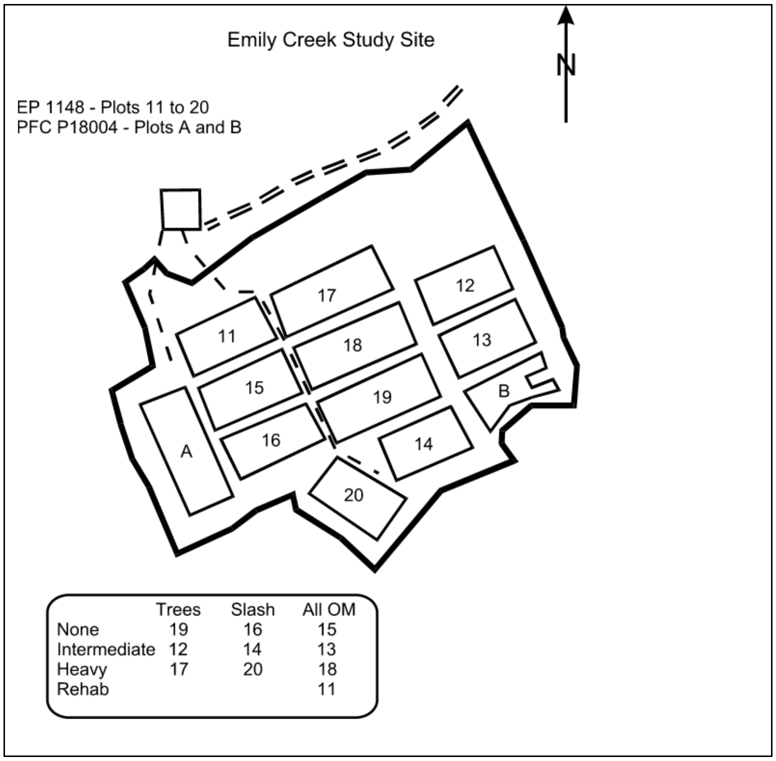


**Figure 3: Mud creek LTSP layout**



| | Trees | Slash | All OM |
|---|---|---|---|
| None | 19 | 16 | 15 |
| Intermediate | 12 | 14 | 13 |
| Heavy | 17 | 20 | 18 |
| Rehab | | | 11 |

**Figure 4: Emily creek LTSP layout.**

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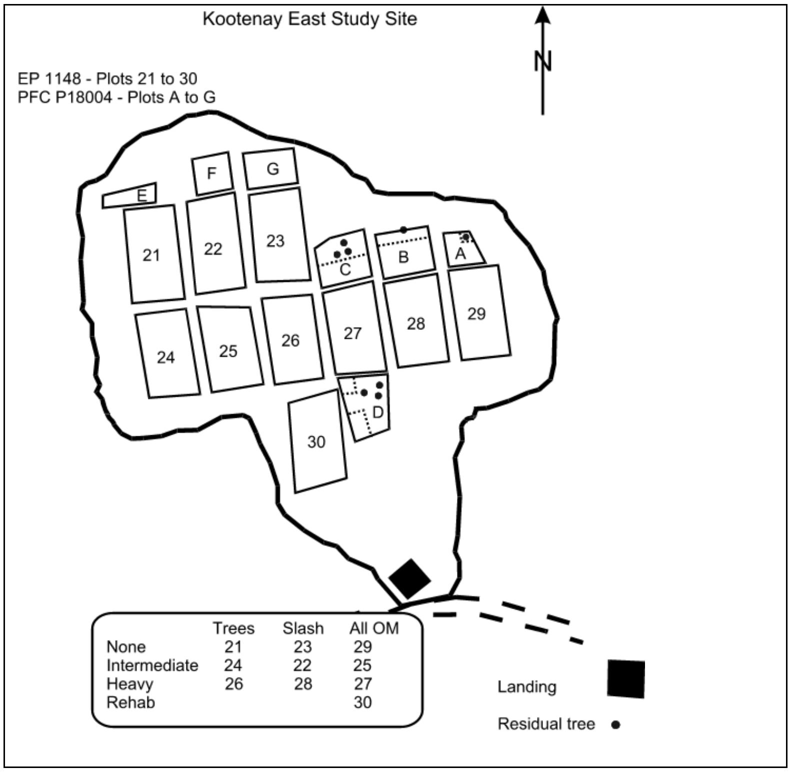

| | Trees | Slash | All OM |
|---|---|---|---|
| None | 21 | 23 | 29 |
| Intermediate | 24 | 22 | 25 |
| Heavy | 26 | 28 | 27 |
| Rehab | | | 30 |

**Figure 5: Kootenay east LTSP layout.**

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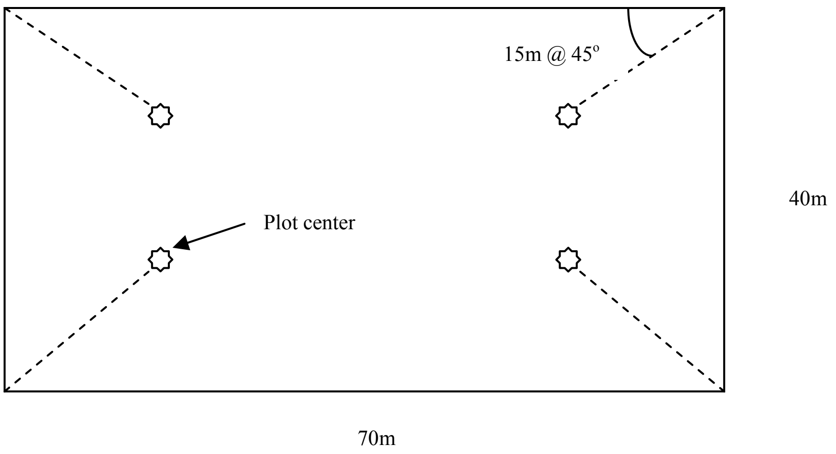

**Figure 6: Vegetation plot location for each treatment unit.**

## 1.6 Study Sites

### 1.6.1 Ecological and Physical conditions

The study sites are located in the east Kootenay region of British Columbia. These sites are classified as the Kootenay dry, mild Interior Douglas-fir variant (IDFdm2) within the provincial biogeoclimatic ecosystem classification system (BEC) (Braumandl and Curran, 1992). These sites were chosen specifically because they represent zonal site conditions within the IDFdm2. Zonal sites are areas that best represent the regional climate of a subzone or variant in the BEC system. As such, they typically have moderate slopes (<25%) and medium soil textures with no root or water restricting layers. Thus, conclusions drawn from these LTSP sites can be extrapolated with caution to other ecosystems in the subzone variant. The IDFdm2 generally has very dry summers and cool winters with light snowfall (Braumandl and Curran, 1992). Soils often freeze during the winter months due to a shallow snow pack. The zonal ecosystem (site series) in the IDFdm2 is identified as the Douglas-fir, lodgepole pine, pinegrass, twinflower BEC site series.

Pre-treatment vegetation conditions were dominated in the tree stratum by Douglas-fir (*Pseudotsuga menziesii*) with minor amounts of lodgepole pine (*Pinus contorta*), engelmann spruce (*Picea engelmannii*) and western larch (*Larix occidentalis*). Percent cover of Douglas-fir was over double at Emily creek (20%) compared with Kootenay east and Mud creek (8% each). The pre-treatment shrub layer was dominated by kinnikinnick (*Arctostaphylos uva-ursi*), common juniper (*Juniperus communis*) and soopolalie (*Sheperdia canadensis*). Kinnikinnick and soopolalie cover was higher at Emily creek and common juniper cover was higher at Kootenay east. Pre-treatment forb cover consisted of Heart-leaved arnica (*Arnica cordifolia*), timber milk-vetch (*Astragalas miser*), and wild strawberry (*Fragaria spp.*); however, arnica cover was the highest at the Emily creek site. Pinegrass and rough fescue (*Festuca campestris*) were the dominant grass species pre-treatment in all three sites. Pinegrass cover was similar between sites; however, rough fescue cover was higher at Emily creek than at the other sites. Sedges (*Carex* spp.) also were a dominant genus in this layer averaging 3% cover over the sites.

Landforms for the LTSP sites are classified as well-drained, silty glacial till deposits (>1m deep) derived from calcareous bedrock with the resulting soils belonging to the Marmalade soil association (Lacelle, 1990). Slopes ranged between 10-15% with a few short, steeper pitches. Site specific soils data collected by the B.C. Ministry of Forests and Range (MOFR) classify the soils as Orthic Eutric Brunisols with free carbonates present at 15-20 cm for Kootenay East, 20-30 cm for Mud creek, and 40cm for Emily creek. These soils are generally classified as calcareous (pH > 7.0) with slightly modified B horizons and little or no organic matter enrichment in the upper ‘A’ horizon. Textures were found to range from fine sandy loam to silty clay loam in the upper 30 cm. Emily creek had slightly coarse-textured fine sandy loam soils; whereas, Kootenay East was found to have slightly higher clay content in the soils than the

Mud creek site. Coarse fragment content ranged from 10-25% in the upper horizons and 25-50% in the lower subsoil horizons. In general, the sites were dominated by very thin Mor humus forms derived from freshly fallen litter and coarse woody debris (M.P. Curran, personal communication, November 30, 2006).

### 1.7 Research questions

This research will determine how vegetation composition and cover changes following soil compaction and organic matter removal on dry, calcareous soils in the Interior Douglas-fir zone of British Columbia. Ground verified vegetation data will be compared with a digital image classification algorithm using Definiens™ software. High resolution aerial remote sensing data will be used to determine if it is capable of detecting changes in vegetation cover after soil treatments. The following research questions are asked:

1. Does vegetation composition and structure change with increasing soil disturbance and, if so, do cover values increase or decrease?
2. Can high-resolution airborne remote sensed data be used to detect changes in vegetation cover in response to site disturbance?

The following hypotheses will be tested in this research:

$H_{o1}$: Differing soil disturbance levels will have no effect on understory vegetation.

$H_{a1}$: Differing soil disturbance levels will have an effect on understory vegetation.

$H_{o2}$: Vegetation response to soil disturbance cannot be detected with high spatial resolution aerial photographs.

$H_{a2}$: Vegetation response to soil disturbance can be detected with high spatial resolution aerial photographs.

### 1.8 Rationale

Whereas many LTSP studies have examined the soil or seedling response to compaction and organic matter removal, no studies have examined the effects on understory vegetation in dry Douglas-fir forests with calcareous soils. Additionally, no studies have applied detailed remote sensing to analyze the response of understory vegetation to differing levels of site disturbance.

Site disturbance can impact socioeconomic and natural resources in a region by decreasing the productivity of an ecosystem (Xulin, Price, & Stiles, 2000). This influences the sustainability of natural ecosystems if site productivity continually diminishes over time. The type of soil on a site determines the type of vegetation community that will develop in a forest ecosystem (Holcomb, 1996). By analyzing the vegetation response to differing levels of soil disturbance, this research seeks to determine what treatment levels significantly alter the vegetation community on a site when compared with an untreated control. This information can be used to determine ecosystem specific thresholds for soil disturbance levels.

The B.C. Minister of Forests and Range recently announced increased funding for ecological restoration in Douglas-fir forests (Province of B.C., 2006) which demonstrates the need for detailed knowledge of ecosystem responses to soil disturbance. Additionally, the Conservation Data Center (2006) lists over thirty rare or endangered vertebrate species and over 50 rare or endangered vascular plant species that are dependent on low elevation forests in the east Kootenay. Grizzly bear (*Ursus arctos*), American badger (*Taxidea taxus*), bighorn sheep (*Ovis canadensis*) and long-billed curlew (*Numenius americanus*) all have habitat requirements that depend on early seral vegetation. Rare plant species such as blue grama (*Bouteloua gracilis*) and wild licorice (*Glycyrrhiza lepidota*) can also potentially inhabit open forest ecosystems.

Since vegetation can be altered dramatically based on site disturbance history, there are obvious links between the habitat alterations that result due to forest harvesting and impacts to early seral dependent species. Harvested areas are also often used in cattle ranching to provide grazing land for domestic livestock. The cattle ranching industry contributes over $100 million annually (B.C Cattlemen's Association, 2006) in total revenue to British Columbia. Early seral vegetation is often grazed in cutover areas following timber harvesting so changes in understory productivity can directly influence the cattle industry. Therefore, this study has implications for rare species management, ranching, wildlife habitat management, forestry, and ecosystem restoration.

Surveying soil and range disturbance condition by site visits in remote field locations can be time consuming and costly. Currently, sites are measured by conducting field surveys to determine if unacceptable disturbance thresholds have occurred. In situations where disturbance is below threshold values, the costs of visiting these field sites could be avoided because no site investigations are needed in the first place. Curran et al. (2005a, 2005b) suggest a need for cost-effective monitoring protocols that produce criteria that are easy to interpret and communicate. Remote sensing allows for multiple areas to be surveyed simultaneously and produce more timely data than equivalent ground surveys. For example, the three project sites in this research were flown in one day; whereas, it would take about several days for field crews to visit all of the sites. Ground sampling of vegetation, including travel between plots, has been found to take over 50% more time than using remote sensing technology combined with image classification software (Laliberte et al., 2006). Additionally, remote sensing analysis can collect data over vast areas, reduce human bias, and can serve as a permanent record for future uses (Booth, Cox, Fifield, Philips, and Williamson, 2005). With remote sensing, the data can be analyzed immediately after surveying to determine areas where excessive of damaging site disturbance is probable. Therefore, remote sensing can be used as a tool to determine areas where site specific surveys are required.

# 2.0 Methods

## 2.1 Data collection

### 2.1.1 Vegetation

Previous to this study, vegetation data were collected pre-treatment, post-treatment (first growing season), and one-year (second growing season) post-treatment. Vegetation data for the present study was collected in the fifth growing season post-treatment for each LTSP installation. Mud creek data were collected between June 20-22, 2004; Emily creek data were collected between July 5-7, 2005; and Kootenay East data were collected between July 4-8, 2006. Vegetation cover data were collected at the same plot centers established in pre-treatment and used the same methodology (see section 1.5.3). In a few cases the plot centers could not be found in year five, so the plots were re-located from treatment unit corners using a nylon measuring tape and Silva™ hand compass. Ground percent cover was estimated using the percentage of ground surface covered when the crowns are projected vertically around the outside perimeter of the vegetation (Province of British Columbia, 1998). The minimum ground cover recorded was 0.5% which included all trace amounts of vegetation.

Vascular plants were identified to species level if all floral parts were observable using keys described by Douglas et al. (1998-2002) and Stewart and Hebda (2000). Percent total cover for mosses was recorded at each sample plot. Survey times were planned between mid-June and Mid-July to maximize the amount of grasses that would be in flower to aid in identification. Mud creek was re-visited in July 4-7, 2006 to estimate the percent change in vegetation cover that may have occurred between the timing of vegetation data collection on June 20-22, 2004 and acquisition of remote sensing images in August 22, 2005.

### 2.1.2 Remote sensing

Remote sensing data was collected for each LTSP by *Terrasaurus Aerial Photography* Ltd. on August 22, 2005. Photographic equipment used included a 16 mega pixel GPS encoded Kodak digital camera capable of 10cm pixel resolution mounted beneath a Cessna 206 aircraft (www.terrasaurus.com). All digital data manipulation and analysis was completed by the Selkirk Geospatial Research Center (SGRC) in Castlegar, B.C. Digital images were initially georectified to a Terrain Resource Information Map (TRIM) and attempted to correct for error by using ground control points from a Trimble Field Ranger™ and Trimble GeoXT™ handheld GPS unit. Error corrections were not as accurate as was originally anticipated. Coordinates were collected for each treatment unit corner and for each vegetation plot center (total 240 data points). Additional GPS ground control points were collected for correcting the digital image. Ground control points included features that could be easily identified on the digital image.

## 2.2 Analysis

### 2.2.1 Vegetation

Vegetation data were entered into Microsoft Excel ™ spreadsheets and copied into a Microsoft Access ™ database to facilitate data management. Vegetation data were summarized by life form (shrubs, forbs, grasses) for each treatment type. Minitab 14™ software was used for statistical and graphical analysis of data (Minitab, 2006). Significant results were recorded for p-values <0.05. Data were treated hierarchically in the following order:

- Arcsine transformation of data percent cover values, (Fowler and Cohen, 1990)
- Test for normality (Anderson-Darling), (Minitab, 2006)
- Test for homogeneity of variance (Levene's test) (Minitab, 2006)

- Statistical analysis,
- Retrospective test for statistical power (Minitab14, 2006).

All cover values were arcsine transformed prior to analysis in order to stabilize data variation. This transformation is suitable if data collection is made of proportions such as percent cover (Fowler and Cohen, 1990). Although not all data required transformation, it was decided this approach would simplify the interpretation of the analyzed data rather than comparing transformed and non-transformed data. Zar (1984) provides the formula for arcsine transformation used in this study, as shown below:

$$p^{/} = \text{arcsine x square root(percent cover} \div 100).$$

Anderson-Darling tests for normality were used to determine whether data were suitable for parametric or non-parametric analysis. This test was chosen because it has higher statistical power for detecting non-normality than other tests available (Minitab, 2006). All data sets met the assumption of a normal distribution.

Data were viewed graphically in interval plots to determine appropriate statistical analysis. Interval plots allowed for data means to be displayed with 95% confidence intervals. Data results where the confidence intervals did not overlap indicated that difference in mean cover may be statistically significant.

One-way ANOVA tests using the General Linear Model procedure in Minitab14™ were used for parametric data with treatment as a single factor. This test allowed for multiple comparisons between factorial treatment types (organic matter removal and compaction), rehabilitated treatments, and the unharvested control. This analysis was completed because the rehabilitated treatments and unharvested control are not crossed for every level of the factorial treatments. One assumption with an ANOVA is that sample populations have similar variances (homoscedasticity). To check this assumption, each sample was tested using a Levene's test (Minitab, 2006). All data sets met the assumption of homoscedasticity. Multiple comparisons between treatments were analyzed using the Tukey Honestly Significant Difference (HSD) test. The Tukey HSD was chosen because it is a suitable multiple comparison test when sample sizes are equal and gives an overall error rate of less than or equal to the chosen alpha level (Sit, 1995). Type I errors (rejection of a null hypothesis when it is actually true) increase with increasing pairs of comparisons so it is important to choose multiple comparison tests that are sensitive to increases in the error rate (Sit, 1995). The OM1C0 treatment was designated as the "harvested control" because that treatment level had the least amount of soil and organic matter disturbance yet it still reflected the ecological conditions of canopy removal. One-way ANOVA were completed for five-year data:

i. Factor = Treatment level (Control, organic matter removal, soil compaction, rehabilitated-OM±); Response = Total % cover, Shrub % cover, Forb % cover, Grass % cover,
ii. Factor = Treatment level (Control, organic matter removal, soil compaction, rehabilitated-OM±); Response = % Saskatoon cover, % prickly rose cover, % kinnikinnick cover, % common snowberry cover, % pinegrass cover, and % rough fescue cover,
iii. Factor = Treatment level (Control, organic matter removal, soil compaction, rehabilitated-OM±); Response = Shannon-Weiner diversity (Total diversity, shrub diversity, forb diversity, grass diversity)
iv. Factor = Treatment level (Control, organic matter removal, soil compaction,

rehabilitated-OM±); Response = Species richness.

A GLM procedure for parametric data was used to test for interactions between site, soil compaction level and organic matter removal level or between treatment level, year and site. The GLM procedure takes a regression approach based on a specified model. The GLM procedure in Minitab14™ was chosen because the software allowed for multiple comparisons to be made; whereas, an equivalent two-way ANOVA did not allow for multiple comparisons (Minitab, 2006).

The generalized model for testing three interactions (A, B, C) in Minitab14 is:

A B C  B x C  A x B  A x C  A x B x C

Two models were used for statistical analysis:

1. Factorial analysis of Site (SITE), Organic matter level (OM) and Compaction (COMP). The model with interaction terms was coded in Minitab14™ as:

   SITE OM COMP  OM x COMP  SITE x OM  SITE x COMP  SITE x OM x COMP

2. One-way randomized block design to test for the effects of the Rehabilitated treatment (Rehab, Rehab OM+) and heavily compacted treatments (OM1C0, OM2C1, OM3C2). The model with interaction terms was coded in Minitab14™ as:

   SITE  OM  SITE x OM

If the interaction term OM x COMP was significant, a one-way model was used to test each level of OM for each level of COMP.

The following factors were tested using the above models:

a) Total cover, shrub cover, forb cover, and grass cover (between years and between treatments for five year data),

b) Cover of Saskatoon, prickly rose, kinnikinnick, common snowberry, pinegrass, and rough fescue (between years and between treatments for five year data),

c) Species richness and Shannon-Weiner diversity

Species Richness and Shannon-Weiner diversity values ($H^{/}$) were calculated for each treatment and for each life form within each treatment according to the formulae below:

Species richness = $\sum$ number species present per treatment

and,

$$H^{/}=\sum_{n=1}^{i} p_i (\ln p_i)$$

where: $p_i$ = the proportion of species per plot (% cover for each species ÷ total % cover in each plot).

Species richness and $H^{/}$ were compared between treatments using one-way ANOVA and GLM procedures as described above.

Retrospective tests for statistical power followed procedures using Minitab14™. Power analysis is performed by entering sample data (# of factors, sample size, maximum difference between means, and standard deviation) and Minitab calculates the noncentrality parameter ($\lambda$) and F-value. Power analysis revealed that most statistical tests had a power greater than 0.7 and often exceeding 0.8. The Discussion section indicates when tests had a low statistical power and greater risk of committing a Type II error (failure to reject the null hypothesis when it is actually false).

Relative Importance Values (R.I.V.) are generally calculated as the relative density + relative frequency + relative cover (Mueller-Dombois, 1974). However, it was not possible to obtain relative density from cover values in this study because only ocular percent cover was collected rather than counts of individual species (i.e. stems $ha^{-1}$). Relative importance value formulae can be different but generally they should include some measure of dominance such as coverage (Howard, 1983). In the present study, the R.I.V. was calculated based on the formula presented by Young and Swiacki (2006):

R.I.V. = (relative cover + relative frequency) ÷ 2

where:

relative cover = average cover of a species in each treatment ÷ total cover in each treatment x 100,

relative frequency = frequency of a species in a treatment (number of plots in which a species occurred) ÷ cumulative frequency of all species in each treatment x 100

Species were chosen for further analysis based on the R.I.V. score. Species with high R.I.V. (>2.0) indicated that they were relatively consistent within treatments and so analysis of results would provide meaningful results. Low R.I.V. scores indicated that species covers were sporadic and any analysis would be less reliable for determining trends.

Rehabilitated plots were analyzed separately to compare the effect of adding organic matter (ameliorated) into heavily disturbed soil. Paired sample t-tests (n=6) were used to test for differences between means for total cover, shrub cover, forb cover, and grass cover on the vegetation plots which were separated based on whether or not the Rehabilitated treatment was ameliorated with the forest floor.

### 2.2.2 Remote sensing

Environmental and Research Institute (ESRI) shape files of treatment unit plot centers were created based on GPS coordinates and ground verification. GPS position data were not accurate enough to precisely locate vegetation plot centres on the digital images at this level of detail (10cm resolution). To overcome this problem, vegetation plot centres were estimated on the digital images and three random plot data points were randomly selected within a 3m radius around each estimated vegetation plot centre and the plant cover results averaged. It was decided that this technique would improve the accuracy of digital image classification rather than relying on GPS data points that were not accurate. At each of the three data points, percent cover of: trees, shrubs, forbs/grass, coarse woody debris, bare soil, and shadow were extracted from a 3.99m radius of the classified layer. Classifications were then converted to ESRI shapefiles. Mean cover values from the three data points were used as the digital image value for each vegetation class for each plot (total of 360 classified plots).

The digital image estimated vegetation cover were compared with ground estimated vegetation plots to determine the accuracy of the digital classification. Scatter plots with fitted regression lines and Pearson-product correlation coefficient procedures were used in the analysis (Minitab, 2006). Pearson-product coefficients were calculated for total cover, tree cover, shrub cover, grass and forb cover, and bare soil for each site.

# 3.0 Results

## 3.1 Five year vegetation response between treatments

### 3.1.1 Total cover

Interaction between site and treatment level was significant (p=0.009) and for the three-way interaction of Site x OM level x compaction (p=0.02)(Table 1). Since site variation was considered to be high, further statistical analysis of total cover data is not appropriate and trends will be reported instead. Compaction had no obvious effect on total vegetation cover and there was no significant interaction between organic matter removal and soil compaction (Figure 7). Forest floor removal resulted in an average of 55% total cover; whereas, bole only removal or boles plus slash removal resulted in 69% and 74% total cover respectively. Trends indicate that total cover at Kootenay east was generally higher than Mud and Emily on OM1 and OM2 treatments and a similar trend was observed in the unharvested control (Figure 8). Both Kootenay east and Mud tended to have higher overall vegetation cover than Emily on OM3 treatments. Both Kootenay east and Emily sites tended to have lower total percent cover on the OM3 sites relative to the OM1 and OM2 sites. Mud creek had little change between OM1, OM2 and OM3 treatments. Total cover values for the rehabilitated treatments tended to be similar to other treatments although sample variation was quite high. Total cover tended to be lower on OM3 and non-ameliorated rehabilitated treatments relative to the control, other treatments where the forest floor was left intact, or the rehabilitated was ameliorated with organic matter (Figure 9).

**Table 1: Summary statistics for five year total vegetation response.**
(Only significant results are shown, for details of analysis refer to Appendix C)

| Analysis | Procedure | n | MS error | Statistic | p-value |
|---|---|---|---|---|---|
| Site x OM | GLM | 36 | 0.14 | 7.14 | <0.009 |
| Site x OM x Comp. | GLM | 36 | 0.02 | 2.35 | 0.02 |

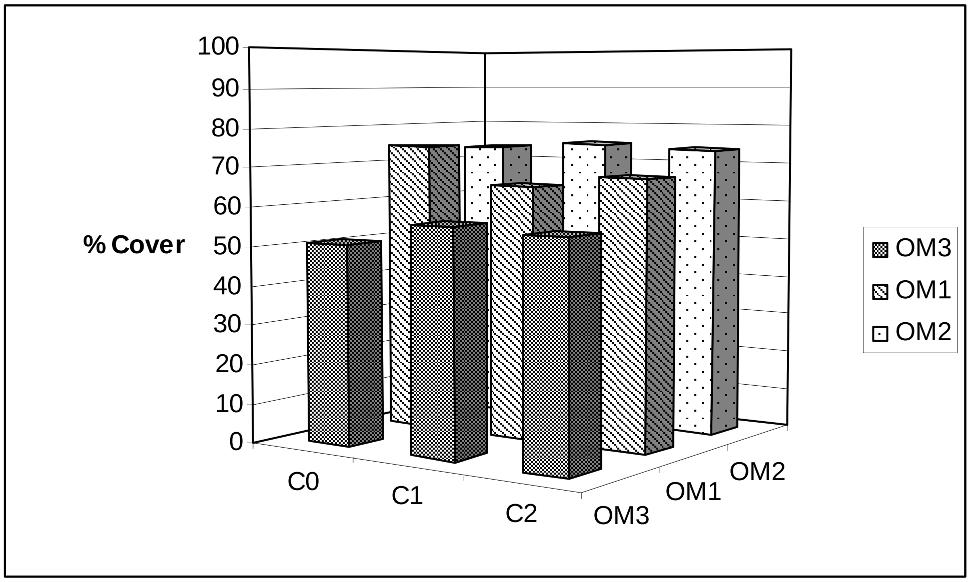

**Figure 7: Graph showing the effect of soil compaction on total cover across different levels of Organic Matter (OM) retention.**

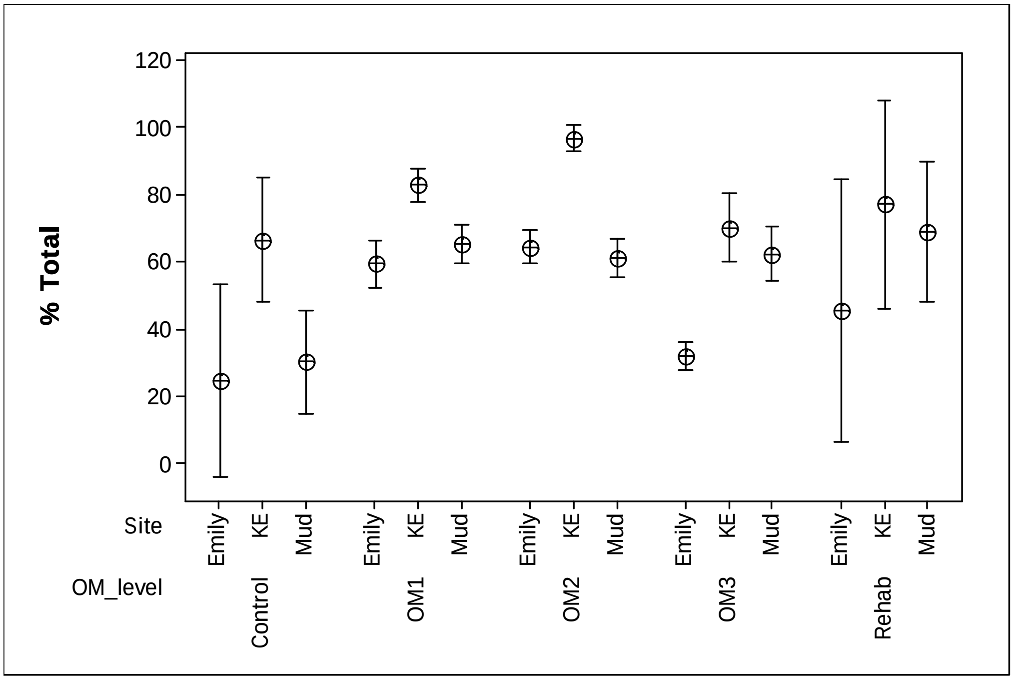

**Figure 8: Interval plot showing total % cover by OM and site.**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

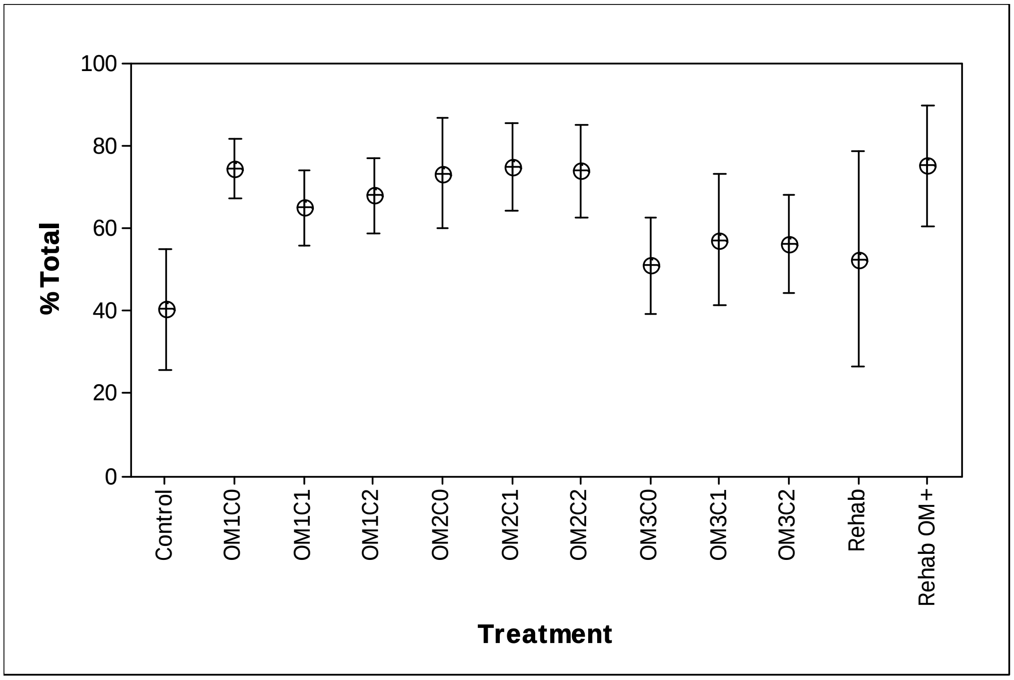

**Figure 9: Mean total cover for all sites by treatment level (5 year results).** Centers are mean cover and bars indicate 95% confidence intervals for mean.

### 3.1.2 Shrub cover

There was no significant difference in total shrub cover between years for each treatment. Shrub cover on OM treatments did not interact significantly with site and there was no significant interaction between OM level and compaction level (Figure 10).

Although there was no statistical difference between sites was detected, Kootenay east tended to have higher shrub cover on the OM2 and OM3 treatments relative to other sites (Figure 10). The unharvested control plot tended to have lower overall shrub cover than any of the treatments; however, this difference was not significant.

There were no significant differences between treatments (Figure 11); however, statistical power was relatively low (<0.7) in this analysis so there is a high likelihood of committing a type II error. To decrease the chance of a type II error, and because there was no interaction between compaction and OM level, results were grouped by OM level (resulting in a power >0.7). ANOVA results indicate that shrub cover values were significantly different (p=0.01) between treatments. Tukey HSD indicated that the OM2 treatment had significantly (p=0.02) higher cover than the unharvested control and tended to have higher cover than the OM3 treatment (p=0.09).There was no significant differences in cover between the OM1, OM2, and OM3 (Table 2). Compaction had no effect on total shrub cover.

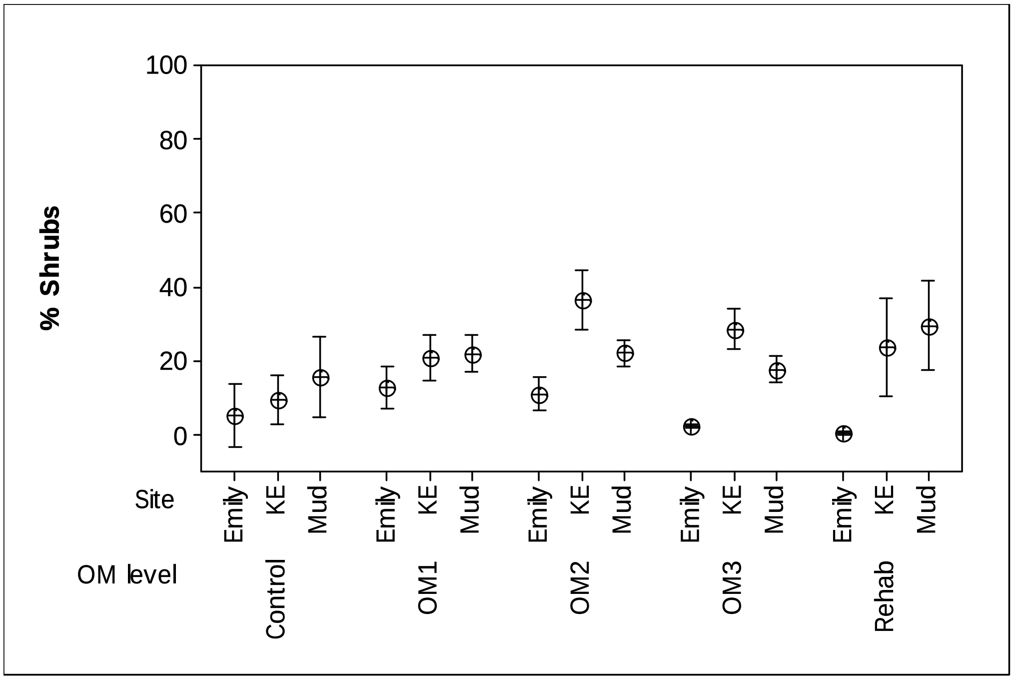

**Figure 10: Interval plot showing shrub % cover by OM and site.**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

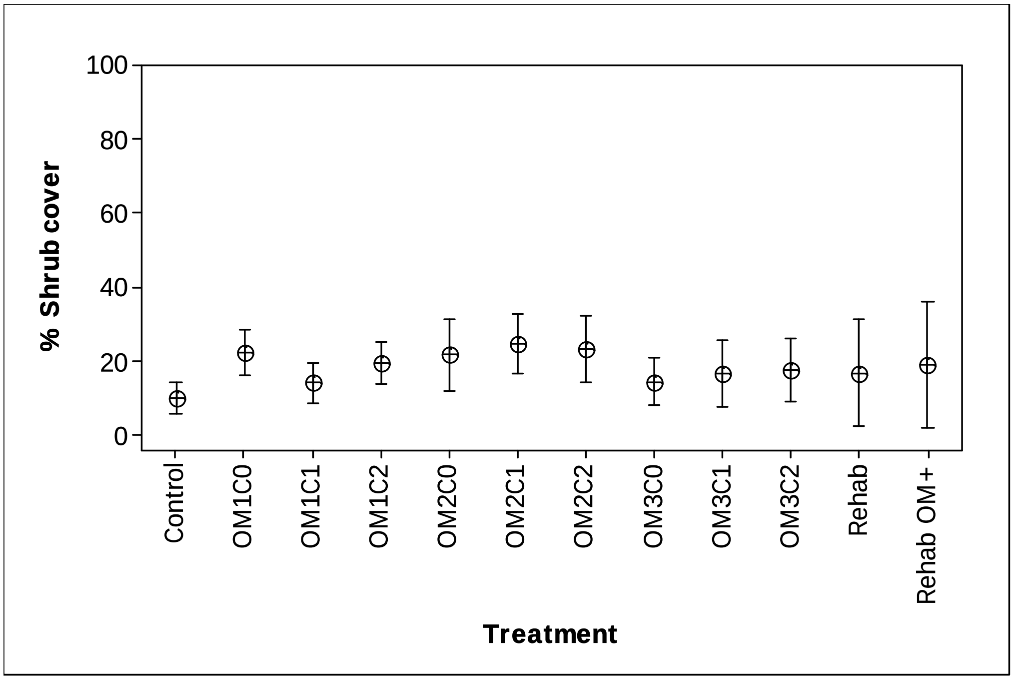

**Figure 11: Mean total shrub cover for all sites by treatment level (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

**Table 2: Summary statistics for five year shrub response.**
(Only significant results are shown, for details of all analysis refer to Appendix C)

| Species or lifeform | Analysis | Procedure | n | MS error | Statistic | p-value |
|---|---|---|---|---|---|---|
| Total Shrub cover | Total shrub cover x OM level | GLM | 36 | 0.03 | F=3.14 | 0.01 |
| | Control minus OM2 | Tukey HSD | 36 | -- | T=3.04 | 0.02 |
| **Individual Species Responses** | | | | | | |
| Birch-leaved spirea | Compaction level | GLM | 36 | 0.01 | 3.02 | 0.054 |
| Saskatoon | Site x OM level | GLM | 12 | 0.03 | 5.02 | 0.002 |
| Snowberry | Snowberry x treatment[1] | One-way ANOVA | 12 | 0.01 | F=2.56 | 0.008 |
| | Control - Rehab with OM+ | Tukey HSD | 12 | -- | T=3.2 | 0.05 |
| | OM1C2 – Rehab with OM+ | Tukey HSD | 12 | -- | T=3.38 | 0.04 |
| kinnikinnick | Treatment x kinnikinnick cover[1] | One-way ANOVA | 12 | 0.08 | F=10.44 | <0.001 |

[1] For specific results of ANOVA tables refer to Appendix C

#### 3.1.2.1 Selected species responses

Relative Importance Value (R.I.V.) was used to select shrub species for further analysis (Figure 12). Shrubs with high R.I.V. (>2.0) scores were chosen for further analysis to determine if significant differences in cover occurred between treatments. Birch-leaved spirea (*Spirea betulifolia*), kinnikinnick (*Arctstaphylos uva-ursi*), saskatoon (*Amelenchier alnifolia*), snowberry (*Symphoricarpos albus*), soopolalie (*Sheperdia canadensis*) and prickly rose (*Rosa acicularis*) were found to have relatively high importance values across most treatments and are included in the analysis below.

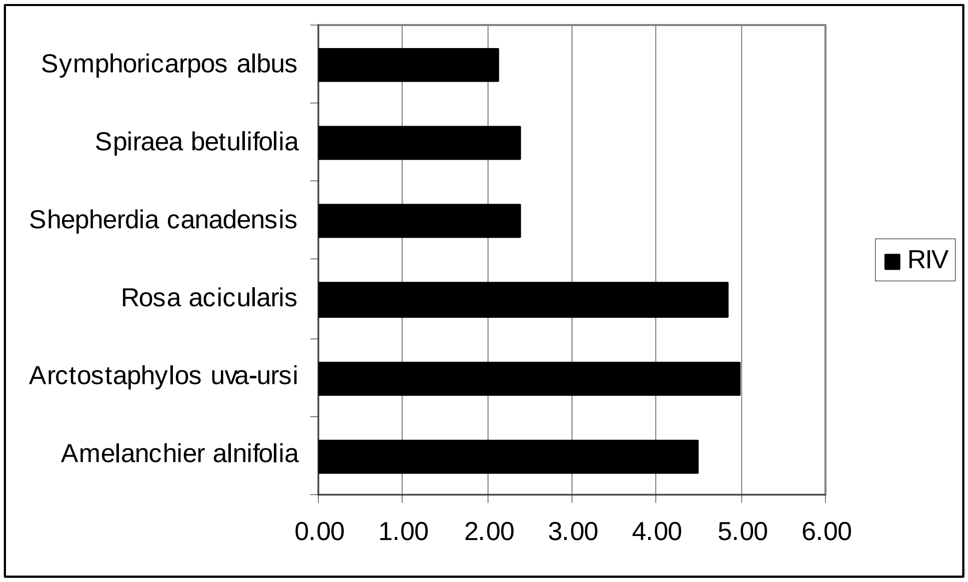

Figure 12: Relative Importance Value (R.I.V.) for selected shrubs at east Kootenay LTSP.

One-way ANOVA between all treatments including the unharvested control and rehabilitated sites indicated that there were no significant differences in mean cover for birch-leaved spirea, saskatoon, prickly rose, and soopolalie. For birch-leaved spirea, there was no significant interaction between site and treatment; however, heavy compaction tended to reduced cover relative to moderate compaction (C1) across all levels of organic matter removal (Figure 13).

Saskatoon had significant interactions between Site and OM level; therefore, no statistical analysis was completed on pooled data. For saskatoon, percent cover at Kootenay east tended to increased by 10% on OM2 treatments and only increase by 4% on OM3 treatments relative to OM1 treatment covers at Kootenay east; whereas, cover values tended to stay relatively the same between treatments at both Mud and Emily sites (Figure 14). Although interactions were not significant for prickly rose, cover followed a decreasing trend from OM1 to OM3 treatments at Emily creek, and cover increased by 4% at Mud creek on OM3 treatments relative to OM1 and OM2 treatments (Figure 15). Cover of prickly rose increased approximately 3% at Kootenay east on OM2 and OM3 treatments compared with OM1 treatments. At Mud creek, cover of prickly rose increased approximately 2% where the forest floor was removed. At Emily creek, percent cover consistently decreased on OM2 and OM3 treatments relative to the OM1 treatment. There were no significant interactions or main effects for soopolalie cover. However, cover tended to be higher at Kootenay east on all treatments compared to Emily creek and Mud creek most noticeably on the OM2 and OM3 treatments (Figure 16). At Kootenay east, cover of soopolalie tended to increase by 2-3% on OM2 and OM3 treatments. Cover of soopolalie was very low (<2%) at Emily and Mud sites and this cover reduced to <0.5% on OM2 and OM3 treatments.

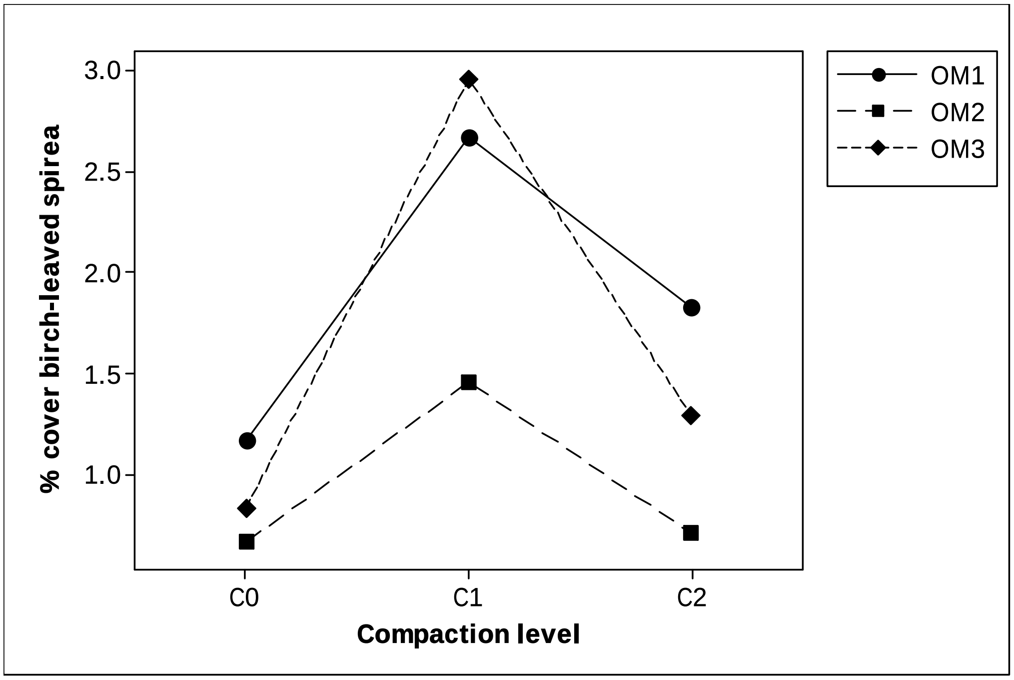

**Figure 13: Birch-leaved spirea cover across treatments under different compaction treatments.**

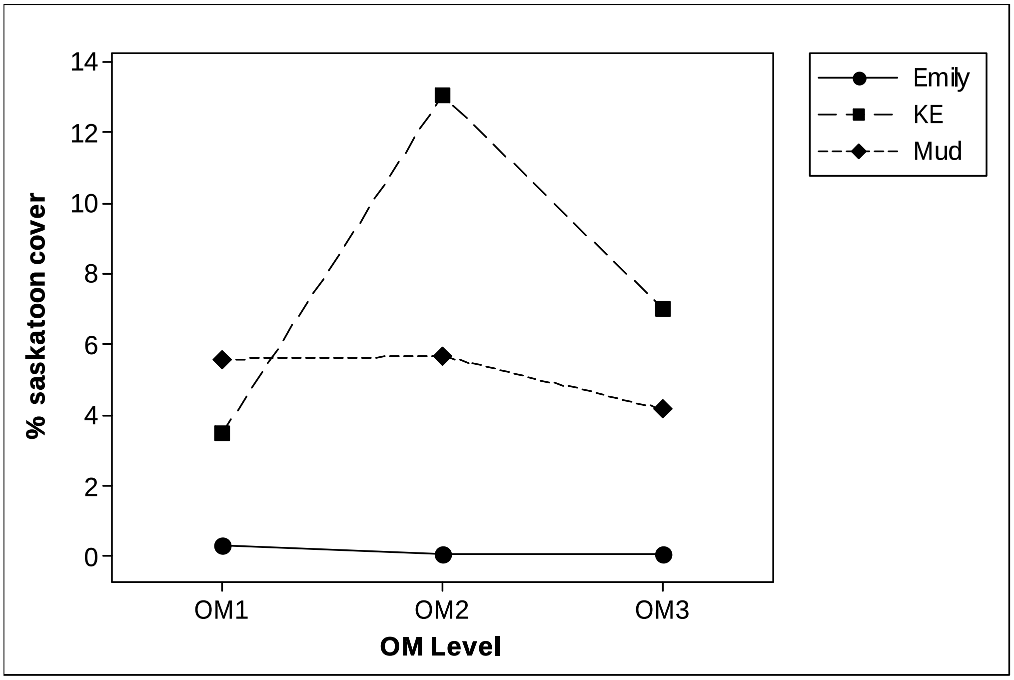

**Figure 14: Interaction plot of saskatoon cover by site and OM level.**

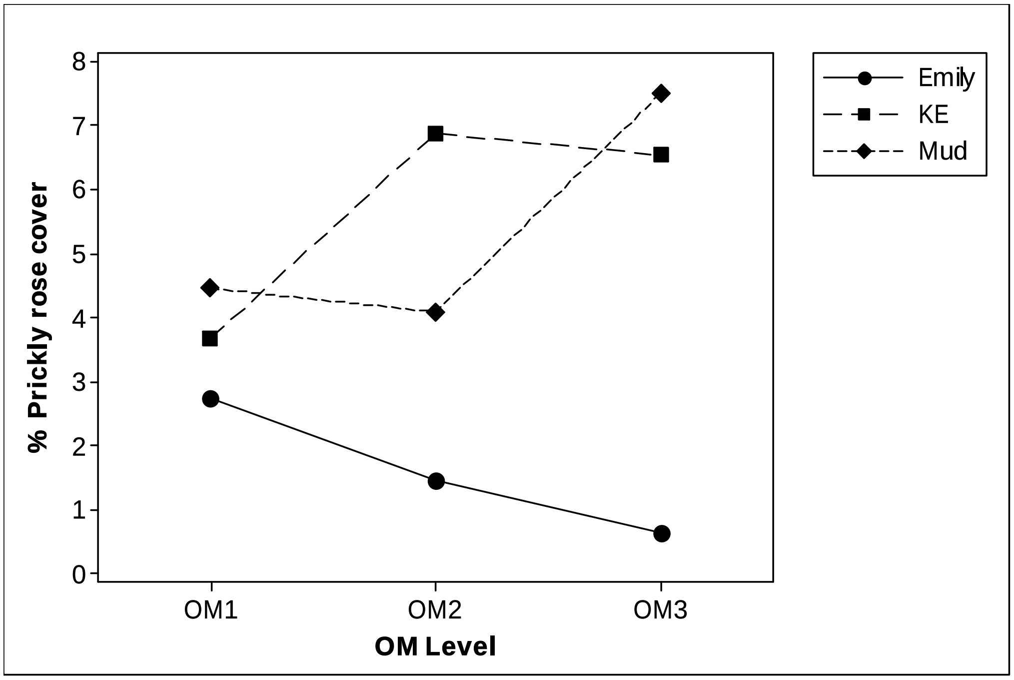

**Figure 15: Interaction plot of prickly rose cover by site and OM level.**

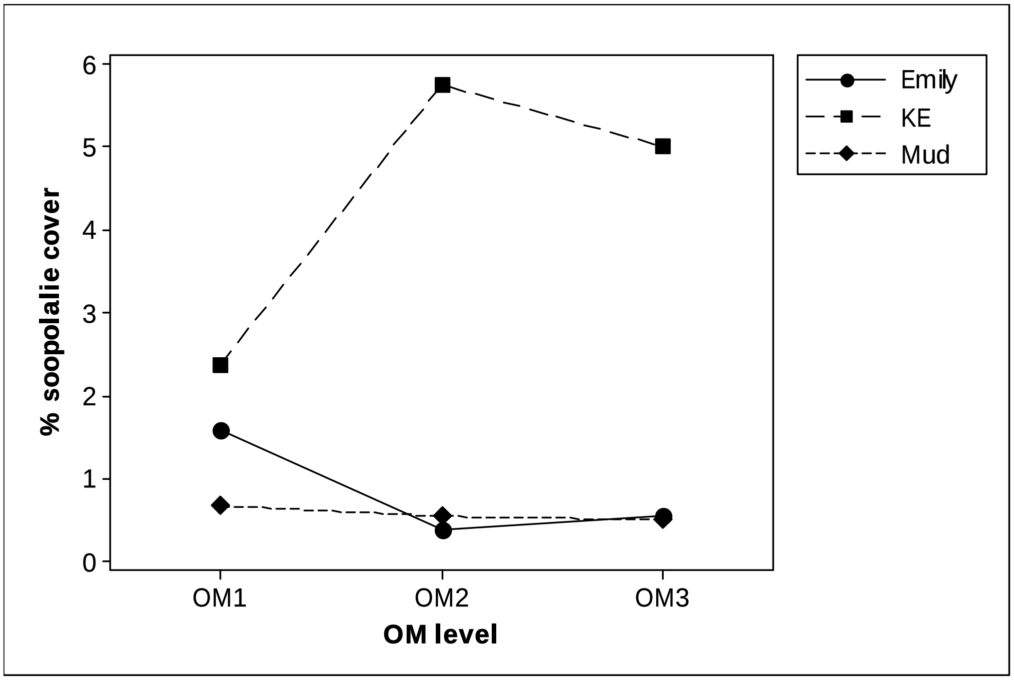

**Figure 16: Interaction plot of soopolalie cover by site and OM level.**

Although interactions between site and treatment levels were not significant, snowberry cover at Kootenay east tended to be higher than Emily or Mud (Figure 17). There was no significant change in snowberry cover across the different factorial treatments or between years. Additionally, there were no significant interaction effects of organic matter removal and soil compaction, main effects of organic matter removal, and main effects of soil compaction. Cover tended to increase on rehabilitated treatments particularly at Mud creek and Kootenay east (16% and 5%, respectively) (Figure 18). In general, rehabilitated treatments ameliorated with organic matter tended to have higher snowberry cover compared to non-ameliorated rehabilitated treatments (Figure 19).At Mud creek, the snowberry cover was concentrated on the half of the Rehabilitated treatment where the soil was ameliorated with organic matter; whereas Kootenay east had snowberry cover slightly higher on the non-ameliorated rehabilitated treatment. There was very little snowberry cover recorded at Emily creek.

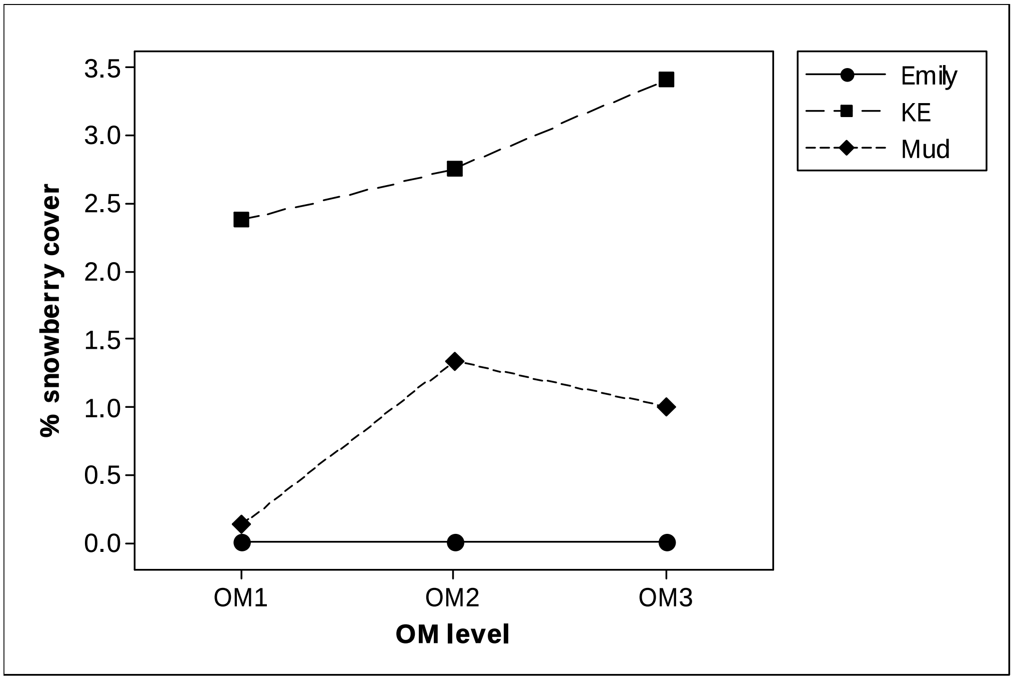

**Figure 17: Interaction plot of snowberry cover by site and OM level.**

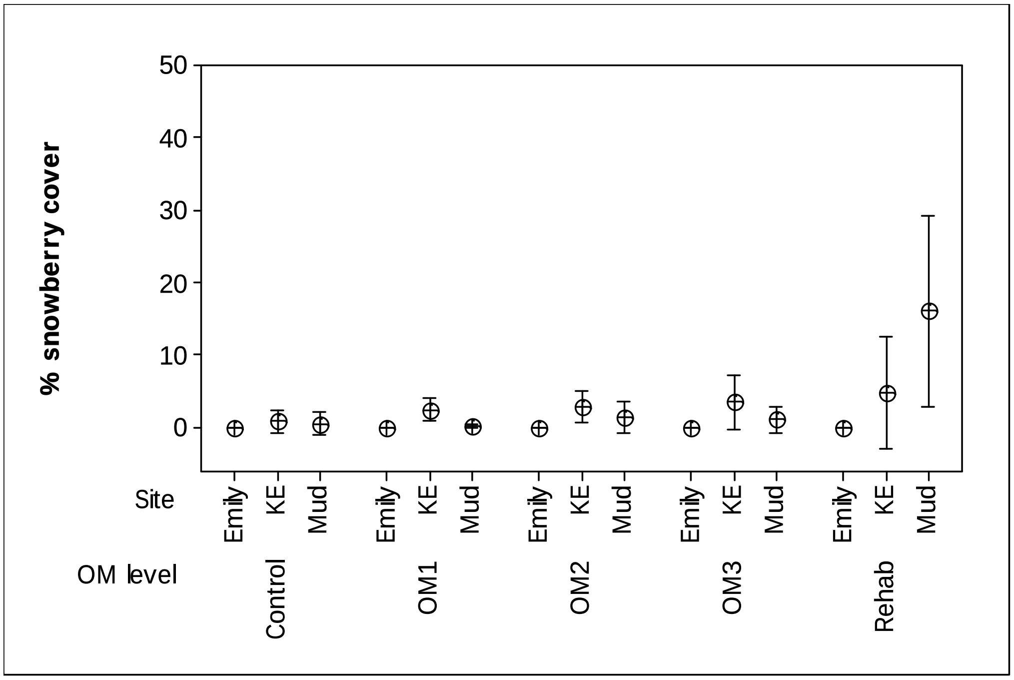

**Figure 18: Mean cover of snowberry for all treatments (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

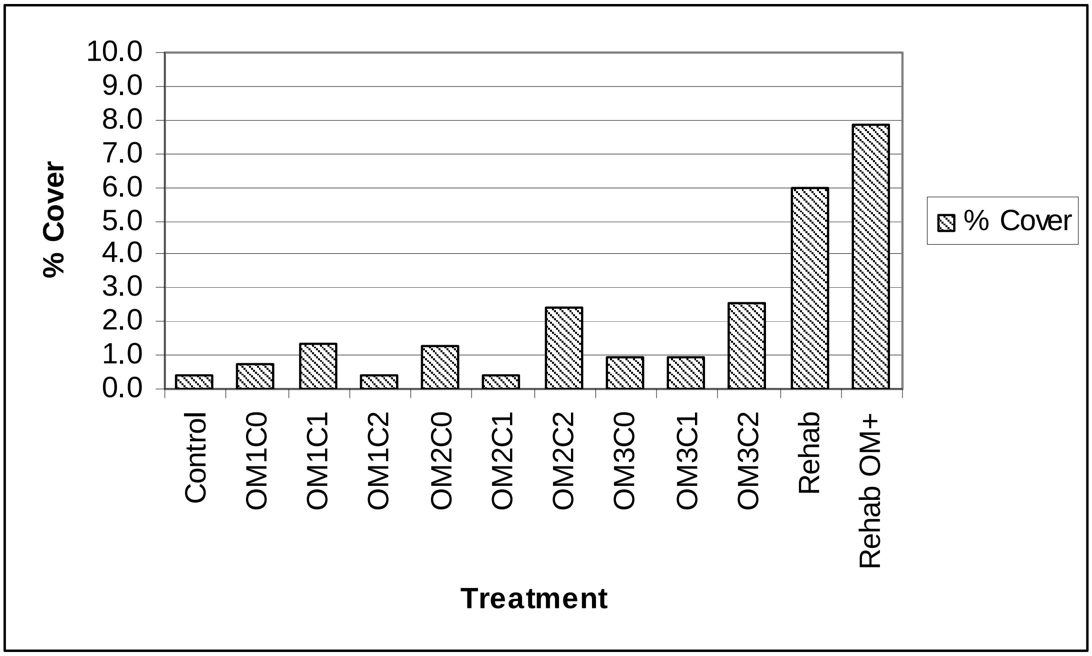

**Figure 19: Percent snowberry cover for all sites by treatment unit (5 year results).**

There were no significant interaction effects for kinnikinnick cover between sites or between years (Figure 20). Cover values were significantly reduced ($p<0.001$) for all treatments where the forest floor was removed or the soil was rehabilitated (Table 2). Cover was reduced by 4% on average between pre-treatment levels on the OM3C0, OM3C1, OM3C2, Rehab, and Rehab OM+ treatments.

Organic matter removal and compaction level tended to interact for kinnikinnick (p=0.06), so main effects were not statistically analyzed further. At all sites, OM1 treatments tended to decrease percent cover of kinnikinnick with moderate compaction (C1) and increased percent cover with heavy compaction (C2) relative to no compaction (Figure 21). In contrast, on OM2 treatments moderate (C1) compaction resulted in an increase in percent cover on the three sites, followed by a decrease in percent cover with heavy compaction (C2) relative to no compaction (C0). Interactions trends were not apparent on OM3 treatments likely because kinnikinnick cover was reduced significantly by removal of the forest floor.

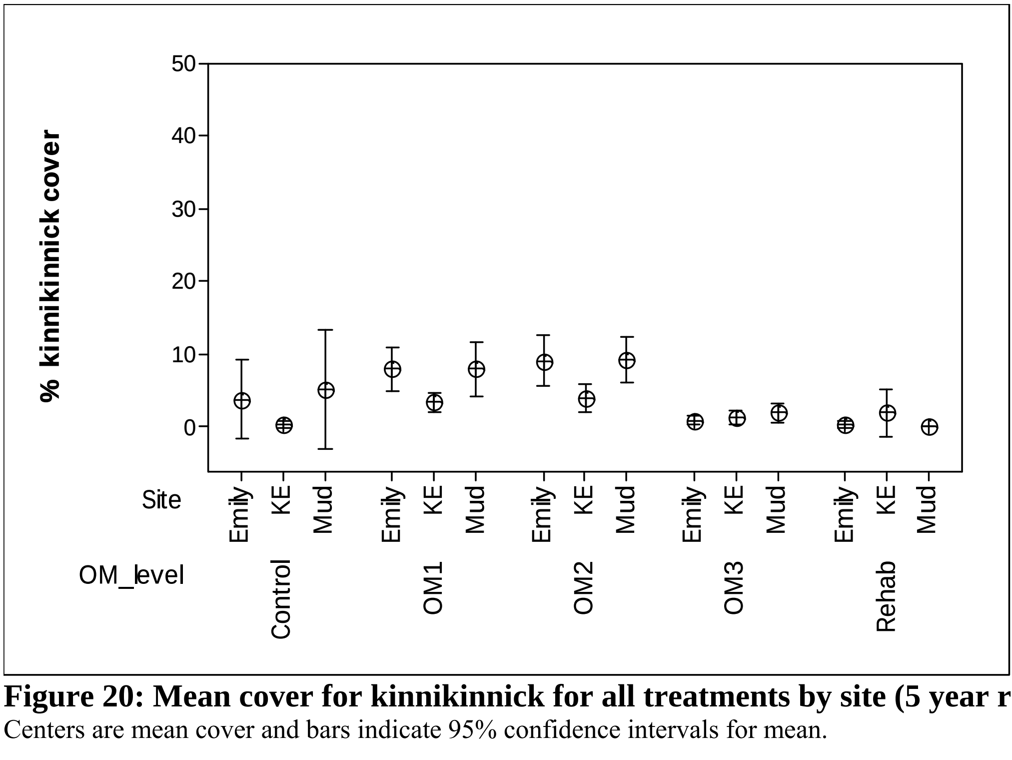

**Figure 20: Mean cover for kinnikinnick for all treatments by site (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

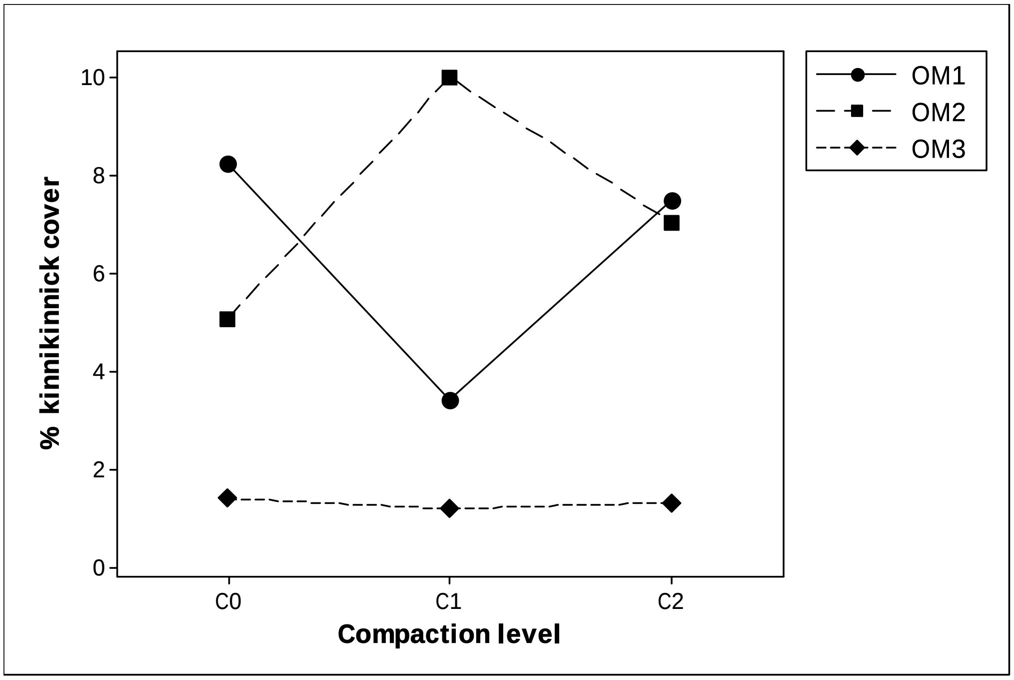

**Figure 21: Interaction plot of kinnikinnick cover by site and OM level**.

### 3.1.3 Forb cover

Although site factors were not significant, forb cover tended to be higher on the OM1, OM2, and rehabilitated treatments at Kootenay east (Figure 22). There were no significant interactions detected between organic matter removal and compaction. The general trend across all sites was an increase in percent forb cover after treatment (Figure 23). Specifically, total cover of forbs pre- and post-treatment was significantly higher on the OM2C1 (p=0.002), OM2C2 (p=0.008), OM3C1 (p=0.004), and Rehab (combined) (p=0.01) (Table 3).

Five year results indicated that total forb cover in the unharvested control was significantly lower (p<0.05) than all treatments except the OM3C2 treatment (Figure 24). Forb cover in the harvested control (OM1C0) was not significantly different from any of the other treatments. Tukey HSD tests indicated that the OM3C2 treatment had significantly lower cover than the OM2C1 and OM2C2 (p=0.005, p=0.015, respectively).

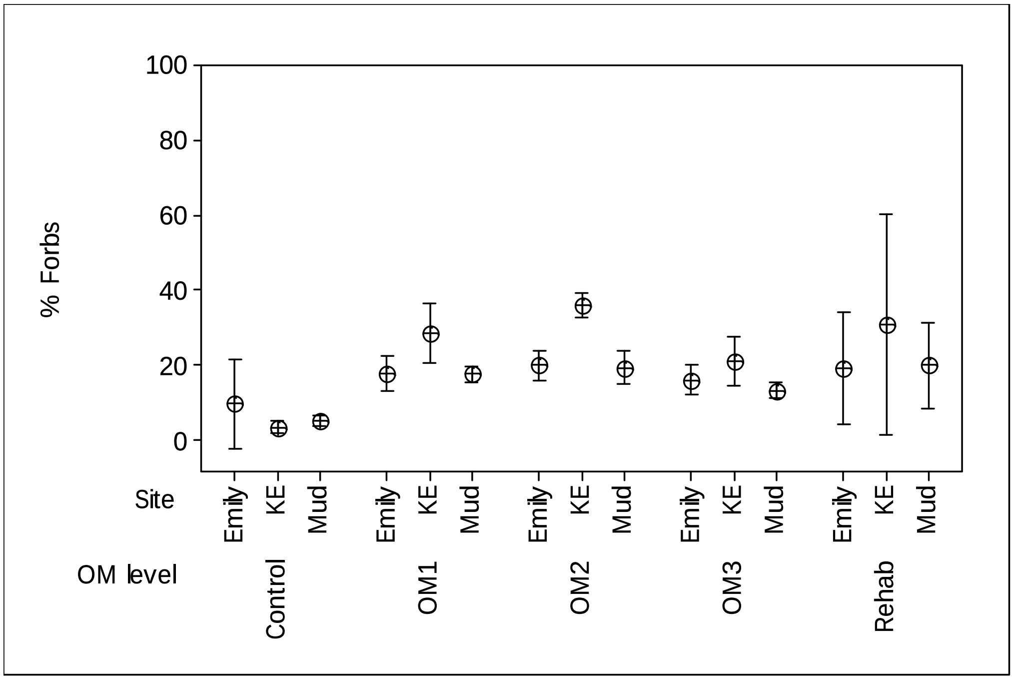

**Figure 22: Interval plot showing forb % cover by OM and site.**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

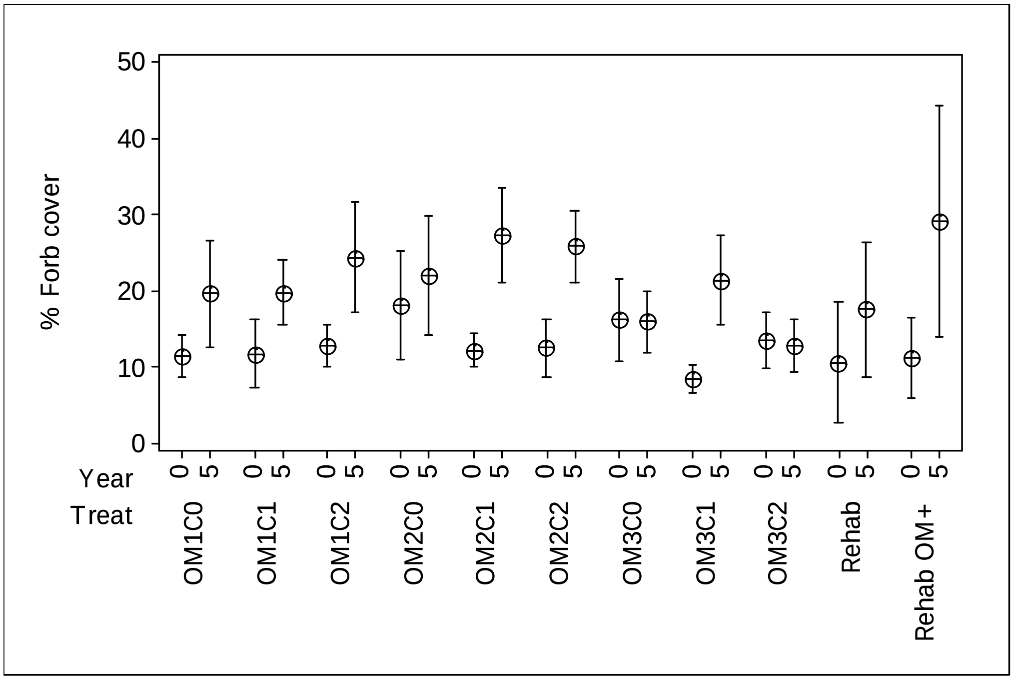

**Figure 23: Mean cover of forbs between years for each treatment.**
Bars indicate 95% confidence intervals and symbols represent mean species richness for each treatment

**Table 3: Summary statistics for five year forb response.**
(Only significant results are shown)

| | **Analysis** | **Procedure** | **n** | **MS error** | **Statistic** | **p-value** |
|---|---|---|---|---|---|---|
| Between years | Forb cover x Treat x Site | GLM | 12 | 0.01 | F=3.07 | 0.002 |
| | OM2C1 x year (forbs) | Tukey HSD | 12 | -- | T=4.46 | 0.002 |
| | OM2C2 x year (forbs) | Tukey HSD | 12 | -- | T=4.12 | 0.008 |
| | OM3C1 x year (forbs) | Tukey HSD | 12 | -- | T=4.29 | 0.004 |
| | Rehab x year (forbs) | Tukey HSD | 12 | -- | T=3.93 | 0.01 |
| Five year response | Forb cover x Treat x Site | GLM | 12 | 0.01 | F=3.07 | 0.03 |
| | Total forb x treatment[1] | GLM | 12 | 0.012 | F= 7.22 | 0.000 |
| | OM2C1 minus OM3C2 | Tukey HSD | 12 | -- | T=-4.01 | 0.005 |
| | OM2C2 minus OM3C2 | Tukey HSD | 12 | -- | T=-3.67 | 0.015 |
| | Total forb cover x OM level | GLM | 36 | 0.013 | F=14.84 | 0.0001 |
| | OM2 minus OM3 | Tukey HSD | 36 | -- | T=-3.82 | 0.002 |
| | OM x Compaction | GLM | 36 | 0.01 | F=2.67 | 0.037 |

[1] For specific results of ANOVA tables refer to Appendix C

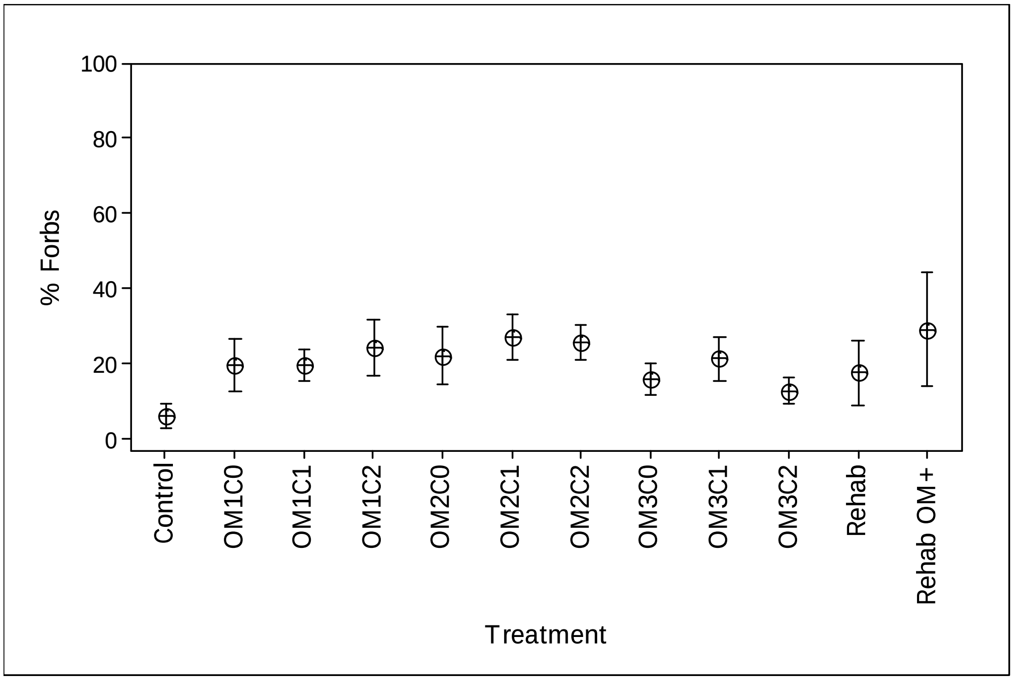

**Figure 24: Mean forb cover for all treatments (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

Forest floor removal (OM3) resulted in significantly lower forb cover than the OM1 and OM2 treatments. Species composition did not appear to change drastically between different treatments. While forb cover decreased with forest floor removal (OM3), there was no noticeable shift in species composition to weedy species. In year five, the few weedy species found on the study sites, such as thistle (*Circium* spp.), were found in sporadic but low cover values across different the different treatment levels.

No individual species of forbs were chosen for further analysis. It was difficult to identify trends with respect to R.I.V. values since many species occurred sporadically across treatment types.

### 3.1.4 Grass cover

Although no significant site interaction was detected, Mud creek tended to have lower grass cover on OM1 and OM2 treatments relative to the other sites. However on OM3 treatments, Mud creek tended to have higher grass cover relative to the other two sites (Figure 25). In general, canopy removal resulted in higher overall grass cover regardless of treatment relative to the unharvested control (Figure 26). The unharvested control had a trend of lower cover compared to the OM3C1 ($p=0.09$) and significantly lower ($p<0.05$) total grass cover compared with all other treatments (Table 4). The harvested control (OM1C0) tended to have higher cover than the OM3C1 ($p=0.096$). Additionally, the OM3C1 treatment had a trend of lower grass cover compared to the OM1C1 and significantly lower cover compared to the OM2C0 ($p=0.02$). There were no significant differences between other treatments.

Interaction effects were not significant so the main effects of organic matter removal were analyzed further. Forest floor removed sites (OM3) resulted in lower grass cover five years after treatment when compared to treatments where the forest floor was left intact (OM1 and

OM2). Tukey HSD tests revealed that cover of grasses in the OM3 (20%) treatment was significantly lower relative to the OM1 (26%) treatments (p=0.0007) and the OM2 (28%) (p=0.0001) treatment. There was no significant difference between OM1 and OM2 treatments and no significant difference in grass cover between the three levels of soil compaction.

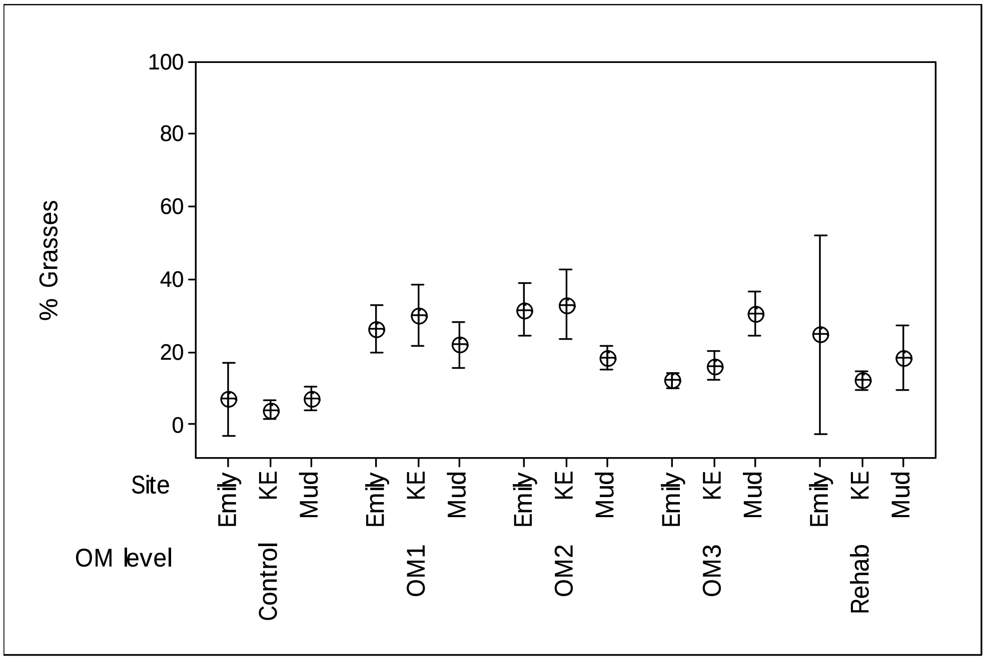

**Figure 25: Interval plot showing grass % cover by OM and site.**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

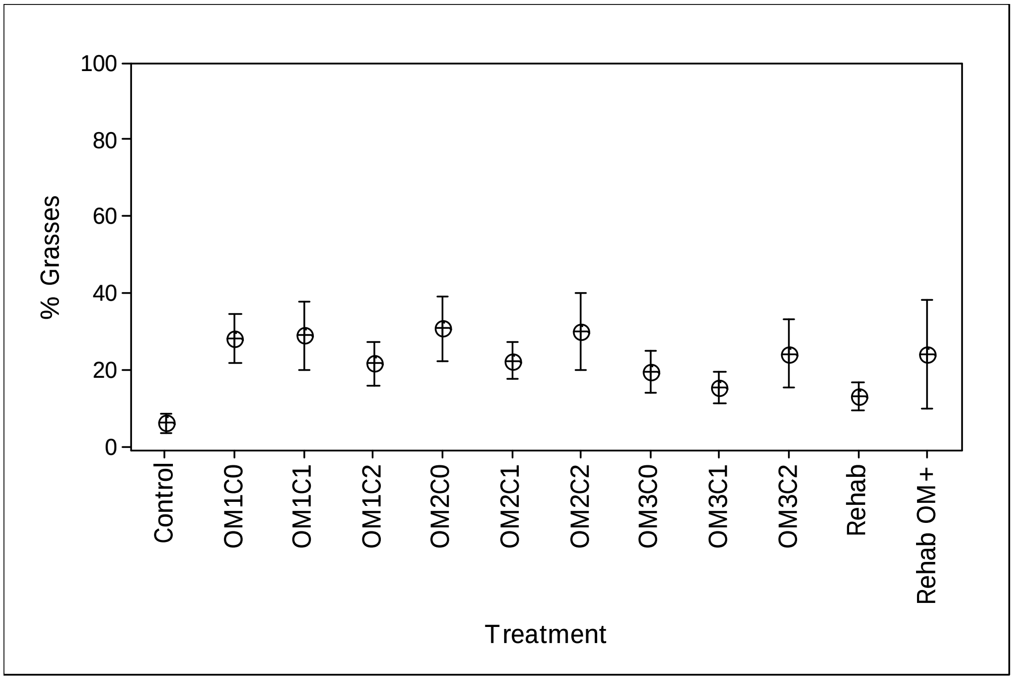

**Figure 26: Mean cover of grasses for all sites by treatment (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

**Table 4: Summary statistics for five year grass response.**
See Appendix C for ANOVA summary tables

| | Analysis | Procedure | n | MS error | Statistic | p-value |
|---|---|---|---|---|---|---|
| Between years | Grass cover x Treat. x year | GLM | 12 | -- | F=3.06 | 0.002 |
| | OM1C0 x year (grasses) | Tukey HSD | 12 | -- | T=3.89 | 0.018 |
| | OM1C1 x year (grasses) | Tukey HSD | 12 | -- | T=5.41 | 0.0001 |
| | OM2C0 x year (grasses) | Tukey HSD | 12 | -- | T=5.47 | 0.0001 |
| | OM2C2 x year (grasses) | Tukey HSD | 12 | -- | T=5.18 | 0.0001 |
| | Pinegrass x Treat. x year | GLM | 12 | 0.01 | F=2.01 | 0.04 |
| | OM1C0 x year (pinegrass) | Tukey HSD | 12 | -- | T=3.96 | 0.01 |
| | OM2C2 x year (pinegrass) | Tukey HSD | 12 | -- | T=3.69 | 0.03 |
| | Festcam x Treat x year[1] | GLM | 12 | 0.006 | F=5.80 | <0.0001 |
| | OM1 x year (festcam) | Tukey HSD | 12 | -- | T=7.30 | <0.0001 |
| | OM2 x year (festcam) | Tukey HSD | 12 | -- | T=10.88 | <0.0001 |
| | OM3 x year (festcam) | Tukey HSD | 12 | -- | T=3.95 | 0.002 |
| Total grass cover | Total grass cover x Treatment | GLM | 12 | 0.016 | F=7.35 | <0.0001 |
| | Control minus treatments[1] | Tukey HSD | 12 | -- | T $\geq$3.72[1] | <0.05 |
| | OM2C0 minus OM3C1 | Tukey HSD | 12 | -- | T=3.56 | 0.022 |
| | Total grass cover x OM level | GLM | 36 | 0.017 | F=5.82 | 0.004 |
| | OM1 minus OM3 | Tukey HSD | 36 | -- | T=3.8 | 0.0007 |
| | OM2 minus OM3 | Tukey HSD | 36 | -- | T=4.5 | <0.0001 |

Table 4 Cont'd

| | Analysis | Procedure | n | MS error | Statistic | p-value |
|---|---|---|---|---|---|---|
| Pinegrass | Pinegrass cover x Treatment | GLM | 12 | 0.019 | F=4.40 | <0.0001 |
| | Control minus treatments | Tukey HSD | 12 | -- | T≥3.12 | <0.1 |
| Rough fescue | Rough fescue cover x Treatment | GLM | 12 | 0.0089 | F=6.88 | <0.0001 |
| | Control minus OM2C0 | Tukey HSD | 12 | -- | T=5.98 | <0.001 |
| | Control minus OM2C2 | Tukey HSD | 12 | -- | T=4.26 | 0.002 |
| | OM2C0 minus OM3C1 | Tukey HSD | 12 | -- | T=-4.26 | 0.002 |
| | OM2C0 minus OM3C2 | Tukey HSD | 12 | -- | T=-4.61 | 0.0006 |
| | OM2C0 minus Rehab | Tukey HSD | 12 | -- | T=5.33 | 0.0001 |
| | OM2C0 minus Rehab OM+ | Tukey HSD | 12 | -- | T=4.83 | 0.0003 |
| | OM2C2 minus OM3C0 | Tukey HSD | 12 | -- | T=-3.32 | 0.05 |
| | OM2C2 minus Rehab | Tukey HSD | 12 | -- | T=-3.93 | 0.007 |
| | OM2C2 minus Rehab OM+ | Tukey HSD | 12 | -- | T=-3.49 | 0.03 |
| | OM level x rough fescue cover | GLM | 36 | 0.010 | F=11.76 | <0.0001 |
| | OM1 minus OM3 | Tukey HSD | 36 | -- | T=-2.86 | 0.02 |
| | OM2 minus OM3 | Tukey HSD | 36 | -- | T=-4.82 | <0.006 |

#### 3.1.4.1 Pinegrass response

Although pinegrass was not significantly different between sites, cover tended to be higher on OM3 treatments at Mud creek relative to the other sites. No significant interaction effects were detected between organic matter removal and treatment (Figure 27).

Although pinegrass cover generally increased in the years following canopy removal, there was no significant change between years on most treatment sites (Figure 28). Severe site disturbance such as Rehabilitation tended to negatively impact the total cover of pinegrass. Cover increased significantly on two treatments where the forest floor was left intact relative to the unharvested control (OM1C1 p=0.01, increase 16% and OM2C2 p=0.03, increase 14%). Forest floor removed sites still had an increase in pinegrass cover but the differences were not significant. Mean cover tended to decrease over the five years on the rehabilitated treatments by 0.5% in contrast to most other treatments where cover tended to increase by 14% on average.

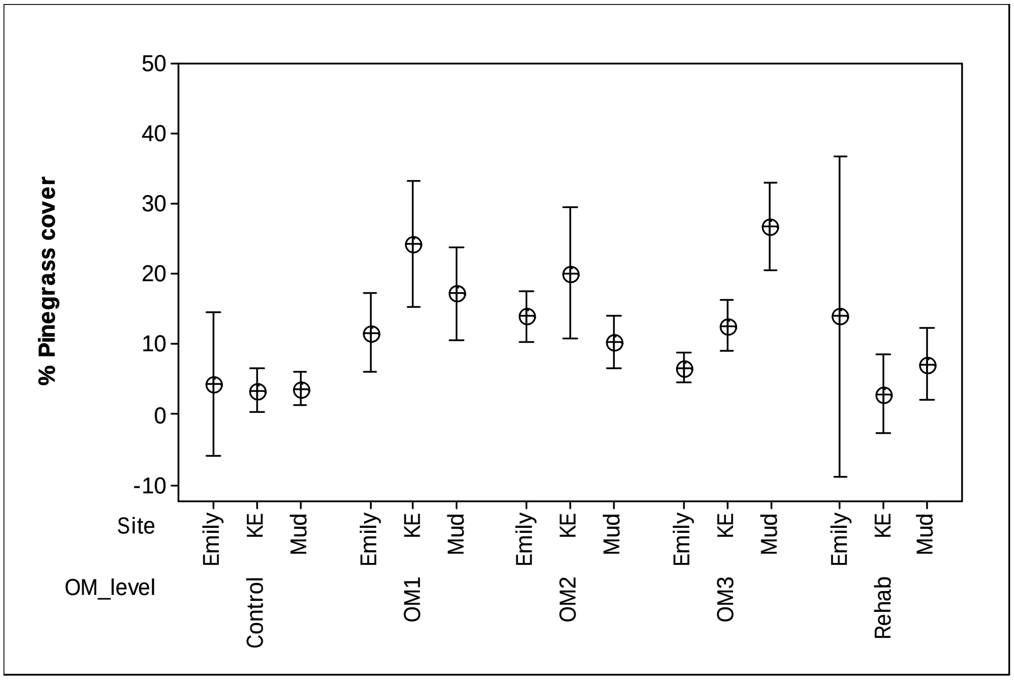

**Figure 27: Interval plot showing total % pinegrass cover by OM and site.**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

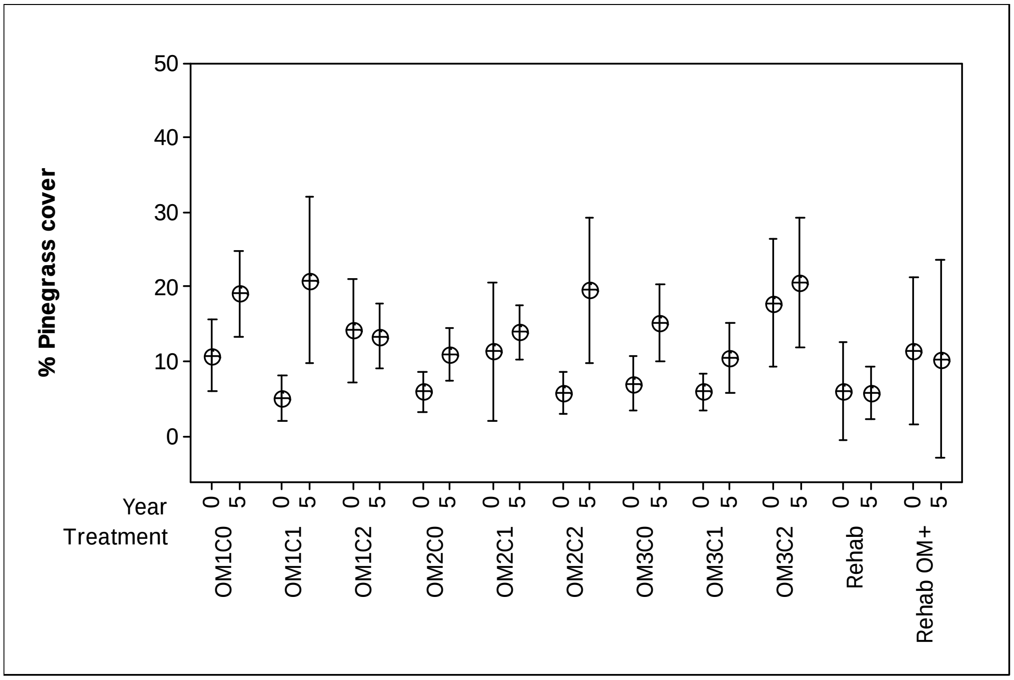

**Figure 28: Mean cover of pinegrass on all sites between years.**
Bars indicate 95% confidence intervals and symbols represent mean species richness for each treatment

Pinegrass cover was lower on the unharvested control compared with most treatments (Figure 29). Tukey HSD tests revealed that the pinegrass had significantly lower cover ($p<0.001$) in the unharvested control compared to all treatments except the OM1C0, OM3C1, and Rehabilitated (OM- and OM+). No other treatments were significantly different from each other and there were no significant interactions or main effects with the factorial treatments.

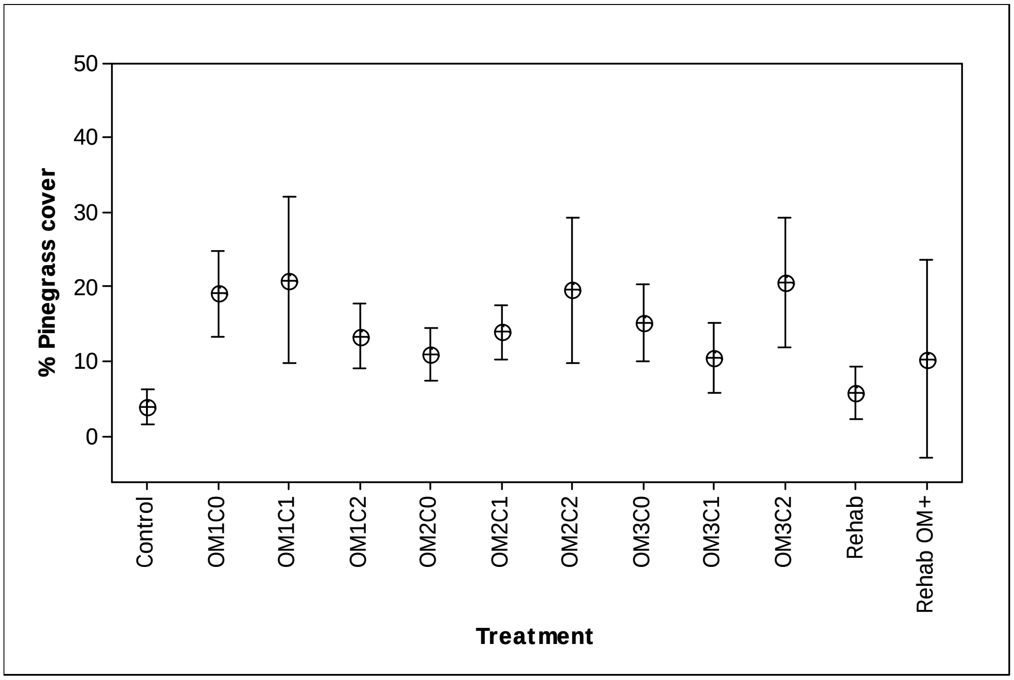

**Figure 29: Mean cover for pinegrass for all sites by treatment (5 year results).** Centers are mean cover and bars indicate 95% confidence intervals for mean.

### 3.1.4.2 Rough fescue response

There was no significant interaction effect between site and treatment for rough fescue and cover values across sites were relatively similar between the sites for each treatment level (Figure 30).

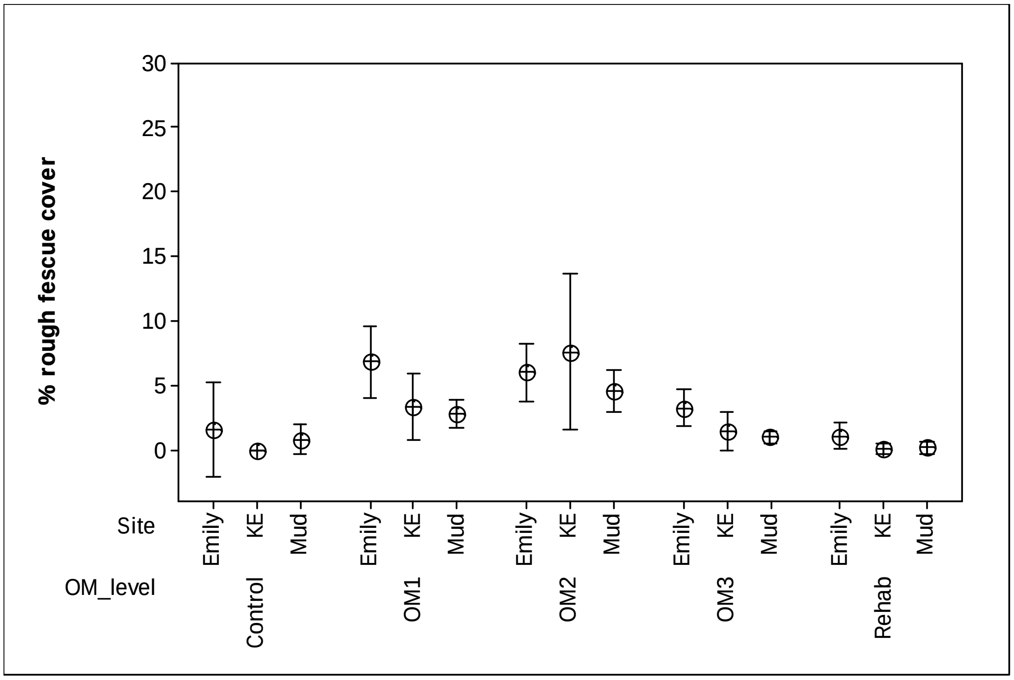

**Figure 30: Interval plot showing total % rough fescue cover by OM and site.**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

Rough fescue cover increased very significantly ($p<0.0001$) on OM1 and OM2 treatment between pre-treatment and post-treatment conditions (Figure 31). Rehabilitation or forest floor removal plus compaction treatments (OM3C1, OM3C2) did not increase cover of rough fescue significantly ($p>0.1$) even though mean covers were higher. There were no significant interactions between organic matter removal and soil compaction for rough fescue. The greatest increases in cover occurred on treatments where the forest floor was left intact. In the OM1 and OM2 treatments cover of rough fescue increased by approximately 5% five years after canopy removal; whereas, cover in the OM3 treatment increased but only by 1.5%. No increase in cover was observed relative to pre-treatment conditions on the Rehabilitated treatment.

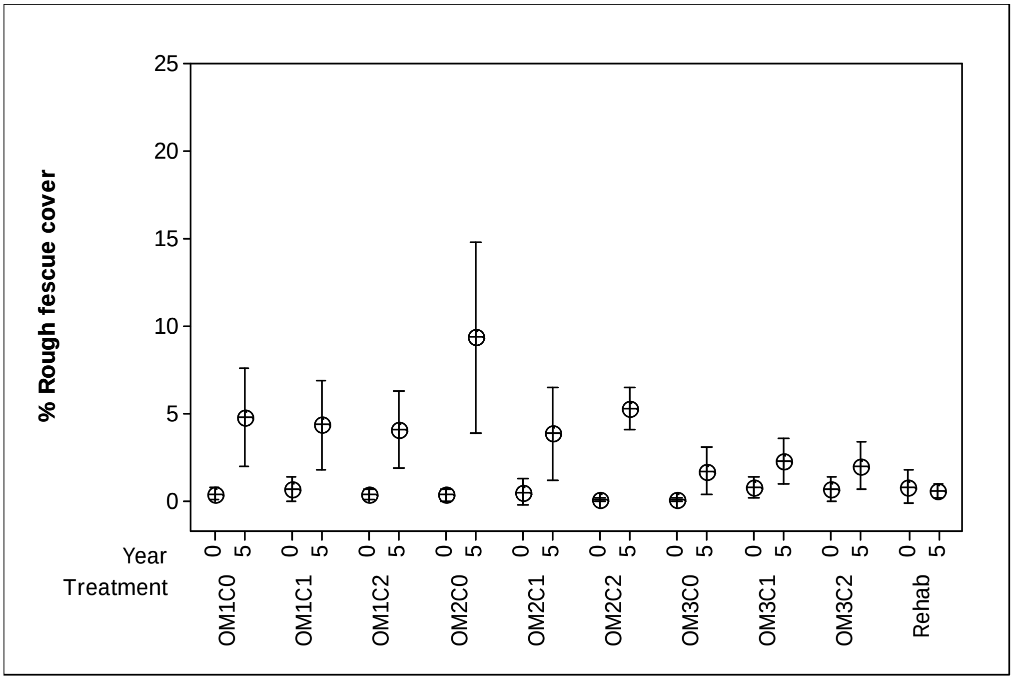

**Figure 31: Mean cover of rough fescue between years for each treatment.**

In general, severe soil disturbances such as forest floor removal and rehabilitation resulted in lower overall cover values of rough fescue (Figure 32). Tukey HSD tests revealed that rough fescue cover in the unharvested control tended to have lower cover relative to the OM1C0 (p=0.07) and OM1C1 (p=0.09) and significantly lower cover than the OM2C0 (p<0.001) and OM2C2 (p=0.002) treatments. The OM2C0 treatment had significantly higher cover compared to the OM3C1 (p=0.002), OM3C2 (p=0.006), and both Rehabilitated treatments (p<0.001)(Table 4, pg. 57). In addition, the OM2C2 treatment had significantly higher cover compared to the OM3C0 (p=0.05), Rehabilitated (p=0.007), and Rehabilitated OM+ (p=0.03) treatments. Forest floor removal resulted in significantly lower cover of rough fescue than the OM1 (p=0.003) and OM2 (p<0.0001) treatments (Figure 33).

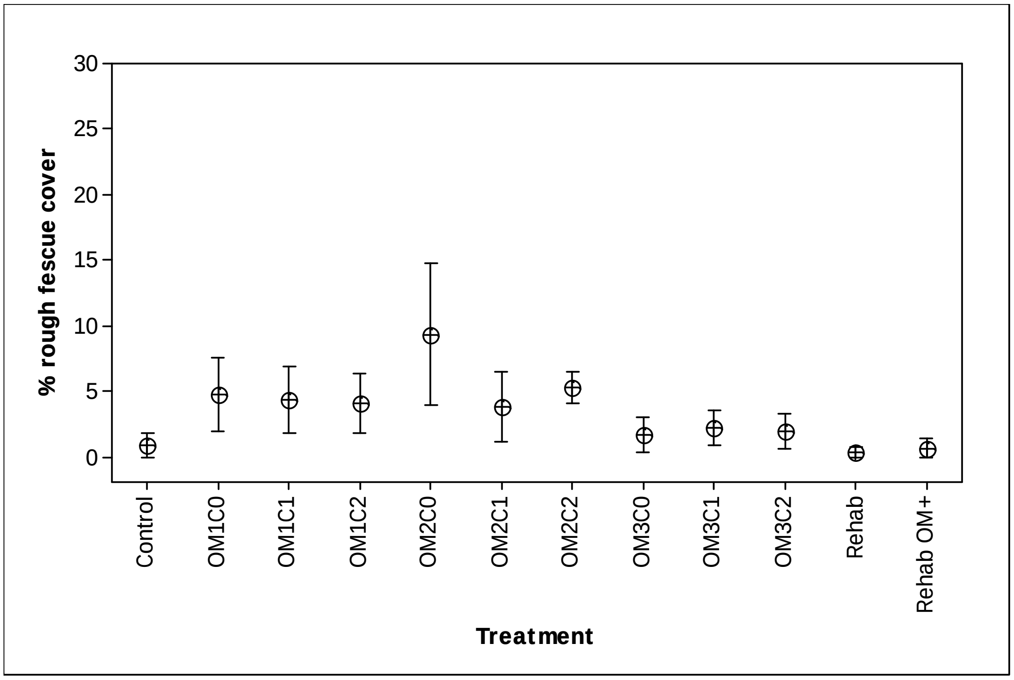

**Figure 32: Mean cover for rough fescue for all sites by treatment (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

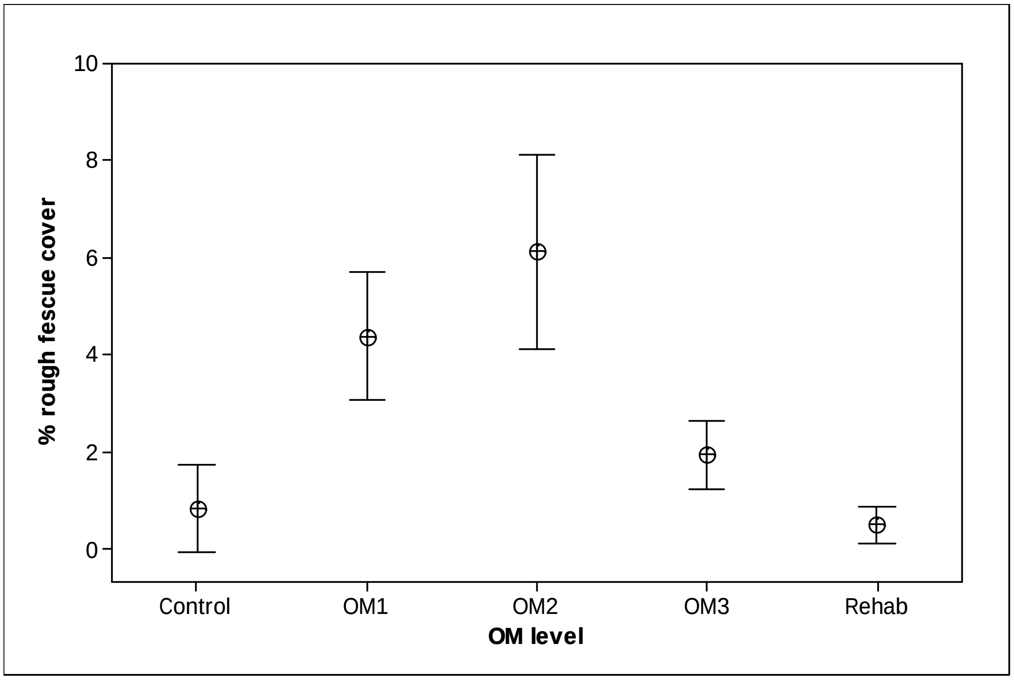

**Figure 33: Mean cover of rough fescue at all sites for three levels of organic matter removal plus Control and Rehabilitated treatments (5 year results).**
Centers are mean cover and bars indicate 95% confidence intervals for mean.

### 3.2 Rehabilitated Treatments

Rehabilitated treatments were examined separately in a one-way randomized block design using only the heavily compacted treatments as a factor (OM1C2, OM2C2, and OM3C2). There were no significant differences for total cover, shrub cover, forb cover, and grass cover. There were significant interactions between site and treatment level for all cover values tested indicating strong differences between sites. Kootenay east had higher overall cover on OM1C2 treatments relative to the other sites. Emily creek tended to have lower total cover and shrub cover on OM3C2 and Rehabilitated (OM±) treatments relative to other sites. Both Kootenay east and Emily had higher overall forb cover on Rehab OM± treatments relative to Mud creek. At Mud creek, OM3C2 treatments had higher grass cover relative to other sites and at Emily creek grass cover was higher on Rehab OM± treatments relative to other sites.

Rough fescue and kinnikinnick cover responded similarly across the different sites and no significant interaction between Site and OM level was detected (Figure 34; Figure 35). Rough fescue cover was significantly lower on the Rehab and Rehab OM+ treatments compared to the OM1 ($p=0.001$ and $p=0.01$, respectively), OM2 ($p<0.001$), and OM3 ($p=0.007$) treatments (Table 5). Kinnikinnick cover was significantly lower on the OM3, Rehab, and Rehab OM+ treatments ($p<0.001$) compared to the OM1 treatment and significantly lower compared to the OM2 treatments on the OM3, Rehab, and Rehab OM+ ($p<0.001$). All other species interacted significantly with site (Site x OM) and there was no main effects difference in percent cover values.

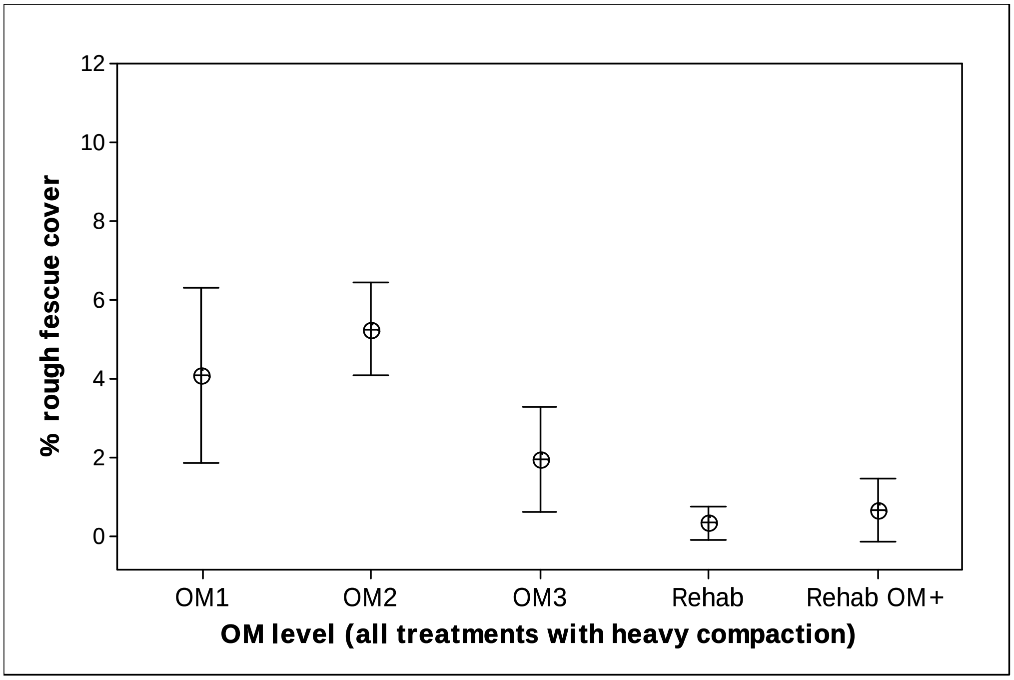

**Figure 34: Rough fescue cover across all treatments with heavy compaction (Rehab and C2) treatments (5 year results).**

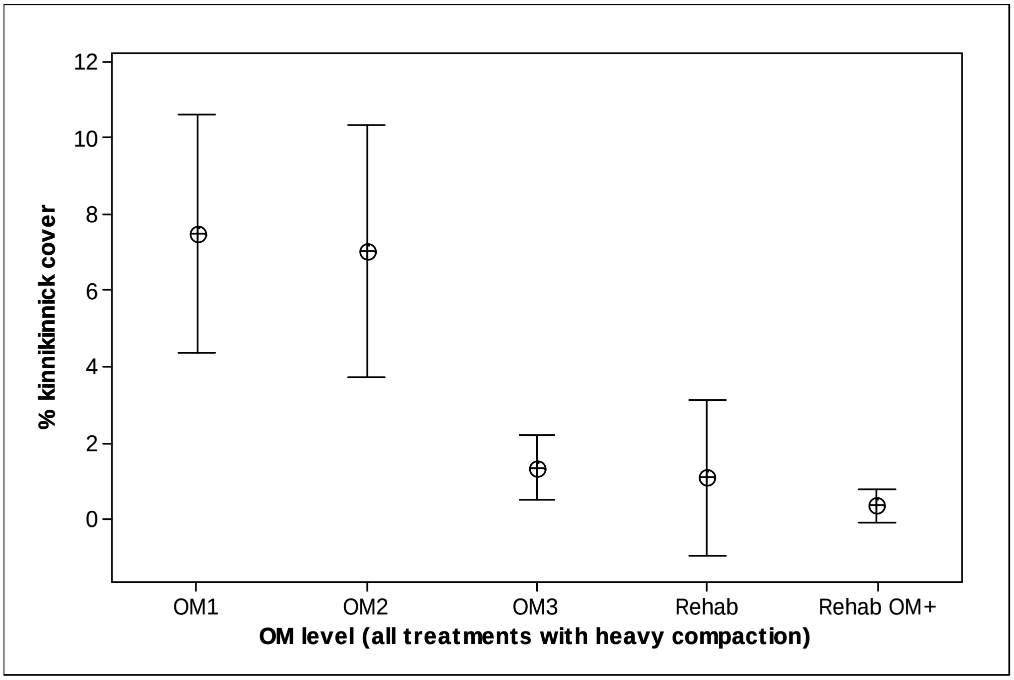

**Figure 35: Kinnikinnick cover across all treatments with heavy compaction (Rehab and C2) treatments (5 year results).**

**Table 5: Summary statistics for rehabilitated treatment analysis.**
(Only significant results are shown, for details of all analysis refer to Appendix C)

| | Analysis | Procedure | n | MS error | Statistic | p-value |
|---|---|---|---|---|---|---|
| Rough fescue | OM level | GLM | 12(6) | 0.05 | F=9.3 | 0.004 |
| | OM1 minus Rehab | Tukey HSD | 36 | -- | T=3.5 | 0.008 |
| | OM1 minus Rehab OM+ | Tukey HSD | 36 | -- | T=2.9 | 0.04 |
| | OM2 minus OM3 | Tukey HSD | 36 | -- | T=3.5 | 0.007 |
| | OM2 minus Rehab | Tukey HSD | 36 | -- | T=4.8 | 0.002 |
| | OM2 minus Rehab OM+ | Tukey HSD | 36 | -- | T=4.21 | 0.001 |
| Kinnikinnick | OM level | GLM | 12(6) | 0.1 | F=8.8 | 0.005 |
| | OM1 minus OM3 | Tukey HSD | 12 | | T=4.9 | 0.001 |
| | OM1 minus Rehab | Tukey HSD | 36 | -- | T=4.8 | 0.002 |
| | OM1 minus Rehab OM+ | Tukey HSD | 36 | -- | T=5.4 | <0.001 |
| | OM2 minus OM3 | Tukey HSD | 36 | -- | T=4.5 | 0.004 |
| | OM2 minus Rehab | Tukey HSD | 36 | -- | T=4.5 | 0.005 |
| | OM2 minus Rehab OM+ | Tukey HSD | 36 | -- | T=5.1 | 0.001 |

[1] For specific results of ANOVA tables refer to Appendix C

Total cover in rehabilitated plots where forest floor was added back to the soil (ameliorated) tended to have higher cover (p=0.074) compared to treatments where soil was not ameliorated with forest floor organic matter (Figure 36). There was no difference in cover for shrubs, forbs or grasses between ameliorated Rehabilitated treatments and non-ameliorated treatments, although Rehabilitated+OM treatments tended to have higher cover values. However, the latter data sets had a low statistical power (<0.7), hence there is a high likelihood of committing a type II error.

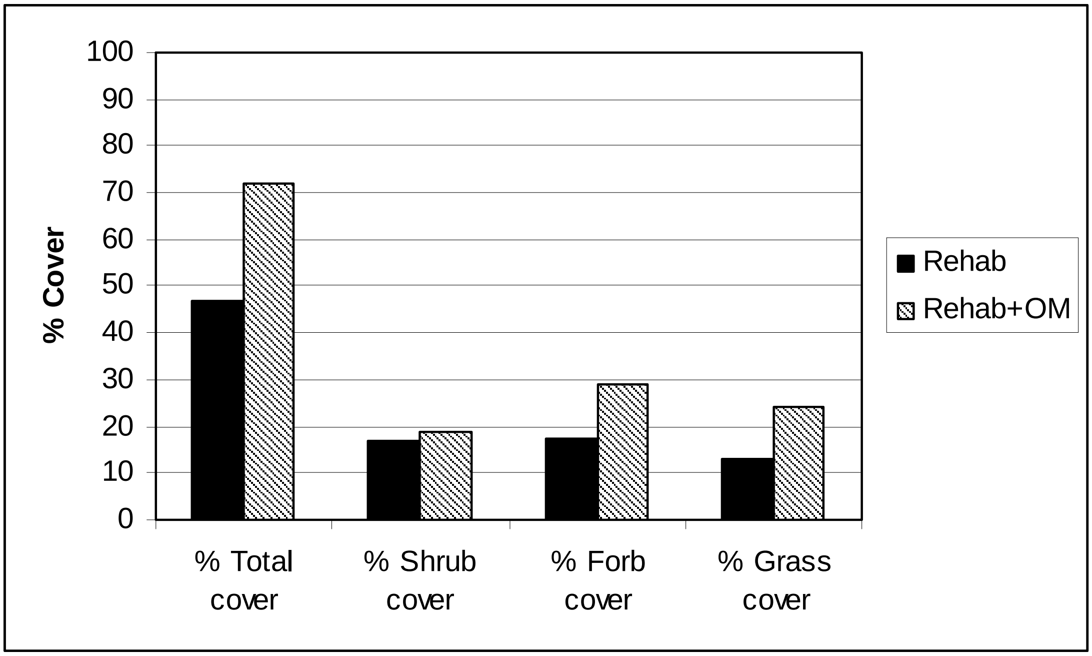

**Figure 36: Percent cover for rehabilitated treatments (Rehab) and ameliorated treatments (Rehab+OM) for east Kootenay LTSP.**

## 3.3 Richness and Diversity

### 3.3.1 Between years analysis

Richness tended to increase following treatment on all sites between years but no results were statistically significant (Figure 37). Richness decreased marginally on the OM2C0 and OM3C2 treatments while all other treatments had minor increases in richness between pre and post treatment conditions.

There was no significant difference in Shannon-Weiner diversity ($H^{/}$) values between years by treatment for shrubs and forbs. For grass cover, the OM1C0, OM2C0, and Rehabilitated treatments had a trend of higher $H^{/}$ value after five years (Figure 38).

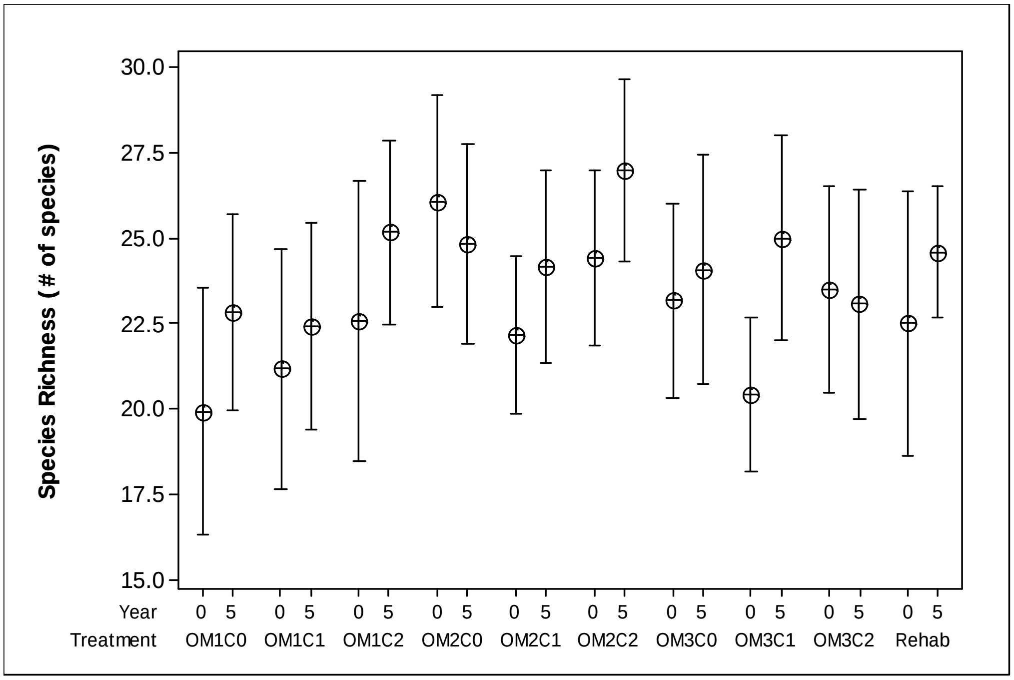

**Figure 37: Total species richness between years for each treatment.**
Bars indicate 95% confidence intervals and symbols represent mean species richness for each treatment

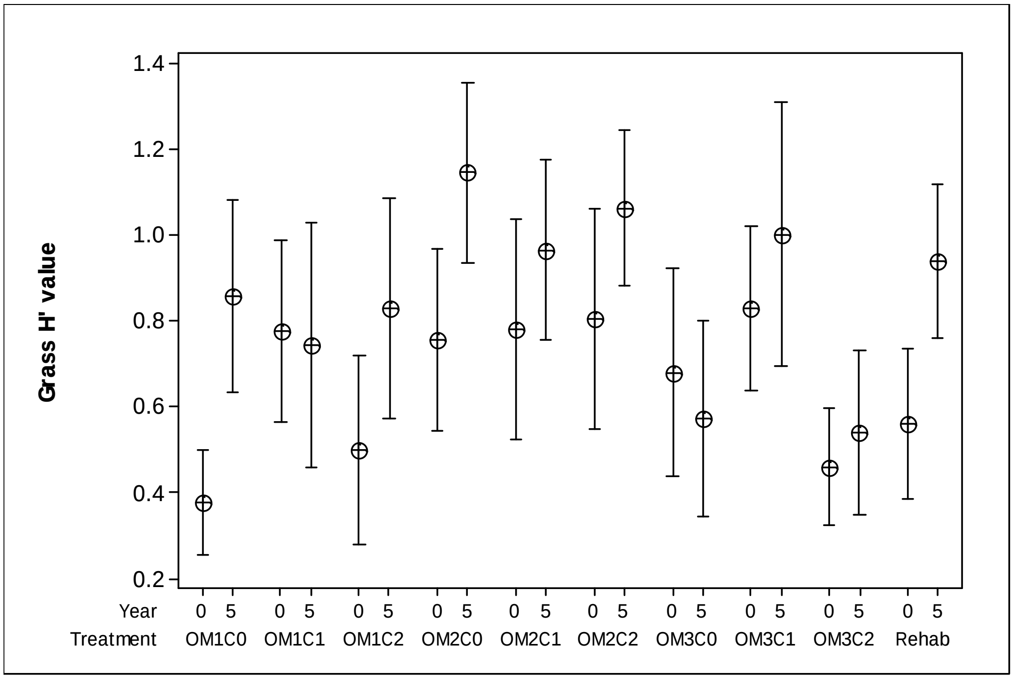

**Figure 38: $H^{/}$ values between years by treatment for grasses.**

### 3.3.2 Between treatments comparisons

There was no significant interaction between site and treatment for species richness (Figure 39). Canopy removal increased species richness significantly over the unharvested control (p<0.0001); however, richness was not significantly different between treatments (Figure 40; Table 6).

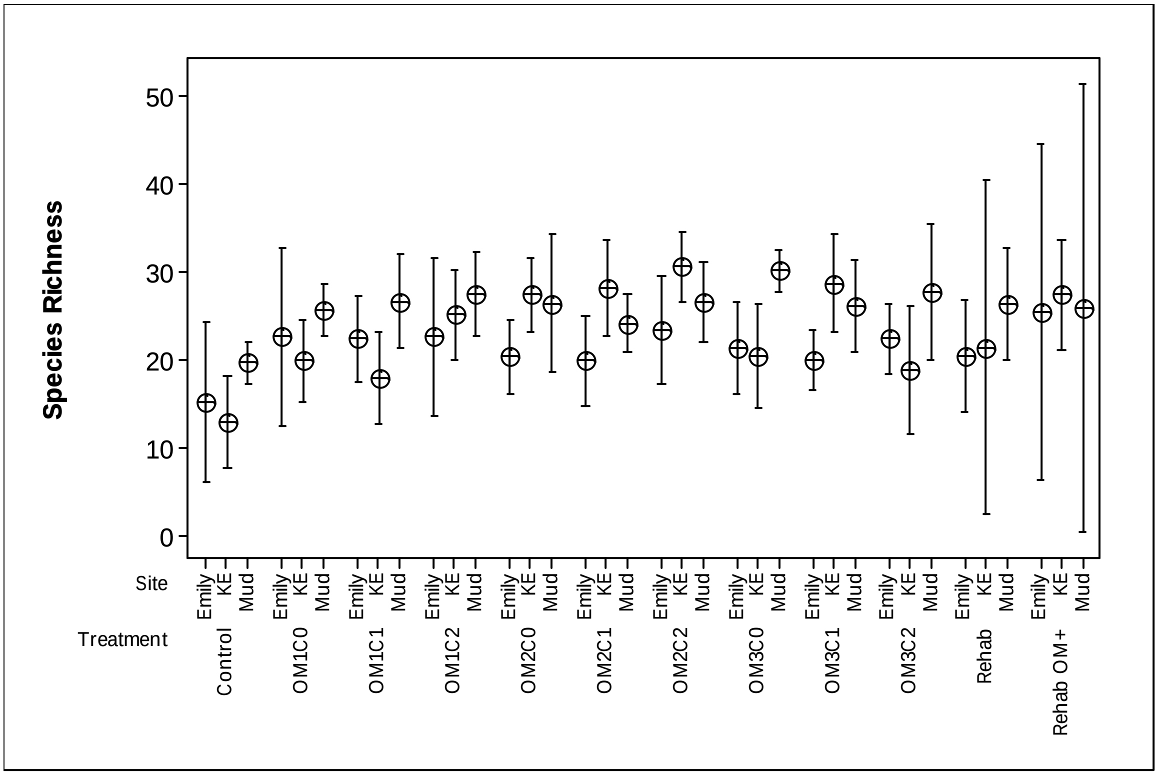

**Figure 39: Species richness between sites at east Kootenay LTSP (5 year results).**

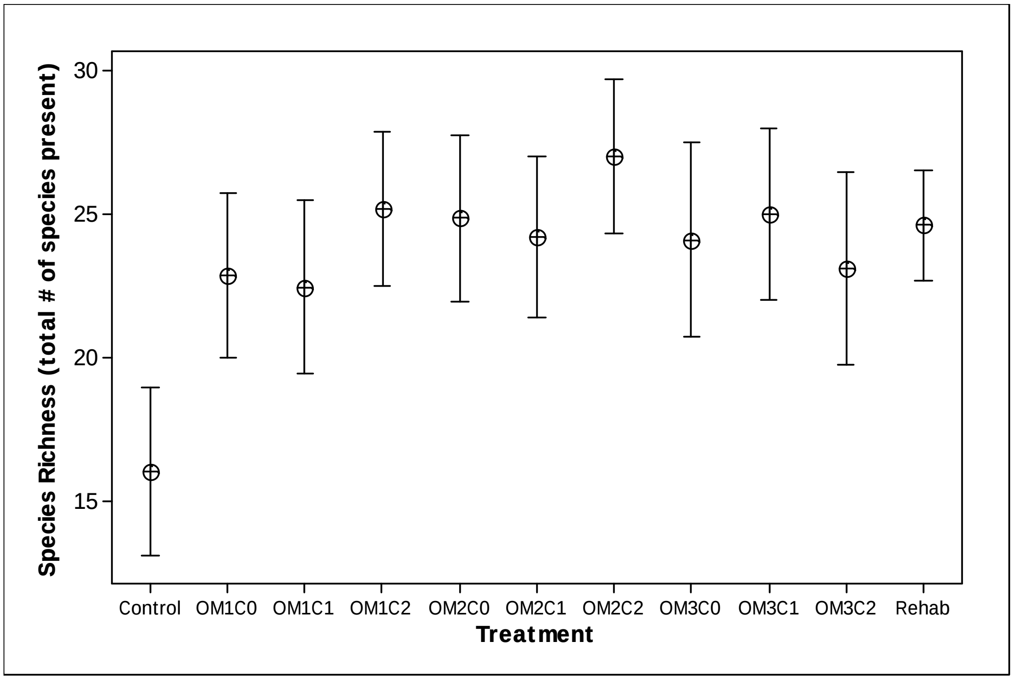

**Figure 40: Total species richness for all treatments (5 year data results).**

**Table 6: Summary statistics for Species Richness and Shannon-Weiner ($H^{/}$) diversity.**
(Only significant results are shown, for details of all analysis refer to Appendix C)

| Analysis | Procedure | n | MS error | Statistic | p-value |
|---|---|---|---|---|---|
| Richness x treatment[1] | GLM | 12 | 20.73 | F=4.57 | <0.0001 |
| $H^{/}$ x treatment[1] | GLM | 12 | 0.12 | F=3.88 | <0.0001 |
| $H^{/}$ x OM level | GLM | 12 | 0.09 | F=2.59 | 0.08 |
| OM x Comp ($H^{/}$) | GLM | 12 | 0.09 | F=3.60 | 0.009 |
| OM1 minus OM2 ($H^{/}$forbs) | Tukey HSD | 36 | -- | T=2.77 | 0.01 |
| OM2 minus OM3 ($H^{/}$forbs) | Tukey HSD | 36 | -- | T=2.54 | 0.03 |
| OM x Comp ($H^{/}$forbs) | GLM | 12 | 0.11 | F=2.61 | 0.04 |
| $H^{/}$ x OM ($H^{/}$grasses) | GLM | 12 | 0.13 | F=8.59 | <0.0001 |
| OM x Comp. ($H^{/}$grasses) | GLM | 12 | 0.13 | F=3.12 | 0.0018 |
| OM2C0 minus OM3C0 ($H^{/}$grasses) | Tukey HSD | 12 | -- | T=-3.77 | 0.008 |
| OM2C2 minus OM3C2 ($H^{/}$grasses) | Tukey HSD | 12 | -- | T=-3.45 | 0.02 |
| OM3C2 minus OM3C0 ($H^{/}$grasses) | Tukey HSD | 12 | -- | T=-3.22 | 0.04 |
| OM3C1 minus OM3C2 ($H^{/}$grasses) | Tukey HSD | 12 | -- | T=-3.05 | 0.06 |
| OM1 minus OM2 ($H^{/}$grasses) | Tukey HSD | 36 | -- | T=2.86 | <0.0001 |
| OM2 minus OM3 ($H^{/}$grasses) | Tukey HSD | 36 | -- | T=-4.03 | 0.0003 |

[1] See Appendix C for specific Tukey HSD analysis for each treatment.

There was no interaction between site and total Shannon-Weiner diversity so $H^{/}$ values were relatively the same across treatments (Figure 41). $H^{/}$ was significantly lower in the unharvested control compared with the OM1C2 (p=0.0007), OM2C0 (p=0.006), OM2C1 (p=0.002), OM2C2 (p=0.001), OM3C1 (p=0.0008), and Rehabilitated (p=0.03) treatments (Table 6, pg 71). However, Kootenay east $H^{/}$ on the unharvested control was less than the other sites. On treatments where the forest floor was retained, the $H^{/}$ value increased marginally with heavy compaction. Table 7 lists the Shannon-Weiner values for each treatment between years.

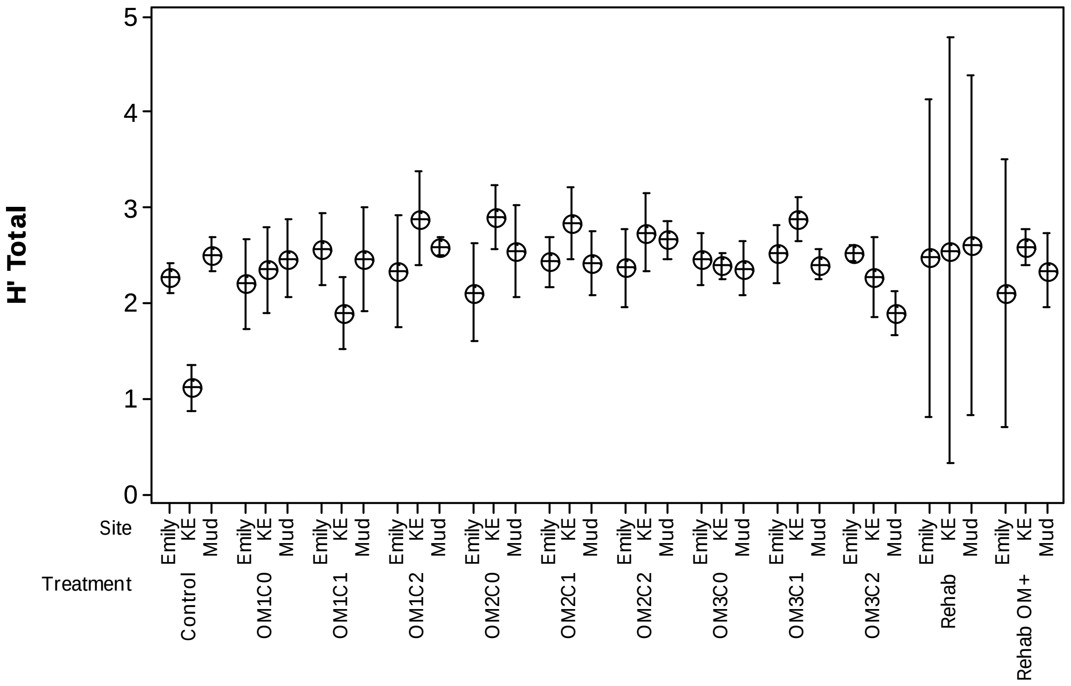

**Figure 41: Total Shannon-Weiner diversity values between sites (5 year data).**

**Table 7: Total $H^{/}$ diversity values between treatments and between years.**

| Year | Control | OM1C0 | OM1C1 | OM1C2 | OM2C0 | OM2C1 | OM2C2 | OM3C0 | OM3C1 | OM3C2 | Rehab |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | n/a | 2.27 | 2.44 | 2.22 | 2.46 | 2.38 | 2.55 | 2.31 | 2.23 | 2.36 | 2.12 |
| 5 | 1.96 | 2.34 | 2.30 | 2.60 | 2.52 | 2.56 | 2.59 | 2.40 | 2.60 | 2.23 | 2.44 |
| Shrubs | | | | | | | | | | | |
| 0 | n/a | 1.10 | 1.17 | 1.05 | 1.25 | 1.02 | 1.23 | 1.05 | 1.12 | 1.27 | 1.05 |
| 5 | 0.95 | 1.04 | 0.89 | 1.01 | 0.92 | 0.88 | 1.05 | 1.03 | 0.94 | 0.90 | 0.84 |
| Forbs | | | | | | | | | | | |
| 0 | | 1.96 | 2.00 | 2.08 | 2.36 | 2.17 | 2.31 | 2.12 | 2.11 | 2.17 | 2.09 |
| 5 | 1.90 | 1.81 | 2.09 | 2.28 | 2.13 | 2.08 | 2.02 | 2.31 | 2.20 | 2.33 | 2.11 |
| Grasses | | | | | | | | | | | |
| 0 | | 0.38 | 0.77 | 0.50 | 0.76 | 0.78 | 0.80 | 0.68 | 0.83 | 0.46 | 0.56 |
| 5 | 0.66 | 0.86 | 0.74 | 0.83 | 1.14 | 0.97 | 1.06 | 0.57 | 1.00 | 0.54 | 0.94 |

$H^{/}$ diversity values were calculated for shrubs, forbs and grasses separately for five year data results. Shrub diversity tended to be lower at Emily creek relative to Kootenay east and Mud creek although interaction effects were not significant (Figure 42). There was no difference in shrub diversity between treatments or between the control and treatments. However, statistical power for shrub diversity was quite low (<0.7) so there is a high likelihood of committing a type II error. Forb diversity was similar between sites for each treatment (Figure 43). Forb diversity was significantly higher in the OM3 treatments over the OM1 ($p=0.02$) and the OM2 ($p=0.03$) (Figure 44). Soil compaction alone did not appear to result in any significant differences in the $H^{/}$ value. Soil compaction resulted in a constant increase in forb diversity on OM1 treatments; however, this trend was not significant (Figure 45).

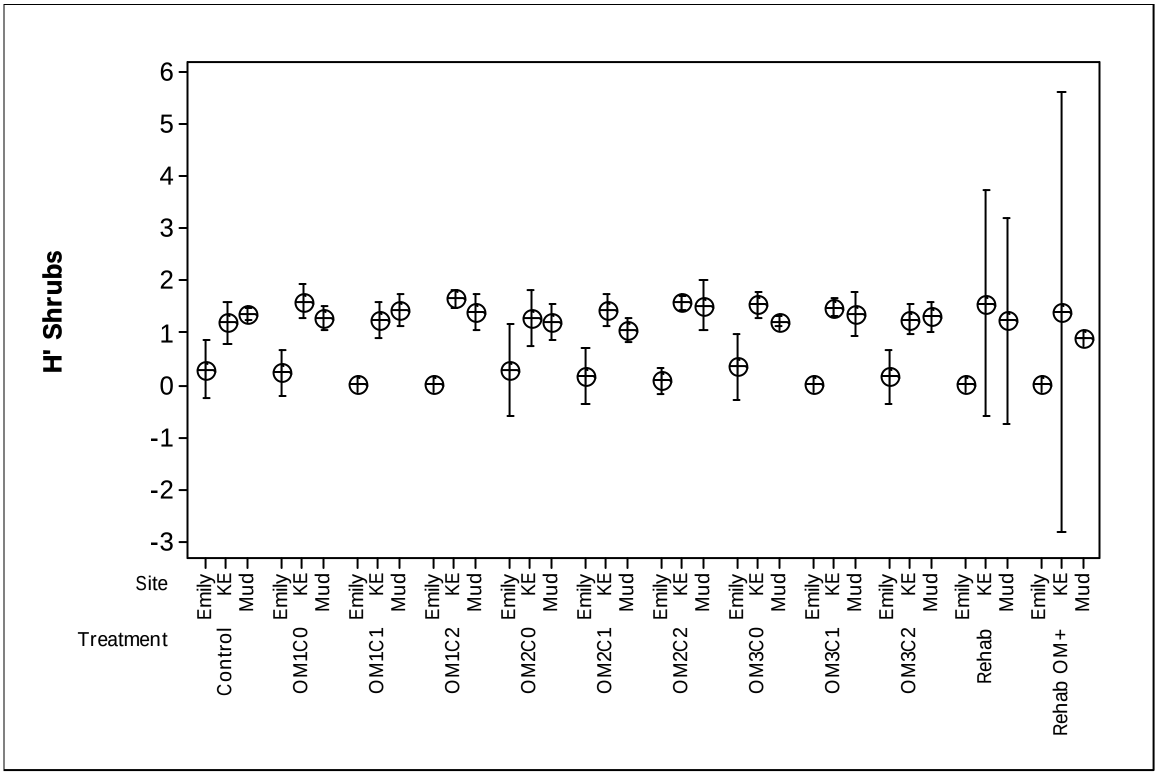

Figure 42: Shannon-Weiner diversity of shrubs between sites (5 year data).

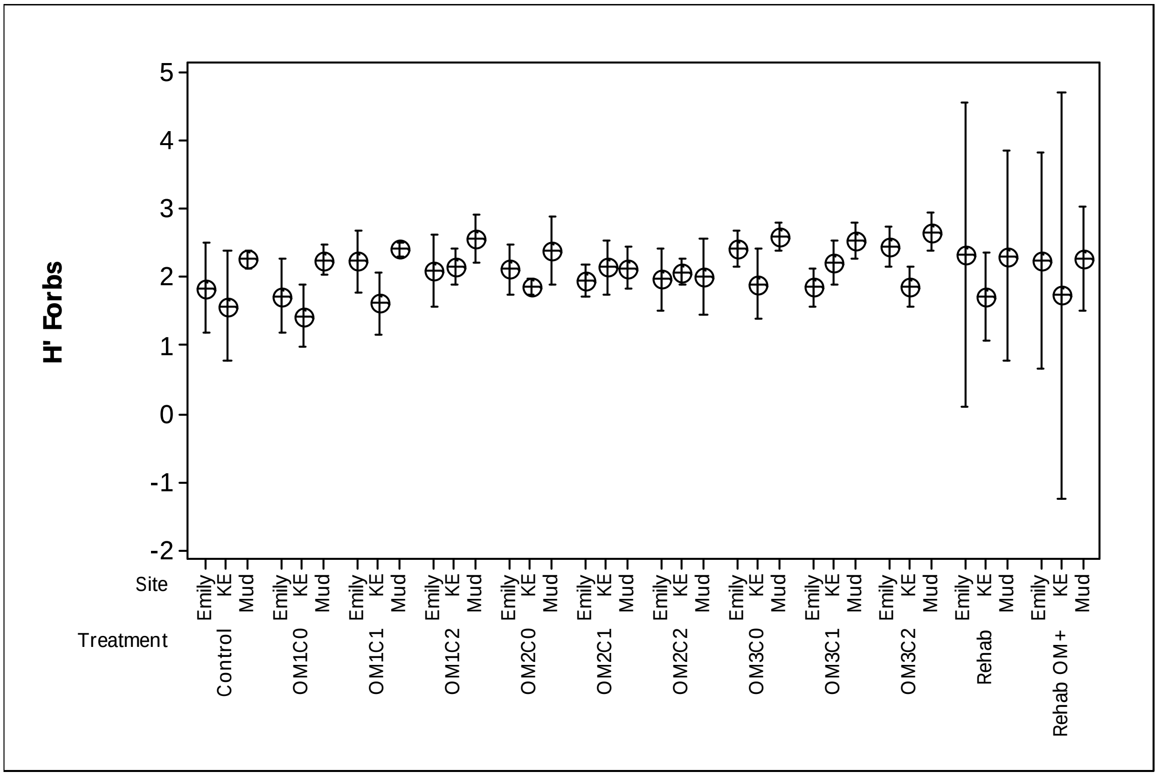

Figure 43: Shannon-Weiner diversity of forbs between sites (5 year data).

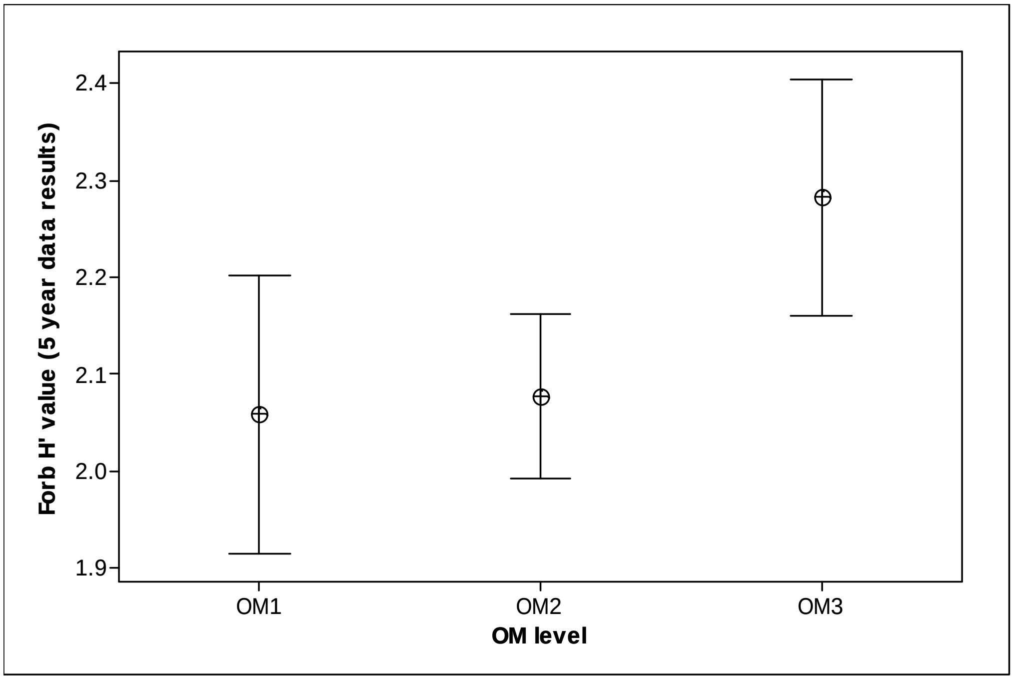

**Figure 44: Effect of organic matter removal level on H/ value for forbs (5 year results).**

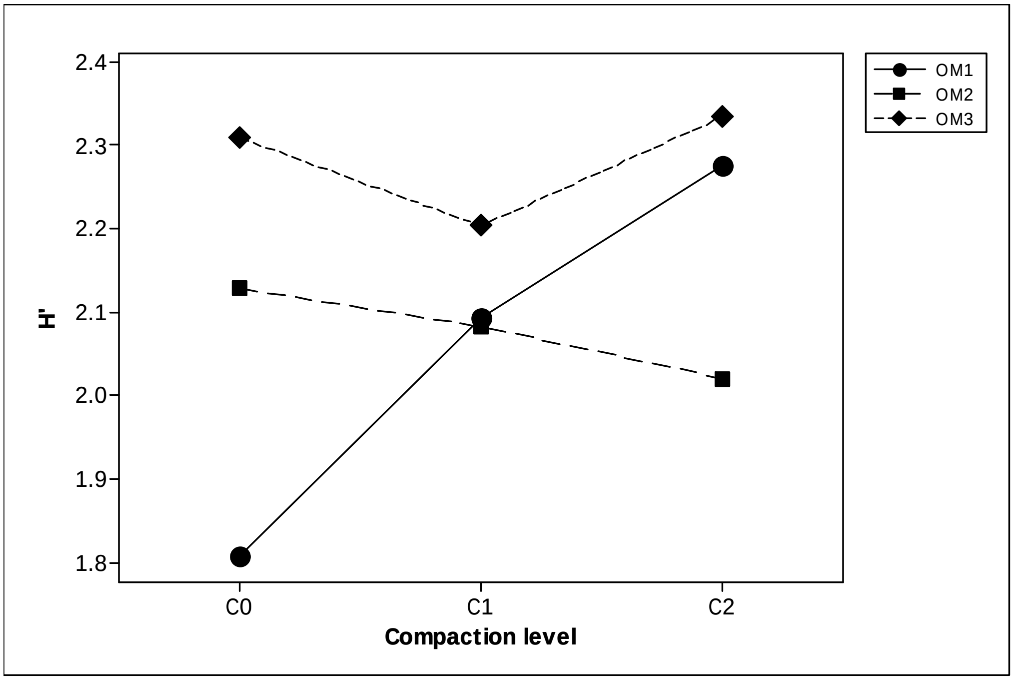

**Figure 45: Shannon-Weiner interaction plot (Forbs) for organic matter removal and soil compaction.**

The H/ value for grasses were similar for each treatment across the different sites (Figure 46). Grass diversity was significantly higher on the OM2C0 treatment compared to the OM3C0 and OM3C2 treatments (p=0.008 and p=0.003, respectively). The OM2C2 treatment had higher $H^{/}$ values compared to the OM3C2 (p=0.02) and OM3C0 (p=0.04) treatments. Additionally, the OM3C2 treatment tended to have higher $H^{/}$ value compared to the OM3C2 treatment. No other treatments were found to be significantly different from each other for grass diversity. Forest floor removal (OM3) and OM1 treatments had similar diversity values five years after treatment (Figure 47).

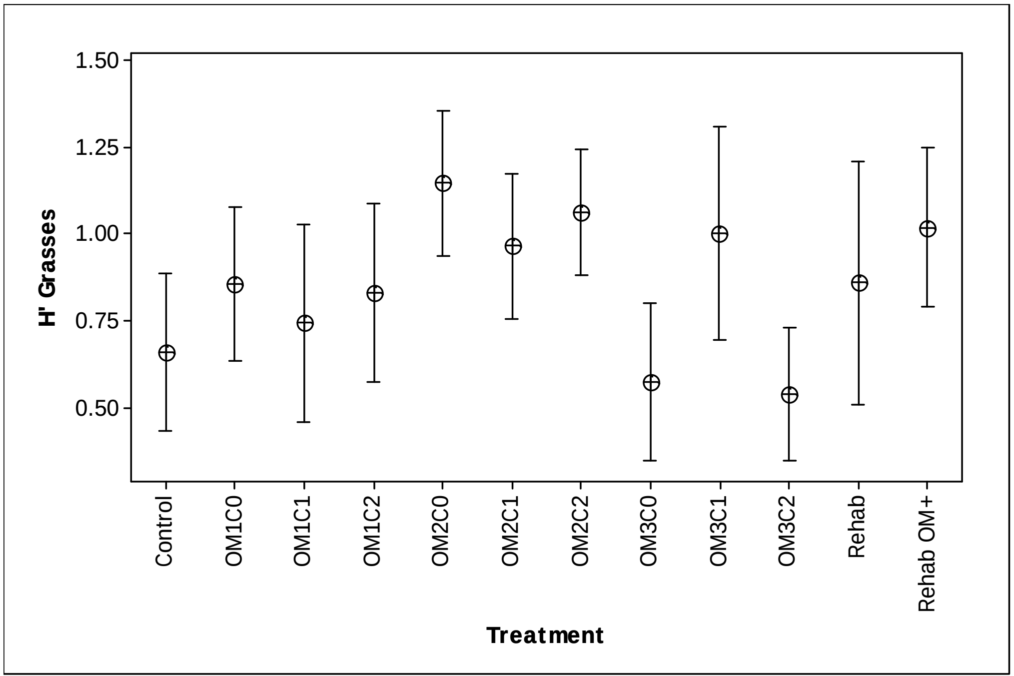

**Figure 46: $H^{/}$ value for grasses for all sites by treatment level. (5 year data results).**

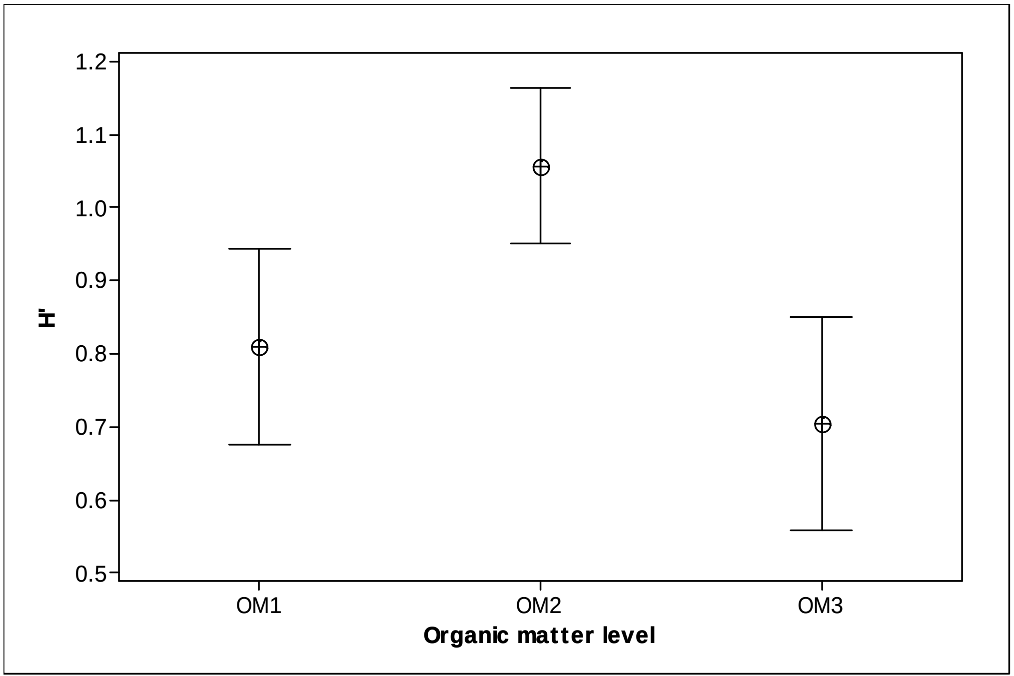

**Figure 47: H$^{/}$ value for grasses for all sites by organic matter removal level. (5 yr results).**

Interaction effects between organic matter removal and compaction were not significant so the main effects of OM level were analyzed further. OM2 treatments had significantly higher grass diversity compared to the OM1 (p=0.01) and OM3 (p=0.0003). Forest floor removal plus moderate soil compaction resulted in a increases in H$^{/}$ for grasses compared with other treatments (Figure 48). Where forest floors were left intact, H$^{/}$ values followed a decreasing trend in under moderate compaction and an increase in diversity under heavy compaction.

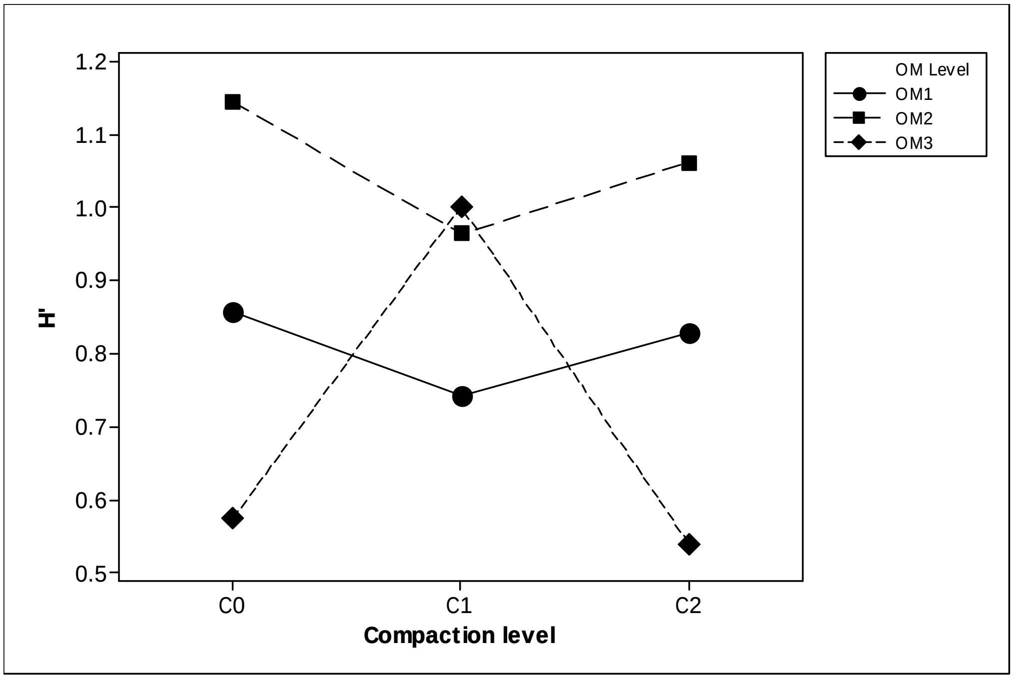

**Figure 48: $H^{/}$ interaction plot (grasses) for organic matter removal and soil compaction.**

## 3.4 Remotely sensed data analysis and correlations to ground data

Remote sensed cover were significant ($p<0.05$) and moderately correlated with ground data at Emily creek (Table 8). Total cover and tree cover were correlated the strongest (0.66 and 0.63 respectively). It was difficult to separate shrub cover well on the digital images, so correlation values were less strong (0.53) than total cover and tree cover. Separation of frobs/grasses from other vegetation also resulted in weaker correlations (0.46). In addition, there difficulties in separating the grass/forb cover from non-vegetated values in the digital image.

Tree cover and grass/forb cover were marginally significant ($p=0.06$) but weakly correlated at Mud creek (0.3 and 0.29 respectively). At Kootenay east correlations were also significant for total cover ($p=0.05$), shrub cover($p=0.03$), grass/forb cover ($p=0.02$) and non-vegetated cover ($p=0.06$); however, all correlations were weak (<0.39).

At Emily creek, remote sensed data tended to over estimate values for total cover, tree cover, shrub cover and grass and forb cover (Figure 49). However, with the exception of tree cover at Mud creek, both Mud and Kootenay east remote sensed data was consistently lower than ground verified data (Figure 50 and 51).

Trends indicate that remotely sensed data cover values followed similar patterns relative to ground data cover values. For example, where values were low for tree cover based on ground data, remotely sensed data followed a similar pattern relative to each other cover class at Mud and Emily sites. At Kootenay east, grass and forb cover was underestimated relative to ground data and Non Veg classes were overestimated. Difficulties were encountered separating grasses/forbs and shrubs.

**Table 8: Remotely sensed data correlation summary.**
(n=36)

| Site | Cover | Pearson product correlation (r) | Correlation index ($r^2$) | p-value | Mean cover ± 1 SE – Ground sampling | Mean cover – Remote sensed |
|---|---|---|---|---|---|---|
| Mud | Total cover | 0.02 | 0.0 | 0.88 | 63.0 ± 1.6 | 45.5 ± 3.4 |
| | Tree cover | 0.30 | 0.09 | 0.06 | 2.0 ± 0.5 | 3.4 ± 0.5 |
| | Shrub cover | -0.08 | 0.01 | 0.60 | 21.4 ± 1.1 | 9.1 ± 1.0 |
| | Grass and Forb cover | 0.29 | 0.08 | 0.06 | 39.5 ± 1.3 | 33.0 ± 2.3 |
| | Non-vegetated cover | 0.28 | 0.08 | 0.28 | 36.9 ± 1.6 | 52.4 ± 3.4 |
| Emily | Total cover | 0.66 | 0.44 | <0.0001 | 52.0 ± 2.6 | 63.6± 2.4 |
| | Tree cover | 0.63 | 0.40 | <0.0001 | 1.9 ±0.3 | 2.4 ±0.4 |
| | Shrub cover | 0.53 | 0.28 | <0.0001 | 2.4 ±0.6 | 14.7 ± 1.3 |
| | Grass and Forb cover | 0.46 | 0.21 | 0.002 | 46.4 ± 2.6 | 46.3 ± 1.9 |
| | Non-vegetated cover | 0.66 | 0.44 | <0.0001 | 47.9 ± 2.6 | 36.3 ± 2.4 |
| Kootenay east | Total cover | 0.30 | 0.09 | 0.05 | 82.8 ± 2.4 | 36.4 ± 2.2 |
| | Tree cover | 0.33 | 0.11 | 0.03 | 5.2 ±0.6 | 1.5 ± 0.2 |
| | Shrub cover | -0.03 | 0.00 | 0.84 | 28.1 ± 1.8 | 11.3 ± 1.0 |
| | Grass and Forb cover | 0.35 | 0.12 | 0.02 | 52.9 ± 2.7 | 23.5 ± 1.9 |
| | Non-vegetated cover | 0.29 | 0.08 | 0.06 | 17.2 ± 2.4 | 62.9 ± 2.2 |

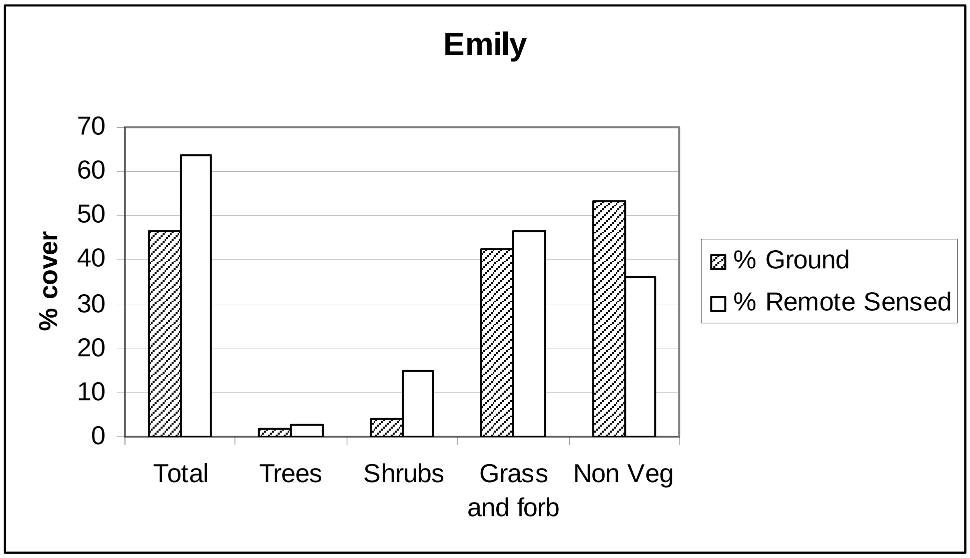

Figure 49: Comparison of ground cover versus remote sensed cover (Emily creek).

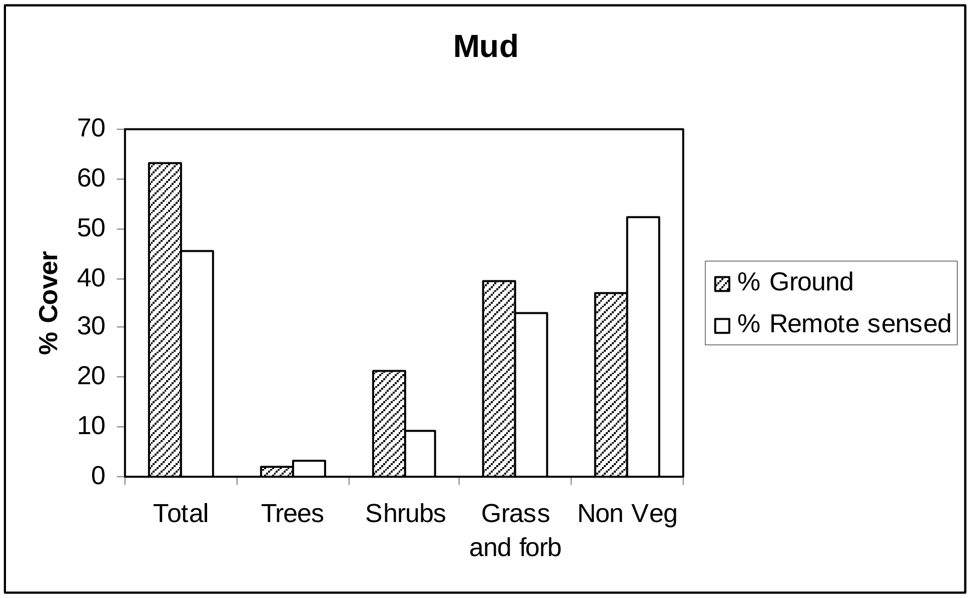

Figure 50: Comparison of ground cover versus remote sensed cover (Mud creek).

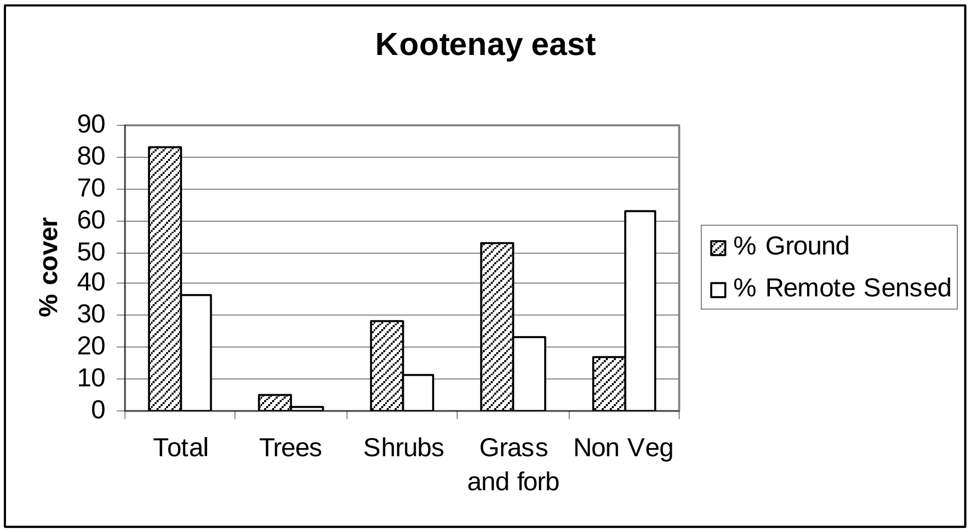

**Figure 51: Comparison of ground cover versus remote sensed cover (Kootenay east).**

## 4.0 Discussion

The results from this research reject the null hypothesis that vegetation cover and composition does not change with differing soil disturbance levels. Therefore, the alternative hypothesis that vegetation cover and composition does change with differing soil disturbance levels is accepted. With respect to the research question, composition did not appear to change dramatically on sites; however vegetation cover tended to decrease where soil was severely disturbed including species differences discussed below.

### 4.1 Effects of Soil Compaction

Compaction alone had little effect on vegetation cover at the east Kootenay LTSP sites in this study. In general, total cover, shrub cover, forb cover and grass cover did not respond to compaction alone. However, birch-leaved spirea tended to decrease under heavy compaction across all levels of organic matter removal. The combined effects of compaction and organic matter removal were most pronounced where the forest floor was removed during treatment. These results generally agree with findings on other LTSP sites (Powers et al. 2004; Fleming et al. 2006; Hope, 2006). Pinegrass cover on dry Douglas-fir sites with acidic soils in British Columbia was also not influenced by soil compaction (Hope, 2006). Early tree seedling diameter did not change under heavy compaction with or without forest floor removal at the Mud creek LTSP (Kamaluddin et al., 2005). However, in boreal ecosystems bluejoint grass cover increased under moderate to heavy compaction (Kabzems, 2000) due to the extensive rhizomatous habit of the species. Pinegrass has a similar root structure so reasons why increases were not observed in this study are not clear. It may be that the effects of soil compaction are not severe enough on the east Kootenay LTSP sites to cause a significant shift in cover values for vegetation.

One reason why the effects of compaction do not seem to be detected in this LTSP research probably lie in the metrics used in data collection for vegetation. In this study, ocular estimation of percent cover was used to compare between different treatments. It is difficult with this metric to detect subtle differences in vegetation cover that may be occurring on sites due to soil compaction. Similar methods are used in turf grass monitoring and cover values have been found to be highly variable between different surveyors which decrease the ability to detect differences (Richardson, Karcher, and Purcell, 2001). Moreover, the vegetation response from compaction may take longer than the length of time in this study and so compaction effects may not be readily detectable until several more years after the treatment. One recommendation is to use biomass (kg ha$^{-1}$) rather than percent cover in future analysis. This data has been collected by the B.C. Ministry of Forests and Range for the present study sites and is in progress.

### 4.2 Effects of organic matter removal

Forest floor removal at the east Kootenay LTSP sites resulted in decreased cover for all plant life forms. Total vegetation cover plays an important role to reduce microclimate extremes and soil losses through erosion. In boreal LTSP sites, forest floor removal resulted in similar decreases in total cover largely due to removal of regenerative structures such as rhizomes, roots, and stem bases (Kranabetter, 1999). However, total productivity on LTSP sites in the United States is reported to be unaffected by forest floor removal (Powers et al., 2004). Although no rationale was provided, it could be assumed that seed germination, and vegetative reproductions from deeper buried rhizomes were sufficient to maintain biomass levels on heavily impacted sites. Soils in those areas are also older, richer and more resilient to disturbance than the young, recently glaciated soils in this study. As well, biomass calculations in that study included planted seedlings; whereas, the present study only considered percent cover of naturally regenerating understory vegetation.

On sites where the forest floor was retained, shrub cover was higher five years after treatment compared with treatments where the forest floor was removed. Kinnikinnick accounted for the majority of shrub cover on the east Kootenay LTSP sites and this species was reduced in cover by forest floor removal. This result is not surprising since kinnikinnick is a low growing shrub with a stoloniferous rooting system (Douglas et al., 1999) that would easily be impacted by removal of the forest floor. In restoration treatments where forest floors were left intact, kinnikinnick cover has increased 3 years after forest harvesting (Newman, Page, and Parminter., 2004). These results were largely in response to increased post-harvest light levels. Similar results were found in this study where the forest floor was retained. Where forest floors were retained in this study, kinnikinnick cover increased by approximately 7% over the unharvested control. The leaves and berries of kinnikinnick are an important non-timber forest product in British Columbia (Keefer, Ehlers and MacPherson, 2005.). Consequently, decreases in kinnikinnick cover and productivity due to intensive soil disturbance may have socioeconomic implications in the east Kootenay region.

Larger shrubs such as prickly rose, saskatoon, soopolalie, and birch-leaved spirea were not detected to change significantly in cover by forest floor removal and covers remained similar to sites where the forest floor was left intact. The fact that browsing has been excluded by the fences in these sites may explain why the greater changes in cover were not detected. Prickly rose cover on boreal sites was also roughly the same cover between intact and removed forest floors (Kabzems, 2000); therefore this species may be tolerant at surviving severe forest floor disturbances in forest ecosystems. At Emily creek, prickly rose followed a decreasing trend in cover with forest floor removal. Emily creek is drier than the other sites and was dominated by fine Sandy loam soil; whereas the other sites were dominated by silt loam soil textures. Thus, the decreasing trend of prickly rose cover may be due to increased water stress on drier sites. Of the dominant shrubs on site, saskatoon is particularly important as a browse species for wintering ungulates. In the short-term on this browse-excluded study, it appears that saskatoon can withstand disturbances as severe as forest floor removal and still maintain a dominant cover on ecosystems in the Interior Douglas-fir zone. The fact that the larger shrub species such as saskatoon are capable of surviving forest floor removal suggests that browse productivity may not be dramatically altered due to disturbance of the forest floor during forest harvesting. However, long-term implications due to forest floor removal may not be detectable this early after the disturbance. Lastly, Keefer et al. (2005) indicates that many of the larger shrubs identified in this study have important socioeconomic value as non-timber forest products in the east Kootenay region. Thus, organic matter removal does not appear to hinder cover values of larger shrub species within five years of disturbance so it appears in the short-term that potential productivity of these species may also not be influenced.

Snowberry cover was highest on the rehabilitated treatments at the east Kootenay LTSP sites. On one half of each Rehabilitated treatment, organic matter was replaced back in the soil matrix so plant root fragments could easily have become spread throughout that half of the treatment. Snowberry cuttings have been found to very successful when staked into non-saturated soils in riparian restoration (Cereghino, 2004). As well, Haeussler et al. (1990) notes that snowberry commonly reproduces from stored seed in the soil. Therefore in the present study, snowberry may have re-sprouted from cuttings produced during the rehabilitation treatment at the LTSP sites or more likely from seed banks persistent in the soil.

Pre-treatment snowberry cover on rehabilitated plots was found at the Kootenay East site

(2-3%) and root fragments may have allowed for cover to increase following treatment. Oddly, there was no pre-treatment cover of snowberry recorded at the Mud creek site so the higher post-treatment cover (7-27%) cannot be explained by the presence of plants before soil ripping; but may be explained by seed banking of snowberry. Although the total vegetation cover was higher on rehabilitated treatments where the soil was ameliorated with organic matter, the plots with higher snowberry cover did not necessarily correspond with the ameliorated half of each treatment. Considering that pre-treatment cover of snowberry did not correspond with higher post-treatment conditions, it is most probable that root fragments were transported by machinery when the treatments occurred or plants germinated from stored seed in the soil.

Total forb cover at the east Kootenay LTSP sites decreased with forest floor removal but remained largely the same where forest floors were retained. This result agrees with a closely related LTSP site on acidic soils near Kamloops B.C. (Hope, 2006). Studies in British Columbia have noted that forest floor removal and exposure of mineral soil provides a suitable seedbed for invasion of weedy species after harvesting (Kranabetter, 1999; Haeussler et al., 2002). However on the east Kootenay sites, no drastic shift in composition toward weedy species was noted. Although black medic (*Medicago lupulina*), and dandelion (*Taraxacum* spp.) were present on forest floor removed sites, these species were also found ubiquitously where the forest floor was retained. Both of these species are common in roadsides and waste areas indicative of soil disturbance in British Columbia (Douglas et al. 1998). Canada thistle (*Circium arvense*), a provincial listed noxious weed (Government of B.C., 2006) was recorded in the forest floor retained sites but not in the forest floor removed sites. Other thistle species (*Circium* spp.) were found; however the cover averaged <0.5% between forest floor removed and forest floor retained sites so no trend was observed with increasing soil disturbance. One year after treatments vegetation data indicated sporadic higher covers (20%) of *Circium* spp.particularly on rehabilitated treatments. It is optimistic to see cover of noxious weeds decrease five years after disturbance on these heavily disturbed sites.

Slight increases (>1%) in cover were observed on forest floor removed treatments for yarrow (*Achillea millefolium*), short-beaked agoseris (*Agoseris glauca*), Holboell's rockcress (*Arabis holboellii*), and timber milk-vetch (*Astragalus miser*). Most of these species reproduce by rhizomes in the mineral soil (Douglas et al. 1998-2002) so they were likely able to persist on the sites despite having the forest floor removed. Slight declines (<1%) in cover were observed for field pussytoes (*Antennaria neglecta*), smooth aster (*Aster laevis*), mariposa lily (*Calochortus apiculatus*), fireweed (*Epilobium angustifolium*), white-flowered hawkweed (*Hieracium albiflorum*), and yellow penstemon (*Penstemon confertus*).These species generally have rooting structures that are bulbous, short rhizomes, or woody taproots (Douglas et al. 1998, 1999) so damage to the root structure may be a likely reason for slight declines in cover. Showy aster (*Aster conspicuous*), leafy aster (*Aster foliaceus*), and wild strawberry (*Fragaria virginiana*) all decreased in cover between 1-2% on forest floor removed sites. Both species of aster reproduce from rhizomes so a reason for the decline in cover is not readily apparent. Wild strawberry reproduces largely from above-ground runners (Douglas et al. 1999) so it is not surprising to see a decline in cover after removal of the forest floor. No other forbs were noted as strongly reflecting a change in cover with an increase in soil disturbance. Pinegrass cover was consistently high on all treatment sites and it could be that this species is able to out compete other forbs for available moisture in these ecosystems and hence reduce the dominance of other forbs.

Although canopy removal resulted in an increase in pinegrass cover, organic matter removal had little effect on total cover of pinegrass. Where forest floors were retained, cover increased by 13-15% over pre-treatment levels; however, there was no change between years where the forest floor was removed. This agrees with other related studies on pinegrass and soil disturbance whereby pinegrass cover generally increased after canopy removal (Newman and Wurtz, 2004; Newman et al., 2004). However, these results differ from a related LTSP study on acidic soils in the Interior Douglas-fir zone where a decrease in pinegrass cover occurred following forest floor removal (Hope, 2006). In the present study, the combined effects of heavy soil compaction and organic matter removal resulted in higher overall percent cover of pinegrass at the east Kootenay LTSP sites relative to no compaction or moderate compaction. As well, cover tended to increase under heavy compaction where the forest floor was retained but boles and branches were removed (OM2). Where boles only were removed and slash retained (OM1), heavy compaction resulted in a decrease in percent cover of pinegrass relative to no compaction. This may be due to competition for growing spaces occupied by heavy slash on these sites. Pinegrass cover was only reduced by the rehabilitated treatments, which includes soil ripping or tilling. Since this treatment has been attributed to destroy the rhizome systems of plants (Frey et al., 2003) it is likely the main reason for the reduction in pinegrass cover at the east Kootenay LTSP sites. These results imply that pinegrass is a resilient species and is tolerant of severe organic matter removal and soil compaction but is not tolerant of soil ripping in the east Kootenay ecosystems.

The east Kootenay LTSP sites are 3m high fenced exclosures so the influence of grazing has been removed from the ecosystems. The exception to this is for the Control plots for Kootenay east and Mud creek which are located outside of the exclosure. As such, these treatments provide valuable insight to the response of key forage species to canopy removal and soil disturbance in the absence of grazing. Pinegrass is consumed by range cattle and has accounted for up to 50% of the forage yield in lodgepole pine forests (Mclean, 1967). However, pinegrass is not listed as a favoured forage species by wild ungulates such as elk (*Cervus elaphus*) and deer (*Oidocoileus* spp.) (Ross, 2001). Consistent cover of pinegrass across the treatments in this study implies that cattle grazing on harvested areas may not be affected on moderately to severely disturbed soils. Although, soil ripping may prove to be a good approach to reduce cover of pinegrass as a competing vegetation species; this practice would have negative implications for domestic range management.

Rough fescue increased in cover after canopy removal even where forest floors were removed. The combined effects of soil compaction and organic matter removal resulted in lower overall cover compared to treatments where the forest floor was retained. This species generally reproduces by seed and seldom is associated with extensive rhizome growth (Stewart and Hebda, 2000).). Five years following treatment, sites where the forest floor was retained had cover values averaging 5%; whereas, cover averaged 2% where forest floors were removed. Increases in bunchgrass growth have also been reported in other studies in the east Kootenay. Three years following ecological restoration in the Interior Douglas-fir zone, Newman et al. (2004) reported a 24% increase in bunchgrass productivity (kg ha$^{-1}$) over pre-treatment conditions. This increase occurred after an initial decline due to a combination of plant damage during timber harvesting and successive years of drought. Increased density of bunchgrasses in that study was attributed to site characteristics that were historically open forest Ponderosa Pine and bunchgrass dominated ecosystems (Page et al., 2005). However, the present study is located in the Interior Douglas-fir zone which is an area thought to historically be composed of open and closed canopy forests (Meidinger and Pojar, 1991). Although the east Kootenay LTSP sites are not being influenced by grazing, it is hypothesized that the response of rough fescue indicates these sites were historically open-canopy forests. Studies on the vegetative reproductive capabilities in sheep fescue (*Festuca ovina*) indicate that individual fescue clumps may be several decades old to 100's of years old based on the average reproductive rate of grass tillers (Harberd, 1962). Additionally, Goodwin et al. (1999) suggested that vegetative longevity may explain the ability of Idaho fescue (*Festuca idahoensis*) to persist on heavily degraded rangelands in sagebrush-steppe ecosystems in central Idaho. The longevity of bunchgrasses has never been studied in the east Kootenay rangelands; however, it is highly likely that rough fescue may be able to remain dormant under a partial canopy for several decades and is able to increase growth once light and moisture conditions become favourable. Thus, low cover of bunchgrasses in closed canopy forests may provide an indication of sites that were historically open canopy forests in the east Kootenay.

### 4.3 Effects of soil amelioration with organic matter

The higher total vegetation cover values on ameliorated soils most likely occurs due to vegetative reproduction by root fragments and seed banks re-introduced when the organic matter is added back to the soil. Although soil amelioration with organic matter resulted in overall higher vegetation cover, few trends were observed with respect to species composition. In general, species that were higher in cover where organic matter was added to rehabilitated soil tended to reproduce by means of rhizomes or through annually dispersed seed. Bluegrass cover (*Poa* spp.) and snowberry tended to have higher overall cover compared with non-ameliorated soils at the Mud creek LTSP and pinegrass had higher cover on ameliorated soils at the Emily creek LTSP. All three species are aggressively rhizomatous species and may have been capable of regenerating from root fragments after organic matter replacement. Fireweed (*Epilobium* *angustifolium*) had 10-15% higher cover on ameliorated soils at the Kootenay east site. This species becomes easily established from wind blown seed on exposed mineral soil and seeds generally remain viable for only a few months (Haeussler et al., 1990) and so the reason why cover is higher where organic matter was added is not as clear. Since the organic matter amelioration would enhance soil moisture retention, these soils may provide a better seedbed for fireweed to germinate.

### 4.4 Richness and Diversity

Total species richness generally increased following canopy removal between years. However, richness did not change with changes in soil disturbance at the east Kootenay LTSP sites. Since herbivory is excluded from these treatments, the lack of animal disturbance may allow for increased numbers of species to flourish. Other research has also noted that richness tends to increase after canopy removal, although, these studies also found a change with increasing soil disturbance (Kabzems, 2000; Kranabetter, 1999; Haeussler et al. 2002; Pykala, 2004). Most other studies have noted that richness increases with site disturbance due to invasion of weedy species on to the site. Regeneration mechanisms are considered to change after severe disturbance such as forest floor removal because of a shift from long-lived perennial vegetation to short-lived seed dispersed plants such as fireweed (*Epilobium angustifolium*) and weedy annuals (Roberts, 2004). However, on restoration treatments in the east Kootenay, Page et al. (2005) found that richness decreased with increasing light availability and two years after harvesting there were few weeds found on the site. Although that study likely had minimal soil disturbance, this agrees with data from the present study in which few weedy annuals were recorded in abundance on heavily disturbed sites. At year five, invasion of species such as Canada thistle and black medic were found in sporadic but low covers across different treatments whether the forest floor was removed or retained. It is well known that grazing animals such as cattle often transport seeds into new sites in hair, hooves and excrement. Again, since grazing animals are excluded from these sites, weeds may have less opportunity for transport onto the exposed soil.

Part of the reason for uniform cover of weeds may be that the metric used for trace amounts of vegetation at the east Kootenay LTSP sites was 0.5%. This indicates that the minimum detectable difference for cover value was also 0.5%, so essentially the resolution of this study may not be capable of observing subtle differences in cover of weeds. With that being said, the results strongly state that weedy species generally did not exceed trace amounts of cover in this study and overall there was little migration of exotic species into disturbed soils. Future studies should consider a sampling design with smaller quadrats in which low cover (<0.5%) of species can be surveyed to see if increasing or decreasing trends can be observed.

In boreal ecosystems, Shannon-Weiner diversity ($H^{/}$) values tend to increase as disturbance severity increased; however, values will decrease when disturbance severity essentially eradicates forest understory species (Haeussler et al., 2002). Similar trends were observed at the east Kootenay LTSP sites. Moderate compaction on forest floor removed sites tended to increase the total diversity and grass diversity while heavy compaction combined with forest floor removal resulted in a decrease in diversity. This trend indicates that severe disturbance that removes or damages existing plant structures will negatively impact the overall diversity of a site; however, moderate disturbances have a tendency to increase the $H^{/}$ values.

Species composition influences resiliency and plays a very important role when comparing $H^{/}$ values (Haeussler et al., 2002). The abundance of long-lived perrenial vegetation may be a better indicator of ecosystem health rather than the diversity value measured (Whitford et al., 1998). Haeussler et al. (2002) indicated that identical sites had similar $H^{/}$ values; however the species composition was quite different. Similar results were noted in rangelands in the southern United States (Whitford, Soyza, van Zee, Herrick, and Havsted, 1998). At the east Kootenay LTSP sites, no trend was observed with weedy annuals increasing in cover with higher soil disturbance levels five years after disturbance. Therefore, the persistence of long-lived perrenials such saskatoon, prickly rose, pinegrass, and rough fescue may indicate higher overall ecosystem resiliency despite increasing soil disturbance on these sites. However, where soils were tilled during the rehabilitation treatments, resiliency tended to decrease as indicated by the highly variable species composition. This effect was less pronounced on rehabilitated treatments ameliorated with organic matter indicating that organic matter enrichment may increase resiliency of highly disturbed soils. With lower resiliency, ecosystems are susceptible to future disturbances such as insects and disease. In addition, the influences of climate change may be more pronounced in severely disturbed sites since opportunistic species such as weedy annuals may out-compete native vegetation for resources.

### 4.5 Application of Remote Sensing

This research rejected the null hypotheses that vegetation response to soil disturbance cannot be detected with high spatial resolution aerial photographs. Remotely sensed data used in this study was capable of detecting severe changes in vegetation cover as a result of soil disturbance. Total cover and tree cover were correlated moderately well with ground vegetation data. Shrubs and grasses/forbs were not correlated as well with ground data; however, there were difficulties in developing rule-based algorithms to separate the vegetation types due to the timing of remotely sensed data acquisition (i.e. after senescence). Subtle changes in cover under differing soil disturbance levels were not easily detectable using remotely sensed data. The present study indicates that digital remotely sensed data is suitable for mapping severe soil disturbances in ecosystems but less sensitive to detecting subtle changes in vegetation cover under increasing soil disturbance levels.

Other studies using high resolution digital imagery have been quite successful at estimating cover values (Bennett et. al., 2000; Booth et al., 2005; Laliberte et al., 2006; Richardson, 2001). In those studies, remotely sensed data acquisition was timed carefully with ground sampling. Thus, correlation between remotely sensed data and ground data were not influenced by phenological changes in vegetation on the sites. Remotely sensed data acquisition in the present study is most likely the biggest factor that influenced the ability to make accurate correlations between ground data and remotely sensed data. For reasons beyond the researchers' control, these study sites were photographed in August 22, 2005 and unfortunately the timing did not correspond with peak vegetation development when field data were collected. Ground verification data for the different sites were collected in July 4-7, 2006 for Mud creek, July 5-8, 2005 for Emily creek, and July 4-8, 2006 for Kootenay east.

Emily creek had the highest, albeit modest, correlations between remote sensed data and ground data. The drawback at Emily creek, and all sites, was that the remote sensed data acquisition occurred well after the typical growing season has ended in the east Kootenay. As a result, most herbaceous vegetation had already entered into senescence by the time remote sense data collection occurred. This created difficulties in separating herbaceous vegetation from bare soil on most sites using rule-based classifications on the digital images. In future studies, it is highly recommended that remote sensing data acquisition is timed as close as possible to field data collection to alleviate differences in results in vegetation cover due to growth and senescence.

Of particular importance is the methods used for validating the remote sensed data. Many studies indicate that digital images provide a superior vegetation cover classification because of the reduction in human estimating bias (Bennett et al., 2000; Booth et al., 2005; and Richardson et al., 2001). Significant differences between trained ecologists estimation of ground cover and known ground cover have been found using high resolution digital images (Bennett et al., 2000). In the present study, ground estimated cover was assumed to be an accurate depiction of actual cover; however, the accuracy of ground collected data is not known with certainty. Thus, correlations between ground data and remote sensed data may be a result of inaccuracies in ground collection techniques, remotely sensed classification techniques, or both.

Difficulties in locating vegetation plots on the digital images from GPS data further complicated the verification of remote sensed data with ground data. This problem was overcome by estimating the plot center visually on each image and collecting a series of estimates of vegetation cover in proximity to each plot. However, it not known with certainty the how closely remotely sensed data plots align with the true vegetation plots on the ground since plot centres were not marked in a manner that allowed their detection from an aerial image. In the future, it is recommended that test plots be established and marked in the field in some way that allows for detection on the digital images. This can be achieved by locating bright coloured markers at plot centers or plot corners prior to remote sensing data acquisition. Alternatively, test plot centres could be physically measured from ground control points such as stumps to locate them on the image accurately. Although GPS technology is advanced, marking plot centres in the field would serve as a back up for locating test plots for digital data analysis.

## 5.0 Conclusions and Recommendations

Organic matter removal had the greatest impact on understory vegetation resulting in decreases in percent cover of kinnikinnick, pinegrass, and rough fescue. Total vegetation cover was also reduced by organic matter removal and soil compaction alone did not appear to have a strong influence on vegetation cover. As well, the combined effects of soil compaction and organic matter removal did not seem to strongly influence vegetation cover except where total forb cover decreased slightly. However, it was noted that the metric of percent ocular cover estimation used in this study may not be capable of detecting subtle changes in cover due to soil compaction and total biomass may be a better estimate of ecosystem changes following soil disturbance. Rehabilitated treatments resulted in responses similar to organic matter removal for most cover values. Snowberry cover was found to increase under some rehabilitated treatments where soil was ameliorated with organic matter. In general, the response was most likely due to the ability of snowberry to germinate from seed banks and root fragments from pre-existing plants created during soil tillage, transported onto the site by machinery, or transported during organic matter amelioration.

Species richness and Shannon-Wiener diversity generally increased following canopy removal and moderate soil disturbance tended to increase the diversity values on the treatments. Organic matter removal appeared to cause a decrease in diversity for grasses and an increase in diversity of forbs. There was no noticeable shift in composition to weedy species on exposed mineral soil in this study which may, in part, be due to the exclusion of grazing animals on these treatments by fencing. Although weeds such as thistle, black medic, and dandelion were present, most cover values were in trace amounts and there was no trend of increasing cover with increasing soil disturbance.

Retrospective statistical power analysis in this study indicates that vegetation cover variability and low sample size contribute to increased chances of a type II error. This conclusion was also reached on boreal LTSP sites studied by Haeussler et al. (2002). Although the research design in the LTSP protocol is adequate for observing trends in vegetation cover, it appears to fall short of the rigour required for detailed statistical analysis of some vegetation types. If future statistical analysis is required, a recommended approach is to increase the sample size per replicate. This could be achieved by designing a grid network across each treatment unit and systematically locate approximately 10 small radius plots (e.g. 1-2m) in combination with the larger (3.99m) radius plots used in this study. Since the plot area would be substantially reduced, this approach would likely facilitate greater accuracy in percent cover estimation by trained ecologists. It is proposed that power analysis from this study be used to design an appropriate sampling methodology for these LTSP sites in year 10. As well, a similar approach should be used for data collection in future studies on the west Kootenay LTSP sites.

Failure to observe stronger correlations using remotely sensed data was largely attributed to the timing of data acquisition. Additionally, accurately locating vegetation plots on digital images was difficult due to problems in GPS field data accuracy. Future studies using remotely sensed data should include marking plot centre locations in the field prior to data acquisition and timing of aerial photography collection should correspond as closely as possible to the timing of field data collection. Nevertheless, these results provide interesting opportunities for the application of remote sensing to ecosystem monitoring if some of the problems described above are corrected in future research.

The results from this study indicate that organic matter removal rather than soil compaction plays an important role in maintaining cover values of important understory species in the short-term. It remains to be seen what the long-term implications of soil compaction will be on understory productivity in these ecosystems. Shrubs and grasses that responded to organic matter removal also are important browse and grazing species in the east Kootenay region. For example, the lower cover increase response of rough fescue under organic matter removal signifies the importance of proper soil management for a wide variety of ecological services. Rough fescue provides critical forage for domestic and wild ungulates and impacts to this species will result in impacts for domestic range management as well as impacts to the management of low elevation winter range for wild ungulates.

Additionally, this study suggests that vegetation cover may be a useful metric for sustainable management of soil resources. Although remote sensed data were not strongly correlated to ground data, there was still a clear trend that exposed mineral soil or total vegetation cover can be used to detect soil disturbance in the landscape using remotely sensed data. As such, acquisition of ground data or remotely sensed vegetation cover data can be used as a visual classification system for adaptive management of soil resources in land management.

In closing, the Long Term Soils Productivity research network is intended to study the impacts of soil disturbance in forest ecosystems over the entire economic rotation of a forest stand. Results from this research will hopefully be reflected upon in decades to come to assess the impacts of soil disturbance on a wide variety of ecological functions in dry, Interior Douglas-fir ecosystems. It is hoped that results from this research will provide useful insight into the effects of soil compaction and organic matter removal on the sustainable management of understory species.

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# 7.0 Appendices

# Appendix A - Species List

Species list from Emily, Mud and Kootenay East LTSP research sites (5 year data).

| **Life form** | ***scientific name*** | **common name** |
|---|---|---|
| Trees | *Abies lasiocarpa* | subalpine fir |
| | *Larix occidentalis* | western larch |
| | *Picea engelmannii* | engelmann spruce |
| | *Pinus contorta* | lodgepole pine |
| | *Pinus ponderosa* | ponderosa pine |
| | *Populus tremuloides* | trembling aspen |
| | *Psedotsuga menziesii* | Douglas-fir |
| Shrubs | *Acer glabrum* | Douglas maple |
| | *Amelanchier alnifolia* | saskatoon |
| | *Arctostaphylos uva-ursi* | kinnikinnick |
| | *Ceanothus velutinus* | snowbrush |
| | *Cerastium arvense* | field chickweed |
| | *Clematis occidentale* | Columbia bower |
| | *Juniperus communis* | common Juniper |
| | *Juniperus scopulorum* | Rocky mtn juniper |
| | *Mahonia aquifolium* | Oregon-grape |
| | *Prunus virginiana* | choke cherry |
| | *Ribes lacustre* | black gooseberry |
| | *Rosa acicularis* | prickly rose |
| | *Rosa woodsii* | prairie rose |
| | *Salix scouleriana* | Scouler's willow |
| | *Shepherdia canadensis* | soopolalie |
| | *Spiraea betulifolia* | birch-leaved spirea |
| | *Symphoricarpos albus* | snowberry |
| | *Symphoricarpos occidentalis* | western snowberry |
| Forbs | *Achillea millefolium* | yarrow |
| | *Agoseris glauca* | short becked agoseris |
| | *Allium cernum* | nodding onion |
| | *Anaphilis margaritacea* | pearly everlasting |
| | *Anenome multifida* | cut-leaved anenome |
| | *Anenome patens* | prairie crocus |
| | *Antennaria microphylla* | white pussytoes |
| | *Antennaria neglecta* | field pussytoes |
| | *Antennaria racemosa* | racemosa pussytoes |
| | *Apocynum androsaemifolium* | spreading dogbane |
| | *Arabis holboellii* | Holboell's rockcress |
| | *Arnica cordifolia* | heart-leaved arnica |
| | *Artemisia campestris* | northern wormwood |
| | *Aster conspicuus* | showy aster |
| | *Aster foliaceus* | leafy aster |

| **Life form** | ***scientific name*** | **common name** |
|---|---|---|
| | *Aster laevis* | smooth aster |
| | *Aster sp.* | aster species |
| | *Astragalus miser* | timber milkvetch |
| | *Astragalus spp.* | milkvetch species |
| | *Balsamorhiza sagitata* | arrow-leaved balsamroot |
| | *Calochortus apiculatus* | mariposa lily |
| | *Campanula rotundifolia* | common harebell |
| | *Castilleja spp.* | paintbrush |
| | *Chenopodium atrovirens* | dark lamb's quarters |
| | *Chimaphila umbellata* | prince's pine |
| | *Cirsium arvense* | common thistle |
| | *Cirsium spp.* | thistle spp. |
| | *Cirsium vulgare* | bull thistle |
| | *Collinsia parviflora* | blue-eyed mary |
| | *Conyza canadensis* | horseweed |
| | *Corallorhiza spp* | coralroot |
| | *Crepis atribarba* | slender hawkweed |
| | *Cynoglossum officinale* | common hounds tongue |
| | *Disporum trachycarpum* | rough-fruited fairy bells |
| | *Dodecatheon pulchellum* | pretty shooting star |
| | *Epilobium angustifolium* | fireweed |
| | *Epilobium ciliatum* | purple-leaved willowherb |
| | *Epilobium minutum* | small-flowered willowherb |
| | *Erigeron corymbosus* | long leaved daisy |
| | *Filago arvensis* | field filago |
| | *Fragaria virginiana* | wild strawberry |
| | *Galium boreale* | bedstraw |
| | *Gentianella propinqua* | gentian |
| | *Gentiannela amarella* | northern gentian |
| | *Geum triflorum* | old-man's whiskers |
| | *Goodyera oblongifolia* | rattlesnake-plantain |
| | *Hedysarum sulphurescens* | yellow hedysarum |
| | *Heuchera cylindrica* | round-leaved alumroot |
| | *Hieracium albiflorum* | white-flowered hawkweed |
| | *Hieracium scouleri* | Scouler's hawkweed |
| | *Hieracium spp* | hawkweed species |
| | *Hieracium umbellatum* | narrow-leaved hawkweed |
| | *Lactuca serriola* | prickly lettuce |
| | *Lactuca spp* | wild lettuce |
| | *Lappula redowskii* | western stickweed |
| | *Lathyrus ochroleucus* | creamy peavine |
| | *Ligusticum canbyi* | canby's lovage |
| | *Lilium philadelphicum* | wood lily |
| | *Linnaea borealis* | twinflower |
| | *Lithospermum ruderale* | lemonweed |
| | *Lomatium triternatum* | nine-leaved desert-parsley |

| **Life form** | ***scientific name*** | **common name** |
|---|---|---|
| | *Medicago lupulina* | black medic |
| | *Melampyrum lineare* | cow-wheat |
| | *Orthillia secunda* | one sided wintergreen |
| | *Osmorhiza chilensis* | mountain sweet-cicely |
| | *Oxytropis campestris* | field locoweed |
| | *Penstemon confertus* | yellow penstemon |
| | *Penstemon procerus* | small-flowered penstemon |
| | *Platanthera dilitata* | fragrant white-rein orchid |
| | *Platanthera orbiculata* | large round-leaved rein orchid |
| | *Potentilla glandulosa* | sticky cinquefoil |
| | *Pyrola chlorantha* | green wintergreen |
| | *Senecio pauperculus* | Canadian butterweed |
| | *Senecio pseudaureus* | streambank butterweed |
| | *Senecio vulgaris* | common groundsel |
| | *Silene menziesii* | Menzies' campion |
| | *Solidago spathulata* | spikelike goldenrod |
| | *Taraxacum officinale* | dandelion |
| | *Trapogon dubius* | yellow salsify |
| | *Trifolium pratense* | clover |
| | *Trifolium repens* | clover |
| | *unknown herb* | unkown herb |
| | *Verbascum thapsus* | great mullein |
| | *Viola adunca* | early blue violet |
| | *Zigadenus elegans* | mountain death cams |
| | *Zigadenus venenosus* | meadow death camas |
| Grasses | *Achnatherum hymenoides* | Indian ricegrass |
| | *Achnatherum occidentalis* | stiff needlegrass |
| | *Achnatherum richardsonii* | spreading needlegrass |
| | *Achnatherum spp.* | needlegrass |
| | *Agoseris spp.* | Agoseris species |
| | *Agropyron trachycaulum* | slender wheatgrass |
| | *Agrostis scabra* | hair bentgrass |
| | *Agrostis spp.* | Agrostis species |
| | *Calamagrostis rubescens* | pinegrass |
| | *Carex spp* | sedges |
| | *Dactylis glomerata* | orchard grass |
| | *Danthonia spicata* | poverty oatgrass |
| | *Elymus glaucus* | blue wildrye |
| | *Elymus spp.* | Elymus grass |
| | *Elymus trachycaulus* | slender wheatgrass |
| | *Festuca campestris* | rough fesue |
| | *Festuca idahoensis* | idaho fescue |
| | *Hordeum jubatum* | foxtail barley |
| | *Koeleria macrantha* | junegrass |
| | *Oryzopsis asperifolia* | rough-leaved ricegrass |
| | *Phleum pratense* | common timothy |

| **Life form** | ***scientific name*** | **common name** |
|---|---|---|
| | *Poa compressa* | Canada bluegrass |
| | *Poa pratensis* | Kentucky bluegrass |
| | *Poa spp.* | bluegrass species |
| | *Pseudoroegneria spicata* | bluebunch wheatgrass |
| | *Schizachne purpurascens* | false melic |
| | *Trisetum spp.* | trisetum |

# Appendix B – Vegetation data summary tables

## Table B.1– Relative Importance Values for vegetation species at east Kootenay LTSP.

| | **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Life form | scientific name | | | | | | | | | | | |
| Trees | *Abies lasiocarpa* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Pinus contorta* | 3.9 | 3.6 | 5.6 | 6.0 | 4.9 | 2.4 | 4.1 | 3.3 | 7.7 | 3.7 | 6.3 |
| | *Pinus ponderosa* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.4 | 0.0 |
| | *Populus tremuloides* | 0.0 | 4.1 | 0.0 | 0.7 | 0.4 | 0.4 | 2.3 | 0.9 | 1.0 | 0.4 | 1.5 |
| | *Psedotsuga menziesii* | 46.4 | 4.1 | 3.4 | 2.3 | 3.1 | 5.7 | 3.2 | 3.2 | 3.8 | 4.4 | 4.7 |
| Shrubs | *Acer glabrum* | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Amelanchier alnifolia* | 5.4 | 8.4 | 6.0 | 7.9 | 12.5 | 12.5 | 7.3 | 8.6 | 10.0 | 10.4 | 6.0 |
| | *Arctostaphylos uva-ursi* | 11.3 | 15.5 | 9.0 | 15.0 | 10.3 | 17.2 | 12.3 | 6.2 | 5.1 | 6.0 | 3.1 |
| | *Ceanothus velutinus* | 0.4 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 2.1 | 0.0 | 0.0 | 1.4 |
| | *Juniperus communis* | 2.8 | 3.0 | 0.5 | 0.5 | 0.0 | 0.0 | 1.1 | 0.4 | 0.0 | 0.0 | 0.0 |
| | *Juniperus scopulorum* | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 |
| | *Mahonia aquifolium* | 1.7 | 3.4 | 1.4 | 1.3 | 1.5 | 0.0 | 2.8 | 3.0 | 3.6 | 1.7 | 2.5 |
| | *Prunus virginiana* | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Ribes lacustre* | 0.4 | 2.0 | 0.4 | 0.0 | 0.0 | 0.5 | 0.7 | 0.0 | 0.4 | 0.0 | 0.5 |
| | *Rosa acicularis* | 5.6 | 8.6 | 9.2 | 7.2 | 8.0 | 8.1 | 9.2 | 12.8 | 11.2 | 13.4 | 9.3 |
| | *Rosa woodsii* | 0.4 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |
| | *Salix scouleriana* | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.5 | 0.6 |
| | *Shepherdia canadensis* | 3.1 | 3.8 | 2.1 | 6.7 | 6.0 | 4.0 | 4.7 | 7.9 | 5.1 | 6.5 | 0.8 |
| | *Spiraea betulifolia* | 9.1 | 4.1 | 6.3 | 5.4 | 3.5 | 3.6 | 3.0 | 3.0 | 7.5 | 5.2 | 6.0 |
| | *Symphoricarpos albus* | 2.9 | 2.0 | 4.0 | 1.3 | 3.3 | 1.9 | 4.8 | 2.9 | 2.9 | 5.6 | 13.6 |
| Forbs | *Achillea millefolium* | 4.7 | 5.1 | 6.7 | 6.0 | 6.1 | 7.9 | 5.7 | 6.9 | 11.2 | 6.9 | 9.3 |
| | *Agoseris glauca* | 0.8 | 1.3 | 0.9 | 3.5 | 1.2 | 2.1 | 3.6 | 2.3 | 5.1 | 3.1 | 2.1 |
| | *Allium cernum* | 0.7 | 0.0 | 0.4 | 0.8 | 0.4 | 0.8 | 1.4 | 0.0 | 0.4 | 0.0 | 0.8 |
| | *Anaphilis margaritacea* | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.8 |
| | *Anenome multifida* | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.9 | 0.4 | 0.0 | 0.8 |
| | *Antennaria microphylla* | 3.0 | 2.0 | 4.2 | 2.2 | 2.6 | 1.9 | 2.9 | 2.6 | 2.0 | 1.4 | 0.8 |

| | **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Antennaria neglecta* | 3.5 | 4.9 | 4.5 | 3.3 | 1.3 | 4.7 | 1.3 | 2.2 | 2.2 | 3.2 | 2.5 |
| | *Antennaria racemosa* | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Apocynum androsaemifolium* | 0.4 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Arabis holboellii* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.9 | 0.8 | 0.4 | 1.2 |
| | *Arnica cordifolia* | 5.0 | 0.7 | 2.9 | 2.0 | 0.0 | 1.7 | 0.0 | 2.1 | 0.4 | 1.2 | 0.0 |
| | *Artemisia campestris* | 0.0 | 0.4 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 1.4 | 2.0 | 1.8 | 2.0 |
| | *Aster conspicuus* | 4.0 | 10.5 | 6.8 | 7.7 | 5.4 | 5.9 | 5.3 | 3.9 | 7.0 | 3.8 | 2.3 |
| | *Aster foliaceus* | 1.9 | 2.1 | 2.4 | 5.0 | 6.8 | 4.6 | 2.9 | 1.8 | 3.4 | 2.0 | 2.2 |
| | *Aster laevis* | 2.5 | 3.1 | 2.8 | 4.0 | 4.1 | 4.8 | 5.1 | 1.7 | 2.3 | 2.0 | 3.2 |
| | *Aster sp.* | 0.1 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 1.4 | 0.0 | 0.4 | 0.8 |
| | *Astragalus miser* | 3.1 | 2.1 | 2.2 | 2.8 | 3.6 | 3.6 | 1.9 | 3.4 | 5.7 | 6.3 | 1.6 |
| | *Astragalus spp.* | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Calochortus apiculatus* | 0.6 | 1.3 | 0.4 | 1.6 | 1.2 | 1.3 | 1.5 | 0.4 | 0.4 | 0.9 | 0.0 |
| | *Campanula rotundifolia* | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.4 | 1.1 | 0.0 | 1.2 | 0.0 | 1.2 |
| | *Castilleja spp.* | 0.0 | 0.4 | 0.0 | 0.6 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Cirsium arvense* | 0.7 | 0.0 | 0.9 | 0.4 | 0.0 | 0.8 | 0.4 | 0.4 | 0.4 | 0.0 | 0.0 |
| | *Cirsium spp.* | 2.2 | 2.3 | 2.9 | 2.0 | 0.8 | 2.1 | 1.8 | 3.4 | 1.8 | 3.5 | 5.6 |
| | *Cirsium vulgare* | 2.2 | 2.3 | 2.9 | 2.0 | 0.8 | 2.1 | 1.8 | 3.4 | 1.8 | 3.5 | 5.6 |
| | *Crepis atribarba* | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 0.0 | 0.8 | 0.9 | 0.0 | 0.0 | 0.4 |
| | *Disporum trachycarpum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
| | *Epilobium angustifolium* | 2.2 | 2.9 | 4.0 | 3.9 | 0.8 | 2.2 | 1.3 | 0.9 | 3.5 | 1.3 | 9.0 |
| | *Epilobium ciliatum* | 0.7 | 0.0 | 0.9 | 0.0 | 0.0 | 0.4 | 1.1 | 0.9 | 0.4 | 0.4 | 0.4 |
| | *Epilobium minutum* | 1.5 | 1.5 | 1.8 | 1.6 | 1.6 | 1.6 | 1.1 | 1.7 | 1.6 | 1.3 | 1.9 |
| | *Erigeron corymbosus* | 0.4 | 0.0 | 0.5 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| | *Filago arvensis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 1.1 | 0.0 |
| | *Fragaria virginiana* | 6.0 | 7.9 | 9.8 | 9.9 | 8.8 | 11.2 | 7.8 | 10.1 | 7.4 | 5.8 | 9.5 |
| | *Galium boreale* | 1.2 | 3.1 | 1.6 | 2.2 | 3.9 | 1.7 | 4.3 | 7.3 | 1.8 | 4.5 | 3.7 |
| | *Gentianella propinqua* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 |
| | *Gentiannela amarella* | 2.5 | 3.0 | 2.7 | 1.8 | 2.0 | 1.9 | 1.5 | 1.7 | 2.0 | 1.3 | 0.8 |
| | *Geum triflorum* | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| | **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Hedysarum sulphurescens* | 2.4 | 1.8 | 2.2 | 2.6 | 3.2 | 3.2 | 0.8 | 3.1 | 3.7 | 1.7 | 1.2 |
| | *Heuchera cylindrica* | 0.5 | 0.0 | 0.4 | 0.0 | 0.4 | 0.6 | 0.7 | 0.4 | 0.4 | 0.0 | 1.2 |
| | *Hieracium albiflorum* | 1.3 | 0.8 | 1.3 | 0.8 | 0.4 | 0.9 | 0.0 | 0.0 | 0.4 | 0.9 | 0.8 |
| | *Hieracium scouleri* | 0.1 | 0.4 | 0.0 | 0.8 | 0.8 | 0.6 | 1.8 | 1.4 | 0.4 | 0.9 | 1.2 |
| | *Hieracium spp* | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.9 | 0.8 |
| | *Hieracium umbellatum* | 0.0 | 0.8 | 0.0 | 1.2 | 0.9 | 1.6 | 0.7 | 0.0 | 1.2 | 0.4 | 0.0 |
| | *Lactuca serriola* | 0.0 | 1.3 | 0.0 | 0.4 | 0.4 | 0.4 | 1.2 | 0.0 | 0.4 | 0.4 | 0.0 |
| | *Lactuca spp* | 0.7 | 0.9 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 |
| | *Lappula redowskii* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |
| | *Lathyrus ochroleucus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |
| | *Lilium philadelphicum* | 0.2 | 0.0 | 0.0 | 0.8 | 0.8 | 1.2 | 1.1 | 0.9 | 0.0 | 0.0 | 0.0 |
| | *Linnaea borealis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.4 | 0.0 |
| | *Lithospermum ruderale* | 2.9 | 2.7 | 2.9 | 3.2 | 3.6 | 3.0 | 0.4 | 3.1 | 3.5 | 1.8 | 0.9 |
| | *Lomatium triternatum* | 0.6 | 0.4 | 0.4 | 0.8 | 1.6 | 1.3 | 1.4 | 0.9 | 0.4 | 0.9 | 0.0 |
| | *Medicago lupulina* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 1.3 | 0.4 |
| | *Orthillia secunda* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Osmorhiza chilensis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Oxytropis campestris* | 0.6 | 0.4 | 0.4 | 0.8 | 1.0 | 1.0 | 3.8 | 0.4 | 0.8 | 0.4 | 0.4 |
| | *Penstemon confertus* | 2.2 | 2.2 | 4.2 | 5.0 | 3.3 | 5.2 | 3.9 | 3.9 | 3.6 | 2.7 | 4.6 |
| | *Penstemon procerus* | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| | *Platanthera dilitata* | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Platanthera orbiculata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 |
| | *Potentilla glandulosa* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 |
| | *Pyrola chlorantha* | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Senecio pauperculus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 |
| | *Senecio pseudaureus* | 0.0 | 0.4 | 0.0 | 1.9 | 1.2 | 1.1 | 1.8 | 1.7 | 0.9 | 1.2 | 0.0 |
| | *Senecio vulgaris* | 0.5 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | *Silene menziesii* | 0.4 | 0.9 | 0.4 | 0.4 | 2.0 | 0.9 | 1.5 | 0.0 | 0.4 | 0.0 | 0.4 |
| | *Solidago spathulata* | 1.1 | 0.8 | 1.3 | 1.6 | 2.6 | 1.7 | 2.0 | 1.9 | 1.8 | 1.7 | 1.6 |
| | *Taraxacum officinale* | 1.5 | 1.7 | 1.4 | 0.4 | 1.6 | 0.8 | 1.4 | 3.0 | 1.7 | 2.7 | 2.2 |
| | *Trapogon dubius* | 3.0 | 2.6 | 3.6 | 1.8 | 1.2 | 1.2 | 0.7 | 1.3 | 2.6 | 3.0 | 2.0 |

|  | **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | *Trifolium pratense* | 0.4 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.8 |
|  | *Trifolium repens* | 0.4 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 | 0.8 |
|  | *Verbascum thapsus* | 0.4 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |
|  | *Viola adunca* | 2.5 | 1.7 | 2.8 | 1.2 | 1.9 | 2.0 | 2.3 | 4.0 | 2.5 | 1.9 | 4.7 |
|  | *Zigadenus elegans* | 0.4 | 0.0 | 0.4 | 3.0 | 0.8 | 1.7 | 1.1 | 0.4 | 0.0 | 0.4 | 0.0 |
|  | *Zigadenus venenosus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Grasses | *Achnatherum occidentalis* | 0.4 | 0.0 | 0.4 | 0.0 | 0.6 | 0.0 | 0.7 | 0.4 | 0.8 | 0.0 | 1.3 |
|  | *Achnatherum richardsonii* | 1.6 | 2.7 | 1.7 | 2.6 | 9.7 | 2.7 | 3.3 | 0.9 | 2.1 | 0.4 | 0.9 |
|  | *Achnatherum spp.* | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 |
|  | *Agoseris spp.* | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|  | *Agropyron trachycaulum* | 0.4 | 0.0 | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 1.7 | 0.4 | 0.0 | 0.4 |
|  | *Agrostis scabra* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.8 | 1.1 | 1.3 |
|  | *Agrostis spp.* | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.4 | 0.9 | 0.0 |
|  | *Calamagrostis rubescens* | 14.1 | 30.0 | 36.6 | 23.6 | 18.3 | 22.4 | 27.5 | 33.9 | 22.4 | 40.9 | 16.4 |
|  | *Carex spp* | 5.5 | 3.9 | 6.1 | 7.0 | 4.3 | 4.2 | 3.8 | 3.5 | 6.1 | 4.4 | 11.4 |
|  | *Dactylis glomerata* | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|  | *Danthonia spicata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
|  | *Elymus glaucus* | 1.7 | 0.4 | 2.4 | 2.9 | 2.1 | 3.0 | 2.9 | 1.0 | 1.7 | 1.2 | 0.9 |
|  | *Elymus trachycaulus* | 0.4 | 1.0 | 0.4 | 0.4 | 0.8 | 0.8 | 1.4 | 0.9 | 0.8 | 0.4 | 2.9 |
|  | *Festuca campestris* | 5.8 | 10.0 | 10.4 | 9.3 | 16.1 | 8.4 | 10.1 | 6.0 | 7.2 | 6.7 | 3.2 |
|  | *Festuca idahoensis* | 0.1 | 1.0 | 0.0 | 0.4 | 1.8 | 0.0 | 1.5 | 0.4 | 0.0 | 0.5 | 0.4 |
|  | *Hordeum jubatum* | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|  | *Koeleria macrantha* | 0.4 | 0.4 | 0.4 | 0.8 | 3.1 | 2.0 | 2.1 | 1.4 | 0.0 | 0.4 | 0.4 |
|  | *Oryzopsis asperifolia* | 0.1 | 1.0 | 0.0 | 0.4 | 1.8 | 0.0 | 1.5 | 0.4 | 0.0 | 0.5 | 0.4 |
|  | *Phleum pratense* | 0.4 | 0.4 | 0.6 | 0.0 | 0.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 2.3 |
|  | *Poa compressa* | 0.5 | 3.8 | 0.8 | 0.8 | 0.4 | 1.3 | 0.4 | 0.0 | 1.4 | 0.0 | 0.0 |
|  | *Poa pratensis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | 0.7 | 0.0 |
|  | *Poa spp.* | 0.7 | 0.9 | 0.9 | 0.5 | 0.0 | 1.6 | 1.6 | 3.2 | 2.2 | 0.9 | 4.4 |
|  | *Pseudoroegneria spicata* | 0.1 | 1.1 | 0.0 | 0.0 | 2.8 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 1.0 |
|  | *Trisetum spp.* | 0.4 | 0.4 | 0.4 | 0.0 | 0.8 | 0.7 | 0.8 | 0.0 | 0.0 | 0.4 | 0.0 |

**Table B.2: Average % cover by treatment for Emily creek**

| **Site** | **Emily Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| scientific name | % | % | % | % | % | % | % | % | % | % | % |
| **Trees** | | | | | | | | | | | |
| *Abies lasiocarpa* | | | | | | | | | | | |
| *Pinus contorta* | | 3.0 | 3.0 | 2.5 | 3.0 | 2.0 | 2.8 | 1.3 | 2.5 | 2.5 | 1.5 |
| *Pinus ponderosa* | | | | | | | | | | | |
| *Populus tremuloides* | | | | | | | | 0.5 | 1.3 | | |
| *Psedotsuga menziesii* | 2.5 | 3.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 0.8 | 0.7 |
| **Shrubs** | | | | | | | | | | | |
| *Acer glabrum* | | | | | | | | | | | |
| *Amelanchier alnifolia* | | 0.5 | | 3.0 | 0.5 | | | 0.5 | | | |
| *Arctostaphylos uva-ursi* | 3.8 | 10.5 | 4.3 | 9.0 | 5.8 | 11.3 | 11.5 | 0.8 | 0.5 | 1.6 | 0.5 |
| *Ceanothus velutinus* | | | | | | | | | | | |
| *Juniperus communis* | 1.0 | 2.0 | | | | | | 0.5 | | | |
| *Juniperus scopulorum* | | | | | 0.5 | | 0.5 | | | | |
| *Mahonia aquifolium* | | | | | | | | | | | |
| *Prunus virginiana* | | | | | | | | | | | |
| *Ribes lacustre* | | | | | | | | | | | |
| *Rosa acicularis* | 0.5 | 9.3 | 1.7 | | | 2.8 | 4.5 | 1.0 | 2.0 | 0.8 | |
| *Rosa woodsii* | | 0.5 | 0.5 | | | | | | | 0.5 | |
| *Salix scouleriana* | | | | | | | | | | | |
| *Shepherdia canadensis* | 2.3 | 8.0 | | 1.5 | 0.5 | 4.0 | | 1.0 | 1.5 | 0.5 | 0.5 |
| *Spiraea betulifolia* | | | | | | | | | | | |
| *Symphoricarpos albus* | | | | | | | | | | | |
| **Forbs** | | | | | | | | | | | |
| *Achillea millefolium* | 0.5 | 0.7 | 3.5 | 0.6 | 0.9 | 2.9 | 1.1 | 2.4 | 8.0 | 2.3 | 6.0 |
| *Agoseris glauca* | 0.5 | 0.8 | 0.8 | 2.3 | 0.5 | 2.0 | 1.9 | 1.4 | 4.2 | 1.9 | 2.5 |
| *Allium cernum* | 0.5 | | | | | | | | | | |
| *Anaphilis margaritacea* | | | | | | | | | | | |
| *Anenome multifida* | | | | | 0.8 | | | 0.8 | | | 0.5 |
| *Antennaria microphylla* | 1.3 | 1.2 | 2.4 | 0.8 | 1.2 | 1.3 | 2.4 | 0.6 | 0.5 | 0.7 | 0.5 |
| *Antennaria neglecta* | 0.8 | 0.7 | 1.7 | 0.7 | | 0.8 | | 0.5 | 0.5 | 0.5 | 0.5 |
| *Antennaria racemosa* | | | | | | | | | | | |
| *Apocynum androsaemifolium* | | | | | | | | | | | |
| *Arabis holboellii* | | | | | | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| *Arnica cordifolia* | 3.3 | 3.0 | 1.3 | 0.5 | | 0.8 | | | | | |
| *Artemisia campestris* | | 0.5 | | 0.5 | | | | 0.7 | 1.1 | 0.6 | 1.3 |

| **Site** | **Emily Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Aster conspicuus* | | | | | | 0.5 | | | | | |
| *Aster foliaceus* | 0.5 | | 0.5 | 0.5 | | | | | | | |
| *Aster laevis* | | | | | | | | | | | |
| *Aster sp.* | | | | | | | 1.0 | | | | 0.5 |
| *Astragalus miser* | 1.8 | 0.5 | 0.7 | 0.5 | 4.5 | 1.7 | 0.9 | 0.7 | 2.3 | 2.5 | 0.5 |
| *Astragalus spp.* | | | 0.5 | | | | | | | | |
| *Calochortus apiculatus* | | | | | | | | | | | |
| *Campanula rotundifolia* | | | | 0.5 | | | | | 0.5 | | 0.5 |
| *Castilleja spp.* | | | | | | 1.0 | | | | | |
| *Cirsium arvense* | | | 0.5 | 0.5 | | 0.5 | | | | | |
| *Cirsium spp.* | | 0.5 | 1.5 | 0.8 | 0.5 | | 0.5 | | | 0.5 | 0.5 |
| *Cirsium vulgare* | | 0.5 | 1.5 | 0.8 | 0.5 | | 0.5 | | | 0.5 | 0.5 |
| *Crepis atribarba* | | | | | 0.5 | | 0.8 | 0.5 | | | 0.5 |
| *Disporum trachycarpum* | | | | | | | | | | | |
| *Epilobium angustifolium* | | 0.6 | 3.1 | 1.4 | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 |
| *Epilobium ciliatum* | | | | | | | | | | | |
| *Epilobium minutum* | | 0.5 | | 0.5 | | | | | | | |
| *Erigeron corymbosus* | | | | | | 0.5 | | | | | |
| *Filago arvensis* | | | | | | | | | | | |
| *Fragaria virginiana* | 1.5 | 2.1 | 2.5 | 3.8 | 0.6 | 5.5 | 1.6 | 0.6 | 1.1 | 0.9 | 0.5 |
| *Galium boreale* | | | | | | | | | | | |
| *Gentianella propinqua* | | | | | | | | | | | 0.5 |
| *Gentiannela amarella* | 0.5 | 0.6 | 0.6 | 1.2 | 0.6 | 1.1 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| *Geum triflorum* | | | | 1.0 | | | | | | | |
| *Hedysarum sulphurescens* | | | 0.5 | | | | | | | | |
| *Heuchera cylindrica* | 0.5 | | 0.5 | | 0.5 | 2.0 | 0.5 | 0.5 | 0.5 | | 0.5 |
| *Hieracium albiflorum* | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | | | 0.5 | 0.5 | 0.5 |
| *Hieracium scouleri* | 0.5 | 0.5 | | | 0.5 | 2.0 | 0.5 | 0.7 | | 0.5 | 0.5 |
| *Hieracium spp* | | 0.5 | | | 0.5 | | | 0.5 | | 0.5 | 0.5 |
| *Hieracium umbellatum* | | | | | | 0.5 | | | | 0.5 | |
| *Lactuca serriola* | | 0.5 | | | 0.5 | | 2.0 | | | | |
| *Lactuca spp* | | | | | | | | | | | |
| *Lappula redowskii* | | | | | | | | | | | |
| *Lathyrus ochroleucus* | | | | | | | | | | 0.5 | |
| *Lilium philadelphicum* | | | | | | | | | | | |
| *Linnaea borealis* | | | | | | | | | | | |
| *Lithospermum ruderale* | | | | | | | | | | | |
| *Lomatium triternatum* | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | |
| *Medicago lupulina* | | | | | | | | | | | |
| *Orthillia secunda* | | | | | | | 0.5 | | | | |

| **Site** | **Emily Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Osmorhiza chilensis* | | | | | | | | | | | |
| *Oxytropis campestris* | 1.0 | 0.5 | 0.5 | 0.5 | 1.8 | 1.3 | 9.3 | 0.5 | | 0.5 | 0.5 |
| *Penstemon confertus* | 0.7 | 0.6 | 5.3 | 5.0 | 2.5 | 6.0 | 3.0 | 1.9 | 3.1 | 1.4 | 3.8 |
| *Penstemon procerus* | | | | | | | | | | | 0.5 |
| *Platanthera dilitata* | | | | | | | | | | | |
| *Platanthera orbiculata* | | | | | | | | | | | |
| *Potentilla glandulosa* | | | | | | | | 0.5 | | | |
| *Pyrola chlorantha* | 0.5 | | | | | | | | | | |
| *Senecio pauperculus* | | | | | | | | | | | |
| *Senecio pseudaureus* | | | | | | | | | | | |
| *Senecio vulgaris* | | | | | | | | | | | |
| *Silene menziesii* | | | | | | | 1.0 | | 0.5 | | |
| *Solidago spathulata* | | 0.5 | 0.5 | 0.5 | 1.0 | 0.7 | 1.1 | 0.8 | 0.5 | 0.5 | 0.5 |
| *Taraxacum officinale* | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 | | 0.5 | 0.5 | 1.0 | 0.5 | 0.5 |
| *Trapogon dubius* | | 0.5 | 0.5 | 0.5 | 0.5 | | | 0.5 | 0.5 | 0.5 | 0.5 |
| *Trifolium pratense* | | | 0.5 | 0.5 | | | | | | | |
| *Trifolium repens* | | | 0.5 | 0.5 | | | | | | | |
| *Verbascum thapsus* | | 0.5 | 0.5 | | | | | | | 0.5 | |
| *Viola adunca* | | 0.5 | | | | | | | 1.0 | | |
| *Zigadenus elegans* | | | | | | | | | | | |
| *Zigadenus venenosus* | | | | | 0.5 | | | | | | |
| **Grasses** | | | | | | | | | | | |
| *Achnatherum occidentalis* | | | 0.5 | | 2.0 | | 0.5 | 0.5 | 0.5 | | 0.5 |
| *Achnatherum richardsonii* | 0.5 | 0.7 | 0.5 | 0.9 | 21.7 | 2.3 | 2.0 | 0.5 | 0.5 | | 4.0 |
| *Achnatherum spp.* | | | | | 3.0 | | | | | | |
| *Agoseris spp.* | | | | | | | | | | | |
| *Agropyron trachycaulum* | | | | | | | | | | | |
| *Agrostis scabra* | | | | | | | | | | | |
| *Agrostis spp.* | | 0.5 | | | | | 0.5 | | 0.5 | 0.5 | |
| *Calamagrostis rubescens* | 4.4 | 18.0 | 3.3 | 14.0 | 14.3 | 12.3 | 15.5 | 8.5 | 3.3 | 8.5 | 14.0 |
| *Carex spp* | 0.7 | 0.9 | 4.9 | 5.4 | 2.0 | 1.5 | 0.5 | 0.6 | 1.9 | 0.5 | 8.3 |
| *Dactylis glomerata* | | | | 1.0 | | | | | | | |
| *Danthonia spicata* | | | | | | | | | | | |
| *Elymus glaucus* | | 0.5 | 3.0 | 7.0 | | 1.3 | | | 0.8 | | |
| *Elymus trachycaulus* | | | | | | | | | | | |
| *Festuca campestris* | 2.2 | 5.9 | 7.3 | 7.5 | 6.0 | 7.3 | 5.0 | 4.0 | 2.1 | 3.8 | 1.1 |
| *Festuca idahoensis* | 0.5 | | | 0.5 | 0.5 | | 0.5 | | | | |
| *Hordeum jubatum* | | | | | | | | | | | |
| *Koeleria macrantha* | | 0.5 | 0.5 | 0.5 | 2.4 | 1.8 | 2.3 | 0.7 | | 0.5 | 0.5 |
| *Oryzopsis asperifolia* | 0.5 | | | 0.5 | 0.5 | | 0.5 | | | | |

| **Site** | **Emily Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Phleum pratense* | | | | | | | | | | | |
| *Poa compressa* | 0.5 | 5.3 | 3.0 | 0.5 | | 3.0 | 0.5 | | 1.0 | | |
| *Poa pratensis* | | | | | | | | | | | |
| *Poa spp.* | | | | | | | | | | | |
| *Pseudoroegneria spicata* | | | | | 7.0 | | | | | | |
| *Trisetum spp.* | | 0.5 | 0.5 | | | | | | | 0.5 | |

**Table B.3: Average % cover by treatment for Kootenay east**

| **Site** | **Kootenay-East** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| scientific name | % | % | % | % | % | % | % | % | % | % | % |
| **Trees** | | | | | | | | | | | |
| *Abies lasiocarpa* | | | | | | | | | | | |
| *Pinus contorta* | 5.0 | 2.0 | 6.0 | 4.8 | 8.5 | 0.5 | 7.5 | 3.0 | 8.7 | 6.0 | 13.5 |
| *Pinus ponderosa* | | | | | | | | | | 0.5 | |
| *Populus tremuloides* | | | | 3.0 | | 0.5 | 2.8 | 0.5 | | 0.5 | 1.2 |
| *Psedotsuga menziesii* | 48.8 | 1.0 | 1.5 | 1.0 | 1.8 | 4.3 | 2.7 | 2.0 | 1.7 | 1.9 | 3.8 |
| **Shrubs** | | | | | | | | | | | |
| *Acer glabrum* | | | | | | | | | | | |
| *Amelanchier alnifolia* | 0.5 | 4.5 | 2.8 | 3.8 | 15.3 | 14.5 | 9.5 | 3.5 | 10.0 | 7.5 | 2.1 |
| *Arctostaphylos uva-ursi* | 0.5 | 4.3 | 3.0 | 4.3 | 2.4 | 4.5 | 4.9 | 0.8 | 2.8 | 0.8 | 1.9 |
| *Ceanothus velutinus* | | | 1.0 | | | | | 2.2 | | | 2.8 |
| *Juniperus communis* | 3.5 | 2.7 | 1.0 | | | | 4.0 | | | | |
| *Juniperus scopulorum* | | 0.5 | | | | | | | 0.5 | | |
| *Mahonia aquifolium* | 0.5 | 0.5 | | 1.0 | 4.0 | | 9.0 | 1.8 | 8.0 | 3.0 | 0.5 |
| *Prunus virginiana* | | | 0.5 | | | | | | | | |
| *Ribes lacustre* | | 4.0 | 0.5 | | | 1.0 | | | | | 1.0 |
| *Rosa acicularis* | 0.6 | 12.0 | 4.0 | 5.0 | 7.1 | 4.5 | 9.0 | 5.3 | 6.5 | 8.0 | 5.6 |
| *Rosa woodsii* | | | | | | | | | | | |
| *Salix scouleriana* | | | | 2.5 | | 3.0 | | | | | 2.0 |
| *Shepherdia canadensis* | 3.0 | 2.5 | 0.5 | 7.7 | 7.8 | 7.0 | 6.0 | 6.7 | 5.0 | 6.3 | |
| *Spiraea betulifolia* | 4.0 | 3.2 | 6.3 | 2.8 | 1.0 | 4.3 | 1.8 | 1.7 | 6.5 | 1.9 | 7.0 |
| *Symphoricarpos albus* | 1.5 | 4.0 | 3.9 | 2.5 | 3.6 | 1.5 | 3.5 | 1.0 | 3.3 | 15.0 | 4.8 |
| **Forbs** | | | | | | | | | | | |
| *Achillea millefolium* | 0.5 | 0.8 | 0.8 | 1.8 | 3.3 | 4.5 | 2.5 | 0.9 | 3.5 | 1.5 | 2.3 |
| *Agoseris glauca* | | 0.5 | | 0.8 | | | 1.0 | | 1.0 | 1.0 | |
| *Allium cernum* | 0.5 | | 0.5 | | | 0.5 | 0.5 | | | | |
| *Anaphilis margaritacea* | | | | | | | | | | | 0.5 |
| *Anenome multifida* | | | | | | | | | | | |
| *Antennaria microphylla* | 0.5 | 1.0 | | | | | 0.5 | | 0.5 | | |
| *Antennaria neglecta* | 0.8 | 2.7 | | 1.8 | 1.0 | 3.0 | 1.2 | | 1.0 | 1.0 | 1.0 |
| *Antennaria racemosa* | | | | | | | | | | | |
| *Apocynum androsaemifolium* | | | 0.5 | | | | | | | | |
| *Arabis holboellii* | | | | | | | | | | | |
| *Arnica cordifolia* | | | 1.0 | | | 0.5 | | | 0.5 | | |
| *Artemisia campestris* | | | | | | | | | | | |
| *Aster conspicuus* | 1.0 | 15.3 | 5.9 | 8.3 | 5.6 | 4.5 | 5.4 | 1.4 | 6.5 | 1.0 | 1.0 |
| *Aster foliaceus* | 0.5 | 6.0 | 2.3 | 6.8 | 12.8 | 7.5 | 4.0 | 0.6 | 3.5 | 2.2 | 2.0 |

| **Site** | **Kootenay-East** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Aster laevis* | 0.5 | | 0.5 | 1.5 | 1.0 | 2.3 | | 0.5 | 0.5 | | 1.2 |
| *Aster sp.* | | | | | | | | | | | |
| *Astragalus miser* | 0.5 | 0.5 | | 0.8 | 0.5 | 0.5 | 0.5 | 1.5 | 1.0 | 2.2 | 0.5 |
| *Astragalus spp.* | | | | | | | | | | | |
| *Calochortus apiculatus* | | | | | | | | | | | |
| *Campanula rotundifolia* | | | | 1.0 | | 0.5 | 0.5 | | 0.5 | | |
| *Castilleja spp.* | | 0.5 | | 2.0 | | | | | | | |
| *Cirsium arvense* | | | | | | | | | | | |
| *Cirsium spp.* | | 0.5 | 0.5 | | 1.0 | 0.8 | 0.7 | 0.5 | 1.3 | 0.5 | 0.8 |
| *Cirsium vulgare* | | 0.5 | 0.5 | | 1.0 | 0.8 | 0.7 | 0.5 | 1.3 | 0.5 | 0.8 |
| *Crepis atribarba* | | | | | | | | | | | |
| *Disporum trachycarpum* | | | | | | | | | 0.5 | | |
| *Epilobium angustifolium* | | 3.0 | 0.5 | 1.3 | 0.5 | 2.3 | 6.0 | | 2.8 | 0.5 | 12.3 |
| *Epilobium ciliatum* | | | 0.5 | | | 0.5 | 0.7 | 0.5 | 0.5 | | 0.5 |
| *Epilobium minutum* | | | | | | | | | | | |
| *Erigeron corymbosus* | | | 1.0 | | | 0.5 | | | | | |
| *Filago arvensis* | | | | | | | | | | | |
| *Fragaria virginiana* | | 4.8 | 6.3 | 7.5 | 6.8 | 9.3 | 7.3 | 7.0 | 4.8 | 2.5 | 7.4 |
| *Galium boreale* | 0.5 | 1.0 | | | 3.2 | 0.5 | 2.5 | 4.5 | | 3.0 | 0.5 |
| *Gentianella propinqua* | | | | | | | | | | | |
| *Gentiannela amarella* | 0.5 | | | | | | | | | | |
| *Geum triflorum* | | | | | | | | | | | |
| *Hedysarum sulphurescens* | 0.5 | 0.8 | | 2.3 | 0.8 | 2.3 | 0.5 | 1.3 | 3.0 | 0.5 | 0.5 |
| *Heuchera cylindrica* | | | | | | | | | | | |
| *Hieracium albiflorum* | | | | | | 1.0 | | | | | |
| *Hieracium scouleri* | | | | | | | | | 0.5 | | |
| *Hieracium spp* | | | | | | | | | | | |
| *Hieracium umbellatum* | | | | 0.7 | 1.0 | 2.5 | 0.5 | | 0.5 | | |
| *Lactuca serriola* | | | | | | | | | | | |
| *Lactuca spp* | | 0.8 | 0.5 | | | | | | | 0.5 | 0.5 |
| *Lappula redowskii* | | | | | | | | | | | |
| *Lathyrus ochroleucus* | | | | | | | | | | | |
| *Lilium philadelphicum* | 1.0 | | | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 | | | |
| *Linnaea borealis* | | | | | | | | | 1.0 | 0.5 | |
| *Lithospermum ruderale* | 0.5 | 1.0 | 0.8 | 1.9 | 1.1 | 1.0 | | 1.3 | 1.4 | 1.0 | 0.8 |
| *Lomatium triternatum* | | | | | | | | | | | |
| *Medicago lupulina* | | | | | | | | | 1.0 | | |
| *Orthillia secunda* | | | | | | | | | | | |
| *Osmorhiza chilensis* | | | | | 0.5 | | | | | | |
| *Oxytropis campestris* | | | | | | | | | 0.5 | | |

| **Site** | **Kootenay-East** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Penstemon confertus* | | | | | | | | | | | |
| *Penstemon procerus* | | | 0.5 | | | | | | | | |
| *Platanthera dilitata* | | | 0.5 | | | | | | | | |
| *Platanthera orbiculata* | | | | | | | | 0.5 | | | |
| *Potentilla glandulosa* | | | | | | 0.5 | | | | | |
| *Pyrola chlorantha* | | | | | | | | | | | |
| *Senecio pauperculus* | | | | | | | | | | | 0.8 |
| *Senecio pseudaureus* | | 0.5 | | 2.3 | 0.7 | 2.0 | 3.0 | 1.3 | 0.8 | 1.5 | |
| *Senecio vulgaris* | 0.5 | | 0.5 | | | | | | | | |
| *Silene menziesii* | | | | | 0.7 | 0.8 | 0.8 | | | | |
| *Solidago spathulata* | | | | | | | | 0.5 | 2.0 | | |
| *Taraxacum officinale* | 0.5 | | | | | 0.5 | | | 0.5 | | |
| *Trapogon dubius* | | 0.7 | 0.8 | 1.2 | | 0.5 | 0.5 | 0.5 | 0.8 | 0.5 | 0.5 |
| *Trifolium pratense* | | | | | | | | | 0.5 | | 0.5 |
| *Trifolium repens* | | | | | | | | | 0.5 | | 0.5 |
| *Verbascum thapsus* | | | | | | | | | | | |
| *Viola adunca* | 0.5 | | 0.8 | | 0.5 | 0.5 | 0.7 | 0.5 | | | 2.5 |
| *Zigadenus elegans* | | | | 2.2 | 1.0 | 0.8 | 0.5 | 0.5 | | 0.5 | |
| *Zigadenus venenosus* | | | | | | | | | | | |
| **Grasses** | | | | | | | | | | | |
| *Achnatherum occidentalis* | | | | | | | | | | | 1.0 |
| *Achnatherum richardsonii* | | 0.5 | | | 1.0 | 1.0 | 1.3 | | 0.8 | | |
| *Achnatherum spp.* | | | | | | | 0.5 | | | 0.5 | |
| *Agoseris spp.* | | | | 0.5 | | | | | | | |
| *Agropyron trachycaulum* | | | | | | | | | | | |
| *Agrostis scabra* | | | | | | 0.5 | | | 0.5 | 2.0 | |
| *Agrostis spp.* | | | | | | | | | | | |
| *Calamagrostis rubescens* | 3.5 | 25.0 | 37.5 | 10.5 | 9.8 | 16.5 | 34.3 | 13.0 | 10.0 | 15.3 | 4.0 |
| *Carex spp* | 0.5 | | | 0.7 | 0.5 | 0.5 | 0.7 | 0.5 | 0.9 | 0.5 | 6.0 |
| *Dactylis glomerata* | | | | | | | | | | | |
| *Danthonia spicata* | | | | | | 0.5 | | | 0.5 | | |
| *Elymus glaucus* | 0.5 | | 2.0 | 0.9 | 2.2 | 1.6 | 2.3 | 1.0 | 0.5 | 1.8 | 0.8 |
| *Elymus trachycaulus* | | | | 0.5 | 0.5 | 0.5 | 0.5 | | | | 0.5 |
| *Festuca campestris* | | 7.3 | 3.5 | 6.0 | 15.5 | 3.0 | 5.3 | | 4.0 | 2.0 | 0.5 |
| *Festuca idahoensis* | | 1.0 | | | 1.3 | | 0.8 | | | 1.0 | |
| *Hordeum jubatum* | | | 0.5 | | | 0.5 | | | | | |
| *Koeleria macrantha* | | | | 0.5 | 0.5 | 0.5 | | | | | |
| *Oryzopsis asperifolia* | | 1.0 | | | 1.3 | | 0.8 | | | 1.0 | |
| *Phleum pratense* | | 0.5 | 2.0 | | | | 0.5 | | | | 1.2 |
| *Poa compressa* | | | | | | | | | | | |

| **Site** | **Kootenay-East** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Poa pratensis* | | | | | | | | | | | |
| *Poa spp.* | | 5.0 | | 1.0 | | 0.5 | 0.5 | | 0.8 | | |
| *Pseudoroegneria spicata* | | 1.5 | | | 0.8 | | | | | | 5.0 |
| *Trisetum spp.* | | | | | 0.5 | 3.0 | 1.0 | | | | |
| unknown grass | | | | 0.5 | | | | | | | |

## Table B.4: Average % cover by treatment for Mud creek

| **Site** | **Mud Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| scientific name | % | % | % | % | % | % | % | % | % | % | % |
| **Trees** | | | | | | | | | | | |
| *Abies lasiocarpa* | | | | | | 0.5 | | | | | |
| *Pinus contorta* | 0.8 | 1.3 | 1.7 | 1.5 | 0.5 | 1.0 | 0.8 | 1.0 | 1.2 | 0.8 | 1.5 |
| *Pinus ponderosa* | | | | | | | | 1.0 | | | |
| *Populus tremuloides* | | 15.0 | | | 0.5 | | 2.5 | | | | |
| *Psedotsuga menziesii* | 1.8 | 0.5 | 0.7 | 1.5 | 0.8 | 0.8 | 0.8 | 1.0 | 1.5 | 0.5 | 1.0 |
| **Shrubs** | | | | | | | | | | | |
| *Acer glabrum* | 1.0 | | | | | | | | | | |
| *Amelanchier alnifolia* | 3.3 | 6.8 | 4.5 | 5.5 | 6.5 | 8.0 | 2.5 | 4.8 | 2.5 | 5.3 | 4.3 |
| *Arctostaphylos uva-ursi* | 5.1 | 10.0 | 4.5 | 9.3 | 8.5 | 14.3 | 4.8 | 3.8 | 0.8 | 2.0 | |
| *Ceanothus velutinus* | | | | | | | | | | | |
| *Juniperus communis* | | 0.5 | | 1.0 | | | 1.0 | | | | |
| *Juniperus scopulorum* | | | | | | | | | | | |
| *Mahonia aquifolium* | 1.3 | 1.5 | 0.7 | 0.5 | 0.5 | | 2.2 | 0.5 | 1.4 | 0.5 | 1.4 |
| *Prunus virginiana* | | | | | | | | | | | |
| *Ribes lacustre* | | 0.5 | | | | | 0.5 | | 0.5 | | |
| *Rosa acicularis* | 1.5 | 2.6 | 6.5 | 4.3 | 5.3 | 3.3 | 3.8 | 9.3 | 6.0 | 7.3 | 7.0 |
| *Rosa woodsii* | | | | | | | | | | | |
| *Salix scouleriana* | | | | | | | | | | 1.0 | |
| *Shepherdia canadensis* | 0.5 | | 1.3 | 1.0 | 1.0 | 1.5 | 0.5 | 1.0 | 0.5 | 0.5 | 0.5 |
| *Spiraea betulifolia* | 4.3 | 1.1 | 4.3 | 2.8 | 1.0 | 0.5 | 0.5 | 5.0 | 3.2 | 2.0 | 1.3 |
| *Symphoricarpos albus* | 2.0 | 0.5 | 1.0 | | 0.5 | 0.5 | 7.5 | 5.3 | 1.0 | 0.5 | 16.0 |
| **Forbs** | | | | | | | | | | | |
| *Achillea millefolium* | 0.5 | 1.3 | 1.0 | 1.8 | 0.6 | 1.4 | 1.3 | 1.0 | 0.9 | 0.5 | 1.8 |
| *Agoseris glauca* | | | | 0.5 | 0.5 | 0.5 | 1.0 | | 0.5 | | 0.5 |
| *Allium cernum* | 0.5 | | | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | | 0.5 |
| *Anaphilis margaritacea* | | | | 0.5 | | | | | 0.5 | | |
| *Anenome multifida* | | | | | | | | | 0.5 | | |
| *Antennaria microphylla* | 0.5 | | 2.8 | | 0.7 | 0.5 | | 0.5 | 0.5 | | |
| *Antennaria neglecta* | 0.5 | 1.5 | 2.5 | 1.3 | 0.5 | 2.5 | | 0.7 | 0.8 | 0.6 | 0.5 |
| *Antennaria racemosa* | | | | 0.5 | | | | | | | |
| *Apocynum androsaemifolium* | | | | | 0.5 | | | | | | |
| *Arabis holboellii* | | | | | | | | | | | |
| *Arnica cordifolia* | 0.5 | | 0.7 | 1.7 | | 0.5 | | 1.1 | | 1.5 | |
| *Artemisia campestris* | | | | | | | | | | | |
| *Aster conspicuus* | 0.5 | 1.8 | 1.6 | 2.0 | 0.8 | 1.9 | 1.5 | 1.2 | 0.9 | 0.5 | 0.8 |
| *Aster foliaceus* | | | | | | | | | | | 0.5 |
| *Aster laevis* | 0.6 | 3.8 | 1.8 | 2.3 | 3.3 | 5.3 | 9.6 | 0.5 | 0.9 | 0.9 | 0.6 |

| **Site** | **Mud Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Aster sp.* | 0.5 | 6.0 | | | | | 3.0 | 0.7 | | 0.5 | |
| *Astragalus miser* | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | 0.5 | 1.8 | 0.5 | 0.5 |
| *Astragalus spp.* | | | | | | | | | | | |
| *Calochortus apiculatus* | 0.5 | 0.7 | 0.5 | 0.5 | 0.5 | 0.7 | 0.6 | 0.5 | 0.5 | 0.5 | |
| *Campanula rotundifolia* | | | | | | | 0.5 | | | | |
| *Castilleja spp.* | | | | | | | | | | | |
| *Cirsium arvense* | | | | | | | 0.5 | 0.5 | 0.5 | | |
| *Cirsium spp.* | | 1.0 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.2 |
| *Cirsium vulgare* | | 1.0 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.2 |
| *Crepis atribarba* | | | | 0.5 | 0.5 | | | | | | |
| *Disporum trachycarpum* | | | | | | | | | | | |
| *Epilobium angustifolium* | | 0.5 | 0.5 | | | | | 0.5 | 0.5 | | |
| *Epilobium ciliatum* | | | | | | | | 0.5 | | 0.5 | |
| *Epilobium minutum* | | 1.8 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.1 |
| *Erigeron corymbosus* | | | | | | | | | | | 0.5 |
| *Filago arvensis* | | | | | | | | 0.5 | 0.5 | 1.3 | |
| *Fragaria virginiana* | 0.5 | 1.0 | 1.6 | 0.8 | 3.8 | 1.5 | 2.7 | 1.5 | 0.7 | 0.8 | 2.5 |
| *Galium boreale* | | 2.6 | 1.3 | 1.8 | 1.1 | 0.8 | 2.0 | 2.4 | 0.8 | 1.0 | 3.8 |
| *Gentianella propinqua* | | | | | | | | | | | |
| *Gentiannela amarella* | | 0.5 | 0.5 | 0.5 | 0.5 | | | | 0.5 | | |
| *Geum triflorum* | | | | | | | | | | | |
| *Hedysarum sulphurescens* | 0.5 | 0.8 | 0.6 | 1.2 | 1.4 | 1.4 | 1.0 | 1.0 | 1.4 | 0.5 | 0.5 |
| *Heuchera cylindrica* | | | | | | | | | | | |
| *Hieracium albiflorum* | | | 0.5 | | 0.5 | | | | | 0.5 | |
| *Hieracium scouleri* | | | | 0.8 | | | 0.5 | | | | |
| *Hieracium spp* | | | | | | | | | | | |
| *Hieracium umbellatum* | | 0.5 | | | | | | | | | |
| *Lactuca serriola* | | 0.5 | | 0.5 | | 0.5 | 0.5 | | 0.5 | 0.5 | |
| *Lactuca spp* | | | | | | | | | | | |
| *Lappula redowskii* | | | | | | | | | | 0.5 | |
| *Lathyrus ochroleucus* | | | | | | | | | | | |
| *Lilium philadelphicum* | | | | | 0.5 | | 0.5 | | | | |
| *Linnaea borealis* | | | | | | | | | | | |
| *Lithospermum ruderale* | 0.5 | 0.7 | 0.8 | 1.0 | 1.0 | 0.6 | 0.5 | 0.9 | 0.8 | 0.5 | |
| *Lomatium triternatum* | | | | | | | | | | | |
| *Medicago lupulina* | | | | | | | | | | 0.5 | 0.5 |
| *Orthillia secunda* | | | | | | | | | | | |
| *Osmorhiza chilensis* | | | | | | | | | | | |
| *Oxytropis campestris* | | | | | | | | | | | |
| *Penstemon confertus* | 0.5 | 0.5 | | 0.5 | 0.8 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 |
| *Penstemon procerus* | | | | | | | | | | | |

| **Site** | **Mud Creek** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Control** | **OM1C0** | **OM1C1** | **OM1C2** | **OM2C0** | **OM2C1** | **OM2C2** | **OM3C0** | **OM3C1** | **OM3C2** | **Rehab** |
| *Platanthera dilitata* | | | | | | | | | | | |
| *Platanthera orbiculata* | | | | | | | | | | | |
| *Potentilla glandulosa* | | | | | | | | | | | |
| *Pyrola chlorantha* | | | | | | | | | | | |
| *Senecio pauperculus* | | | | | | | | | | | |
| *Senecio pseudaureus* | | | | | | | | | | | |
| *Senecio vulgaris* | | | | | | | | | | | |
| *Silene menziesii* | | 0.8 | 0.5 | 0.5 | 0.5 | | 0.5 | | | | 0.5 |
| *Solidago spathulata* | | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | | | | |
| *Taraxacum officinale* | 0.5 | 0.5 | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.7 | 0.9 |
| *Trapogon dubius* | | 0.5 | 0.5 | | 0.5 | | | 0.5 | | 0.5 | |
| *Trifolium pratense* | | | | | | | | | | | |
| *Trifolium repens* | | | | | | | | | | | |
| *Verbascum thapsus* | | | | | | | | | | | |
| *Viola adunca* | 0.5 | 0.5 | 0.8 | 0.5 | 0.5 | 0.5 | 0.8 | 2.0 | 1.1 | 0.8 | 2.5 |
| *Zigadenus elegans* | | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | | | |
| *Zigadenus venenosus* | | | | | | 0.5 | | | | | |
| **Grasses** | | | | | | | | | | | |
| *Achnatherum occidentalis* | | | | | | | | | | | |
| *Achnatherum richardsonii* | | 1.3 | | 0.8 | 0.5 | | 0.5 | 0.5 | | 0.5 | |
| *Achnatherum spp.* | | | | | | | | | | | |
| *Agoseris spp.* | | | | | | | | | | | |
| *Agropyron trachycaulum* | | | 0.5 | | 0.5 | | | 0.5 | 0.5 | | 0.5 |
| *Agrostis scabra* | | | | | | | 0.5 | | | 0.5 | 2.3 |
| *Agrostis spp.* | | | | | | | | | | | |
| *Calamagrostis rubescens* | 3.8 | 14.3 | 22.0 | 15.5 | 9.0 | 13.3 | 9.0 | 24.0 | 18.3 | 38.0 | 7.3 |
| *Carex spp* | 2.4 | 1.3 | 1.1 | 0.9 | 1.6 | 2.0 | 1.2 | 0.5 | 0.9 | 0.5 | 0.7 |
| *Dactylis glomerata* | | | | | | | | | | | |
| *Danthonia spicata* | | | | | | | | | | | |
| *Elymus glaucus* | | | 0.5 | | 0.5 | | 0.5 | | | | |
| *Elymus trachycaulus* | | 1.0 | 0.5 | | 0.5 | | 0.5 | 0.5 | 0.5 | 0.5 | 2.7 |
| *Festuca campestris* | 0.9 | 3.7 | 4.0 | 1.8 | 6.5 | 2.5 | 5.5 | 1.0 | 1.0 | 1.6 | 0.5 |
| *Festuca idahoensis* | | | | | | | | 0.5 | | | 0.5 |
| *Hordeum jubatum* | | | | | | | | | | | |
| *Koeleria macrantha* | | | | | | | | | | | |
| *Oryzopsis asperifolia* | | | | | | | | 0.5 | | | 0.5 |
| *Phleum pratense* | | | | | | 0.5 | | | | | 0.8 |
| *Poa compressa* | | | | | 0.5 | | | | | | |
| *Poa pratensis* | | | | | | | | 0.8 | | 2.0 | |
| *Poa spp.* | | | 0.8 | | | 2.5 | 2.0 | 4.3 | 0.5 | 0.8 | 8.7 |
| *Pseudoroegneria spicata* | 0.5 | | | | 0.5 | | 7.0 | | | | |

| Site | Mud Creek | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Control | OM1C0 | OM1C1 | OM1C2 | OM2C0 | OM2C1 | OM2C2 | OM3C0 | OM3C1 | OM3C2 | Rehab |
| *Trisetum spp.* | | | | | | | | | | | |
| unknown grass | | | | | | | | | | | |

**Table B.5: Mean percent vegetation cover ± 1 SE at east Kootenay LTSP sites.**

| Total Cover | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 74.50±3.29 | 65.00±4.17 | 68.04±4.16 |
| OM2 | 73.38±6.05 | 74.88±4.83 | 73.92±5.14 |
| OM3 | 50.96±5.33 | 57.04±7.26 | 56.25±5.39 |
| Rehab | 63.79±6.55 | | |
| Control | 40.29±6.66 | | |

| % Shrub Cover | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 22.17±2.85 | 14.08±2.48 | 19.38±2.50 |
| OM2 | 21.67±4.41 | 24.75±3.66 | 23.13±4.06 |
| OM3 | 14.38±2.98 | 16.54±4.13 | 17.38±3.84 |
| Rehab | 17.79±4.15 | | |
| Control | 10.04±1.95 | | |

| % Forbs cover | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 19.54±3.17 | 19.67±1.92 | 24.25±3.30 |
| OM2 | 22.00±3.54 | 27.21±2.78 | 25.71±2.16 |
| OM3 | 15.83±1.84 | 21.29±2.64 | 12.71±1.61 |
| Rehab | 23.25±3.69 | | |
| Control | 6.04±1.40 | | |

| **% Grass Cover** | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 28.08±2.93 | 28.83±4.05 | 21.50±2.61 |
| OM2 | 30.75±3.88 | 22.33±2.20 | 29.96±4.48 |
| OM3 | 19.21±2.50 | 15.29±1.79 | 24.21±4.05 |
| Rehab | 18.42±3.16 | | |
| Control | 6.00±1.14 | | |

| **% Snowberry cover** | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 0.7±0.6 | 1.4±0.6 | 0.4±0.3 |
| OM2 | 1.2±0.8 | 0.4±0.2 | 2.4±1.2 |
| OM3 | 0.9±0.8 | 0.9±0.5 | 2.5±1.8 |
| Rehab | 6.9±2.5 | | |
| Control | 0.4±0.3 | | |

| **% kinnikinnick cover** | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 8.2±1.5 | 3.4±0.9 | 7.5±1.4 |
| OM2 | 5.1±1.3 | 10.0±1.4 | 7.0±1.5 |
| OM3 | 1.4±0.6 | 1.2±0.5 | 1.3±0.4 |
| Rehab | 0.7±0.4 | | |
| Control | 3.0±1.1 | | |

| **% Pinegrass cover** | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 19.08±2.64 | 20.92±5.05 | 13.33±1.97 |
| OM2 | 11.00±1.59 | 14.00±1.66 | 19.58±4.40 |
| OM3 | 15.17±2.36 | 10.50±2.12 | 20.58±3.99 |
| Rehab | 8.08±2.65 | | |
| Control | 3.88±1.04 | | |

| **% Rough fescue cover** | | | |
|---|---|---|---|
| **OM level** | **Compaction level** | | |
| | C0 | C1 | C2 |
| OM1 | 4.71±1.27 | 4.33±1.16 | 4.08±1.00 |
| OM2 | 9.33±2.48 | 3.79±1.21 | 5.25±0.53 |
| OM3 | 1.66±0.63 | 2.20±0.60 | 1.95±0.61 |
| Rehab | 0.50±0.17 | | |
| Control | 0.83±0.41 | | |

## Table B.6: Cover values ± 1 SE for Rehabilitated treatments

| | Rehab | Rehab+OM |
|---|---|---|
| % Total cover | 47.08 ± 9.93 | 71.83 ± 4.22 |
| % Shrub cover | 16.67 ± 5.65 | 18.92 ± 6.57 |
| % Forb cover | 17.50 ± 3.43 | 29.00 ± 5.92 |
| % Grass cover | 12.92 ± 1.42 | 23.92 ± 5.47 |

# Appendix C - Statistical analysis tables

## Total Cover

### General Linear Model: Total_arcsine versus Treat

```
Factor  Type   Levels  Values
Treat   fixed      11  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                       OM3C0, OM3C1, OM3C2, Rehab


Analysis of Variance for Total_arcsine, using Adjusted SS for Tests

Source   DF   Seq SS   Adj SS   Adj MS     F      P
Treat    10  2.36739  2.36739  0.23674  4.06  0.000
Error   121  7.04795  7.04795  0.05825
Total   131  9.41535


S = 0.241345   R-Sq = 25.14%   R-Sq(adj) = 18.96%
```

### General Linear Model: total_arcsin versus Site, OM level, Compaction l

```
Factor            Type    Levels  Values
Site              random       3  Emily, KE, Mud
OM level          fixed        3  OM1, OM2, OM3
Compaction level  fixed        3  C0, C1, C2


Analysis of Variance for total_arcsine, using Adjusted SS for Tests

Source                             DF   Seq SS   Adj SS   Adj MS     F      P
Site                                2  1.87207  1.87207  0.93604  6.97  0.068 x
OM level                            2  0.66658  0.66658  0.33329  2.23  0.223
Compaction level                    2  0.02089  0.02089  0.01044  1.72  0.290
OM level*Compaction level           4  0.06365  0.06365  0.01591  0.76  0.578
Site*OM level                       4  0.59651  0.59651  0.14913  7.14  0.009
Site*Compaction level               4  0.02436  0.02436  0.00609  0.29  0.875
Site*OM level*Compaction level      8  0.16706  0.16706  0.02088  2.35  0.025
Error                              81  0.72016  0.72016  0.00889
Total                             107  4.13128

x Not an exact F-test.


S = 0.0942915   R-Sq = 82.57%   R-Sq(adj) = 76.97%
```

## Shrub Cover

### General Linear Model: Shrub_arcsine versus Treat

```
Factor  Type   Levels  Values
Treat   fixed      11  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                       OM3C0, OM3C1, OM3C2, Rehab
```

```
Analysis of Variance for Shrub_arcsine, using Adjusted SS for Tests

Source   DF   Seq SS   Adj SS   Adj MS     F      P
Treat    10  0.49654  0.49654  0.04965  1.61  0.110
Error   121  3.72219  3.72219  0.03076
Total   131  4.21872

S = 0.175391   R-Sq = 11.77%   R-Sq(adj) = 4.48%
```

## General Linear Model: Shrub_arcsin versus Site, OM level, Compaction l

```
Factor            Type    Levels  Values
Site              random       3  Emily, KE, Mud
OM level          fixed        3  OM1, OM2, OM3
Compaction level  fixed        3  C0, C1, C2


Analysis of Variance for Shrub_arcsine, using Adjusted SS for Tests

Source                             DF   Seq SS   Adj SS   Adj MS      F      P
Site                                2  3.72346  3.72346  1.86173  39.83  0.018
OM level                            2  0.03431  0.03431  0.01715   0.29  0.762
Compaction level                    2  0.00464  0.00464  0.00232   0.18  0.843
OM level*Compaction level           4  0.08075  0.08075  0.02019   0.81  0.555
Site*OM level                       4  0.23510  0.23510  0.05878   2.34  0.142
Site*Compaction level               4  0.05212  0.05212  0.01303   0.52  0.724
Site*OM level*Compaction level      8  0.20052  0.20052  0.02507   2.90  0.007
Error                              81  0.70082  0.70082  0.00865
Total                             107  5.03172


S = 0.0930167   R-Sq = 86.07%   R-Sq(adj) = 81.60%
```

## General Linear Model: Shrub_arcsine versus OM_level

```
Factor    Type   Levels  Values
OM_level  fixed       5  Control, OM1, OM2, OM3, Rehab


Analysis of Variance for Shrub_arcsine, using Adjusted SS for Tests

Source     DF   Seq SS   Adj SS   Adj MS     F      P
OM_level    4  0.37993  0.37993  0.09498  3.14  0.017
Error     127  3.83880  3.83880  0.03023
Total     131  4.21872


S = 0.173858   R-Sq = 9.01%   R-Sq(adj) = 6.14%


Unusual Observations for Shrub_arcsine

Obs  Shrub_arcsine       Fit    SE Fit   Residual  St Resid
  4       0.000000  0.375479  0.050189  -0.375479     -2.26 R
 22       0.000000  0.479812  0.028976  -0.479812     -2.80 R
 24       0.070770  0.479812  0.028976  -0.409042     -2.39 R
 73       0.845543  0.479812  0.028976   0.365731      2.13 R

R denotes an observation with a large standardized residual.
```

```
Tukey Simultaneous Tests
Response Variable Shrub_arcsine
All Pairwise Comparisons among Levels of OM_level
OM_level = Control  subtracted from:

          Difference       SE of           Adjusted
OM_level    of Means  Difference  T-Value   P-Value
OM1          0.12826     0.05795    2.213    0.1815
OM2          0.17619     0.05795    3.040    0.0236
OM3          0.07365     0.05795    1.271    0.7095
Rehab        0.07185     0.07098    1.012    0.8493


OM_level = OM1  subtracted from:

          Difference       SE of           Adjusted
OM_level    of Means  Difference  T-Value   P-Value
OM2          0.04792     0.04098    1.169    0.7687
OM3         -0.05462     0.04098   -1.333    0.6714
Rehab       -0.05641     0.05795   -0.973    0.8667


OM_level = OM2  subtracted from:

          Difference       SE of           Adjusted
OM_level    of Means  Difference  T-Value   P-Value
OM3          -0.1025     0.04098   -2.502    0.0966
Rehab        -0.1043     0.05795   -1.800    0.3780


OM_level = OM3  subtracted from:

          Difference       SE of            Adjusted
OM_level    of Means  Difference   T-Value   P-Value
Rehab      -0.001794     0.05795  -0.03096     1.000
```

## General Linear Model: spirbet_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for spirbet_arcsine, using Adjusted SS for Tests

Source                     DF    Seq SS    Adj SS    Adj MS      F      P
Site                        2  0.408412  0.408412  0.204206  15.04  0.011 x
OM_level                    2  0.016442  0.016442  0.008221   1.38  0.349
Comp_level                  2  0.028061  0.028061  0.014030   1.25  0.378
OM_level*Comp_level         4  0.014765  0.014765  0.003691   1.04  0.444
Site*OM_level               4  0.023767  0.023767  0.005942   1.67  0.248
Site*Comp_level             4  0.044752  0.044752  0.011188   3.15  0.078
Site*OM_level*Comp_level    8  0.028387  0.028387  0.003548   0.76  0.634
Error                      81  0.375765  0.375765  0.004639
Total                     107  0.940350

x Not an exact F-test.


S = 0.0681108   R-Sq = 60.04%   R-Sq(adj) = 47.21%
```

## General Linear Model: amelaln_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for amelaln_arcsine, using Adjusted SS for Tests

Source                      DF    Seq SS    Adj SS    Adj MS      F      P
Site                         2  1.263125  1.263125  0.631562  20.02  0.021 x
OM_level                     2  0.062115  0.062115  0.031057   0.84  0.497
Comp_level                   2  0.004210  0.004210  0.002105   1.15  0.402
OM_level*Comp_level          4  0.055973  0.055973  0.013993   1.89  0.205
Site*OM_level                4  0.148417  0.148417  0.037104   5.02  0.025
Site*Comp_level              4  0.007291  0.007291  0.001823   0.25  0.904
Site*OM_level*Comp_level     8  0.059093  0.059093  0.007387   1.21  0.305
Error                       81  0.495351  0.495351  0.006115
Total                      107  2.095574

S = 0.0782013   R-Sq = 76.36%   R-Sq(adj) = 68.77%
```

## General Linear Model: rosa_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for rosa_arcsine, using Adjusted SS for Tests

Source                      DF    Seq SS    Adj SS    Adj MS      F      P
Site                         2  0.465240  0.465240  0.232620  12.99  0.145 x
OM_level                     2  0.016586  0.016586  0.008293   0.32  0.743
Comp_level                   2  0.004589  0.004589  0.002295   0.19  0.833
OM_level*Comp_level          4  0.018528  0.018528  0.004632   0.23  0.914
Site*OM_level                4  0.103828  0.103828  0.025957   1.29  0.350
Site*Comp_level              4  0.048129  0.048129  0.012032   0.60  0.674
Site*OM_level*Comp_level     8  0.160708  0.160708  0.020089   2.24  0.033
Error                       81  0.727393  0.727393  0.008980
Total                      107  1.545002

S = 0.0947637   R-Sq = 52.92%   R-Sq(adj) = 37.81%
```

## General Linear Model: shpecan_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for shpecan_arcsine, using Adjusted SS for Tests

Source                      DF    Seq SS    Adj SS    Adj MS     F      P
Site                         2  0.325515  0.325515  0.162758  5.53  0.061 x
```

```
OM_level                   2  0.011984  0.011984  0.005992  0.31  0.751
Comp_level                 2  0.029405  0.029405  0.014702  0.78  0.516
OM_level*Comp_level        4  0.029594  0.029594  0.007399  0.84  0.536
Site*OM_level              4  0.077807  0.077807  0.019452  2.21  0.157
Site*Comp_level            4  0.075010  0.075010  0.018752  2.13  0.168
Site*OM_level*Comp_level   8  0.070278  0.070278  0.008785  1.08  0.383
Error                     81  0.656835  0.656835  0.008109
Total                    107  1.276429

S = 0.0900504   R-Sq = 48.54%   R-Sq(adj) = 32.02%
```

## General Linear Model: sympalb_arcsine versus Treatment

```
Factor     Type   Levels  Values
Treatment  fixed      12  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                          OM3C0, OM3C1, OM3C2, Rehab, Rehab OM+


Analysis of Variance for sympalb_arcsine, using Adjusted SS for Tests

Source      DF   Seq SS   Adj SS   Adj MS     F      P
Treatment   11  0.29908  0.29908  0.02719  2.31  0.013
Error      120  1.41054  1.41054  0.01175
Total      131  1.70962


S = 0.108418   R-Sq = 17.49%   R-Sq(adj) = 9.93%
```

## General Linear Model: sympalb_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for sympalb_arcsine, using Adjusted SS for Tests

Source                    DF    Seq SS    Adj SS    Adj MS     F      P
Site                       2  0.304981  0.304981  0.152490    **
OM_level                   2  0.008507  0.008507  0.004254  2.26  0.221
Comp_level                 2  0.006523  0.006523  0.003262  0.81  0.507
OM_level*Comp_level        4  0.035951  0.035951  0.008988  0.74  0.592
Site*OM_level              4  0.007539  0.007539  0.001885  0.15  0.956
Site*Comp_level            4  0.016113  0.016113  0.004028  0.33  0.850
Site*OM_level*Comp_level   8  0.097542  0.097542  0.012193  1.78  0.092
Error                     81  0.553386  0.553386  0.006832
Total                    107  1.030542

S = 0.0826555   R-Sq = 46.30%   R-Sq(adj) = 29.06%
```

## General Linear Model: arctuva_arcsine versus Treatment

```
Factor     Type   Levels  Values
Treatment  fixed      12  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                          OM3C0, OM3C1, OM3C2, Rehab, Rehab OM+


Analysis of Variance for arctuva_arcsine, using Adjusted SS for Tests
```

```
Source      DF    Seq SS    Adj SS    Adj MS      F      P
Treatment   11  0.966781  0.966781  0.087889  10.44  0.000
Error      120  1.010050  1.010050  0.008417
Total      131  1.976830


S = 0.0917447   R-Sq = 48.91%   R-Sq(adj) = 44.22%

Tukey Simultaneous Tests
Response Variable arctuva_arcsine
All Pairwise Comparisons among Levels of Treatment
Treatment = Control  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM1C0         0.13787     0.03745    3.681    0.0174
OM1C1         0.02220     0.03745    0.593    1.0000
OM1C2         0.12730     0.03745    3.399    0.0414
OM2C0         0.06012     0.03745    1.605    0.9040
OM2C1         0.17329     0.03745    4.627    0.0006
OM2C2         0.11276     0.03745    3.011    0.1184
OM3C0        -0.04293     0.03745   -1.146    0.9918
OM3C1        -0.05279     0.03745   -1.409    0.9595
OM3C2        -0.04110     0.03745   -1.097    0.9943
Rehab        -0.07293     0.04587   -1.590    0.9095
Rehab OM+    -0.09872     0.04587   -2.152    0.5871


Treatment = OM1C0  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM1C1         -0.1157     0.03745   -3.088    0.0974
OM1C2         -0.0106     0.03745   -0.282    1.0000
OM2C0         -0.0778     0.03745   -2.076    0.6406
OM2C1          0.0354     0.03745    0.946    0.9985
OM2C2         -0.0251     0.03745   -0.671    0.9999
OM3C0         -0.1808     0.03745   -4.827    0.0003
OM3C1         -0.1907     0.03745   -5.091    0.0001
OM3C2         -0.1790     0.03745   -4.778    0.0003
Rehab         -0.2108     0.04587   -4.595    0.0007
Rehab OM+     -0.2366     0.04587   -5.158    0.0001


Treatment = OM1C1  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM1C2          0.1051     0.03745    2.806    0.1910
OM2C0          0.0379     0.03745    1.012    0.9972
OM2C1          0.1511     0.03745    4.034    0.0053
OM2C2          0.0906     0.03745    2.418    0.4026
OM3C0         -0.0651     0.03745   -1.739    0.8464
OM3C1         -0.0750     0.03745   -2.002    0.6910
OM3C2         -0.0633     0.03745   -1.690    0.8693
Rehab         -0.0951     0.04587   -2.074    0.6421
Rehab OM+     -0.1209     0.04587   -2.636    0.2721


Treatment = OM1C2  subtracted from:

           Difference       SE of           Adjusted
```

```
Treatment    of Means  Difference  T-Value   P-Value
OM2C0         -0.0672     0.03745   -1.794    0.8183
OM2C1          0.0460     0.03745    1.228    0.9857
OM2C2         -0.0145     0.03745   -0.388    1.0000
OM3C0         -0.1702     0.03745   -4.545    0.0008
OM3C1         -0.1801     0.03745   -4.808    0.0003
OM3C2         -0.1684     0.03745   -4.496    0.0010
Rehab         -0.2002     0.04587   -4.365    0.0016
Rehab OM+     -0.2260     0.04587   -4.927    0.0002


Treatment = OM2C0  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM2C1          0.1132     0.03745    3.021    0.1153
OM2C2          0.0526     0.03745    1.405    0.9604
OM3C0         -0.1030     0.03745   -2.751    0.2150
OM3C1         -0.1129     0.03745   -3.015    0.1173
OM3C2         -0.1012     0.03745   -2.702    0.2381
Rehab         -0.1330     0.04587   -2.900    0.1543
Rehab OM+     -0.1588     0.04587   -3.463    0.0343


Treatment = OM2C1  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM2C2         -0.0605     0.03745   -1.616    0.8999
OM3C0         -0.2162     0.03745   -5.773    0.0000
OM3C1         -0.2261     0.03745   -6.036    0.0000
OM3C2         -0.2144     0.03745   -5.724    0.0000
Rehab         -0.2462     0.04587   -5.367    0.0001
Rehab OM+     -0.2720     0.04587   -5.930    0.0000


Treatment = OM2C2  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM3C0         -0.1557     0.03745   -4.157    0.0034
OM3C1         -0.1655     0.03745   -4.420    0.0013
OM3C2         -0.1539     0.03745   -4.108    0.0041
Rehab         -0.1857     0.04587   -4.048    0.0051
Rehab OM+     -0.2115     0.04587   -4.610    0.0006


Treatment = OM3C0  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM3C1        -0.00986     0.03745   -0.263    1.0000
OM3C2         0.00183     0.03745    0.049    1.0000
Rehab        -0.03000     0.04587   -0.654    1.0000
Rehab OM+    -0.05579     0.04587   -1.216    0.9867


Treatment = OM3C1  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
OM3C2         0.01169     0.03745    0.312    1.0000
Rehab        -0.02014     0.04587   -0.439    1.0000
```

```
Rehab OM+    -0.04593     0.04587   -1.001    0.9974


Treatment = OM3C2  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
Rehab        -0.03183     0.04587   -0.694    0.9999
Rehab OM+    -0.05762     0.04587   -1.256    0.9828


Treatment = Rehab  subtracted from:

           Difference       SE of           Adjusted
Treatment    of Means  Difference  T-Value   P-Value
Rehab OM+    -0.02579     0.05297  -0.4869     1.000
```

## General Linear Model: arctuva_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for arctuva_arcsine, using Adjusted SS for Tests

Source                      DF    Seq SS    Adj SS    Adj MS      F      P
Site                         2  0.125985  0.125985  0.062992   7.47  0.280 x
OM_level                     2  0.555552  0.555552  0.277776  19.74  0.008
Comp_level                   2  0.006994  0.006994  0.003497   0.51  0.635
OM_level*Comp_level          4  0.169069  0.169069  0.042267   3.38  0.067
Site*OM_level                4  0.056279  0.056279  0.014070   1.13  0.409
Site*Comp_level              4  0.027402  0.027402  0.006851   0.55  0.706
Site*OM_level*Comp_level     8  0.099898  0.099898  0.012487   1.99  0.058
Error                       81  0.507642  0.507642  0.006267
Total                      107  1.548820

x Not an exact F-test.


S = 0.0791656   R-Sq = 67.22%   R-Sq(adj) = 56.70%
```

## Forb Cover

## General Linear Model: forb_arcsine versus Treat, Year

```
Factor  Type   Levels  Values
Treat   fixed      11  OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0, OM3C1,
                       OM3C2, Rehab, Rehab OM+
Year    fixed       2  0, 5


Analysis of Variance for forb_arcsine, using Adjusted SS for Tests

Source        DF   Seq SS   Adj SS   Adj MS      F      P
Treat         10  0.23012  0.23012  0.02301   2.14  0.023
Year           1  0.76960  0.78040  0.78040  72.45  0.000
Treat*Year    10  0.32391  0.32391  0.03239   3.01  0.001
Error        218  2.34806  2.34806  0.01077
Total        239  3.67168
```

```
S = 0.103783   R-Sq = 36.05%   R-Sq(adj) = 29.89%
```

### General Linear Model: forb_arcsine versus Site, OM level, Compaction l

```
Factor            Type    Levels  Values
Site              random       3  Emily, KE, Mud
OM level          fixed        3  OM1, OM2, OM3
Compaction level  fixed        3  C0, C1, C2


Analysis of Variance for forb_arcsine, using Adjusted SS for Tests

Source                            DF    Seq SS    Adj SS    Adj MS      F
Site                               2  0.344342  0.344342  0.172171  10.61
OM level                           2  0.350622  0.350622  0.175311  22.86
Compaction level                   2  0.032740  0.032740  0.016370   0.60
OM level*Compaction level          4  0.125772  0.125772  0.031443   1.69
Site*OM level                      4  0.030675  0.030675  0.007669   0.41
Site*Compaction level              4  0.108484  0.108484  0.027121   1.46
Site*OM level*Compaction level     8  0.148542  0.148542  0.018568   2.81
Error                             81  0.535706  0.535706  0.006614
Total                            107  1.676883

Source                               P
Site                             0.193 x
OM level                         0.006
Compaction level                 0.590
OM level*Compaction level        0.244
Site*OM level                    0.795
Site*Compaction level            0.300
Site*OM level*Compaction level   0.008
Error
Total
```

## Grass Cover

### General Linear Model: Grass_arcsine versus Treat

```
Factor  Type   Levels  Values
Treat   fixed      12  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                       OM3C0, OM3C1, OM3C2, Rehab, Rehab OM+


Analysis of Variance for Grass_arcsine, using Adjusted SS for Tests

Source   DF   Seq SS   Adj SS   Adj MS     F      P
Treat    11  1.24611  1.24611  0.11328  7.12  0.000
Error   120  1.90928  1.90928  0.01591
Total   131  3.15539


S = 0.126138   R-Sq = 39.49%   R-Sq(adj) = 33.94%
```

### General Linear Model: grass_arcsin versus Site, OM level, Compaction l

```
Factor             Type    Levels  Values
Site               random       3  Emily, KE, Mud
OM level           fixed        3  OM1, OM2, OM3
Compaction level   fixed        3  C0, C1, C2


Analysis of Variance for grass_arcsine, using Adjusted SS for Tests

Source                            DF    Seq SS    Adj SS    Adj MS     F
Site                               2  0.020330  0.020330  0.010165  0.08
OM level                           2  0.198236  0.198236  0.099118  0.70
Compaction level                   2  0.039820  0.039820  0.019910  0.86
OM level*Compaction level          4  0.134899  0.134899  0.033725  0.81
Site*OM level                      4  0.564424  0.564424  0.141106  3.37
Site*Compaction level              4  0.092446  0.092446  0.023112  0.55
Site*OM level*Compaction level     8  0.335095  0.335095  0.041887  5.04
Error                             81  0.673188  0.673188  0.008311
Total                            107  2.058438

Source                              P
Site                            0.922 x
OM level                        0.548
Compaction level                0.489
OM level*Compaction level       0.555
Site*OM level                   0.068
Site*Compaction level           0.704
Site*OM level*Compaction level  0.000
Error
Total

x Not an exact F-test.


S = 0.0911645   R-Sq = 67.30%   R-Sq(adj) = 56.80%
```

## Pinegrass

### General Linear Model: calarub_arcsine versus Treatment

```
Factor     Type   Levels  Values
Treatment  fixed      12  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                          OM3C0, OM3C1, OM3C2, Rehab, Rehab OM+


Analysis of Variance for calarub_arcsine, using Adjusted SS for Tests

Source      DF   Seq SS   Adj SS   Adj MS     F      P
Treatment   11  0.88567  0.88567  0.08052  4.00  0.000
Error      120  2.41699  2.41699  0.02014
Total      131  3.30266


S = 0.141921   R-Sq = 26.82%   R-Sq(adj) = 20.11%
```

### General Linear Model: calarub_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
```

```
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for calarub_arcsine, using Adjusted SS for Tests

Source                     DF    Seq SS    Adj SS    Adj MS     F      P
Site                        2  0.294371  0.294371  0.147186  1.35  0.386 x
OM_level                    2  0.023588  0.023588  0.011794  0.10  0.908
Comp_level                  2  0.034240  0.034240  0.017120  0.47  0.654
OM_level*Comp_level         4  0.196274  0.196274  0.049068  1.06  0.435
Site*OM_level               4  0.476839  0.476839  0.119210  2.58  0.118
Site*Comp_level             4  0.144840  0.144840  0.036210  0.78  0.567
Site*OM_level*Comp_level    8  0.369844  0.369844  0.046231  4.71  0.000
Error                      81  0.795184  0.795184  0.009817
Total                     107  2.335180

x Not an exact F-test.


S = 0.0990812   R-Sq = 65.95%   R-Sq(adj) = 55.02%
```

## Rough Fescue

### General Linear Model: festcam_arcsine versus Treatment

```
Factor     Type   Levels  Values
Treatment  fixed      12  Control, OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2,
                          OM3C0, OM3C1, OM3C2, Rehab, Rehab OM+


Analysis of Variance for festcam_arcsine, using Adjusted SS for Tests

Source      DF    Seq SS    Adj SS    Adj MS     F      P
Treatment   11  0.617607  0.617607  0.056146  6.23  0.000
Error      120  1.082068  1.082068  0.009017
Total      131  1.699675


S = 0.0949591   R-Sq = 36.34%   R-Sq(adj) = 30.50%
```

### General Linear Model: festcam_arcsine versus Site, OM_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
OM_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for festcam_arcsine, using Adjusted SS for Tests

Source                     DF    Seq SS    Adj SS    Adj MS     F      P
Site                        2  0.117912  0.117912  0.058956    **
OM_level                    2  0.237957  0.237957  0.118979  9.38  0.031
Comp_level                  2  0.021860  0.021860  0.010930  1.81  0.275
OM_level*Comp_level         4  0.086597  0.086597  0.021649  0.88  0.518
Site*OM_level               4  0.050755  0.050755  0.012689  0.51  0.728
Site*Comp_level             4  0.024139  0.024139  0.006035  0.24  0.905
Site*OM_level*Comp_level    8  0.197283  0.197283  0.024660  3.26  0.003
```

```
Error                       81  0.611905  0.611905  0.007554
Total                      107  1.348408

** Denominator of F-test is zero.


S = 0.0869160   R-Sq = 54.62%   R-Sq(adj) = 40.05%
```

## Rehabilitated site analysis

### General Linear Model: calarub_arcs, festcam_arcs, ... versus Site, OM_level

```
Factor    Type    Levels  Values
Site      random       3  Emily, KE, Mud
OM_level  fixed        5  OM1, OM2, OM3, Rehab, Rehab OM+


Analysis of Variance for calarub_arcsine, using Adjusted SS for Tests

Source         DF   Seq SS   Adj SS   Adj MS     F      P
Site            2  0.02612  0.02668  0.01334  0.18  0.837 x
OM_level        4  0.29530  0.29530  0.07382  0.93  0.492
Site*OM_level   8  0.63417  0.63417  0.07927  6.07  0.000
Error          33  0.43118  0.43118  0.01307
Total          47  1.38677

x Not an exact F-test.


S = 0.114307   R-Sq = 68.91%   R-Sq(adj) = 55.72%


Analysis of Variance for festcam_arcsine, using Adjusted SS for Tests

Source         DF    Seq SS    Adj SS    Adj MS     F      P
Site            2  0.075180  0.065137  0.032569  5.94  0.022 x
OM_level        4  0.209033  0.209033  0.052258  9.33  0.004
Site*OM_level   8  0.044821  0.044821  0.005603  1.34  0.261
Error          33  0.138439  0.138439  0.004195
Total          47  0.467474

x Not an exact F-test.


S = 0.0647699   R-Sq = 70.39%   R-Sq(adj) = 57.82%


Analysis of Variance for sympalb_arcsine, using Adjusted SS for Tests

Source         DF   Seq SS   Adj SS   Adj MS     F      P
Site            2  0.24277  0.31240  0.15620  4.74  0.042 x
OM_level        4  0.20007  0.20007  0.05002  1.43  0.309
Site*OM_level   8  0.28026  0.28026  0.03503  3.25  0.008
Error          33  0.35527  0.35527  0.01077
Total          47  1.07836

x Not an exact F-test.


S = 0.103757   R-Sq = 67.06%   R-Sq(adj) = 53.08%
```

```
Analysis of Variance for shpecan_arcsine, using Adjusted SS for Tests

Source          DF    Seq SS    Adj SS    Adj MS     F      P
Site             2  0.187109  0.100014  0.050007  4.50  0.046 x
OM_level         4  0.084683  0.084683  0.021171  1.81  0.220
Site*OM_level    8  0.093386  0.093386  0.011673  2.24  0.049
Error           33  0.171808  0.171808  0.005206
Total           47  0.536986

x Not an exact F-test.


S = 0.0721547   R-Sq = 68.01%   R-Sq(adj) = 54.43%


Analysis of Variance for spirbet_arcsine, using Adjusted SS for Tests

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Site             2  0.219832  0.240071  0.120035  13.66  0.002 x
OM_level         4  0.020482  0.020482  0.005120   0.55  0.705
Site*OM_level    8  0.074465  0.074465  0.009308   2.85  0.016
Error           33  0.107751  0.107751  0.003265
Total           47  0.422529

x Not an exact F-test.


S = 0.0571418   R-Sq = 74.50%   R-Sq(adj) = 63.68%


Analysis of Variance for amelaln_arcsine, using Adjusted SS for Tests

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Site             2  0.434675  0.361155  0.180578  21.89  0.000 x
OM_level         4  0.019155  0.019155  0.004789   0.56  0.699
Site*OM_level    8  0.068573  0.068573  0.008572   1.78  0.118
Error           33  0.159274  0.159274  0.004826
Total           47  0.681677

x Not an exact F-test.


S = 0.0694728   R-Sq = 76.64%   R-Sq(adj) = 66.72%


Analysis of Variance for rosa_arcsine, using Adjusted SS for Tests

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Site             2  0.403718  0.385055  0.192528  15.87  0.001 x
OM_level         4  0.039720  0.039720  0.009930   0.78  0.568
Site*OM_level    8  0.101702  0.101702  0.012713   2.13  0.061
Error           33  0.196845  0.196845  0.005965
Total           47  0.741985

x Not an exact F-test.


S = 0.0772335   R-Sq = 73.47%   R-Sq(adj) = 62.22%


Analysis of Variance for arctuva_arcsine, using Adjusted SS for Tests
```

```
Source          DF    Seq SS    Adj SS    Adj MS     F      P
Site             2  0.022602  0.009223  0.004611  0.41  0.679 x
OM_level         4  0.419282  0.419282  0.104820  8.79  0.005
Site*OM_level    8  0.095446  0.095446  0.011931  2.22  0.052
Error           33  0.177654  0.177654  0.005383
Total           47  0.714984

x Not an exact F-test.


S = 0.0733721   R-Sq = 75.15%   R-Sq(adj) = 64.61%
```

## Paired T-Test and CI: % Total cover-Rehab, % Total cover-Rehab+OM

```
Paired T for % Total cover-Rehab - % Total cover-Rehab+OM

                  N      Mean    StDev  SE Mean
% Total cover-Re  6   47.0833  24.3340   9.9343
% Total cover-Re  6   71.8333  10.3425   4.2223
Difference        6  -24.7500  26.9309  10.9945


95% CI for mean difference: (-53.0123, 3.5123)
T-Test of mean difference = 0 (vs not = 0): T-Value = -2.25  P-Value = 0.074
```

## Paired T-Test and CI: % Shrub cover-Rehab, % Shrub cover-Rehab+OM

```
Paired T for % Shrub cover-Rehab - % Shrub cover-Rehab+OM

                  N      Mean     StDev  SE Mean
% Shrub cover-Re  6   16.6667   13.8516   5.6549
% Shrub cover-Re  6   18.9167   16.0886   6.5681
Difference        6  -2.25000  11.71644  4.78322


95% CI for mean difference: (-14.54565, 10.04565)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.47  P-Value = 0.658
```

## Paired T-Test and CI: % Forb cover-Rehab, % Forb cover-Rehab+OM

```
Paired T for % Forb cover-Rehab - % Forb cover-Rehab+OM

                  N      Mean    StDev  SE Mean
% Forb cover-Reh  6   17.5000   8.4024   3.4303
% Forb cover-Reh  6   29.0000  14.5052   5.9217
Difference        6  -11.5000  18.2975   7.4699


95% CI for mean difference: (-30.7021, 7.7021)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.54  P-Value = 0.184
```

## Paired T-Test and CI: % Grass cover-Rehab, % Grass cover-Rehab+OM

```
Paired T for % Grass cover-Rehab - % Grass cover-Rehab+OM

                  N      Mean    StDev  SE Mean
% Grass cover-Re  6   12.9167   3.4701   1.4167
% Grass cover-Re  6   23.9167  13.3993   5.4702
Difference        6  -11.0000  14.5327   5.9330


95% CI for mean difference: (-26.2512, 4.2512)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.85  P-Value = 0.123
```

## Between-years analysis

## General Linear Model: total_arcsine versus Treat, Year

```
Factor  Type   Levels  Values
Treat   fixed      10  OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0, OM3C1,
                       OM3C2, Rehab
Year    fixed       2  0, 5


Analysis of Variance for total_arcsine, using Adjusted SS for Tests

Source       DF    Seq SS    Adj SS   Adj MS      F      P
Treat         9   1.12198   1.12198  0.12466   2.26  0.020
Year          1   0.83364   0.83364  0.83364  15.11  0.000
Treat*Year    9   1.46255   1.46255  0.16251   2.94  0.003
Error       220  12.14144  12.14144  0.05519
Total       239  15.55961


S = 0.234922   R-Sq = 21.97%   R-Sq(adj) = 15.23%
```

## General Linear Model: shrub_arcsine versus Treat, Year

```
Factor  Type   Levels  Values
Treat   fixed      10  OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0, OM3C1,
                       OM3C2, Rehab
Year    fixed       2  0, 5


Analysis of Variance for shrub_arcsine, using Adjusted SS for Tests

Source       DF   Seq SS   Adj SS   Adj MS     F      P
Treat         9  0.38067  0.38067  0.04230  1.74  0.082
Year          1  0.00031  0.00031  0.00031  0.01  0.911
Treat*Year    9  0.32543  0.32543  0.03616  1.49  0.155
Error       220  5.35550  5.35550  0.02434
Total       239  6.06191


S = 0.156023   R-Sq = 11.65%   R-Sq(adj) = 4.02%
```

## General Linear Model: forb_arcsine versus Treat, Year

```
Factor  Type   Levels  Values
```

```
Treat   fixed      10  OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0, OM3C1,
                       OM3C2, Rehab
Year    fixed       2  0, 5


Analysis of Variance for forb_arcsine, using Adjusted SS for Tests

Source       DF   Seq SS   Adj SS   Adj MS      F      P
Treat         9  0.19505  0.19505  0.02167   1.98  0.042
Year          1  0.76960  0.76960  0.76960  70.41  0.000
Treat*Year    9  0.30243  0.30243  0.03360   3.07  0.002
Error       220  2.40460  2.40460  0.01093
Total       239  3.67168

S = 0.104547   R-Sq = 34.51%   R-Sq(adj) = 28.85%
```

## General Linear Model: grass_arcsine versus Treat, Year

```
Factor  Type   Levels  Values
Treat   fixed      10  OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0, OM3C1,
                       OM3C2, Rehab
Year    fixed       2  0, 5


Analysis of Variance for grass_arcsine, using Adjusted SS for Tests

Source       DF   Seq SS   Adj SS   Adj MS      F      P
Treat         9  0.31983  0.31983  0.03554   1.95  0.046
Year          1  1.74902  1.74902  1.74902  96.19  0.000
Treat*Year    9  0.50143  0.50143  0.05571   3.06  0.002
Error       220  4.00036  4.00036  0.01818
Total       239  6.57063


S = 0.134846   R-Sq = 39.12%   R-Sq(adj) = 33.86%
```

## General Linear Model: festcam_arcsine versus Treatment, Year

```
Factor     Type   Levels  Values
Treatment  fixed      10  OM1C0, OM1C1, OM1C2, OM2C0, OM2C1, OM2C2, OM3C0,
                          OM3C1, OM3C2, Rehab
Year       fixed       2  0, 5


Analysis of Variance for festcam_arcsine, using Adjusted SS for Tests

Source           DF    Seq SS    Adj SS    Adj MS       F      P
Treatment         9  0.231412  0.231412  0.025712    4.23  0.000
Year              1  0.937529  0.937529  0.937529  154.22  0.000
Treatment*Year    9  0.317098  0.317098  0.035233    5.80  0.000
Error           220  1.337447  1.337447  0.006079
Total           239  2.823486


S = 0.0779699   R-Sq = 52.63%   R-Sq(adj) = 48.54%
```

### Species Richness

## General Linear Model: Species Richness versus Site, OM level, Comp level

```
Factor      Type    Levels  Values
```

```
Site        random       3  Emily, KE, Mud
OM level    fixed        3  OM1, OM2, OM3
Comp level  fixed        3  C0, C1, C2


Analysis of Variance for Species Richness_5, using Adjusted SS for Tests

Source                      DF   Seq SS   Adj SS  Adj MS     F      P
Site                         2   465.35   465.35  232.68  3.05  0.220 x
OM level                     2    65.24    65.24   32.62  0.34  0.728
Comp level                   2    34.30    34.30   17.15  1.18  0.397
OM level*Comp level          4    93.15    93.15   23.29  0.70  0.612
Site*OM level                4   379.43   379.43   94.86  2.86  0.096
Site*Comp level              4    58.37    58.37   14.59  0.44  0.777
Site*OM level*Comp level     8   265.52   265.52   33.19  2.67  0.012
Error                       81  1006.75  1006.75   12.43
Total                      107  2368.10

x Not an exact F-test.


S = 3.52548   R-Sq = 57.49%   R-Sq(adj) = 43.84%
```

## Species Diversity

### General Linear Model: H_Total versus Site, Om_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
Om_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for H_Total, using Adjusted SS for Tests

Source                      DF    Seq SS   Adj SS   Adj MS     F      P
Site                         2   0.67586  0.67586  0.33793  1.34  0.516 x
Om_level                     2   0.49434  0.49434  0.24717  0.56  0.610
Comp_level                   2   0.08881  0.08881  0.04441  0.46  0.662
Om_level*Comp_level          4   1.37337  1.37337  0.34334  1.20  0.382
Site*Om_level                4   1.76513  1.76513  0.44128  1.54  0.279
Site*Comp_level              4   0.38841  0.38841  0.09710  0.34  0.845
Site*Om_level*Comp_level     8   2.29242  2.29242  0.28655  5.36  0.000
Error                       81   4.32965  4.32965  0.05345
Total                      107  11.40799

x Not an exact F-test.


S = 0.231198   R-Sq = 62.05%   R-Sq(adj) = 49.86%
```

### General Linear Model: H_Shrubs versus Site, Om_level, Comp_level

```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
Om_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2
```

```
Analysis of Variance for H_Shrubs, using Adjusted SS for Tests

Source                      DF   Seq SS   Adj SS   Adj MS       F      P
Site                         2  37.0636  37.0636  18.5318  354.95  0.150 x
Om_level                     2   0.0138   0.0138   0.0069    0.15  0.861
Comp_level                   2   0.1831   0.1831   0.0916    0.80  0.510
Om_level*Comp_level          4   0.2671   0.2671   0.0668    0.63  0.657
Site*Om_level                4   0.1779   0.1779   0.0445    0.42  0.792
Site*Comp_level              4   0.4573   0.4573   0.1143    1.07  0.430
Site*Om_level*Comp_level     8   0.8526   0.8526   0.1066    1.97  0.060
Error                       81   4.3786   4.3786   0.0541
Total                      107  43.3940

x Not an exact F-test.


S = 0.232502   R-Sq = 89.91%   R-Sq(adj) = 86.67%
```

## General Linear Model: H_Forbs versus Site, Om_level, Comp_level

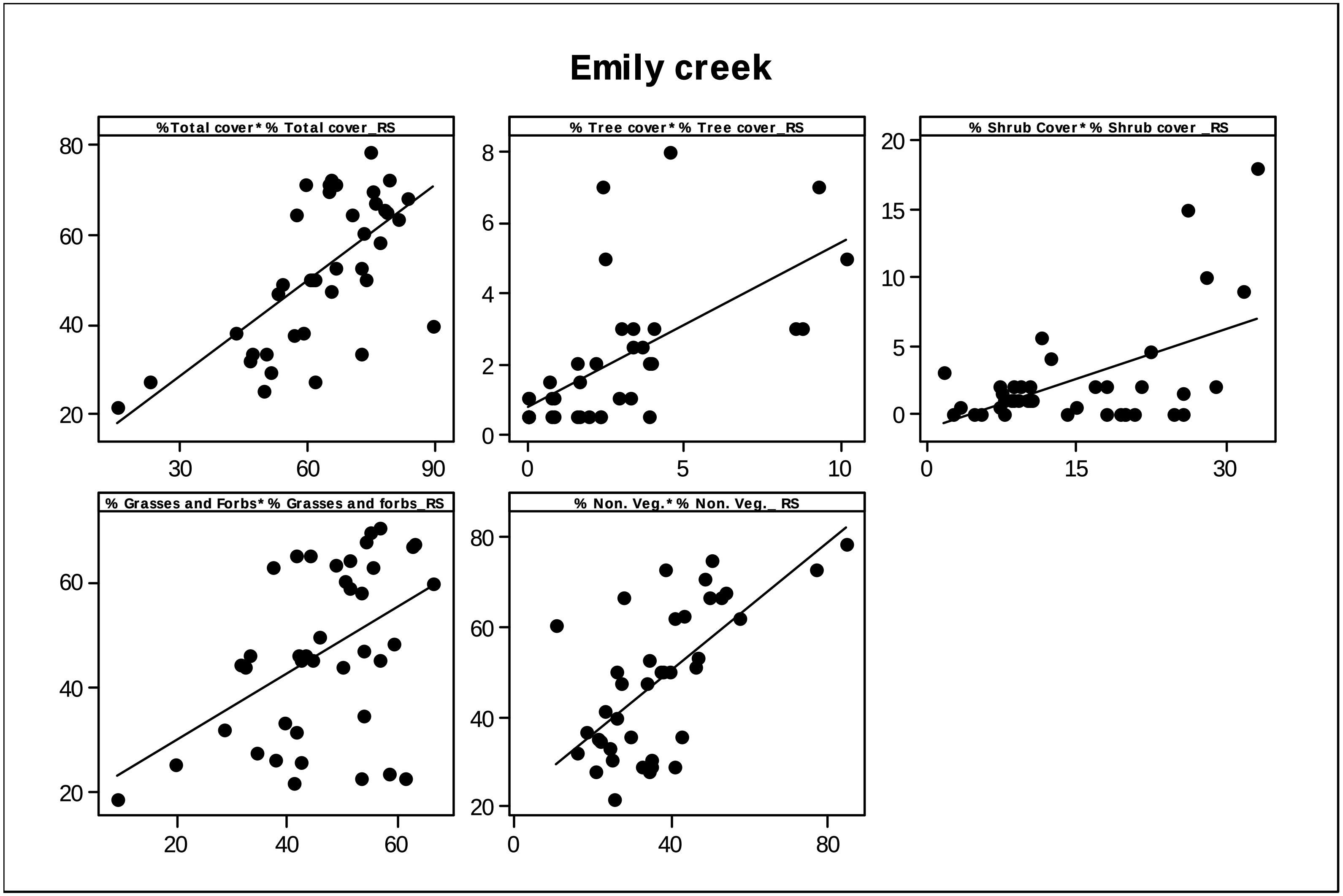
```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
Om_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for H_Forbs, using Adjusted SS for Tests

Source                      DF    Seq SS   Adj SS   Adj MS      F      P
Site                         2   4.17477  4.17477  2.08739  12.83  0.173 x
Om_level                     2   1.11134  1.11134  0.55567   2.30  0.217
Comp_level                   2   0.30694  0.30694  0.15347   1.21  0.389
Om_level*Comp_level          4   1.22152  1.22152  0.30538   1.48  0.295
Site*Om_level                4   0.96806  0.96806  0.24201   1.17  0.392
Site*Comp_level              4   0.50889  0.50889  0.12722   0.62  0.663
Site*Om_level*Comp_level     8   1.65253  1.65253  0.20657   3.92  0.001
Error                       81   4.26577  4.26577  0.05266
Total                      107  14.20983

x Not an exact F-test.


S = 0.229486   R-Sq = 69.98%   R-Sq(adj) = 60.34%
```

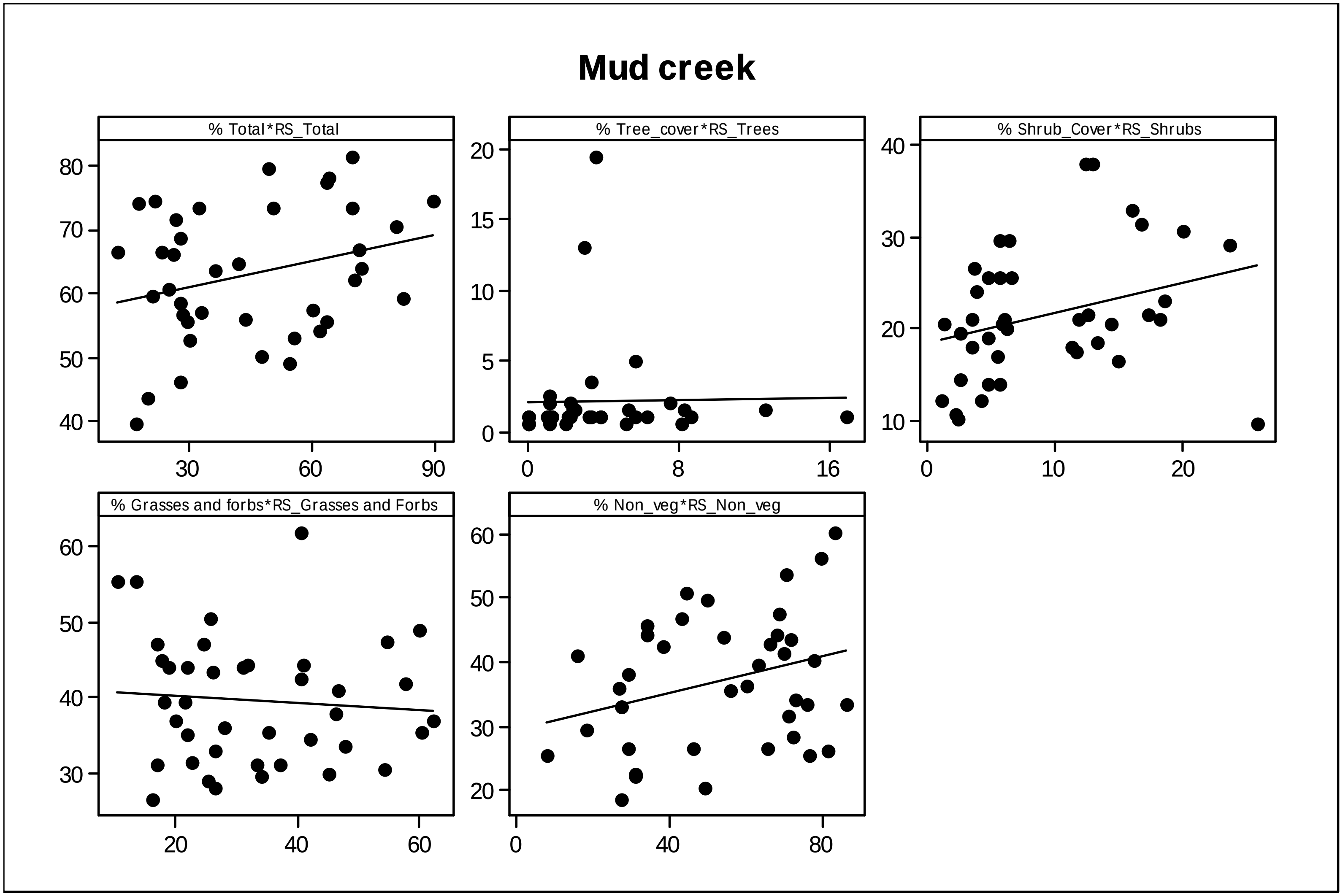
## General Linear Model: H_Grasses versus Site, Om_level, Comp_level

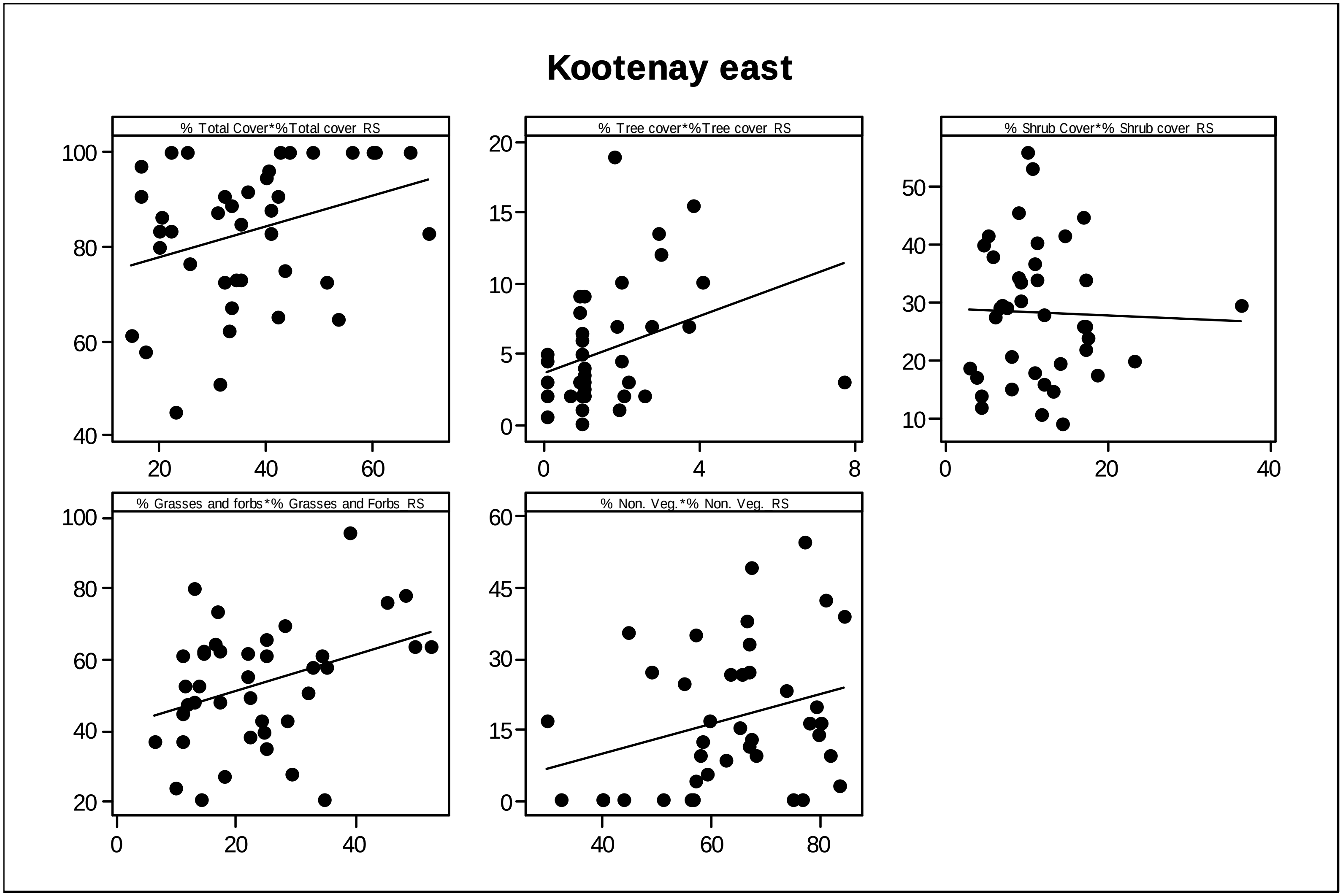
```
Factor      Type    Levels  Values
Site        random       3  Emily, KE, Mud
Om_level    fixed        3  OM1, OM2, OM3
Comp_level  fixed        3  C0, C1, C2


Analysis of Variance for H_Grasses, using Adjusted SS for Tests

Source                      DF    Seq SS   Adj SS   Adj MS      F      P
Site                         2   3.88421  3.88421  1.94210  15.83  0.240 x
Om_level                     2   2.35940  2.35940  1.17970   6.27  0.058
Comp_level                   2   0.15506  0.15506  0.07753   0.53  0.625
Om_level*Comp_level          4   1.71460  1.71460  0.42865   2.02  0.184
Site*Om_level                4   0.75235  0.75235  0.18809   0.89  0.513
```

```
Site*Comp_level             4   0.58548  0.58548  0.14637   0.69  0.618
Site*Om_level*Comp_level    8   1.69427  1.69427  0.21178   2.57  0.015
Error                      81   6.68155  6.68155  0.08249
Total                     107  17.82693

x Not an exact F-test.


S = 0.287208   R-Sq = 62.52%   R-Sq(adj) = 50.49%
```

## Appendix D – Remote sensing correlation plots




Mud creek
% Total*RS_Total
80
70
60
50
40
30
60
90
% Tree_cover*RS_Trees
20
15
10
5
0
0
8
16
% Shrub_Cover*RS_Shrubs
40
30
20
10
0
10
20
% Grasses and forbs*RS_Grasses and Forbs
60
50
40
30
20
40
60
% Non_veg*RS_Non_veg
60
50
40
30
20
0
40
80


Kootenay east
% Total Cover*%Total cover RS
100
80
60
40
20
40
60
% Tree cover*%Tree cover RS
20
15
10
5
0
0
4
8
% Shrub Cover*% Shrub cover RS
50
40
30
20
10
0
20
40
% Grasses and forbs*% Grasses and Forbs RS
100
80
60
40
20
0
20
40
% Non. Veg.*% Non. Veg. RS
60
45
30
15
0
40
60
80