Determining Optimum Seeding Densities of a Native Plant Mixture on Degraded Sites

by

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Abstract

Establishing vegetation to control erosion, rebuild the soil and improve the visual appearance of degraded sites is an important aspect of ecosystem restoration. However, the maintenance of biodiversity and ecosystem function, wildlife management and aesthetic appeal are also important factors. The use of native species for purposes of revegetation is an important consideration in addressing all of these issues, but there is little information regarding their use.

An experiment was designed using native plant species to test seeding densities, fertilizer use, season of seeding and their interaction on six degraded sites in the northwestern interior of British Columbia. In the fall of 1999 and the spring of 2000, a single seed mixture consisting of a fixed proportion of 20% *Achillea millefolium*, 20% *Festuca occidentalis*, 20% *Elymus glaucus*, 20% *Carex aenea,* 16% *Geum macrophyllum* and 4% *Lupinus polyphyllus* was applied at six different densities at all replicate locations. A total of 24 treatment combinations were applied in 2.5 m by 2.5 m rototilled test plots at each location. Seed densities tested were 0, 375, 750, 1500, 3000 and 6000 pure live seed (PLS)/m^2 in fall- and spring-sown plots. At all sites, commercial fertilizer (18-18-18 N-P-K) was applied in one plot of each density treatment; a corresponding density treatment plot was left untreated. Plots were monitored for plant density and cover for two years, at the end of each growing season.

The highest mean cover (62%) was achieved after two growing seasons in the fertilized spring plots sown at 6000 PLS/m^2. However, statistical tests revealed that there was no significant difference in cover between densities of 3000 and 6000 PLS/m^2 in the first year. By the second year, there was no significant difference in cover between densities of 1500, 3000 and

6000 PLS/m^2. There was no significant difference between fall seeding and spring seeding, and there were few treatment interactions.

Results revealed that exotic cover declined significantly in Year 2, especially in plots sown at densities of 3000 and 6000 PLS/m^2. There was also significantly less cover of exotic species in the unfertilized plots in Year 1. By Year 2, this trend was no longer significant and the cover of exotics was similar in both the fertilized and unfertilized plots.

Based on the results of this experiment, it is concluded that native plant seed can be successfully used to restore vegetation cover on degraded sites. A revised seeding mix consisting of *Achillea millefolium*, *Festuca occidentalis*, *Elymus glaucus* and *Lupinus polyphyllus* is recommended for use with fertilizer to achieve the best cover. If rapid cover establishment in the first growing season is required, seeding densities of at least 3000 PLS/m^{2}are recommended. Densities of 1500 PLS/m^2 are acceptable if rapid establishment of cover is not essential. Seeding densities of 3000 to 6000 PLS/m^2 are recommended for exotic species control where the cover of exotic plants is expected to be greater than >3.3%.

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Chapter 1 Introduction

1.0 Rationale and purpose

The purpose of this study is to determine optimal seeding densities for the revegetation of degraded sites in the northern interior of British Columbia (B.C.). This research is the first of its kind because the plants tested are all native[1] to the northern interior of B.C. Native plant seed mixtures have not been routinely used for revegetation or ecological restoration in this region. Indeed, the use of native plant mixtures in ecosystem restoration is in its infancy in western North America. This study is also important in that it systematically tests a wide range of seed densities under different fertilization regimes and seasons of seeding, generating new information that is apparently not known even for cultivated species.

Revegetation of degraded lands began in North America in the 1930's in response to severe land degradation caused by overgrazing, farming, drought, wind erosion and fires. Range seeding on overgrazed land and land damaged by drought has been carried out for over 60 years. More recently seeding for mine reclamation and the rehabilitation of industrial disturbances began in earnest in the 1970's (Brink 1998). By 1995, on public lands in British Columbia, nearly 300 ha per year were being seeded for grassland rehabilitation[1] and more than 5,700 ha per year of disturbed forest lands were being treated (B.C. Ministry of Forests 1995).

As in the past, efforts in North America to revegetate land degraded by human activities currently depend on domesticated[1] grass and legume species of European origin, because they are reliable in germination and growth, inexpensive, and seed is readily

[1] Terms with a "1" superscript are defined in Section 1.8.

available. Even though the use of native plant species for revegetating degraded lands is considered an integral component of ecosystem restoration (Harker et al. 1993, Lippitt et al. 1994), native species are not widely used because they are untested. Furthermore, their seed is relatively expensive and rarely available.

This thesis specifically addresses issues relating to the use a suite of native plant species for revegetating degraded sites, with an aim to promoting and optimizing their use. In general, the study consists of a factorial field experiment established in the northern interior of B.C. and monitored for two years. The experiment examines specifically the interactions between seeding density, fertilizer and the season of seeding.

The remainder of this chapter outlines the rationale for the research in detail. A comprehensive literature review is provided in Chapter 2. Chapter 3 describes the methods used in the study, Chapter 4 presents the results, and Chapter 5 discusses the implications of this work. Chapter 6 concludes with a summary of the main findings and suggestions for future research. It also includes recommendations for the practical applications of the results.

1.1 Seeding density

Formal research on herbaceous plant density began in the 1920's in an attempt to understand the tendency in nature for populations to be controlled through density-dependent mortality or "self-thinning." Harper (1977) reviewed the contributions of early researchers such as Sukatschew, Donald, and Kira in recognizing and quantifying the phenomena of self-thinning in plant populations. This work has been further formalized and applied in agriculture and forestry (Harper 1977, White 1985).

Despite the relatively long history of plant density research, a review of the literature reveals that there are few studies related to how or on what basis recommended seeding densities for agricultural or revegetation purposes were derived. The issue of seeding density is an important one, because density could be expected to vary according to the plant species involved, and with climatic and site conditions. Seeding at densities that are too low can result in inadequate cover for the goal of revegetation to be achieved. Establishing vegetation is important because bare ground can lead to soil erosion, nutrient loss and weed invasion. Densities that are too high might inhibit the growth of native species and natural successional development. The issue of high densities can be a particular problem with agronomic[1] perennial grasses, because they are competitive and persistent, with the potential to dominate a mixed native-non-native plant community (Schuman et al. 1982, Martens and Younkin 1989). In the case of revegetating a site with native species (as with agronomic ones), recovery of the other native species in the seed bank and colonization by adjacent species could be compromised if too much seed is used, thus reducing native biodiversity. Furthermore, the hard-to-get native seed will be wasted.

Seeding densities in general, appear to be prescribed based on the desire to produce an adequate number of plants to produce seed or forage (Drinkwater 1993, Broersma pers. comm. 2000), to attain cover for erosion control (Carr 1980, USDA 2001) to build up soil or organic matter and management of soil moisture (USDA 2001), and for visual "green-up" or aesthetic purposes. Seeding practices seem to reflect time-honoured approaches (Hafenrichter et al. 1968, Anonymous 1990, Gayton1990, Agriculture Canada 1991),

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[1] Terms with a "1" superscript are defined in Section 1.8.

however their scientific basis has been lost or is not well documented (Broersma pers. comm. 2000).

Why particular densities were chosen in the early days of revegetation is not clear. One view is that seed companies recommended high density seeding on roadsides and other degraded sites merely so they could sell more seed, rather than for any rigorous scientific reasons or in response to published research on optimum densities (Broesrma pers. comm. 2000). Another view is that high densities are recommended simply because revegetated sites are not often revisited, so over-seeding is simply an insurance policy (Hebda pers. comm. 2003). Today however, standardized seeding densities, such as those recommended by Carr (1980), Hardy (1989), Schwab (1991), and Drinkwater (1993), seem to be routinely prescribed and implemented. Drinkwater (1993) states that site- or purpose-specific densities are being modified as the results of operational trials and research become available.

Seeding densities, based primarily on seeding with agronomic species, are reported to range from 1.1 to 39.2 kg/ha for grasses and 1 to 50.4 kg/ha for legumes, depending on the goals and objectives of seeding (Hardy 1989, Agriculture Canada 1991, Drinkwater 1993). There seems to be little basis for the application of these recommendations to native species, primarily because (unlike agricultural varieties) native plants have not been selected for reliable germination and uniform traits. However, some basic principles may be transferable based on seed size, mature plant size, growth form and the desired ratio of grasses to legumes.

When working with new species (such as newly developed sources of native seed) with unique characteristics pertaining to seed weight, plant stature, competitiveness, longevity and other characteristics new data are clearly needed. It is inadequate to simply apply seeding rates and other revegetation protocols devised for non-native species.

1.2 The problem with exotic plants

A major rationale for this study is to promote the use of native plant species for revegetation of degraded sites, rather than species from other regions or continents. Introduced species are a major concern in terms of ecosystem integrity and biodiversity conservation. It is estimated that, in the United States, from 5 to 25% of the vascular plant species in nature reserves are non-native, and in Canada, overall, non-native species are estimated to make up 24% of the flora (Vitousek et al. 1996). Berger (1993) estimated that approximately 3000 different exotic species grow wild in North America and few areas remain free of their influence. Some of these exotic plants were inadvertently introduced from Europe and Asia, whereas others arrived as domesticated species and escaped and persisted in the wild (Baker 1986). Many exotic grasses and legumes were purposely seeded along roadsides, on mine spoils, on landslides, after forest fires, and on degraded grasslands. Because of exposed soil and high light conditions, these same habitats (i.e., disturbed grasslands and savannahs, riparian habitats, roadsides, paths and open forests) are among the ecosystems most susceptible to invasion by weedy exotics and other aggressive non-native vascular plants. Therefore, the continued use of common European species for revegetation exacerbates exotic species invasion, and contributes to the suppression of the native flora (Baker 1986, Wilson 1989, Berger 1993).

Vitousek (1986) concluded that invasive plants with a different life form than the indigenous vegetation can alter ecosystem characteristics. A particularly pertinent example of this can be found in the northwestern North America where the nitrogen fixing shrub *Cytisus scoparius* L. (broom) Fabaceae is invading the few remaining savannahs of *Quercus garryana* Dougl. (Garry Oak) Fagaceae. Vitousesk (1986) also concluded that the negative impact on ecosystem characteristics was less clear for invasion by species of the same life form. Some studies confirm that exotic species introduced for revegetation purposes on prairie sites and disturbed forested land inhibit growth of native species (Younkin and Martens 1987, Wilson 1989).

It is not only lands purposely reseeded with introduced species that are the victims of the exotic invasion. *Phleum pratense* L. (timothy) Poaceae, introduced from Eurasia, has partly naturalized near settled areas and is now found throughout much of B.C. (MacKinnon et al. 1992). As a consequence of this invasion, for example, native plants now do grow in places currently occupied by timothy.

1.3 Use of agronomic species for revegetation

Initially, domesticated grasses and legumes of European and Asian origin (commonly called "agronomic species") were used for revegetation work in North America. Many species were used simply because farmers, seed growers and agronomists had experience with them for pasture improvement and hay production. These species include common forage plants such as *Bromus inermis* Leys (smooth brome) Poaceae, *Phleum pratense*, and *Trifolium* spp. (clovers) Fabaceae. To rehabilitate prairie farmland and grassland devastated by drought in the 1930's, *Agropyron cristatum* (L.) Gaertn. and *A. desertorum* Fisch. Ex Link (crested wheatgrasses) Poaceae were widely sown because they germinated well, were drought tolerant, grew rapidly, and were readily available (Looman and Heinrichs 1973).

Today, a standard seed mix of agronomic grasses and legumes is still widely used to revegetate land disturbed by farming, grazing, forestry, road construction, industrial activities and urban expansion as well (Hardy BBT 1989, Agriculture Canada 1991, Schwab 1991, Drinkwater 1993).

In B.C., where there is much degraded land in need of revegetation, thousands of hectares of roadsides, grazing lands, mine spoils, clear-cuts and other disturbed sites are revegetated annually using domesticated grasses and legumes (Drinkwater 1993, B.C. Ministry of Forests 1995). Grass (Poaceae) species typically used include *Agropyron cristatum* as well as other *Agropyron* (wheatgrass) species, *Bromus inermis* and other bromes, *Phleum pratense*, *Festuca* spp. (fescues), *Poa* spp. (bluegrass), *Agrostis stolonifera* L. (redtop bentgrass), and *Dactylis glomerata* L. (orchardgrass). The legume (Fabaceae) component consists primarily of *Melilotus* spp. (sweetclovers), *Medicago sativa* L. (alfalfa) and *Trifolium* spp. (Hardy BBT 1989, Agriculture Canada 1991, Drinkwater 1993). Other plant families such as sedges (Cyperaceae) or composites (Asteraceae) never appear in agronomic seed mixtures.

1.4 Use of native species for revegetation

Maintaining ecosystem integrity (composition and diversity) is an important issue in public land management across North America (Woodley et al. 1993), partly due to the spread of exotic plant species. An imperative to understand and work with native species is thus beginning to develop. Even though native plant species are not yet widely used for revegetating degraded lands, the reestablishment of natural vegetation has long been a fundamental principle of ecosystem restoration (Jordan et al. 1990). To this end, information about the propagation and growth of native species is beginning to accumulate. The results of this research, and increasing practical experience, suggest that native species should and could be used in place of domesticated grasses and legumes for erosion control, slope stabilization, restoration of soil structure and productivity, and other revegetation purposes (Darroch 1994). For example, Brown and Johnston (1980) found introduced species began to decline after three growing seasons at high altitudes, while native species increased in vigour and rate of spread once they were established. Thornburg (1982) and Hardy BBT (1989) reported that many native plant species are adapted to lower nutrient conditions and, as a result, grow on degraded sites without the frequent use of fertilizer.

Native plants used in revegetation not only perform specific functions, but also help maintain ecosystem biodiversity. They provide natural habitat and food for native animal life, such as browsers, pollinating insects, and songbirds. To people who are concerned about biodiversity, conservation and "a sense of place," plants indigenous to the region are also more aesthetically pleasing and culturally appropriate.

Despite these important values, native plant species are rarely included in revegetation projects, partly due to their high cost and limited availability (Joyce 1993). These barriers are difficult to overcome, because the high cost of native plant seed results partly from its lack of availability, and its scarcity is the result of high costs for collection or production of native seed. Because the seeds are not readily available, they are not widely prescribed and used. Furthermore, because they are not widely used, research on agronomic and restoration practices associated with the use of native species is not carried out.

If ecosystem restoration using native species is to replace the current practice of revegetation with agronomic varieties, then the seed must be readily available at reasonable prices (Vaartnou 2000). Since seed from plant species native to B.C. is not widely used, little is known about their germination rates, appropriate seeding densities, growth requirements, and optimal seeding times. These factors must be better understood before native seed can be effectively used for revegetation on a large scale, even if it were widely available.

1.5 Soil amendments

Successful revegetation of a disturbed site depends not only on the composition of a seed mixture but also on site conditions. Often the physical and chemical properties of the soil are not suitable to support any kind of vigorous growth and need to be remedied. Common amendments include peat moss or manure to improve organic matter content and soil structure, lime to raise the pH, and fertilizer (whether organic or manufactured) to supplement nutrients (Bradshaw 1987). There are currently no clear guidelines regarding fertilizer use in revegetation projects with native species. When restoring grasslands to native species, the addition of fertilizer is generally discouraged, since the aggressive growth of annual weeds is associated with nutrient-rich soils (Huenneke et al. 1990, Wilson and Tilman 1993). The consensus is that weeds in the seed bank will grow more rapidly than native species if fertilizer is added (Gerling et al. 1996). Likewise, fast-growing agronomic species (already present on most revegetation sites) respond strongly to fertilizer. It is widely believed that native species are well adapted to grow and compete with exotic weeds and agronomic species in nutrient-poor conditions (Hardy 1989, Thornburg 1982, Wilson and Gerry 1995). Consequently, the use of fertilizer is often discouraged when attempting restoration work with native plants.

However, Bradshaw (1987) suggests that when attempting revegetation of severely degraded sites with little or no topsoil, the addition of nitrogen (N) is always beneficial and the addition of phosphorus (P) and potassium (K) is often beneficial. Presumably, the issue of the growth of exotics does not apply on these severe, nutrient impoverished sites (e.g., mine spoils), where there is probably no seed bank of exotic species or established sod of domestic grasses to take advantage of the enriched soil conditions. On disturbed high-elevation sites, Brown and Chambers (1990) likewise recommend the use of fertilizer, although they suggest that the response to fertilizer is species-specific and that individual species response needs to be considered when developing a seeding mix. It remains to be seen whether a particular combination of native plants, growing on typical disturbed sites in northern B.C., would benefit or suffer from fertilization.

1.6 Season of seeding

The seasonal timing of seeding is considered to be important in the successful establishment of vegetation on degraded sites (Brown and Johnston 1980, Chambers 1989, Gerling et al. 1996). For some native species and under some site conditions, fall seeding will be beneficial because the seeds can be naturally stratified[1] during winter conditions and will be in place to grow as soon as conditions are suitable for germination in the spring (Vartnou 1982, Brown and Chambers 1990, Burton 2002). For different species and different site conditions, spring seeding will be preferable (Gerling et al. 1996). For any particular site, or perhaps just for any particular climate, it needs to be locally or regionally

[1] Terms with a "1" superscript are defined in Section 1.8.

determined whether a particular mixture of native plant species would establish better if sown in the spring or fall.

1.7 Purpose of this research

The research project reported in this thesis developed as a consequence of another project, funded by Forest Renewal B.C., carried out by Symbios Research and Restoration from 1996 to 2001 (Burton and Burton 2001). The goal of the original project was to develop reliable sources of native grass and legume seed at competitive prices for use in ecosystem restoration while maintaining a higher level of genetic variability than is usually found in cultivated varieties (Burton and Burton 2002).

The ideas for the research reported in this thesis were developed when monitoring the results of revegetation trials using native plant seed produced in the Symbios project. In almost all of the plots (269 25m^2 plots distributed among 24 sites) the plant cover achieved was abysmal. In these trials, the standard agronomic recommendations for density, seasonal timing and fertilizer (Drinkwater 1993) were used since there was little information on native species. It was difficult to determine why such poor cover results were achieved without more systematic trials. This thesis was undertaken to address these practical issues.

Specifically, the goals of this research are:

- To review literature concerning seeding densities, the use of fertilizer, and season of seeding for both agronomic and native species;
- To test different seeding densities for a mixture of some promising native herbaceous plant species (Table 1);

- To test the effects of a single application of fertilizer on a mixture of promising native herbaceous plant species;
- To compare the effectiveness of spring versus fall seeding on the establishment of a mixture of promising native herbaceous plant species; and
- To test for the interaction of fertilization and the season of seeding on different seeding densities using a mixture of promising native herbaceous plant species.

Table 1. Species composing the seed mix used for this project.

Species	Authority	Common Name	Family
Achillea millefolium	L.	common yarrow	Asteraceae
Carex aenea	Fern.	bronze sedge	Cyperaceae
Elymus glaucus	Buckl.	blue wildrye	Poaceae
Festuca occidentalis	Hook.	western fescue	Poaceae
Geum macrophyllum	Willd.	large-leaved avens	Rosaceae
Lupinus polyphyllus	Lindl.	large-leaved lupine	Fabaceae

In pursuit of these goals, the following corresponding hypotheses were developed for testing in a field experiment:

- H1: Greater plant cover will be provided by high seeding densities.
  - Rationale: more seeds produce more plants, more plants produce more cover.
- H2: Seeding at low densities will not provide adequately high (e.g., >50%) levels of cover.
  - Rationale: each plant species typically has a maximum size per individual; low densities of plants may not cover most of the available ground space.
- H3: Application of a complete (balanced N-P-K) fertilizer will increase in cover at all densities.
  - Rationale: fertilizer will add key nutrients to the soil; increased nutrient availability will increase overall growth of all plants.

- H4: A low density treatment with fertilizer will provide cover equivalent (or higher) than a high-density treatment without fertilizer.
    - Rationale: The fertilizer will enhance growing conditions sufficiently for a few plants in the fertilized plots to grow bigger and provide equal or greater cover than a larger number of smaller plants growing in unfertilized plots.
- H5: Fall seeding will result in higher levels of seedling emergence[1] in the first growing season than spring seeding.
    - Rationale: the seeds will be naturally stratified over winter and will be in place to take advantage of favourable conditions for growth early in the spring.
- H6: There will be lower weed cover in the most densely sown plots.
    - Rationale: As more seed is purposefully introduced, there will be less growing space and resources available for other plants
- H7: Fertilizer will increase the cover of exotic species, especially at low sown densities.
    - Rationale: Most agronomic and weedy species are considered more responsive to high nutrient conditions than native species.

Based on these hypotheses, the overall null hypotheses is that there will be no significant difference in plant densities, emergence[2] rates, or total plant cover related to seeding density, fertilizer treatments, the season of seeding, or their interaction.

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[1] Terms with a "1" superscript are defined in Section 1.8.
[2] Terms with a "1" superscript are defined in Section 1.8.

None of these issues have yet been thoroughly examined, since using native species for revegetation purposes in B.C. remains a relatively novel and minor component of land management. Thus, this research will contribute significantly to our knowledge and understanding of seeding with native species for ecosystem restoration, especially for the northern part of the province.

1.8 Definitions

Throughout this thesis, the following words are used specifically as follows:

agronomic or **domesticated species** -- plants that have been cultivated for a long period of time, typically for agricultural (seed, forage, or hay production) purposes; these species are usually of Eurasian origin, the products of selective breeding.

emergence – appearance of a newly germinated seedling above the soil surface; when numerically expressed refers to count per unit area of seedlings observed divided by the density of seeds sown there.

native species – as defined by the California Native Plant Society "...any plant which is a member of a species which was present at a given site prior to European contact". (Smith and Winslow 1999).

plant density – observed (counted) number of plants per unit area (a $0.25m^2$ quadrat in this thesis).

pure live seed (PLS) -- the amount of living or healthy seed found in a seed mix or applied to an area of ground, excluding non-viable seeds, weed seeds, chaff and other impurities. Specifically, PLS is calculated on the basis of laboratory analysis of a given seed lot, where PLS = # of seeds x % germination x % purity.

revegetation includes the establishment of plants for the purposes of:

- **reclamation** -- the process of returning land to its fohrmer or any other productive use (Powter 1994).
- **rehabilitation** -- the creation of an ecosystem with a structure and function that improves upon a degraded state, but is different from the original system (Gerling et al. 1996).
- **restoration** -- the process of establishing the ecological characteristics of a site which existed prior to land disturbance or degradation (Gerling et al. 1996).

stratification of seeds -- the breaking of seed dormancy under natural or artificially imposed circumstances by exposing seeds to prolonged cold (usually 0 to 5° C) under conditions sufficiently moist for them to be physiologically active. Many temperate and northern species require stratification of their seeds for germination.

Chapter 2 Literature Review

2.0 Introduction

There is no single answer to the question of how revegetation of degraded sites should be carried out, because degradation of ecosystems is a complicated process and its reversal is difficult. Different kinds and intensities of disturbance on a variety of sites result in diverse growing conditions and restoration challenges. As a result, there are many approaches to revegetation, dependent upon site-specific history, conditions, and goals. On some sites revegetation will be accomplished using seedling transplants or cuttings, whereas other sites can be revegetated with seed, either native or non-native. The focus of this review is related to revegetation with native seeds.

Regardless of site characteristics, there are fundamental issues to consider before effective revegetation can occur. These include plant growth and competition for space, how these factors are affected by seeding density, soil fertility and time of seeding. This chapter reviews the literature pertaining to these issues, focussing on treatments tested in this project.

2.1 Plant demography theory

The question of optimal plant density is a major component of this research. There are many factors to be considered pertaining to how much seed per unit area should be sown and what density of seedlings and mature plants will result, so the implications of seed and seedling density are discussed at some length. Plant demographic theory and research is not specifically tested in the research described in the following chapters, but is discussed here to emphasize the importance and complexity of seedling density in stand establishment. Most early research related to density-dependent plant mortality describes intra-specific interactions, but since natural populations are usually mixtures of species, later research included interactions between two or more species.

Early studies on the density of seedlings were not related to the revegetation of disturbed lands but were attempts to explain plant demography, intra-specific competition and population ecology. In 1928, Sukatschew (*fide* Harper 1977) noted that natural self-thinning of seedlings occurred in fir *Abies* sp. (fir) stands, where plots with the highest density had the greatest mortality. Similar patterns of self-thinning in trees had been noted and manipulated by foresters since the early 1800's (Fernow 1913). Sukatschew, influenced by these findings, however, designed an experiment with a native annual, *Matricaria inodora*, L. (scentless chamomile) Asteraceae to examine the phenomenon with smaller plants and in a controlled setting. The results of his experiment suggested the universal nature of what he had observed in the fir stands: that plots with the highest plant density had the highest mortality (Harper 1977).

The same phenomena were observed in animal populations, where it was found that the mortality rates increased as population density increased. As a result of these wildlife observations, H.S. Smith coined the term density-dependent mortality in 1935 to describe the increased risk of death when density increased in animal populations. This term and the term "self-thinning" have since been used to describe mortality related to high density in plant populations as well (Harper 1977). Density-dependent mortality, then, can be considered an extreme form of competition. This competition is one reason that increased plant cover does not always result from the addition of more seeds to a given area of ground. Depending on site conditions, there is a point where the emergence of too many seedlings will merely result in the death of additional plants.

The mechanisms of plant density dynamics are not simple. Donald's (1951) research suggested that plant density is related to variation in the growth of individual plants. He experimented with seven different densities of *Trifolium subterraneum* L. (subterranean clover) Fabaceae and concluded that, over time, changes in mean plant weight compensate for changes in density. That is, regardless of density, the biomass of a given population, if it fully occupies the site, remains the same: there will either be many small plants or few big plants. Subsequent work by other researchers indicated that this relationship holds true for a wide range of species. Kira et al. (1953 *fide* Harper 1977 described this relationship as the "law of constant final yield."

Later, Shinozak and Kira (1956 *fide* Harper 1977) described the "reciprocal yield law" in reference to density-dependent mortality. It is also known as the self-thinning law when referring to intra-specific relationships. The reciprocal yield law describes an intra-specific linear relationship (when plotted on logarithmic scales) between mean plant weight and density, such that for every increase of two logarithmic units in mean plant density, mean plant weight declines by a corresponding three logarithmic units. That is, the more plants that are growing, the smaller the size of the plants. During the course of stand development, total plant weight will increase so long as growing space is available or so long as density is falling as a result of self-thinning. Similar results (known as "alien thinning") have been achieved in density experiments with two or more species, but the rate of mortality was usually greater in one species than the other(s) (Harper 1961, Bazzaz and Harper 1976). Regardless of the number of species in a population then, the results of these experiments suggest that, once growing space is fully occupied, whether by a few large plants or many small ones, a given site will usually produce a fixed amount of biomass, hence the law of constant yield.

Silvertown (1984) expanded the explanation of density self-control in plants. He viewed populations as having self-regulating mechanisms, which he described as density-dependent mortality and density-dependent fecundity. According to Silvertown (1984), these mechanisms ensure that populations remain relatively stable in the number of individuals regardless of environmental fluctuations. The density-dependent mortality factor relaxes as population density declines and thus slows down any decrease in populations. When populations increase, the density-dependent factors lead to the decline of an increasing number of plants, reducing a wide range of seedling densities to a smaller range of adult densities, within a single generation. Density-dependent fecundity helps to regulate density by controlling the number of fertile seeds produced in a given population, thereby affecting the number of adults in the next generation.

These "laws" and mechanisms appear to hold true in nature, in both wild and cultivated stands of plants. But despite their predictability, these and other laws of nature do not "control" density in populations; they merely describe it. It could be said that local conditions, including site characteristics, density and the composition of species on hand, as well as the physiological and genetic traits of those species, ultimately determine competitive outcomes and stand productivity. Together, these factors set limits to overall stand productivity, biomass, and the number of plants that will survive on a given site (Gross 1984, Grace 1990, Wedin and Tilman 1993, Halpern et al. 1997). Therefore, plant populations growing on any particular site can be described as integrated systems, reacting to a variety of intrinsic and environmental factors.

From plant demographic theory, then, it is evident that individual seedling growth within any population is governed by seedling density. Whether a particular seedling density is conducive to the establishment of a healthy plant community depends on site conditions as well as species traits, and genotypic variation within and among the species growing at any given site. But the achievement of constant yield (and presumably full or constant cover) depends on achieving full site occupancy. That is, in order for the law of constant yield and the self-thinning law to come into effect, some minimum number of plants must be in place so that they fully occupy the growing space. If only a few plants are in place and they do not fully occupy the site, they may grow to full size without providing full cover. But once that critical density and full cover are achieved, any additional plants will likely be small and most will die. Consequently, one must assume that when revegetating a site, there is a seeding density that will be most stable or efficacious for that particular site. Determining that optimum density is a key issue: how can full cover be achieved without using an excess number of seeds that will only die upon establishment and be wasted?

2.2 Seeding density research

There are a variety of experiments reported in the literature that examine different factors as they interact with density to influence plant populations. For example, Sukatschew (1928 *fide* Harper 1977) worked with *Matricaria inodora* and Yoda et al. (1963 *fide* Harper 1977) worked with *Erigeron canadensis* L. (Canada fleabane) Asteraceae. Their experiments manipulated fertilizer treatments to mimic rich and impoverished sites. Results of their work clearly demonstrated what has come to be known as the "Sukatschew effect" where self-thinning is most intense on highly fertile plots (Harper 1977).

Harper and Chancellor (1959) conducted a complex set of experiments with five *Rumex* species (family Polygonaceae) at two densities, in two soil types, under three experimental moisture regimes. They examined how physical and biotic variation determines the success or failure of closely related species in terms of emergence, size and seed production. Their results suggest that although the negative effects of high density on mean plant performance is universal, the exact relationship varies with species and with resource availability.

Bazzaz et al. (1982) studied the survival of *Phlox drummondii* Hook. (annual phlox) Polemoniaceae in crowded populations under conditions of high and low soil fertility. From the results of two separate experiments with this species, one with ten different cultivar populations and the other with a natural population, they concluded that survival in dense populations is determined by genetic identity (i.e., the cultivated variety or natural population from which it was derived) as well as external environmental factors.

Jacobson et al. (1994) described an approach to revegetation that they call "sculptured seeding." This approach is based on increasing seeding density on sites with increased soil moisture. In 1981 and 1982, previously cultivated fields were first sown with a base mixture of native grasses at a rate of 300 PLS/m^2. Wetter areas of the site were then sown with a supplemental mix of three additional native species at a rate of 86 PLS/m^2. The authors reported that this kind of selective seeding resulted in excellent stand establishment on both sites, but they did not explore the mechanisms involved. Success may have been due to the fact that the three additional species were well adapted to moist sites, or to the fact that total sown density at moist sites was higher than at the drier sites.

Fairey and Lefkovitch (1995) examined seed production of *Festuca rubra* L. var. *rubra* (creeping red fescue) Poaceae as it related to seeding density and row spacing. They found that a moderately high density of well-spaced plants is required to promote optimal formation of filled seed-heads, but that very high density is detrimental to subsequent formation of the seed-heads and to overall seed yield.

Stevenson and Wright (1996) studied seed yield in *Linum usitatissimum* L. (flax) Linaceae at three different seeding densities and row spacings in the presence and absence of broadleaf and grassy weeds. Broadleaf weeds included *Chenopodium album* L. (lambs quarters) Chenopodiaceae and *Thlaspi arvense* L. (stinkweed) Cruciferae. Weedy grasses (Poaceae) included *Hordeum vulgare* L. (barley) and *Avena fatua* L. (wild oats). When weeds were present, increasing seeding density improved seed yield and decreased weed yields. Under weed-free conditions, seed yield was not affected by density sown. Seed yield was highest at the closest row spacing in the absence of weeds, but not in the presence of weeds.

These studies collectively demonstrate that the reciprocal yield law affects the ability of plant stands to produce cover, biomass, or seed, and that density-dependent mortality is a factor in controlling population density. They also show that a variety of external factors interact with density to exert control on plant survival and growth.

2.3 Seeding density prescriptions

Understanding exactly how much seed is actually used in any one seeding prescription described in the literature can be a confusing issue, depending on the units of measurements that are used. The density at which seeds are applied to the land is usually called the "seeding rate," which is synonymous with seeding density and has nothing to do with the speed of application. Seeding rates can be given in kg/ha, lb/acre or pure live seed/m^2 (PLS/m^2). When drill seeding is employed, the overall number of seeds per unit area may not be specified at all: rather, row spacing (between seeder discs) and the density of seeds per metre or foot of row are sometimes reported and sometimes not, further making conversion to an area basis difficult.

"Pure live seed" (PLS) is the amount of live or healthy seed found in a seed mix or applied to an area of ground, excluding non-viable seeds, weed seeds, chaff and other impurities (see Section 1.8). Specifically, PLS is calculated on the basis of laboratory analysis of a given seed lot, where PLS = # seeds x % germination x % purity. It is particularly useful for prescriptions of native seed, where germination rates and seed-lot purity can be variable.

Recommended seeding densities with agronomic species differ according to the reason for seeding, and the seeding method to be employed. However, from the literature reviewed, it is difficult to determine whether densities have been derived from rigorous experiments that included replication, controls, a wide range of treatments and statistical analysis. Rather, it appears that seeding densities are prescribed based on historical usage and a few "rules of thumb" which have been adjusted following observation or trial and error, most of which has largely remained undocumented and unproven.

For agricultural purposes, seeding densities are more or less standard with little or no rationale provided for the recommendations. Suggested densities for grasses range from 2 to 11 kg/ha (55 – 1200 PLS/m^2) for seed production and 5 to 14.5 kg/ha (188 – 1560 PLS/m^2) for forage production. Recommended densities for legumes range from 1 to 11 kg/ha (39 – 388 PLS/m^2) for seed production and 4.5 to 45 kg/ha (79 – 355 PLS/m^2) for forage production (Agriculture Canada 1991). These wide ranges in recommended densities, specified as kg/ha, for grasses or legumes is partly due to the range of seed sizes within any of these groups. A standardized and widely accepted approach to seeding for agricultural purposes is understandable since this kind of seeding is carried out under fairly uniform conditions. The soil is generally well prepared, fertilizer is applied on the basis of soil testing in order to achieve recommended fertility levels, and cultivars with reliable germination are sown. Klaus Broersma (pers. comm. 2000) suggests that agronomic seeding densities are set for convenience, usually at a high rate to cover all types of seeding methods. He further comments that seed companies may inflate recommended densities in order to increase the amount of seed they sell. Since grass and legume seeding for agricultural purposes and forage production has been carried out in British Columbia for over 60 years, recommended densities now simply seem to be accepted.

According to Drinkwater (1993), seeding density prescriptions with agronomic species vary depending on the goal for seeding (e.g., for erosion control, range improvement, silvicultural enhancement, or non-crop vegetation control) and the method of application. Seeds can be sown either by drill seeding or a variety of broadcast seeding methods. In drill seeding, seeds are inserted directly (by spouts from a seed box) into the soil in rows created by machine-mounted discs, a method rarely used in revegetating industrial disturbances or rough terrain. Different broadcast methods of sowing include hand spreading, the use of manual cyclone seeders or "seed slingers," cyclone seeders attached to an all terrain vehicle (ATV), air-blown seeders, hydroseeding (broadcast seeding in a slurry of water, fertilizer, mulch and sometimes a "tackifier" that essentially glues seed onto steep slopes), and seeding by helicopter.

Broadcast seeding of agronomic species does not use seed as efficiently as drill seeding. Holechuk et al. (1998) suggest that broadcast seeding should be avoided because many of the seeds are left on the soil surface. As a result, germination and seedling establishment are unreliable and two to four times the amount of seed is needed than would be needed with drill seeding. Schwab (1991) recommends rates for hydroseeding that are approximately three times those recommended for dry seeding. The need for more seed in hydroseeding, compared to dry seeding, may be due the fact that some seed remains perched on top of the mulch, rather than under it, and so seeds and seedlings may dry out and die. In addition, seed is likely wasted because it lands on rocks, logs and other non-target surfaces, so revegetation practitioners compensate by applying extremely high densities of seed.

Densities of grass and legume seeding for silvicultural purposes are frequently lower than densities recommended for agricultural purposes because they are intended to supplement other plants already growing on the site. Low rates may also be prescribed so that natural succession to tree-dominated vegetation is not prevented through competition from sown herbaceous species. Prescriptions for silvicultural seeding of grasses and legumes are often species-specific, possibly because silviculture seeding is relatively new and likely involves active experimentation. For example, one silvicultural seed mix recommends *Festuca rubra* L. var. *commutata* (chewings fescue) Poaceae be sown at a density of 3.7

kg/ha (399 PLS/m^2) with a mix of three legumes sown at densities ranging from 0.7 – 3.9 kg/ha (91-277 PLS/m^2). Silvicultural seeding densities are adjusted as results from research and operational trials are evaluated (Drinkwater 1993, 1994).

Seeding for reclamation of deactivated roads and landings can be up to three times more than densities recommended for agricultural and silvicultural purposes. Hardy BBT (1989) recommends densities ranging from 250 to 2,000 PLS/m^2 for grasses and 260 to 1,350 PLS/m^2 for legumes for reclamation purposes. These high densities may be considered necessary because of generally poor growing conditions on most reclamation sites compared to agricultural sites. The attitude may simply be that if research is lacking, when in doubt, "more is better."

Seeding density given in kg/ha frequently has no reference to seed viability, seed size differences among species, or species proportions in a mixture. According to Broersma (pers. comm. 2000), the issue of seed viability is not questioned for agronomic species because seed quality and seed germination is reliably high, i.e. >90%. However, seed size is an issue, regardless of seed viability. A general weight-based prescription is not adequate if it does not specify the species to be used, and take into account the number of seeds per kg for a particular species. For example, *Phleum pratense* has 2,700,000 seeds per kg, whereas *Bromus biebersteinii* Roem. Schult. (meadow brome) Poaceae, with larger, heavier seeds, has 175,000 seed/kg (Hafenrichter et al. 1968). If a general prescription is made in kg/ha without mentioning the species and taking seed size into account, a site may be sown too sparsely or densely, or there may be an unintended asymmetry in species composition. Perhaps practitioners are used to dealing with a standard seed mix (e.g., Schwab 1991), but this routine practice can lead to unbalanced and inadequate prescriptions when applied to new situations (e.g. new combinations of species, a different climate, or particularly harsh sites).

Drinkwater's (1993) seeding recommendations are given in kg/ha, and are considered the accepted standard for revegetation on public land in the Prince Rupert Forest Region. Recommended seeding rates range from 4 to 80 kg/ha, depending on the seeding purpose and the method of sowing. Drinkwater (1993) recognizes four broad categories for the use of grass and legume seed mixtures on northwestern forest lands: silviculture, erosion control, fire rehabilitation, and forage mixtures for livestock. He is not specific about a grass to legume ratio, and species-specific weights or proportions in the mix are not delineated in any of ten recommended mixtures.

Close examination of the literature reveals that mean seed weights and recommended seeding densities are available by species, so prescriptions can be designed based on specific seed weights. Agriculture Canada (1991) provides species-specific information in their recommended seeding densities (Table 2) for agricultural purposes.

Table 2. Recommended seeding densities for agricultural and reclamation species.

Species	Common name	Agricultural (kg/ha)	Agricultural (PLS/m^2)	Reclamation (kg/ha)	Reclamation (PLS/m^2)
Bromus inermis	smooth brome	9.0	194	9.0	254
Agropyron cristatum	crested wheatgrass	8.0	249 – 285	11.2 - 22.4	463 - 698
Agropyron intermedium	Intermed. wheatgrass	14.5	223 – 258	9.0	190
Bromus biebersteinii	meadow brome	11.0	118 – 139	3.7	1.1 - 39.2
Elymus junceus	Russian wildrye	11.0	219	9.0 - 11.2	341 - 425
Agropyron elongatum	tall wheatgrass	13.0	183	9.0 - 11.2	156 - 195
Elymus trachycaulus	slender wheatgrass	11.0	256	6.7 - 9.0	215 - 287
Phalaris arundinacea	reed canary grass	6.0 - 8.0	514 – 685	5.6 - 11.2	637 - 1222
Phleum pratense	timothy	5.0 - 6.0	1000 - 1200	1.1	292
Medicago sativa	alfalfa or lucerne	6.8	303	9.0 - 16.8	440 - 825
Mellilotus alba	white sweet clover	11.0	535	11.2 - 16.8	618 - 967
Mellilotus officinalis	yellow sweet clover	11.0	469	11.2 - 16.8	618 - 967
Lotus corniculatus	birds-foot trefoil	4.5	388	11.2 - 16.8	1071 - 1606
Onobrychis viciifolia	sainfoin	22 – 45	79 – 161	39.2 - 50.4	259 - 333
Trifolium pratense	red clover	not recomm.	n/a	9.0 - 11.2	548 - 645

Data from Hardy BBT Ltd. (1989) for reclamation rates and Agriculture Canada (1991) for agricultural rates

Table 2 shows that, except for *Phleum pratense* and *Phalaris arundinacea* L. (reed canarygrass) Poaceae, the recommended agricultural seeding rate is consistent among species when expressed in PLS/m^2, ranging from 118-285 PLS/m^2 for most grass species and 318 to 535 PLS/m^2 for four of the five legume species. Timothy and reed canarygrass are prescribed at double the general rate. This difference may be because the seeds of both these species are quite small and agronomists are reluctant to use a seeding density in kg/ha that would seem too low. Alternatively, seedlings emerging from such small seeds may have a high mortality rate.

For reclamation purposes, Carr (1980), Schwab (1991) and Drinkwater (1993) suggest a combination of two to five common agronomic species. Their prescriptions for reclamation applications, with a recommended ratio of grasses to legumes of 70:30 in wet regions and 80:20 in dry regions, typically contain *Festuca rubra* L. (red fescue) Poaceae, *Agrostis stolonifera* L. (redtop bentgrass) Poaceae, *Secale cereale* L. (fall rye) Poaceae, *Lolium perenne* L. (perennial ryegrass) Poaceae, *Trifolium* spp. (clovers) Fabaceae, and other agronomic species.

In contrast to the relatively uniform seeding density recommendations for agricultural applications, densities for reclamation vary widely within and among species. These variations likely reflect the many goals of reclamation and may indicate an understanding of the broader differences in the survivorship and vigour of each species over a wide range of site conditions. Legumes are routinely prescribed at a high rate in reclamation, usually to provide nitrogen for depauperate soils.

If seeding densities for revegetation purposes are calculated based on the results of germination tests under lab conditions, densities may have to be adjusted upward since germination rates and survival in the field are considerably lower than germination rates under laboratory conditions (Bazzaz 1986). A study of *Trifolium hirtum* All. (rose clover) Fabaceae by Martins and Jain (1979) further suggests that only ~12% of newly emerged seedlings survive into the next growing season. Fenner (1985) generalizes that predation, disease and competition generally contribute to high seedling mortality rates in the first year. He also cites examples in which dessication is the main cause of seedling death, as do Martins and Jain (1979) for the *Trifolium hirtum* population they introduced into annual grasslands in central California.

Some researchers have offered broad recommendations for successful revegetation. According to Broersma (pers. comm. 2000), a suggested goal for agronomic purposes is the establishment is 215 seedlings/m^2. For reclamation on slopes, Carr (1980) recommends establishment of 70 to 80% cover in as short a time as possible. Townley-Smith and Wright (1994) and Stevenson and Wright (1996) suggest that seeding rates should be increased on weedy sites. Carr (1980) indicates that for reclamation purposes, dry seeding should be limited to slopes of 2:1 (50% or 22.5^o) or less, while slopes of 1:1 (100% or 45^o) must be hydroseeded. The B.C. Forest Practices Code "*Soil Rehabilitation Guidebook*" (Anonymous 1997), however, recommends dry seeding only up to slopes of almost 3:1 (35% or 19.3^o). Ideally, seeding density rates should be decided based on the reason for seeding and site characteristics (Hardy BBT 1989, Drinkwater 1993, Gerling et al. 1996).

Whether seeding for agricultural or reclamation purposes, with native or non-native species, the best seeding density for successful revegetation must be site-specific because soil moisture, nutrients, compaction and slope stability vary from location to location. It is unknown whether seeding densities are determined based on rules of thumb or on the results of valuable local site-specific experience. To date, published research that relates to seeding densities and how they were derived is sparse. The results of the research presented in this thesis will contribute to the body of knowledge related to seeding density and therefore can be used to guide decisions before revegetation work is undertaken.

2.4 Use of native species

The use of exotic instead of native species for revegetation purposes is becoming an important area of research in conservation biology, restoration ecology, and sustainable land management. Currently, vast stretches of logging roads, landings and mine tailings are being seeded with readily available, highly successful exotic seed mixes, thereby promoting the spread of introduced species across the landscape. It is widely acknowledged that the use of native species is preferable for restoration purposes but its limited availability, high cost and the tendency of many native species to establish slowly frequently precludes their use (Joyce 1993, Darroch 1994). Research related to the importance of using native species has only been undertaken in the last 25 years, with most research in western Canada carried out in Alberta.

A guide prepared by Hardy BBT Limited (1989) provides species information, including recommended densities for some native grasses and forbs, as well as for shrubs and trees, for reclamation projects in Alberta (Table 3). An examination of this manual reveals that the range of recommendations for sowing native seed is species-specific, probably reflecting seed size, germination capacity and species aggressiveness.

Table 3. Seeding density recommendations for revegetation with species native to Alberta.

Species	Common name	Seeding Rate (kg/ha)	Seeding Rate (PLS/m^2)
Grasses			
Bromus marginatus	mountain brome	6.7 – 9.0	134 - 178
Deschampsia caespitosa	tufted hairgrass	1.1 – 2.2	495 - 991
Oryzopsis hymenoides	Indian ricegrass	6.7 – 9.0	349 - 465
Phalaris arundinacea	reed canarygrass	5.6 - 11.2	637 - 1272
Poa alpina	alpine bluegrass	1.1	282
Stipa viridula	green needlegrass	9.0 - 11.2	2583 - 3875
Trisetum spicatum	spike trisetum	0.9 – 1.1	358 - 447
Forbs			
Epilobium spp.	willow-herb or fireweed	0.3	444
Hedysarum spp.	Eskimo root	16.8	122

Source: Hardy BBT (1989).

Densities recommended in Table 3 are comparable to the densities recommended for the agronomic species in Table 2. This is not surprising since they are derived from the same source (Hardy BBT 1989). But it is unlikely that these densities are the results of rigorous research, more probably they were extrapolated from agricultural species of the same genus, stature or seed size. It should be noted that many other native species are listed in the Hardy BBT (1989) manual, for which no seeding rate recommendations are included. The table is short, considering the hundreds of native vascular species in Alberta. Clearly, there is still much work to be done in determining the optimum seeding densities when using native seed for restoration purposes.

The seeding densities listed in Table 3 are low compared to rates tested by Walker and Harrison (1985) in their study to identify techniques and plant species suitable for rehabilitation in the Canadian Rocky Mountains. Their seeding density x fertilizer trials, which included some native species, tested densities ranging from 538 - 50,000 PLS/m^2. Most remarkable is the use of *Trisetum spicatum* (L.) Richt (spike trisetum) Poaceae sown at densities ranging from 8,334 - 50,004 PLS/m^2, compared to Hardy BBT's (1989). recommendation of 358 - 447 PLS/m^2 for this species. Walker and Harrison (1985) did not give results on a single species basis, so it is not possible to comment on the effect of seeding *Trisetum spicatum* at such a high density. However, they do conclude that high seeding rates increase ground cover, but reduce plant vigour. Because some of the densities tested were so high, it is likely that plants suffered from competitive stress and density-dependent mortality (see Section 2.1).

Gerling et al. (1996) have produced an extensive guide on the use of native plants on disturbed lands in Alberta. This guide provides useful information on site preparation, seeding guidelines, and an extensive list of the characteristics and requirements of native grasses and forbs. The issue of seeding density is only addressed in a superficial manner. Hammermeister (1998) provides guidelines for seeding rates of native species in Alberta, ranging from 150 to 500+ PLS/m^2, depending on erosion risk, the surrounding plant community, risk of exotic species invasion, seedbed, mode of seed application, expected weed competition, and desired rate of cover establishment. Once again, however, no replicated, controlled or published research is cited as the basis for these recommendations.

Pahl and Smreciu (1999) also produced a guide to growing native plants in Alberta, intended for growers interested in the production of seed for use in restoration projects. It is a comprehensive manual with information on seed characteristics, land preparation, seeding methods, row spacing, timing of seeding and seeding density rates needed to produce a successful crop of seed. Their guidelines for seeding density are based on seed germination information, but they were developed on the basis of drill seeding well-prepared land for production of a seed crop, not densities for application to degraded land for cover production.

It is especially important to consider germination capacity when working with native species, because native plant populations are variable and have not been selected for reliable germination. In contrast, agronomic species reliably have a germination rate of >90% (Hafenrichter et al. 1968, Broersma pers. comm. 2000). Native seeds are therefore more likely to be prescribed in terms of PLS/m^2 so that the density of seeds likely to establish can be controlled.

Preliminary field trials conducted by Symbios Research and Restoration in their native plant project were designed to test seeding mixtures of grasses and forbs native to the northern interior of British Columbia (Burton and Burton 2001). Seed was generally applied as part of multi-species mixtures sown at 15 – 2,432 PLS/m^2. Individual species densities ranged from 5 to 286 PLS/m^2 (Table 4). After two years of monitoring, the mean emergence of all species was only 5.6%. No test plot achieved the desired 215 plants/m^2 or 70% cover, suggesting that much higher seeding densities are needed to achieve acceptable seedling densities. Very high densities might be needed before density-dependent mortality could be expected.

Table 4 does not evaluate the effects of total seeding density, but it nevertheless demonstrates the very low emergence experienced on severely degraded sites. To counteract low establishment rates after seeding on barren and compacted soils, seeding rates ranging from 1,327 to 43,000 PLS/m^2 would have to be used, if any one of those species were employed (alone) to achieve a desired plant density of 215 individuals per m^2 (as shown in the last column of table 4). It is worth noting that the two agronomic species, *Phleum* *pratense* and *Trifolium hybridum* L. (alsike clover) Fabaceae, did not have the highest emergence on these sites and so would not necessarily be the species of choice, if other (native) seed was available.

Since Table 4 combines the results of a wide range of revegetation treatments, the early Symbios results (Burton and Burton 2001) should be interpreted as guidelines for future study rather than as recommendations for revegetation purposes. Seeding any species at a density of 43,000 PLS/m^2 is likely to be impractical on an operational basis, and would probably result in either incomplete germination or intense competition. When using native species, even densities much over 1,000 PLS/m^2 are "high" relative to widely recommended seeding rates, and considering the relatively high cost and low availability of the seed.

Table 4. Summary of first-year seedling emergence from Symbios Research & Restoration field trials conducted in 1998 and 1999 (Burton and Burton 2001). Species are listed in the order of emergence success, which is used to determine recommended**sowing densities.

Species	No. Plots Sampled	Average Density Sown	Average Seedling Emergence	%* Emergence	No. of Desired Seedlings**	Recom-mended** Density
	(n)	(PLS/m^2)	(plants/m^2)	(% of PLS)	(plants/m^2)	(PLS/m^2)
Elymus glaucus	115	110.3	17.9	16.2	215	1327
Festuca occidentalis	117	98.1	14.2	14.5	215	1483
Bromus ciliatus	34	58.7	7.8	13.3	215	1617
Achillea millefolium	133	124.9	14.1	11.3	215	1903
Elymus trachycaulus	18	125.7	12.1	9.6	215	2240
****Trifolium hybridum*	12	50.0	4.7	9.4	215	2287
Lupinus polyphyllus	32	44.7	2.4	5.3	215	4057
****Phleum pratense*	6	174.0	6.4	3.7	215	5811
Geum macrophyllum	64	33.1	1.2	3.6	215	5972
Lupinus arcticus	87	53.1	1.6	3.1	215	6935
Anaphalis margaritacea	106	71.1	1.2	1.7	215	12647
Carex mertensii	98	106.3	1.7	1.6	215	13438
Carex aenea	52	285.9	2.0	0.7	215	30714
Dryas drummondii	8	186.1	0.9	0.5	215	43000
Arnica cordifolia	9	4.9	0.0	0	215	--
Luzula parviflora	8	4.9	0.0	0	215	--
Vicia americana	20	6.0	0.0	0	215	--

* Calculated as seedling emergence/density sown for individual plots.

** Based on recommendations by K. Broersma (pers. comm. 2000), given as 20 seedlings per sq ft., if a single species were to achieve desired seedling density.

*** Non-native agronomic species

Substantiated recommendations for the effective use of native seed for restoration purposes are not yet possible because research has been so limited. There are still many unanswered questions with regard to seeding protocol, seed dormancy, optimum seeding conditions and species mixtures when sowing native grasses and legumes. Answers to these questions may not have been actively pursued because native species are reported to establish slowly, making weed control difficult and limiting their use for effective erosion control and quick "green-up" (Darroch 1994, Gerling et al. 1996).

Despite the limitations involved in using native species, research suggests they are often a desirable option for use in revegetation, for several reasons. Native plants are sometimes better adapted to local conditions than exotic species, and they grow better under the harsh conditions typical of most degraded sites (Brown et al. 1976, Thornburg 1982, Hardy BBT 1989, Pahl and Smreciu 1999). Brown and Johnston (1980) found that *Bromus inermis* Leyss. (smooth brome) Poaceae and *Agropyron intermedium* (Host) Beauv. (intermediate wheatgrass) Poaceae did not successfully establish on a subalpine site where the native species *Deschampsia cespitosa* (L.) Beauv. (tufted hairgrass) Poaceae and *Poa alpina* L. (alpine bluegrass) Poaceae were successful. Use of bioregionally appropriate natives also helps maintain ecosystem composition, function and structure (Vitousek 1986).

2.5 Fertilizer as a soil amendment

Experiments measuring plant growth after fertilization have been conducted in North America for over 100 years (Morgan 1912). Fertilization to compensate for low nutrient conditions, to accelerate plant growth and to enhance crop yields (even on relatively fertile soils) has been routinely recommended for over fifty years (Hollowell and Tysdal 1948, McCaughey and Simons 1996). Considerable research has been conducted on the use of fertilizer for revegetation purposes as well. Although much research related to fertilization does exist, there is a dearth of such research on degraded soils in the northwest interior of British Columbia.

Research results suggest that the effectiveness of fertilizer depends on site location, site conditions and plant species. Fertilizer may aid in the establishment and survival of species on degraded sites, however, excess amounts can cause unbalanced growth of foliage with subsequent depletion of soil moisture (McKell 1982).

On infertile degraded montane, alpine and subalpine habitats in Alberta, Ziemkiewicz (1985) considers fertilization for three years necessary to promote establishment and rapid cover development. Mougeot (1996) likewise suggested fertilizer could be beneficial in alpine and subalpine sites in the Yukon. In the Northwest Territories, Maslen and Kershaw (1989) found that only one species out of seven responded significantly to the addition of fertilizer. Brown et al. (1976) stated that fertilizer application is essential to successful establishment of plant cover on alpine disturbances. As a result of subsequent studies, Brown and Chambers (1989) concluded that in high mountain ecosystems, fertilizer can enhance the growth of some species but not others.

Research suggests that high nitrogen fertilization has an impact on the legume component of any seed mix (Dyrness 1975, Ziemkiewicz 1985, Panciera and Sparrow 1995). Dyrness (1975) believed that this negative impact is because legumes cannot compete successfully with grasses that respond to the increased soil nitrogen, while Ziemkiewicz

(1985) said that too much nitrogen may inhibit the growth and/or development of nitrogen-fixing nodules on legume roots.

Dyrness (1975) recommended roadside seedings should be re-fertilized every four to seven years. His studies in Oregon showed that plots that were initially fertilized had 91% cover three years after seeding, 10% cover five years after establishment, but 95% cover one year after re-fertilization in year seven. Walker and Harrison (1985) found that, on deactivated road sites in the Rocky Mountains, fertilization at the time of seeding can have a positive effect on ground cover, and its effect lasts at least three years. On deactivated roads and erosion scars in coastal B.C., Schwab (1991) recommends a combination of two to five grasses and legumes, with fertilization every three to five years to maintain plant vigour.

In some grassland restoration projects, fertilizer use is not only discouraged but "soil impoverishment" is implemented. This technique involves the addition of straw or sawdust, which will then be decomposed by bacteria and fungi that consume much of the soil's nitrogen), thus discouraging the growth of exotic species. (Morgan et al. 1995). Wilson and Gerry (1995) recommend the use of herbicide on a site before seeding, but not fertilizer, in order to control weeds and better promote rapid establishment of native seedlings.

Discrepancies regarding the importance and effectiveness of fertilization can be explained. Most rangeland and prairie grassland restoration is being conducted at low elevations in temperate climates on intact topsoil, which has an inherent amount of organic matter and nutrients. In prairie restoration, where control of exotic species is an objective, fertilizer use is discouraged. This approach is understandable, because fast-growing nong-native annuals and perennial weeds are generally better at taking up nutrients than slower growing native perennials, so weed competition on these sites is exacerbated by the addition of fertilizer and native species may be suppressed (Huenneke et al. 1990, Wilson and Tilman 1993, Townley-Smith and Wright 1994, Stevenson and Wright 1996).

In contrast, roadside revegetation and reclamation is usually undertaken on newly exposed subsoil, or even bare parent materials (glacial till and fractured rock), which are typically low in nitrogen, available phosphorus, potassium, sulphur, micro-nutrients and organic matter. In British Columbia, roadside revegetation and mine reclamation are often conducted in severe climates with short growing seasons, in which plants might more clearly benefit from added nutrients. On the other hand, it is not unusual for factors such as compaction, moisture stress to be more limiting to plant growth on severe sites than nutrient stress (Brown and Chambers 1989, Maslen and Kershaw 1989).

2.6 Season of seeding

Research related to herbaceous species and season of seeding does exist, but to date this topic has not been thoroughly investigated. Studies of germination phenology suggest that grasses germinate at a variety of times throughout the growing season, depending on the species and climate (Baskin and Baskin 1998). Such variation in emergence suggests that there is a time of year that is optimal for seeding a given site or species in order to ensure maximum establishment success. For example, a study of six agronomic species found that some grasses respond negatively to freezing. This calls into question the common practice of fall seeding for all grass species in central California (Laude 1956). In the Pacific Northwest, for purposes of erosion control, Schwab (1991) recommends fall seeding with agronomic species in areas with summer drought, so seeds will be in place to take advantage of early spring rains. He does not recommend late fall seeding for legume species because they tend to have low emergence rates if sown too late in the season. Guidelines for reclamation seeding in the Yukon suggest that seeding of either agronomic or native species can be done in early spring or fall, depending on site moisture regime (Kennedy 1992). Brown and Chambers (1990) suggest that high-elevation disturbances should always be revegetated in the fall because, if spring planting is attempted, suitable seedbeds for germination are inaccessible until the growing season is well advanced. If sown six to eight weeks before a period of drought or freezing cold, seed should have a sufficient period of time to germinate and acquire dormancy (Carr 1980). On the other hand, seed is sometimes sown late enough in the season that it will remain dormant (if it is too late in the season for seedlings to establish and acquire cold hardiness) but will be in place to germinate when conditions are optimal in the spring.

At lower elevations, fall seeding is not so crucial. Seeding can be carried out successfully in spring, summer or fall, depending on the species in question, year-to-year weather variation, and the timing of optimum growing conditions at any given site (Gerling et al. 1996). As with seeding density and fertilizer, there is no published research comparing the season of seeding grass-legume mixtures in the northern interior of B.C. It is difficult to extrapolate the results of studies dealing with different species and under different climates to a new area. So it remains to be determined whether a particular mixture of native plant species would establish better if sown in the spring or autumn on degraded sites in the northern interior of B.C.

2.7 Chapter summary

Plants scientists have recognized that nature imposes limits, allowing either a few large plants or many small ones to survive on any piece of ground, and many experiments have been conducted to understand the reciprocal yield law and density-dependent mortality. However, just recognizing the existence of yield-density relationships does not provide guidance or the appropriate criteria for evaluating the success of seeding. Such evaluation is dependent upon the particular objectives of seeding. The goal of agricultural seeding is to produce crops for forage or seed production, so forage yield (above-ground biomass) or seed yield, in kg/ha, are the logical measures of success. Seeding for silvicultural purposes is often intended to provide quick ground cover that will help check the growth of more competitive non-tree species. Roadside revegetation usually has the goal of preventing erosion and providing visual green-up, both of which depend on the development of rapid shoot cover. In landing rehabilitation and minespoil reclamation, the goals may include soil decompaction to improve soil porosity and enrichment with organic matter and nutrients. For these purposes, success is logically measured in terms of percent cover of the sown species compared to that of undesired species.

Revegetation is frequently considered successful when a specific level of cover has been attained without regard to species composition. Ecological restoration, however, places a premium not only on the total cover achieved, but on species composition compared to some pre-treatment or benchmark site condition.

A review of common practices reveals the importance of specifying seeding rates in PLS/m^2, rather than in kg/ha, due to the wide range of seeds per kg characteristic of different species. When working with native seed supplies, with variable germination rates and variable seed purity, PLS determination (based on germination testing and purity analysis) is even more important.

The use of native species to maintain ecosystem integrity in terms of species composition and diversity has become an especially important issue in North America over the last 10 or 20 years. Information gleaned from this literature review reveals that native species are being used for revegetation purposes at various locations in North America. Some of the findings may be applicable regionally, but the biology of different species growing in different climates needs to be addressed. The optimum use of plant species native to B.C. has not yet been widely researched, especially for forest roadside revegetation and restoration purposes. In particular, there are no B.C. studies that have systematically tested seeding density, fertilizer use, or season of seeding for native grasses and legumes; indeed, such research has rarely been done elsewhere. The research reported in this thesis addresses this lack of information for the northern interior of British Columbia, and will hopefully contribute to a better understanding of herbaceous stand density relationships in general.

Chapter 3 Methods

3.0 Introduction

A complete factorial field experiment was established at six locations in northern B.C. to test the effects of seeding density, use of fertilizer, season of seeding and their interaction on the establishment of cover. A full set of treatment combinations was tested in order to determine which seeding density produced the highest cover and whether fertilization and/or season of seeding influenced cover. The six replicate sites chosen for this research are all in the northern interior of B.C. and were all disturbed by industrial or agricultural activity. Soils at the sites had uniformly low nutrient levels and were compacted by heavy machinery.

The species used in the experiment were all native to the northern interior of B.C. The proportion of each species in the seed mix was identical for all sites and for all treatments. The mix consisted of two grass species, one sedge, one legume, and two non-leguminous forbs. Species selected for the mix (Tables 1 and 4) were chosen based on their performance in preliminary field seeding trials conducted by Symbios Research and Restoration (Burton and Burton 2001), as well as on seed availability and the desire to create a mix that consisted of a variety of growth forms, including a nitrogen-fixing plant. All seed used in the mix was from the Symbios Research and Restoration seed increase plots. The seed densities used in this experiment, 375 to 6000 PLS/m^2, broadly bracket the results of preliminary trials and the recommendations of other researchers. Two seeding times were tested (spring and fall) to determine if one season was better than the other for achieving high germination rates and establishment of cover.

3.1 Experimental design

Six replicate sites were established and are treated as statistical blocks throughout this thesis (Table 5). The main treatments consisted of all combinations of six seeding densities, with and without fertilizer, assigned randomly to twelve contiguous 2.5 m x 2.5 m plots in the fall of 1999, and then again to another 12 nearby plots sown in the spring of 2000. Fall plots were established, as time and logistics permitted, in September and October of 1999; one site (Francois Lake) was sown in September and the remaining five plots were sown in the first two weeks of October. Spring plots were established, adjacent to the fall plots at each site over a one-week period in June 2000.

Table 5. Location of study sites.

Location	Biogeoclimatic Classif.		Latitude		Longitude		Elevation
	Zone	Sub-zone	Deg.	Min.	Deg.	Min.	(metres)
Viewmount	SBS	dk	54°	45'	127°	06'	510
Francois	SBS	dk	54°	00'	126°	20'	760
Ptarmigan	SBS	dk	54°	43'	127°	11'	800
Chapman	SBS	mc	54°	51'	126°	35'	880
McKendrick	ESSF	mc	54°	51'	126°	44'	920
Nass	ICH	mc	55°	12'	129°	07'	200

Note biogeoclimatic zones have been abbreviated as follows: SBS= sub-boreal spruce, ESSF= Engelman spruce - subalpine fir, ICH= interior cedar-hemlock; Biogoclimatic sub-zones have been abbreviated as follows: dk=dry cool; mc= moist cold

The division of the sites into sub-blocks was necessary since the experiment required seeding immediately after rototilling, and it was impractical to rototill 2.5 m x 2.5 m plots individually. Therefore, all fall rototilling was done as one sub-block and all spring rototilling was done as another sub-block. This practical requirement of freshly rototilling plots (to loosen the compacted soil prior to sowing) meant that the spring- and fall-seeding treatments were implemented in clusters, rather than independently randomized among the 24 plots. Consequently, the season-of-seeding treatment has been applied as a "split block" or "strip plot" factor, and each cluster of spring- or fall-seeded plots can be considered a statistical sub-block (Little and Hills 1978).

According to Little and Hills (1978), one of the disadvantages of the split-block design is that it is not as precise at estimating the average effects of the treatments assigned to the main plots (i.e., the fertilizer and density treatments) but it can improve precision in comparing, in this case, the interaction between time of sowing and density x fertilizer treatments. Therefore, this experiment (as a split-block design) allows a more precise evaluation of the effect of spring versus fall seeding and its effect on density and fertilizer treatments. However, it is less precise in evaluating the main effects of the season of seeding.

To provide a uniform and favourable seedbed, each plot was first cleared of large rocks and vegetation, just prior to sowing the plots. Small, planted conifers were left on the sites so as not to interfere with reforestation efforts, and never occupied more than 5% cover at the two locations in which they were encountered. Plots were rototilled to a depth of approximately 12 cm, and then were raked by hand. Each 75 m^2 test site sub-block was divided into twelve 2.5 m x 2.5 m plots, and demarcated with all-weather pink plastic flagging tape anchored with 20 cm long galvanized metal spikes pounded into the ground. Figure 1 shows a typical plot layout. Each sub-block at the six sites was laid out in a contiguous array of either 1 x 12, 2 x 6, or 3 x 4 plots, depending on the terrain and the distribution of vegetation growing on any particular site.

Plot 1 6000 F fall	Plot 4 750 NF fall	Plot 7 375 NF fall	Plot 10 750 F fall	Plot 13 Control F spring	Plot 16 3000 NF spring	Plot 19 Control NF spring	Plot 22 1500 F spring
Plot 2 1500 NF fall	Plot 5 375 F fall	Plot 8 3000 NF fall	Plot 11 1500 F fall	Plot 14 750 NF spring	Plot 17 375 F spring	Plot 20 3000 F spring	Plot 23 750 F spring
Plot 3 3000 F fall	Plot 6 Control NF fall	Plot 9 6000 NF fall	Plot 12 Control F fall	Plot 15 6000 F spring	Plot 18 1500 NF spring	Plot 21 6000 NF spring	Plot 24 375 NF spring

←N

2.5 m

Figure 1. A typical plot layout at Chapman Rd. (Figure 2) in two 3 x 4 plot clusters or sub-blocks, one for fall (left) and one for spring (right) seeding. The numbers 375, 750, 1500, 3000 and 6000 denote seeding density treatments in total sown PLS/m^2, with Control = 0 PLS/m^2. F = fertilized, NF= not fertilized.

Density and fertilizer combinations were randomly allocated to the 12 plots in each sub-block at each site. Plots were sown by hand in the spring and fall at each site with a standard seed mix at densities of 0 (control), 375, 750, 1500, 3000 or 6000 pure live seeds (PLS) per m^2, then fertilized with 184.5 g of 18-18-18 NPK fertilizer per plot (=295 kg/ha). Plots were lightly raked after seeding.

The randomization of the density and fertilizer treatments was achieved by sketching the plot layout at each location and numbering plots 1 through 12 consecutively (e.g., Figure 1). A complete set of the six densities with two fertilizer treatment combinations was written out on twelve pieces of paper, thrown in a hat, then drawn out at random and assigned to the pre-numbered plots in the order that they were drawn. This process was repeated independently for the spring and fall plots. Thus, density and fertilizer treatments were truly randomized at each site.

Densities were chosen based on recommendations in the literature suggesting that effective erosion control on road slopes requires plant cover of 70 to 80% after the first growing season (Carr 1980). Schwab (1991) recommends 1500 to 3000 PLS/m^2 for revegetating degraded soils on landslide-prone terrain with agronomic species. Since all test sites are more or less level, and there is no experience in using these native species for revegetation, a geometric series of densities were chosen as treatments in order to bracket Schwab's (1991) proposed density of 1500 PLS/m^2 in a broad and systematic manner.

Seeding rates were calculated in PLS /m^2 for each species. The use of pure live seed as the measure of seeding density ensured that the intended proportion of each species in the seed mix was consistent for all treatments. A constant proportion of species in a seed mixture allows measurement of the abundance of each species as an indication of its relative success and response to treatment (Chambers 1990).

To compare fertilized vs. non-fertilized treatments, 184.5 g of fertilizer (NPK18-18-18) was applied in one of two plots sown to each density, just after sowing. This rate is equivalent to 295 kg/ha, as per provincial recommendations for roadside seeding of agronomic species (Carr 1980). This rate was chosen in an attempt to mimic the current standard applications for reseeding degraded sites with agronomic species.

3.2 Site description

Six sites, degraded through industrial forest activities, road construction, log loading, log sorting or agricultural activity, were selected for broadcast seeding, by hand, in October 1999. The map in Figure 2 shows the geographical location of these six sites in northwestern B.C. These sites are referred to as:

- Ptarmigan Road, Viewmount Road and Francois Lake located in the dry cool sub-zone of the Sub-Boreal Spruce biogeoclimatic zone (SBSdk);
- Chapman Road in the moist cold sub-zone of the Sub-Boreal Spruce biogeoclimatic zone (SBSmc);
- McKendrick Pass in the Engelmann Spruce-Subalpine Fir biogeoclimatic zone (ESSFmc); and
- Nass Valley, in the Nass variant of the moist cold sub-zone of the Interior Cedar-Hemlock biogeoclimatic zone (ICHmc).

All biogeoclimatic zone classifications follow Banner et al. (1993).

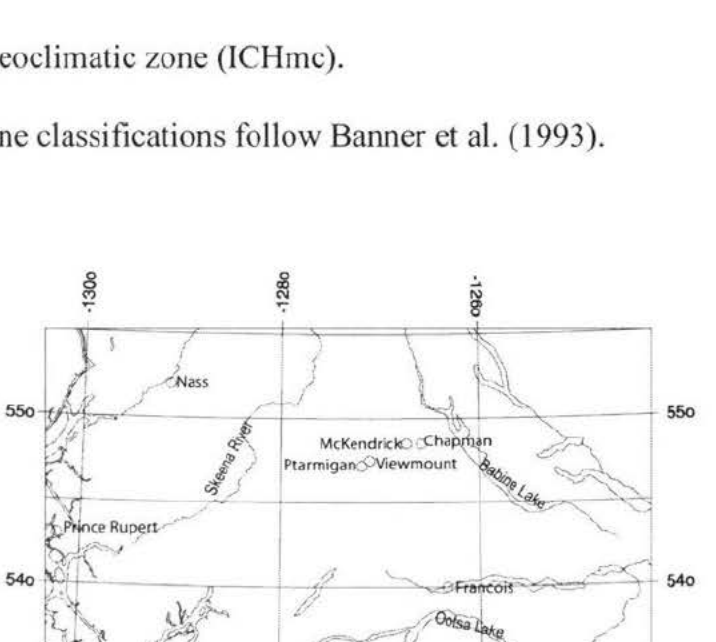

Figure 2. Location of the six research sites in northwestern B.C. Generated using the on-line map creation utility available at www.aquarius.geomar.de/omc/.

Although the trial locations span a large area of northwestern British Columbia, the sites were similar in that they all had little or no topsoil, were heavily compacted and were generally free of woody plants. The sites share a broadly similar climate, characterized by a predominantly continental influence with cordilleran modifications, having long cold winters with deep snow and cool moist summers (CCELC 1989). All six sites were within the collection range of the original seed used to establish the Symbios Research and Restoration seed plots mentioned earlier (Section 1.7) and described in detail in Burton and Burton (2002).

Table 5 specifies the location of the sites presented in Figure 2 in terms of latitude, longitude and elevation.

3.2.1 Climate and weather

Climate data compiled by the Research Branch of the B.C. Ministry of Forests provides estimates of the average maximum, minimum and mean temperatures and mean precipitation for each of the six study sites over the last 30 years (Table 6). These data were derived from observations made at all nearby Environment Canada weather stations, interpolated and adjusted for elevation and rain shadows by the PRISM (**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel) program developed at Oregon State University (Daly et al. 1994; also see http://www.ocs.orst.edu/prism/przfact.html). The summary presented in Table 6 show that climatic conditions differ as expected for the biogeoclimatic zones represented in this study. However, growing conditions during the summer were largely similar, with precipitation ranging from 41 to 64 mm and mean maximum temperatures ranging between 17° C at the highest altitude and 21° C at the lowest altitude. Note that precipitation is usually twice as great in the Nass Valley as it is at Francois Lake.

The same PRISM modeling approach could not be used to estimate the weather during the experiment (1999, 2000 and 2001), because it generates predictions on the basis of long-term norms, not individual years (Spittlehouse, pers. comm. 2002). Instead, the Environment Canada data for the weather stations located closest to each test site were summarized for those three years, to document any year to year differences in growing conditions. Ideally, temperature and rainfall sensors and dataloggers would have been installed at each location to provide more accurate local weather information but finances were a limiting factor.

Table 6. Thirty-year summary of the climatic conditions experienced at the six study sites, interpolated from Environment Canada weather stations using PRISM (Daly et al. 1994).

Climatic Attribute	Nass	Viewmount	Ptarmigan	McKendrick	Chapman	Francois
Spring (Apr-May)						
Maximum Temp.	13.9	12.4	12.2	8.0	10.4	11.1
Minimum Temp.	2.0	-1.0	-1.0	-2.1	-1.7	-1.1
Mean Temp.	7.9	5.8	5.6	2.9	4.4	5.0
Precipitation (mm)	37.0	24.5	23.5	33.5	29.5	19.5
Summer (Jun-Aug)						
Maximum Temp.	21.3	20.4	20.3	17.0	19.0	19.0
Minimum Temp.	8.3	5.8	5.9	5.0	5.8	6.0
Mean Temp.	14.8	13.1	13.1	11.1	12.4	12.5
Precipitation (mm)	49.3	44.0	42.7	64.3	52.0	40.7
Yearly (Jan-Dec)						
Maximum Temp.	10.6	8.9	8.7	5.7	7.3	7.9
Minimum Temp.	1.2	-2.8	-2.8	-3.9	-3.3	-2.9
Mean Temp.	5.9	3.0	3.0	0.9	2.0	2.5
Precipitation (mm)	982.0	507.0	509.0	739	583.0	429

3.2.2 Soil analysis

Representative soil samples were taken for nutrient analysis in September 2000, during the monitoring of plots after the first growing season, to verify the similarity of these widely dispersed sites. At each of the six locations, three random soil samples measuring approximately 300 cm^3 each were taken: one from the untreated area (control plot) in the fall-seeded sub-block; one from the untreated area in the spring-seeded sub-block and one from the general site area. Control plots had been rototilled at the time of plot setup, while the "general area" sample had not. Each sample was collected from a depth of 5 to 10 cm using a soil corer. It was then air-dried, passed through a 2 mm sieve, placed in a labelled zip-loc bag and frozen until all samples from each site had been collected and prepared accordingly. In October 2000, samples were sent to Norwest Labs (Langley, B.C.) for a standard agricultural soil analysis. Attributes tested included concentrations of available nitrogen, phosphorus, potassium and sulphur, % organic matter, salinity as indicated by electrical conductivity, and soil pH. Soil textures were determined by hand at the time of sample collection, using the key provided in Banner et al. (1993).

3.3 Species selection

The first consideration in choosing species in any revegetation project is to select those appropriate to the site, in order to achieve successful establishment, long-term survival and reproduction (Brown and Chambers 1990). As noted previously, the species chosen for this work are all native to the northern interior of B.C. (Burton and Burton 2002), consisting of two grasses (*Elymus glaucus, Festuca occidentalis*), a sedge (*Carex aenea*), and three forbs (*Achillea millefolium*, *Lupinus polyphyllus* and *Geum macrophyllum*) (Table 1 and Figure 3). The mix is a combination of tall and short grasses, fast and slow germinators, a rhizomatous species and a nitrogen fixer, representing a balance of life history and physiological traits. Such a range is considered important because increased species and structural diversity improves the chance of stand success across a broad range of microsites, and positively influences stand survival in the event of insect invasion, drought or disease (Brown and Chambers 1990).

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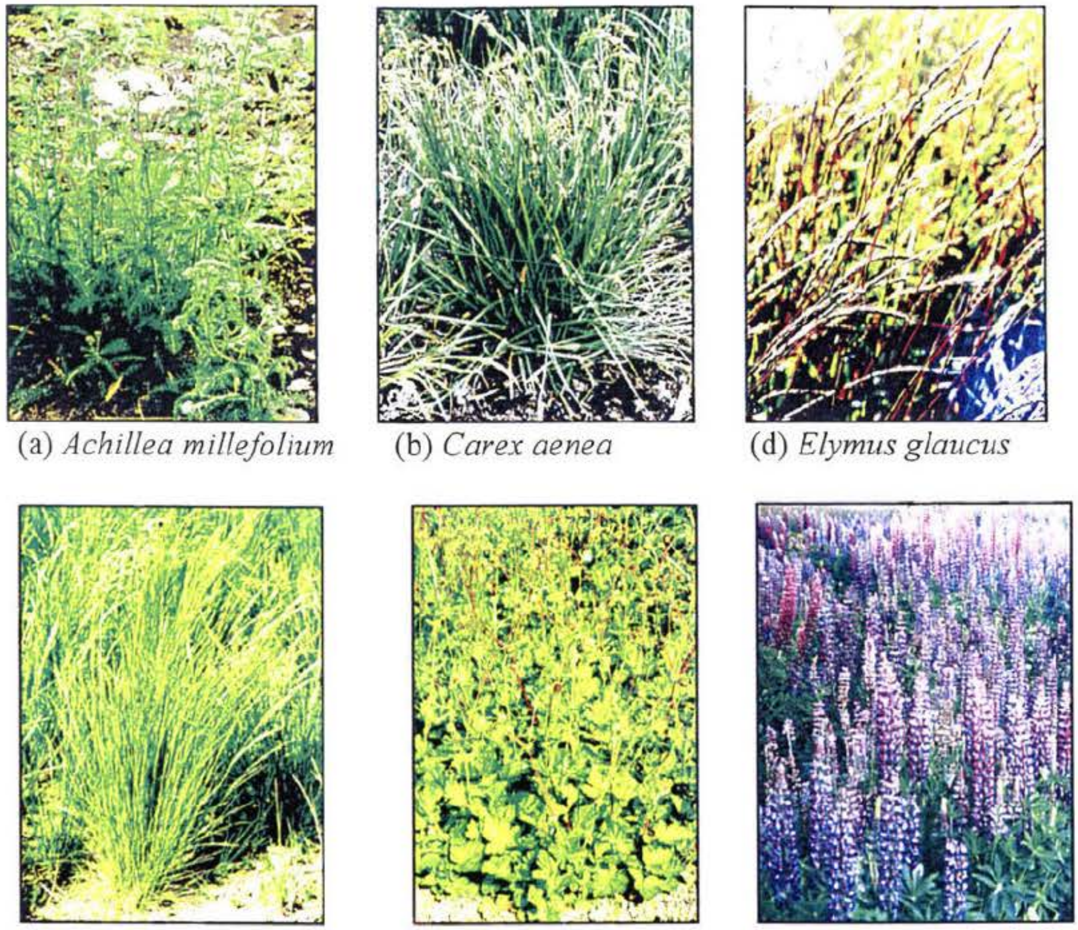


(a) *Achillea millefolium* (b) *Carex aenea* (d) *Elymus glaucus*

(c) *Festuca occidentalis* (f) *Geum macrophyllum* (e) *Lupinus polyphyllus*

Figure 3. The six native plant species used in the experimental seeding mixture. The pure live seeds applied to each sown plot consisted of 20% *Achillea millefolium*, 20% *Carex aenea*, 20% *Elymus glaucus*, 20% *Festuca occidentalis*, 16% *Geum macrophyllum*, and 4% *Lupinus polyphyllus*.

These six species were chosen from a suite of native plant candidates that had reliable germination under laboratory conditions and were available in sufficient quantities to be used in such a large-scale field trial. The seeds used in the experiment were grown in

Table 7. Seed characteristics of the species selected for use in this experiment.

Species	Germ.[a] Capacity	Mean Seed Length (mm)	Mean Seed Width (mm)	Mean Seed Weight (mg/seed)	Seedling Emergence: Mean Days to start	Mean Days To 50%[b]	Mean Days to finish	Mean GDD[c] to start	Mean GDD[c] To 50%[b]
Achillea millefolium	97.7	2.15	0.78	0.012	5.0	6.0	33.5	32.5	38.7
Carex aenea	77.7	4.35	1.78	0.054	37.7	47.0	61.7	297.1	417.3
Elymus glaucus	81.0	11.66	1.81	0.422	9.5	9.7	39.0	68.6	69.8
Festuca occidentalis	84.7	4.00	1.30	0.037	9.0	9.8	26.2	63.9	72.5
Geum macrophyllum	62.8	6.24	1.90	0.053	13.2	17.1	44.4	84.6	110.5
Lupinus polyphyllus	66.3	3.90	2.64	1.064	7.9	21.5	52.5	60.8	180.7

[a] Germination tested under lab conditions 30°C days, 20°C nights.
[b] number of days or GDD to achieve the 50% or one-half of the final germination capacity.
[c] GDD = Growing Degree Days, base 5°C; each day's average temperature has 5° subtracted from it and is summed over the period from sowing until seedlings are observed emerging (data from Burton and Burton 2001).

The seed mix employed at all densities consisted of 20% *Achillea millefolium* L., 20% *Carex aenea* Fern., 20% *Elymus glaucus* Buckl., 20% *Festuca occidentalis* Hook., 16% *Geum macrophyllum* Willd. and 4% *Lupinus polyphyllus* Lindl., measured as numbers of pure live seed.

Initially a proportion of 20% for each of five species (excluding *Geum macrophyllum*) was chosen as a way to introduce equal amounts of seed of all species into the mix. However there were not sufficient quantities of *Lupinus polyphyllus* seed available, so *Geum macrophyllum* was chosen to supplement the *Lupinus* at a rate of 16% because it is also a forb (although not a nitrogen-fixing one) and because sufficient seed was available.

3.3.1 Individual species descriptions

Achillea millefolium L. (common yarrow) Asteraceae is a common aromatic rhizomatous perennial herb with vegetative growth typically less than 10 - 15 cm tall and flowering stalks to 60 cm tall. It is reported to grow abundantly on dry to moist but well drained open sites at low to high elevations, and does well on disturbed sites and poor soils (MacKinnon et al. 1992, Small and Catling 1998, Douglas et al. 1998). Seeds are 1.82 to 2.48 mm long and 0.61 to 0.94 mm wide and the average seed weight is 0.0130 mg per seed (7,668 seeds per gram). For the seed lot sown in this experiment, average germination capacity was 86%, time to first germination under greenhouse conditions (variable elevated temperatures, ambient sunlight) was 5.0 days, with 50% of potential germination achieved at 6.0 days. Seed longevity is at least 5 years under cool dry conditions (Burton and Burton 2001). Germination tests for this species and for subsequent species reported here were all conducted under standard laboratory conditions in a programmable incubator set to 12 hour 30°C days and 12 hour 20° C nights.

Carex aenea Fern. (bronze sedge) Cyperaceae is a sedge with densely tufted basal foliage on slender wiry stems, bent over at the tip with 4 - 8 sessile (stalkless) spikes in a loose awned cluster, and lower spikes well separated. Achenes are enclosed in bronze perigynia. It has soft flat leaves 2 - 4 mm wide and grows up to 100 cm tall (MacKinnon et al. 1992, Douglas et al. 1994). It can be found on open dry to moist open forests, meadows and clearing at low to mid elevations and often grows in profusion on disturbed sites (MacKinnon et al. 1992). Seeds are 3.92 - 4.78 mm long and 1.45 - 2.11 mm wide, with an average seed weight of 0.0673 mg per seed (1,487 seeds per gram). For the seed lot sown in this experiment, average germination capacity was 73%, time to first germination under greenhouse conditions was 37.7 days, with 50% of potential germination not achieved until 47.0 days (Burton and Burton 2001), making this a very slow germinating species.

Elymus glaucus Buckl. (blue wildrye) Poaceae is a perennial grass that grows in clumps with culms in loose to dense tufts. The inflorescence is 5 - 15 cm long and the mature plant size is 50 - 150 cm tall. It is reported to grow on moist to dry slopes in meadows and open forests at low to medium elevations (MacKinnon et al. 1992, Douglas et al. 1994). Seeds (without awns) are 9.98 to 13.34 mm long and 1.47 to 2.14 mm wide with an average seed weight of 0.4367 mg per seed (229 seeds per gram). For the seed lot sown in this experiment, average germination capacity was 85%, time to first germination under greenhouse conditions was 9.5 days, with 50% of potential germination achieved at 9.7 days (Burton and Burton 2001).

Festuca occidentalis Hook. (western fescue) Poaceae is a small tufted perennial grass with a few slender stems with open fine panicles, drooping at the top. The mature plant size ranges from 25 - 70 cm (MacKinnon et al. 1992). It is reported to grow on xeric to mesic, poor to rich sites (Beaudry et al. 1999) and is shade tolerant (Pavlick 1983). Seeds are 2.30 - 5.69 mm long and 0.99 to 1.60 mm wide with an average seed weight of 0.034 mg per seed (2,960 seeds per gram). For the seed lot sown in this experiment, average germination capacity was 85%, time to first germination under greenhouse conditions was 9.0 days, with 50% of potential germination achieved at 9.8 days (Burton and Burton 2001).

Geum macrophyllum Willd. (large-leaved avens) Rosaceae is a perennial herb with a short rhizome on a stout base. It has several heart-to-kidney shaped basal leaves that are hairy along the veins, deeply lobed and blunt tipped, and an open terminal cluster of saucer-shaped flowers with yellow corollas and five petals. It produces numerous achenes which are hooked at the ends. Mature plant size is 30 - 100 cm tall (Douglas et al. 1999). It can be found in moist meadows, fields, clearings, roadsides, stream banks and open forests at low to middle elevations through the northern interior (Douglas et al. 1999). It is reported to be shade tolerant to shade intolerant, to be associated with seepage or fluctuating water table, and to be partial to mineral soil (Beaudry et al. 1999). Seeds are 4.77 - 7.70 mm long and 1.48 - 2.13 mm wide, with an average seed weight of 0.0345 mg per seed (2,895 seeds per gram). For the seed lot sown in this experiment, average germination capacity was 75.5%. Time to first germination was 13.2 days, with 50% of potential germination achieved at 17.1 days (Burton and Burton 2001).

Lupinus polyphyllus Lindl. ssp. *polyphyllus* (large-leaved lupine) Fabaceae is a perennial nitrogen-fixing rhizomatous herb that grows up to 150 cm tall. It has 9 - 17 palmately arranged leaflets per leaf with a dense raceme of bluish to violet pea-like flowers maturing from bottom to top. It grows on moist to mesic meadows in gravel bars, stream banks, clearings, roadsides and open forests (MacKinnon et al. 1992, Douglas et al. 1999). Seeds are hard-coated, 3.48 - 4.31 mm long and 2.31 - 2.96 mm wide, with an average seed weight of 0.955 mg per seed (105 seeds per gram). For the seed lot sown in this experiment, average germination capacity was 62%, time to first germination under greenhouse conditions was 7.9 days, with 50% of potential germination achieved at 21.5 days (Burton and Burton 2001).

3.4 Plot Monitoring

All plots were monitored for plant cover and density at each location between September 13th and September 17th in 2000, and between August 15th and August 24th in 2001. At each location, monitoring of all 24 plots was completed in one day. Each plot was monitored using a 0.25 m^2 (0.5 x 0.5 m square) quadrat at three non-overlapping randomly selected locations. Sample locations were selected using random x,y coordinates generated using the "RAND" function of Microsoft Excel, version 7. For each sown species, emergent seedlings were first counted, then a cover estimate was noted. All other species growing within

the quadrat were also identified to species, counted, and assigned a cover estimate. A cover estimate of rocks, moss and litter was also recorded for each quadrat.

Within each plot, species that had gone to seed were noted. At some sites in the first year, some *Festuca occidentalis* plants produced seed which began to germinate in the same growing season. These very small seedlings were counted separately as "*Festuca* seedlings" in the second year of monitoring. Appendix 1 provides a sample of the data collection form.

3.5 Data analysis

As described in Section 3.1, the experiment is a three-way factorial balanced design (i.e., all treatment combinations were tested and there were the same number of replicates for all treatment combinations) replicated in six individual blocks. Data from the three sample quadrats within plots were averaged before statistical analysis, with replication provided by the six locations. Collected data were analyzed using the SAS procedure ANOVA (ANalysis Of Variance; SAS Institute 1988), with error terms specified to accommodate the split block design (see Appendix 2). An ANOVA examines the variation within and among treatments and evaluates it compared to the variation within and among replicates (in this case, locations). This same model structure was applied for testing treatment effects on a number of dependent variables, including:

- plant densities (counted # of plants per 0.25m^2 quadrat;
- emergence rates (# of plants / # of seeds sown);
- total plant cover;
- cover of individual species;

- cover of species groups (sown, exotics, native invaders)

Seeding density, fertilizer and season of seeding are considered categorical independent variables in this experiment. Appendix 2 presents the analysis of variance model employed for most hypotheses testing, using the total cover of all sown species as an example of the response or dependent variable.

When ANOVA results revealed a significant density effect, a Tukey multiple comparison test (as an option in SAS proc ANOVA, SAS Institute 1988) was conducted to identify which density treatments differed significantly (at p=0.05) from each other. When ANOVA indicated significant season of seeding or fertilizer effect, however, no multi-comparison was required because there are only two treatment levels in those factors. In those cases, a significant F-ratio in the ANOVA meant that the treatment with the higher mean value was significantly greater than the treatment responsible for the lower mean value.

In order to examine a variety of plant community dynamics, particularly the potential for trade-offs between different components, selected pairs of species or species groups were evaluated using correlation analysis (Pearson test, SAS proc CORR, SAS Institute 1988). Cover correlations were tested between:

- *Elymus glaucus* and *Achillea millefolium* (to see if *Elymus* might be suppressing *Achillea* or vice versa);
- *Elymus glaucus* and *Festuca occidentalis* (to see if *Elymus* might be suppressing *Festuca* or vice versa);
- *Elymus glaucus* and *Lupinus polyphyllus* (to see if *Elymus* might be suppressing *Lupinus* or vice versa);
- *Achillea millefolium* and *Festuca occidentalis* (to see if *Achillea* might be suppressing *Festuca* or vice versa);

- *Achillea millefolium* and *Lupinus polyphyllus* (to see if *Achillea* might be suppressing *Lupinus* or vice versa);
- *Festuca occidentalis* and *Lupinus polyphyllus* (to see if Festuca might be suppressing *Lupinus* or vice versa);
- sown species and exotic species (to determine the degree to which sowing native plants can deter weed invasion);
- sown species and other native species (to see if sowing inhibits the natural invasion of other indigenous vegetation); and
- the legume *Lupinus polphyllus* and other sown species, particularly in the unfertilized plots (to see if the abundance of a nitrogen-fixing species enhances the performance of other species which cannot fix nitrogen).
- the grass species (*Elymus glaucus* and *Festuca occidentalis)* with *Lupinus polyphyllus* to see if grasses were suppressing the growth of lupine.

A linear regression analysis (SAS proc REG; SAS Institute 1988) was run after some correlation tests, in order to derive equations that described these relationships.

Though many attributes were measured in the experimental plots, the results presented in the next chapter emphasize the ability of the three factors tested (seeding density, fertilizer and season of seeding) to influence sown cover production and their ability to exclude exotic plants.

Chapter 4 Results

4.0 Introduction

The vegetation in experimental plots was monitored for plant density (plant "count" as defined in Section 1.8) and cover of each species in the late summer of 2000 (Year 1) and 2001 (Year 2) at all six locations. Strong treatment differences were clearly visible as a result of the treatments (Figure 4). Summaries of these measurements and their statistical analysis constitute the principal results of this project. Supportive information on soil conditions at each location and year-to-year differences in weather during the experiment is also reported.

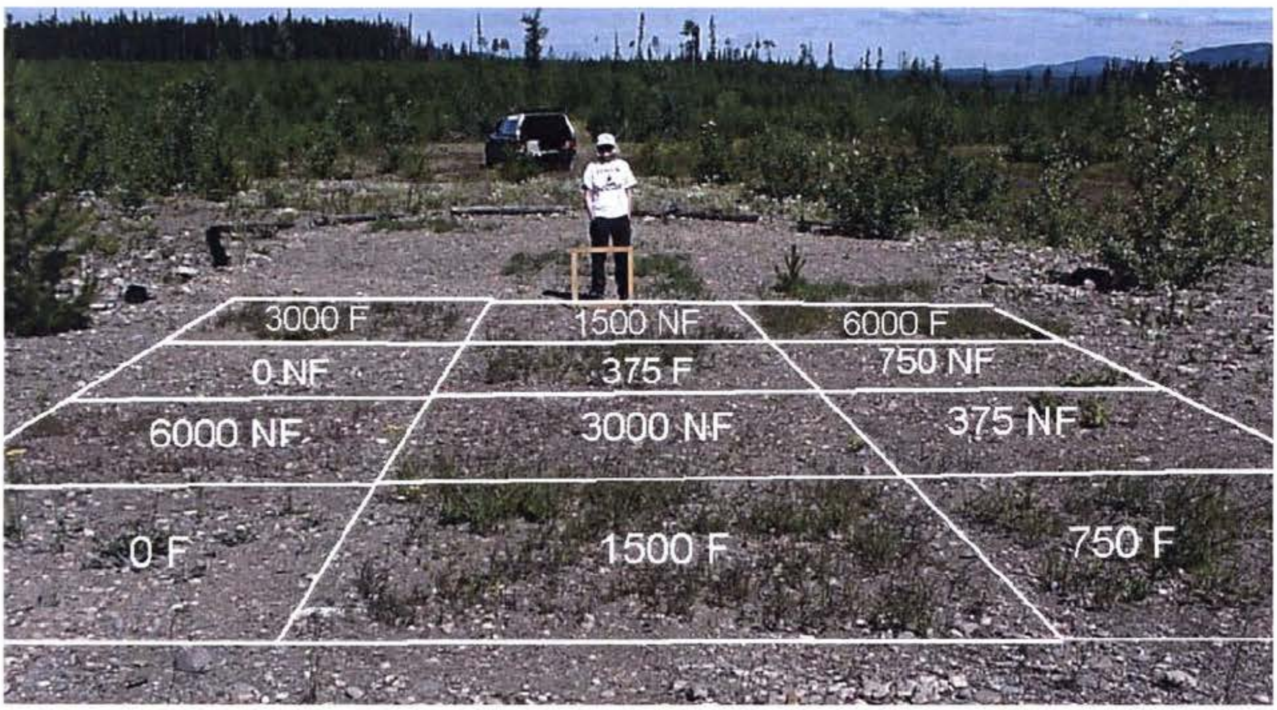


Figure 4. The Chapman Rd. field site after the first growing season, with treatments in the fall-sown sub-block demarcated to illustrate plot boundaries and different treatments. Note differences in plant cover, stature, and colour associated with seeding density (0, 375, 750, 1500, 3000, or 6000 PLS/m^2) and fertilizer (F vs. NF) treatments.

Results are first presented for environmental conditions during the study, then plant density and seedling emergence results are briefly described. More in-depth results are presented for cover, followed by trends in the abundance and inter-relationships between various species that make up the vegetation monitored.

4.1. Environmental conditions

Results of soil analysis and regional weather data are reported here to document the growing conditions prevailing during the experiment at all six locations. No statistical analyses of site differences, yearly differences, or treatment differences are presented. Rather, some of the trends noted are used in explaining plant cover results and in guiding the development of recommendations (Chapter 5, Discussion).

Soil and weather conditions at the sites do vary with location to a limited degree. All sites are similar in that soils are nutrient deficient, and the climate is characterized by cool temperatures, and a short growing season. The compacted loamy soils, consisting of mixed topsoil and subsoil or subsoil only, are typical of those left after road construction and logging activities. They have no obvious limitations due to salinity or texture, but all have low nitrogen.

Sites were purposely chosen to represent a range of biogeoclimatic zones (and hence climatic conditions) common to the northern interior of B.C. The differences in temperature and precipitation among sites are similar to the year-to-year differences at any given site. There were no indications that any site experienced unusual or extreme conditions such as growing season frosts or severe summer drought.

4.1.1 Soil analysis results

Soils analysis results confirm that the soil at all sites was similar, prior to the application of fertilizer, in several important respects (Table 8). Based on the ranking scheme utilized by Norwest Labs for nutrient analysis, all sites can be considered deficient in nitrogen and potassium. Three sites had optimum amounts of phosphorus, and three were either marginal or deficient. Soils were not particularly saline or alkaline, and generally had relatively high amounts of organic matter, though much of this consisted of un-decomposed wood and bark debris.

Table 8. Summary of soil analysis results, with rankings by Northwest Labs (Langley, B.C.).

	Location					
Attribute	Viewmount	Francois	Ptarmigan	Chapman	McKendrick	Nass
Texture (determined by hand)	loam	clay loam	loam	sandy loam	sandy loam	gravelly sandy loam
Nitrogen, ppm	3.00[d]	<1[d]	3.50[d]	<1[d]	<1[d]	<1[d]
Phosphorus, ppm	13.50[m]	>60[o]	5.75[d]	38.00[o]	2.50[d]	59.00[o]
Potassium, ppm	72.00[d]	163.5[m]	63.50[d]	71.00[d]	39.50[d]	52.50[d]
Sulphate, ppm	10.00[o]	4,50[o]	4.00[m]	4.00[m]	5.00[m]	2.00[m]
PH	6.4[n]	6.4[n]	5.9[a]	5.9[a]	6.7[n]	5.6[a]
Electrical conductivity, dS/m	0.21[g]	0.09[g]	0.15[g]	0.09[g]	0.12[g]	0.10[g]
Organic matter, %	7.90[hn]	1.82[*]	2.55[ln]	8.50[hn]	4.80[n]	8.80[h]

d = deficient m = marginal o = optimum

n = neutral a = acidic

g= good h = high hn= high normal ln = low normal

*Francois spring sown sub-block: low/normal; Francois fall sown sub-block: deficient, average to low

4.1.2 Weather conditions during the study

The location of the three weather stations from which weather data was obtained is presented in Table 9. The Nass weather station is 13 km NW of the study site located in the Nass Valley. The weather station at the Smithers airport is 9 km NNW of the Viewmount site and 12 km N of the Ptarmigan site. It is also the closest weather station to the McKendrick site, which is 29 km to the east and the Chapman site, which is 39 km to the east, both of which are at higher elevations. The Wisteria weather station is 23 km NE of the Francois study site.

Table 9: Location of weather stations closest to study sites

Location	Latitude		Longitude		Elevation
	Deg.	Min.	Deg.	Min.	(metres)
Nass Camp	55	28	128	97	290
Smithers Airport	54	82	127	18	522
Wisteria	53	82	126	17	860

Weather conditions recorded at the Environment Canada meteorological stations closest to the study sites are presented in Table 10 for the three calendar years in which this study was established and monitored.

At all three weather stations, annual precipitation was less than the 30 year norm in 1999. Precipitation in the spring of 2000 (the main period of germination) was lower than the 30 year norm at the Nass Station and the Smithers station but higher than normal at the Wisteria station. Precipitation in the summer of that year was lower at all three sites. In 2001, the spring and summer were wetter than normal at the Smithers station but drier than normal at the Nass and Wisteria stations.

Mean spring temperatures in 2000, the main period of germination, were 1.7°C higher in the Nass and 0.1° higher at Wisteria than the 30 year norms. In Smithers, the mean spring temperature was 0.5° lower than the 30 year norm.

In the summer, mean temperatures were higher at all three stations than the 30 year norm in 2000, the first growing season. In 2001, mean summer temperature was higher at the Nass station (by 0.5°) and close to normal at the other two locations (0.2° lower at Smithers and 0.1° lower than normal at Wisteria). In general, the 2002 growing conditions for the sites close to Smithers can be considered wetter and slightly cooler than normal, but still not greatly different from conditions prevailing at Nass and Wisteria.

Table 10. Comparison of annual weather conditions with 30 year normals for Environment Canada weather stations closest to the study sites.

	Nass				Smithers				Wisteria			
Climatic Attribute	30yr	1999	2000	2001	30yr	1999	2000	2001	30yr	1999	2000	2001
Spring (Apr-May)												
Maximum Temp., °C	12.0	11.7	13.7	12.2	12.8	11.5	12.3	11.6	10.0	9.1	10.1	9.0
Minimum Temp. , °C	0.3	1.6	1.9	0.8	0.2	-0.2	0.1	-0.3	-1.4	-2.4	-2.1	-2.1
Mean Temp. , °C	6.2	6.7	7.8	6.5	6.5	5.6	6.2	5.7	2.9	3.3	4.0	3.5
Precipitation, mm	95	141.8	88.0	82.5	52.0	84.6	48.2	71.6	51.0	43.2	57.8	45.4
Summer (Jun-Aug)												
Maximum Temp. , °C	19.2	20.0	[1]19.7	18.9	20.4	19.5	20.2	18.8	18.0	17.4	18.1	18.0
Minimum Temp. , °C	7.3	9.0	[1]9.6	8.9	6.9	7.5	7.7	7.2	5.8	6.6	6.0	5.6
Mean Temp. , °C	13.3	14.5	[1]14.5	13.9	13.7	13.5	13.9	13.0	11.9	11.7	12.4	11.8
Precipitation, mm	195	233.6	[1]76	173.2	133.0	210.4	118.0	175.4	133.0	184.4	119.6	121.4
Yearly (Jan-Dec)												
Maximum Temp. , °C	8.5	[2]10.1	[3]10.1	[4]10.4	9.0	9.3	8.9	8.6	7.2	8.5	[5]8.8	[6]9.4
Minimum Temp. , °C	-0.9	[2]1.5	[3]0.7	[4]1.6	-1.8	-0.8	-1.2	-1.2	-3.0	-1.7	[5]-1.8	[6]-1.4
Mean Temp. , °C	3.8	[2]5.8	[3]5.4	[4]6.0	3.6	4.2	3.9	3.7	2.1	3.4	[5]3.5	[6]4.0
Precipitation, mm	1156	[2]899.2	[3]734.9	[4]615.0	516.0	501.4	419.6	526.8	511.0	476.5	338.4	[5]267.8

[1]=Data missing for Aug
[2]=Data missing for Oct
[3]=Data missing for Aug, Oct, Dec
[4]=Data missing for Dec
[5]=Data missing for Dec
[6]=Data missing for Nov, Dec

4.2 Plant density and seedling emergence

As a first step in evaluating the field trials, it is useful to see how many plants of each species were able to establish under the different treatment combinations. Furthermore, it is important to determine the percentage of sown seeds that actually germinated and grew.

These results for plant density are summarized below in Tables 11 and 12. In these tables the different species are grouped by year, experimental treatment and plant origin.

4.2.1 Plant density

A summary of the mean number of plants counted in 0.25 m^2 quadrats in 2000 is presented in Table 11, and a summary for 2001 is presented in Table 12. These tables show that mean total sown plant count increased as sown density increased (as expected) under all treatments in 2000 and 2001. The highest mean plant count occurred in the fall-seeded fertilized 6000 PLS/m^2 treatment in both years (Table 11 and Table 12). By the second year, the number of sown plants had generally increased at the lower seeding densities, and had decreased at the higher seeding densities.

In the first year the mean exotic plant count was approximately twice as great at all seeding densities in the spring-sown plots as in the fall-sown plots (Table 11). By the second year, the number of exotic plants decreased, especially in the spring-sown plots (Table 12).

In 2000, the number of native volunteer plants tended to be greater in the fall-sown plots than in the spring-sown plots (Table 11). The difference in count between the spring and fall sowing treatments was less pronounced in the second year (Table 12). From Year 1 to Year 2 the count of native volunteers tended to decrease in the fall sown plots and increase in the spring sown plots

Table 11. Summary of plant counts (per 0.25 m^2 quadrat) after one growing season under all treatment combinations.

			Plant Count							
Season		Sown	Sown Species		Exotic Species		Native Volunteer		All Species	
Sown	Fertilization	Density	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Fall	Fertilized	0	6.2	8.2	7.4	15.0	10.6	7.8	24.3	16.68
		375	31.8	16.8	7.0	11.4	27.7	35.6	72.1	36.07
		750	52.1	39.1	6.9	16.4	12.0	12.5	83.2	30.54
		1500	75.7	38.0	7.1	14.7	32.3	65.7	124.6	63.14
		3000	99.1	40.9	5.2	11.5	10.3	15.7	137.4	42.49
		6000	176.6	114.8	5.7	13.2	12.1	22.1	242.1	108.94
	Non-Fertilized	0	2.4	3.0	5.0	7.9	28.1	51.2	35.5	57.93
		375	24.2	13.1	4.2	9.2	6.3	4.3	34.7	14.88
		750	24.1	8.1	3.6	8.2	15.2	31.5	42.9	34.01
		1500	65.9	32.3	4.6	10.2	32.1	63.5	102.6	52.14
		3000	84.7	57.5	4.8	10.9	6.4	11.9	95.9	57.98
		6000	147.7	85.9	6.0	11.5	29.7	43.2	183.4	80.31
Spring	Fertilized	0	0.2	0.3	10.1	14.6	3.3	2.6	13.7	14.81
		375	15.3	7.0	10.8	22.3	2.5	3.3	28.6	24.36
		750	30.5	15.9	19.9	44.9	8.4	13.3	58.8	52.33
		1500	50.3	30.3	17.8	38.7	4.3	8.8	72.4	51.95
		3000	86.4	52.4	13.2	30.0	5.8	10.9	105.4	56.56
		6000	112.8	60.8	14.4	34.6	1.3	1.1	128.6	55.61
	Non-Fertilized	0	0.9	1.6	20.6	49.5	4.2	4.0	25.7	51.21
		375	16.5	13.3	19.2	45.8	2.3	1.5	37.9	46.23
		750	24.0	15.1	11.4	27.2	3.4	4.0	38.8	36.65
		1500	44.6	23.9	18.6	44.1	3.2	4.5	66.4	46.89
		3000	83.4	49.7	18.1	43.3	1.1	1.1	102.6	61.88
		6000	127.2	80.3	7.8	17.3	1.6	2.9	136.7	85.30

Table 12. Summary of plant counts (per 0.25 m^2 quadrat) after two growing seasons under all treatment combinations.

Season		Sown	Plant Count							
			Sown Species		Exotic Species		Native Volunteers		All Species	
Sown	Fertilization	Density	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Fall	Fertilized	0	19.8	15.4	9.7	16.2	40.7	59.4	70.2	76.2
		375	31.7	20.8	8.4	10.0	10.2	6.4	50.4	13.3
		750	86.4	62.3	10.6	23.0	10.9	11.3	107.8	52.4
		1500	88.4	44.8	3.9	7.8	6.7	11.3	99.0	47.9
		3000	96.0	29.0	3.1	5.4	4.2	5.9	103.3	21.6
		6000	148.7	67.0	11.2	27.0	8.4	12.0	168.3	54.6
	Non-Fert.	0	6.2	5.5	6.7	13.1	14.0	9.6	26.9	19.1
		375	26.0	8.5	4.9	10.3	11.7	17.6	42.6	31.7
		750	23.4	11.0	3.7	8.0	5.3	3.5	32.4	17.9
		1500	39.3	15.5	5.2	9.7	10.5	9.3	55.0	20.7
		3000	53.3	23.3	1.9	4.1	3.7	3.3	58.9	25.1
		6000	78.7	41.4	2.0	3.4	3.0	3.3	83.7	41.4
Spring	Fertilized	0	0.6	0.8	12.3	18.3	13.1	8.1	26.0	20.6
		375	17.4	7.4	7.8	12.4	5.7	4.9	30.9	13.6
		750	29.2	12.2	4.4	7.1	5.7	4.1	39.3	14.2
		1500	46.8	13.6	5.5	10.4	7.8	7.6	60.1	12.4
		3000	77.7	34.0	2.9	4.8	3.4	3.3	84.1	32.4
		6000	105.2	47.0	4.7	10.3	5.8	8.6	115.7	43.3
	Non-Fert.	0	1.2	2.0	9.7	17.3	13.7	16.3	24.7	33.2
		375	18.1	10.8	6.2	13.7	7.3	6.8	31.6	20.1
		750	25.2	11.2	5.9	11.7	7.6	9.1	38.7	25.4
		1500	39.6	21.5	8.4	16.6	10.3	20.5	58.3	37.3
		3000	72.1	22.5	4.9	11.2	5.8	7.5	82.8	25.7
		6000	112.6	38.4	3.2	5.9	4.3	4.6	120.2	36.0

4.2.2 Plant emergence

Table 13 summarizes emergence information, breaking it down by each treatment combination, and for each of the species sown. Emergence (as defined in Section 1.8) was generally calculated from the number of plants observed in the first growing season, the first time plots were monitored after sowing. Some species went to seed after the first year and presumably could have sprouted new second-generation plants in the plot, and some rhizomatous species (*Achillea millefolium, Elymus glaucus* and *Lupinus polyphyllus*) had begun to spread vegetatively after the first year. However, where plants had not gone to seed and Year 2 counts were higher than in Year 1 (which sometimes occurred for *Geum macrophyllum* and *Carex aenea*), the higher counts were used based on the assumption that they included late-germinating plants from the original sowing. The final column in Table 13 presents the mean density (count converted to a standard per m^2 basis) of sown plants produced by the corresponding treatment and emergence rates.

Note that the overall average emergence was only 16% and it varied among species. *Elymus glaucus* (33% emergence) and *Lupinus polyphyllus* (31% emergence) were the most successful germinators, followed by *Festuca occidentalis* (26% emergence). *Achillea millefolium* exhibited only 8.5% successful emergence, *Geum macrophyllum* had 6.5% emergence and *Carex aenea* a dismal 0.7% emergence. Because emergence rates were generally low, all seeding density treatments (375, 750, 1500, 3000, and 6000 PLS/m^2) resulted in comparatively low plant densities relative to the density of seed sown. It is possible that viable seed of all species remains in the seedbank at these sites and may germinate in the future.

Table 13. Total emergence of sown plant species after one growing season under all treatment combinations

Season Sown	Fertilization	Sown Density	Mean Plant Emergence, % *Achillea millefolium*	*Elymus glaucus*	*Festuca occidentalis*	*Carex aenea*	*Geum macrophyllum*	*Lupinus polyphyllus*	All Species %	All Species *Plants/m2*
Fall	Fertilized	375	14.8	43.6	85.9	3.0	20.7	37.0	34.3	128
		750	12.9	39.1	65.6	1.6	14.1	41.5	27.8	208
		1500	11.9	39.6	39.7	0.6	5.9	23.0	20.2	303
		3000	8.7	27.2	23.7	0.1	3.0	19.8	13.2	396
		6000	8.4	25.5	20.3	0.0	2.8	14.5	11.9	713
	Non-Fert.	375	9.5	66.4	30.5	1.8	13.3	50.4	25.8	97
		750	4.6	37.0	11.0	0.2	5.2	37.0	12.9	96
		1500	5.9	48.7	20.4	0.8	5.9	37.0	17.6	264
		3000	8.6	25.6	11.6	0.5	4.4	33.5	11.3	339
		6000	6.2	23.9	11.2	0.2	3.9	23.6	9.8	591
Spring	Fertilized	375	13.6	32.0	24.0	1.8	8.5	50.4	17.7	66
		750	9.9	31.4	32.9	0.3	6.7	29.6	17.2	129
		1500	8.3	27.5	25.2	0.4	3.2	22.2	13.7	205
		3000	6.9	23.5	22.2	0.2	3.5	21.7	12.0	359
		6000	4.7	15.2	14.9	0.2	1.6	12.0	7.7	464
	Non-Fert.	375	10.7	37.8	29.3	0.6	7.8	45.9	18.8	70
		750	5.9	33.6	15.3	0.9	9.3	38.5	14.2	106
		1500	4.7	32.3	15.1	0.2	3.9	33.7	12.4	186
		3000	4.7	28.9	14.8	0.4	2.4	34.1	11.5	346
		6000	9.7	14.8	13.8	0.2	4.7	18.7	9.2	552
	Overall average		8.5	32.7	26.4	0.7	6.5	31.2	15.9	281.0

[shaded] =values based on Year 2 count due to delayed germination of some species

Many of the treatments and treatment combinations were statistically significant in their effect on seedling emergence. However, emergence is not an accurate measurement of germination in the field in this experiment because it was determined only near the end of the growing season after many successful germinants may have died. Since the overall experiment was primarily designed to evaluate plant cover rather than survival or emergence success, no further emergence results are presented.

4.3 Effects of treatments on plant cover

The treatment factors tested in this study include:

- spring seeding compared with fall seeding;
- fertilizer compared with no fertilizer application;
- six seed density treatments ranging from 0 (control) to 6000 PLS/m^2.

The effects on plant cover of these three treatment factors, applied in all possible combinations, are the primary focus for the statistical results presented here. Table 14 presents the mean and standard deviation of Year 1 plant cover summarized by sown species, other native plant species, exotic species, and summed for all species. Table 15 presents the same results after the second year of monitoring.

To begin with, some general trends in plant cover are worthy of note. Even when considering all species (sown, exotics and native volunteers) growing in the plots, the 70% cover as recommended by Carr (1980) was not achieved under any treatment conditions. In Year 1, the spring-seeded fertilized plots sown at 6000 PLS/m^2 came closest to this standard with a mean cover of 68.1% (Table 14). However, mean cover in these plots declined by 2.1% to support only 66.0% cover in Year 2 (Table 15). In 21 out of 24 treatment

Table 14. Total plant cover after one growing season under all treatment combinations.

Season		Sown	Plant Cover, %							
			Sown Species		Exotic Species		Native Volunteer		All Species	
Sown	Fertilization	Density	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Fall	Fertilized	0	6.0	6.2	16.3	38.0	5.2	4.5	27.5	41.63
		375	27.9	27.4	12.2	22.6	6.6	7.7	46.7	32.46
		750	27.3	11.3	17.2	41.6	4.0	3.5	48.5	33.27
		1500	35.0	15.6	9.2	15.4	5.3	7.4	49.5	20.20
		3000	29.8	13.7	9.4	21.9	2.1	1.0	41.3	30.12
		6000	50.5	14.2	10.1	24.5	2.4	1.8	63.0	25.01
	Non-Fertilized	0	1.3	1.7	5.6	10.7	10.6	12.6	17.5	19.18
		375	9.7	8.1	9.6	23.0	6.4	11.2	25.6	31.36
		750	10.4	9.4	5.5	12.4	4.2	5.2	20.1	20.69
		1500	13.7	8.2	11.6	28.1	3.9	5.6	29.2	34.58
		3000	15.6	10.5	5.6	13.0	2.3	4.2	23.5	26.89
		6000	26.3	14.9	6.1	12.1	4.9	6.1	37.3	28.64
Spring	Fertilized	0	0.7	1.1	15.5	25.0	3.1	4.1	19.3	24.41
		375	19.7	17.5	14.1	25.7	3.1	4.8	36.8	22.78
		750	21.1	14.4	12.1	27.7	2.1	3.6	35.4	23.28
		1500	28.2	17.7	12.1	27.6	1.2	1.3	41.5	29.15
		3000	49.5	39.7	12.3	28.8	1.0	0.9	62.8	40.35
		6000	52.7	45.4	13.2	31.4	2.2	4.3	68.1	42.22
	Non-Fertilized	0	0.4	0.6	8.8	20.7	2.4	3.1	11.5	20.24
		375	4.2	2.9	9.1	21.6	0.9	1.1	14.2	22.01
		750	9.9	12.0	8.0	19.3	1.1	1.2	19.0	28.50
		1500	9.1	10.4	12.8	30.8	0.5	0.3	22.3	32.14
		3000	13.4	10.2	8.2	19.8	0.3	0.3	21.9	24.97
		6000	22.4	24.7	5.8	12.7	0.3	0.3	28.4	35.67

Table 15. Total plant cover after two growing seasons under all treatment combinations.

			Plant Cover, %							
Season		Sown	Sown Species		Exotic Species		Native Volunteer		All Species	
Sown	Fertilization	Density	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Fall	Fertilized	0	9.7	10.5	14.5	28.7	6.2	6.3	30.4	25.0
		375	30.0	35.8	15.6	20.6	9.2	14.2	54.8	44.7
		750	36.8	17.1	7.2	15.9	3.3	3.0	47.3	26.9
		1500	41.7	27.2	4.3	9.9	2.3	2.7	48.3	28.5
		3000	41.9	17.5	2.8	4.5	1.1	1.5	45.9	20.0
		6000	57.2	22.4	7.8	19.0	1.3	1.3	66.3	32.9
	Non-Fertilized	0	4.6	5.7	9.8	20.9	13.2	24.0	27.6	32.1
		375	25.7	24.7	7.2	15.3	9.6	19.3	42.4	45.4
		750	28.9	30.8	7.8	18.9	2.7	4.3	39.4	43.6
		1500	27.0	26.4	5.6	12.0	3.7	4.3	36.4	31.3
		3000	20.3	23.4	4.6	11.1	0.8	0.5	25.6	33.7
		6000	32.6	32.9	2.0	3.9	2.0	3.2	36.6	36.5
Spring	Fertilized	0	0.2	0.3	13.2	16.8	7.6	7.8	21.0	14.4
		375	23.2	15.7	6.4	9.3	1.7	2.1	31.3	16.0
		750	32.6	17.9	3.4	5.6	2.4	2.3	38.5	18.6
		1500	37.6	30.7	5.6	11.9	1.9	1.5	45.1	30.9
		3000	45.1	18.6	1.1	2.2	1.2	2.1	47.1	19.8
		6000	62.3	25.0	2.5	5.8	1.2	2.3	66.0	24.8
	Non-Fertilized	0	0.2	0.2	10.7	14.8	6.9	8.7	17.7	14.2
		375	15.8	18.8	6.1	14.4	1.5	2.1	23.4	24.3
		750	13.7	14.0	6.7	15.7	1.6	2.4	22.0	24.2
		1500	22.6	27.9	7.6	17.7	1.3	1.6	31.6	36.3
		3000	24.4	21.6	2.4	5.7	0.7	0.5	27.6	25.8
		6000	36.0	42.1	1.7	3.4	0.7	1.0	38.3	43.2

combinations, mean cover of sown species increased from Year 1 (Table 14) to Year 2 (Table 15), and the only decline in cover was in three of the four control plots. Conversely, the cover of exotic species declined from Year 1 (Table 14) to Year 2 (Table 15) in all but three plots. Native volunteer cover had declined in ten treatment combinations by the second year.

4.3.1 Treatment effects on sown plant cover

Total mean plant cover of the sown species mix, for Year 1 and 2 under all treatment combinations, is summarized in the first data columns of Table 14 and Table 15. The highest mean plant cover for sown species was achieved after two growing seasons in the most densely sown fertilized plots. Fertilized fall-sown plots had 57.2% cover fertilized spring plots had 62.3% cover. In sharp contrast, the highest mean cover of sown species was achieved in Year 2 in unfertilized plots was only 32.6% for fall-sown plots and 36.0% for spring-sown plots. Sown cover increased, but not significantly from Year 1 to Year 2 for all treatments, with the exception of the spring seeded fertilized plots at 3000 PLS/m^2, which declined from 49.5% cover to 45.1% cover.

4.3.2 Effect of seeding density on sown cover

In general, there was greater sown plant cover in plots which received the greatest amount of seed. When evaluated across all sites, fertilizer treatments and seasons of seeding, mean cover varied significantly among density treatments for both years tested. In Year 1, $F_{5,55} = 13.07$, $p= 0.0001$ (where the subscripts to F denote the degrees of freedom of the treatment term and the error term respectively, and the p value denotes the significance of the F test). In Year 2, $F_{5,55} = 15.53$, $p = 0.0001$, with the highest density (6000 PLS/m^2)

yielding the highest mean cover (Figure 5). Note the continued increase in cover with increased seeding density (Figure 5), ranging from 15% cover at 375 PLS/m^2 to a maximum cover of 38% achieved at 6000 PLS/m^2 in Year 1. In Year 2, cover ranged from an average of 24% at 375 PLS/m^2 to 47% at 6000 PLS/m^2.

The overall cover of sown species in control plots was never greater than 6% in Year 1 (Table 14) and 10% in Year 2 (Table 15). These "sown" plants may have arisen from seeds that spilled over from adjacent plots, or may have invaded naturally from the surrounding vegetation.

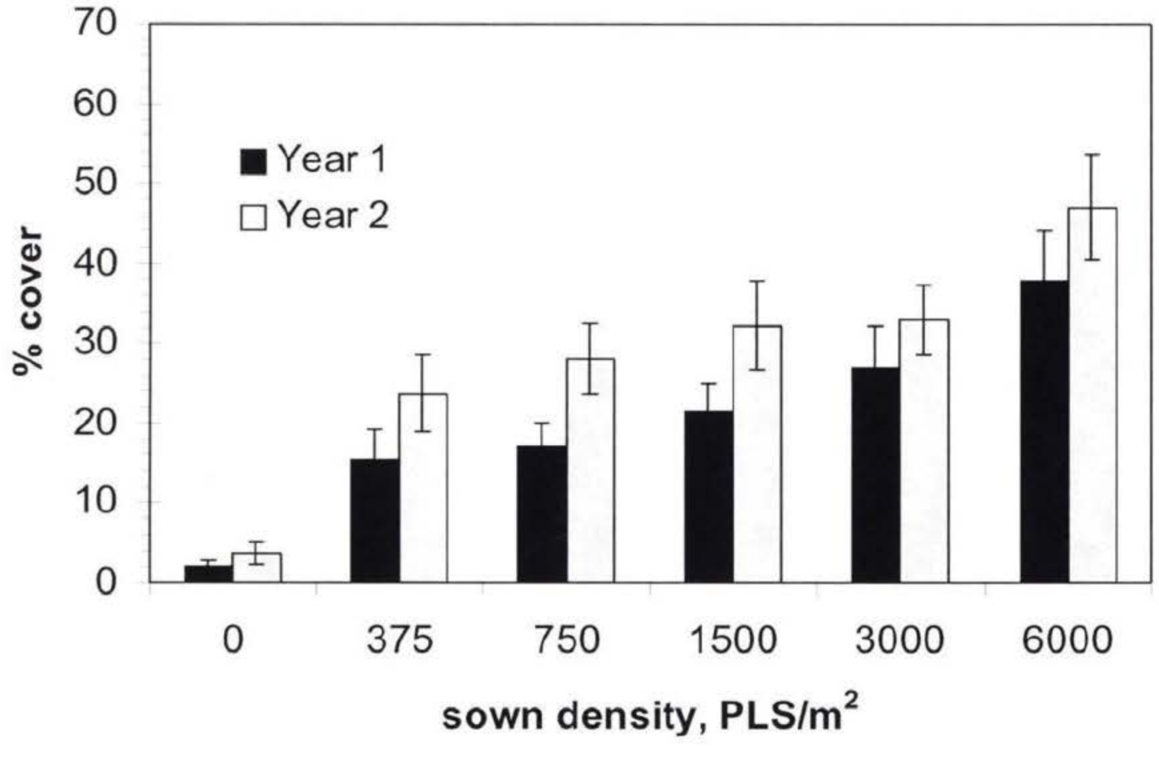


Figure 5. Mean (± S.E.M.) cover of sown species in response to density treatments, summarized for all six locations, both fertilization treatments and both seasons of sowing, n=24.

A subsequent Tukey multiple comparison test (Table 16) revealed that in Year 1, the 6000 PLS/m^2 treatment achieved significantly greater cover than all other densities except the 3000 PLS/m^2 treatment. Interestingly, the 3000, 1500, 750, 375 PLS/m^2 treatments were not significantly different from each other, and cover produced by the 375 PLS/m^2 treatments was not significantly greater than that found in the control plots. A Tukey test on Year 2 cover data revealed that 6000 PLS/m^2 treatment again yielded the greatest cover but then was not significantly different from 3000 and 1500 PLS/m^2 density treatments. Again, none of the 3000, 1500, 750, 375 PLS/m^2 treatments were significantly different from each other, but all produced greater cover than was found in the control plots.

Table 16. Summary of overall density treatment effects on the cover of sown species, with results of Tukey multiple comparison tests.

	Year 1 (2000)		Year 2 (2001)	
Density Treatment	Sown Cover (mean %)	Tukey Results*	Sown Cover (mean %)	Tukey Results*
0 PLS/m^2	2.1	c	3.7	c
375 PLS/m^2	15.4	b,c	23.7	b
750 PLS/m^2	17.2	b	28.0	b
1500 PLS/m^2	21.5	b	32.2	a,b
3000 PLS/m^2	27.1	a,b	33.0	a,b
6000 PLS/m^2	38.0	a	47.0	a

*Means in the same year are not significantly different at the 95% confidence level ($p = 0.05$) if sharing the same letter.

4.3.3 Effect of fertilizer on sown cover

Fertilized plots achieved higher cover in both Year 1 and Year 2 than the non-fertilized plots. Mean cover of fertilized plots was 29% in Year 1, significantly greater than the 11% in the non-fertilized plots (Figure 6). In Year 2, fertilized plots achieved a mean cover of 35%, significantly greater than the 21% in the non-fertilized plots in Year 2 (Figure 6). Mean sown plant cover varied significantly between fertilizer treatments in both years across all sites, density treatments and seasons of sowing. In Year 1, $F_{1,55} = 42.15$, $p= 0.0001$; in Year 2, $F_{1,55} = 22.13$, $p = 0.0001$.

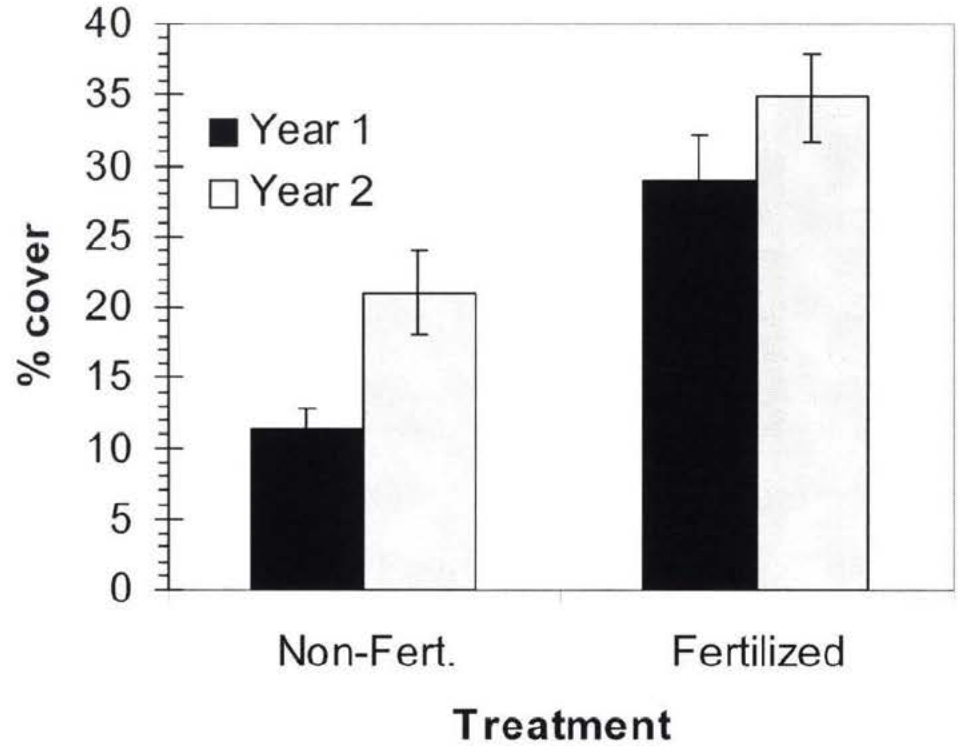


Figure 6. Mean (± S.E.M.) cover of sown species in response to fertilization treatments, summarized for all six locations, six density treatments and both seasons of sowing, n=72.

4.3.4 Effect of season of seeding on sown cover

Seeding in either fall or spring produced similar cover results. There was no significant effect of season of seeding in Year 1 ($F_{1,5}=0.42$, $p= 0.5451$), assessed across all six sites, all density treatments and both fertilizer treatments, with an average mean cover of 21% in fall sown plots and 19% cover in spring sown plots. Likewise, in Year 2 the season of seeding had no significant effect on sown cover, ($F_{1,5}$=1.65, p= 0.2551), with an average mean cover of 30% in fall-sown plots and 26% in the spring-sown plots (Figure 7).

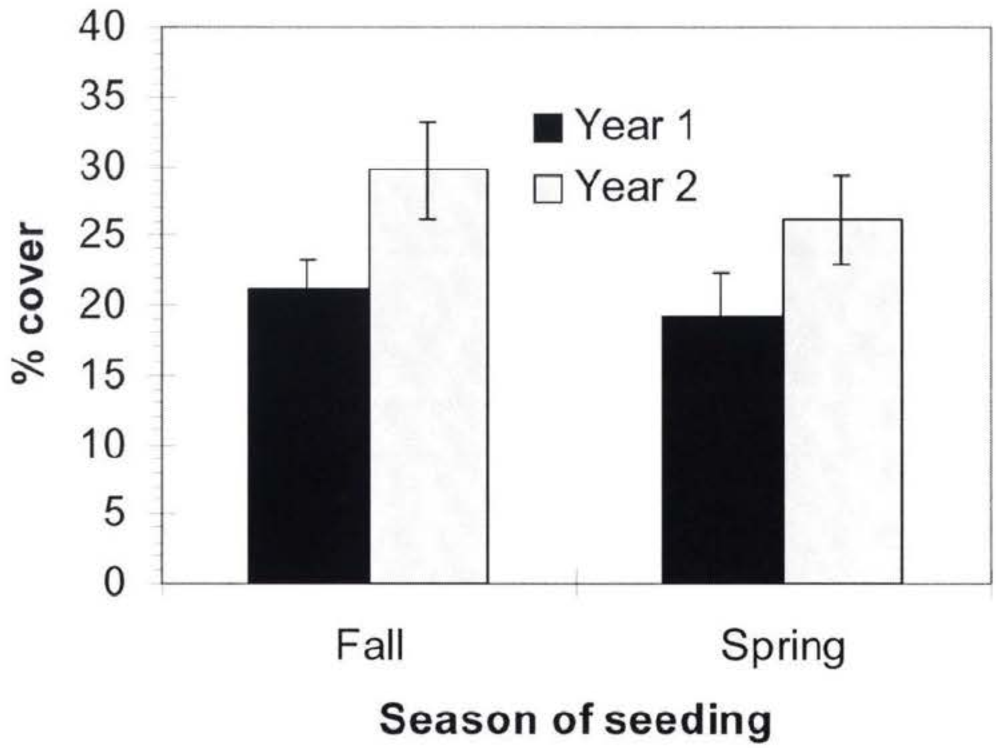


Figure 7. Mean (± S.E.M.) cover of sown species in response to seasons of sowing treatments, summarized for all six locations, six density treatments and fertilizer treatments, n=72.

4.3.5 Effect of treatment interactions on sown cover

The treatment interactions did not seem to influence cover in a statistically significant manner. Analysis of variance revealed that none of the treatment interactions were significant in their effects on sown cover in either Year 1 (all $p > 0.12$) or Year 2 (all $p > 0.16$). Table 17 shows the ANOVA results for all treatment interactions for both years. Although not statistically significant, the results suggest that fall seeding might generate more cover at seeding densities up to 1500 PLS/m^2; at densities higher than that, spring seeding produced greater mean cover (Figure 8).

Table 17. Anova results of treatment interactions in Year 1 and Year 2

	Year 1		Year 2	
Treatment interactions	F value	p value	F value	p value
density x fertilizer	1.79	0.1299	1.46	0.2174
density x season of seeding	1.25	0.3002	1.64	0.1647
fertilizer x season of seeding	0.29	0.5949	0.18	0.6704
density x fertilizer x season of seeding	1.11	0.3677	0.98	0.4704

p is significant at 0.05

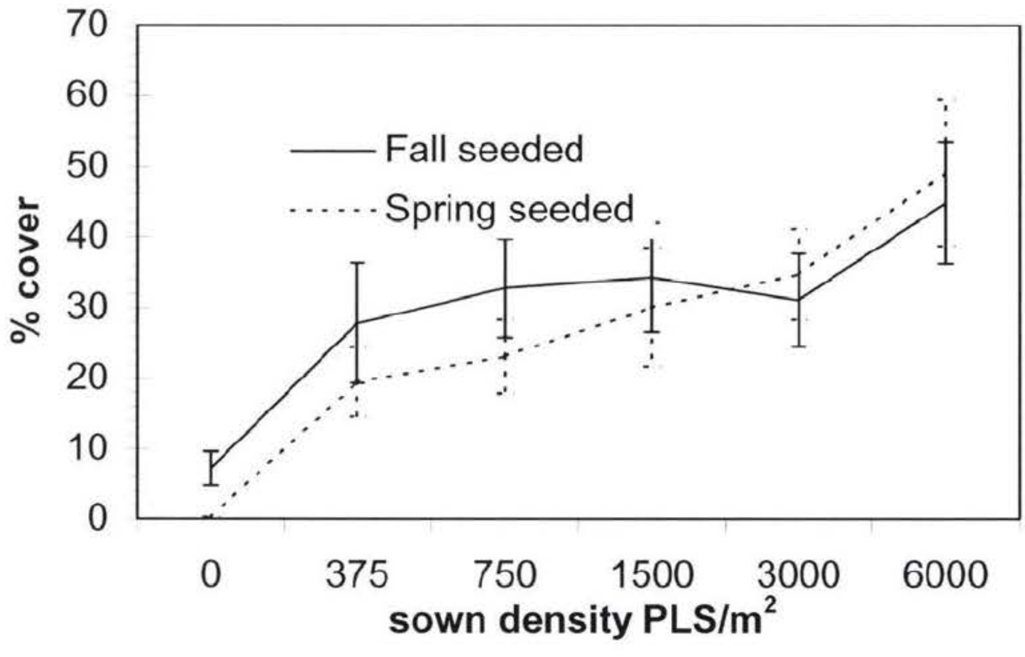


Figure 8. Year 2 cover of sown species across the gradient of seeding density treatments, implemented through spring or fall sowing. Each point portrays the mean, ± S.E.M., for all treatments at all six locations, n=12.

4.3.6 Effect of treatments on year-to-year differences in sown cover

The difference in cover from one year to the next was not influenced by any of the treatments, suggesting that the treatment effects were largely expressed in the first year. An

ANOVA was performed to test whether any treatments influenced the ability of sown species to grow or expand from one year to the next. For each of the 144 plots (six sites, 24 plots in each site) the difference between total sown cover from Year 1 to Year 2 was calculated. Those differences were examined using the same ANOVA model shown in Appendix 2, and this test yielded no significant treatment effects. Specifically, the ANOVA F tests for main effects were as follows: density treatment, $F_{5,55}=1.21$, $p=0.3167$; fertilizer treatment, $F_{1,55}=2.14$, $p=0.1492$; season of seeding treatment, $F_{1,5}=0.20$, $p=0.6703$. All treatment interactions were likewise insignificant, with all $p > 0.58$.

4.4 Individual species response

Mean cover of individual species, by site, is presented in table format in Appendices 3a through 3f. These tables present mean cover of individual sown species, native volunteers and exotic invaders, summarized by treatment for each of the experimental locations. These were the data on which ANOVA tests for treatment effects on each species were conducted. Due to the low and sporadic occurrence of most native volunteer and exotic species, only the statistical results for sown species are presented here.

Correlation analyses were conducted to compare any correspondence or trade-off in cover values between *Elymus glaucus, Festuca occidentalis, Achillea millefolium* and *Lupinus polyphyllus.* Results revealed positive correlations between these species in both the fertilized and unfertilized plots in Year 1 at all densities ($r=0.32$ to 0.66). By Year 2, in the fertilized plots, there were positive correlations only at densities of 375 PLS/m^2 and 1500 PLS/m^2 ($r=0.33$ to 0.43). However, in the unfertilized plots, there were the same total number of positive relationships in Year 2 as there were in Year 1 ($r=0.33$ to 0.83).

4.4.1 Effect of sown density on individual species

High densities of seeding resulted in higher cover of each sown species in both years, though not for *Carex aenea* and *Geum macrophyllym* (Table 18). Subsequent Tukey tests (results also portrayed in Table 18) revealed that in Year 1 seeding density treatments of 750 PLS/m^2 and higher were not significantly different from each other for *Achillea millefolium*. Similarly, seeding density treatments of 1500 PLS/m^2 and higher were not significantly different from each other for *Elymus glaucus*, *Festuca occidentalis* and *Lupinus polyphyllus*. By Year 2 however, the cover of *Achillea millefolium* and *Elymus glaucus* in plots sown at 375 PLS/m^2 and higher were not significantly different from each other, and for *Lupinus polyphyllus* cover in plots sown at 750 PLS/m^2 and higher were not significantly different from each other. However, for *Festuca occidentalis*, its Year 2 cover in plots sown at 6000 PLS/m^2 was significantly greater than that found under all other treatments.

Table 18. The effect of density treatments on mean cover (%) of individual species.

		Seeding Density Treatment, PLS/m^2						ANOVA Results	
Sown Species	Overall	0	375	750	1500	3000	6000	$F_{5,55}$	p
Year 1									
Achillea millefolium	3.5	0.5c	2.6bc	3.1abc	3.1abc	5.2ab	6.9a	5.17	**0.0006**
Carex aenea	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.34	0.8850
Elymus glaucus	6.6	0.8c	5.3bc	5.8b	7.6ab	9.5ab	10.9a	9.10	**0.0001**
Festuca occidentalis	6.7	0.3c	5.0bc	5.5bc	7.2abc	8.0ab	14.0a	6.16	**0.0001**
Geum macrophyllum	0.6	0.3	0.7	0.4	0.6	0.8	1.0	1.10	0.3732
Lupinus polyphyllus	2.6	0.1c	1.6bc	2.4bc	2.9ab	3.5ab	5.2a	7.29	**0.0001**
Year 2									
Achillea millefolium	5.4	1.0b	4.8ab	5.2ab	5.7ab	8.1a	7.7a	4.15	**0.0029**
Carex aenea	0.1	0.2	0.2	0.0	0.1	0.1	0.1	0.49	0.7859
Elymus glaucus	7.0	0.8b	7.4a	7.6a	9.0a	7.6a	9.7a	6.27	**0.0001**
Festuca occidentalis	9.2	1.7c	6.4bc	8.2bc	11.0b	9.6b	18.5a	12.5	**0.0001**
Geum macrophyllum	1.8	0.1	1.7	2.0	1.7	1.9	3.2	1.92	0.1051
Lupinus polyphyllus	4.4	0.0c	3.2bc	5.0ab.	4.7ab	5.7ab	7.8a	7.72	**0.0001**

Letters a,b,c denote the results of Tukey multiple comparison tests; values on the same line sharing the same letter are not significantly different from each other (p=0.05).
Means and letters with an underscore highlight the values that are not significantly different from the highest mean for that species.

4.4.2 Effect of fertilizer on individual species

Fertilized plots supported greater average cover for most species except *Lupinus polyphyllus, Geum macrophyllum* and *Carex aenea.* As shown in Table 19, *Achillea millefolium*, *Elymus glaucus* and *Festuca occidentalis* had significantly higher cover in the fertilized plots in both years. In contrast, fertilizer treatments had no significant effect on the cover of *Carex aenea, Geum macrophyllum* and *Lupinus polyphyllus* in either Year 1 or Year 2 (Table 19).

Table 19. Effect of fertilizer treatment and season of sowing on the mean cover of individual sown species.

	Main fertilizer effects				Main season effects			
	Treatment		Anova Results		Treatment		Anova Results	
Sown Species	Fertilized	Non-fert	$F_{1,55}$	p	Fall	Spring	$F_{1,5}$	p
Year 1	(% cover)				(% cover)			
Achillea millefolium	4.7	2.4	8.64	**0.0048**	3.7	3.3	0.24	0.6417
Carex aenea	0.1	0.1	1.18	0.2827	0.2	0.1	3.33	0.1276
Elymus glaucus	9.8	3.5	40.34	**0.0001**	6.3	7.0	0.09	0.7808
Festuca occidentalis	11.2	2.2	37.54	**0.0001**	6.9	6.4	0.14	0.7231
Geum macrophyllum	0.8	1.8	1.23	0.2721	1.1	0.2	2.55	0.1710
Lupinus polyphyllus	2.5	2.8	0.52	0.4733	2.9	2.3	0.46	0.5498
Year 2	(% cover)				(% cover)			
Achillea millefolium	6.4	4.4	4.12	**0.0473**	5.5	5.3	0.08	0.7841
Carex aenea	0.2	0.1	3.00	0.0888	0.1	0.1	0.15	0.7175
Elymus glaucus	9.1	5.0	15.34	**0.0003**	6.6	7.4	0.27	0.6250
Festuca occidentalis	13.6	4.9	45.52	**0.0001**	9.4	9.1	0.06	0.8231
Geum macrophyllum	1.8	1.7	0.00	0.9885	2.8	0.7	1.48	0.2782
Lupinus polyphyllus	3.9	5.0	1.95	0.1686	5.3	3.5	0.68	0.4466

If the p value given under ANOVA results is less than 0.05, then the two preceding treatment means are significantly different.

4.4.3 Effect of season of seeding on individual species cover

Season of seeding did not significantly affect the cover of any species in either Year 1 or Year 2. Though sown plant cover tended to be somewhat higher (except for *Elymus glaucus* in Year 2), in fall-seeded plots than spring-seeded plots (Table 19), the relationship was not significant.

4.4.4 Effect of treatment interactions on individual species

There were no significant treatment interaction effects on the cover of *Achillea millefolium*, *Carex aenea* or *Geum macro*phyllum in either Year 1 or Year 2 (all $p > 0.21$). In Year 1, for *Elymus glaucus*, the combination of 3000 PLS/m^2 sowing density and fall seeding produced an average of 13% cover, significantly higher than under any other density x season of seeding treatments for that species ($F_{5,55}$=2.18, p=0.0369). By Year 2 that cover had declined to 9% and was not significantly different from any other density x season of seeding interaction ($F_{5,55}$=0.76, p=0.5828).

There was also a significant interaction between fertilizer and season of seeding for *Lupinus polyphyllus* in Year 1 in the fall-sown non-fertilized treatment ($F_{1,55}$=6.63, p=0.0128). By Year 2 this interaction was no longer significant ($F_{1,55}$=1.90, p=0.1740).

The density x fertilizer interaction for *Festuca occidentalis* was the sole treatment interaction that was significant in both years (Figure 9). Year 1 values were $F_{5,55}$=2.45, p=0.0451 and Year 2 values were even more strongly significant, with $F_{5,55}$=3.83, p=0.0048. As indicated by Figure 9, a Tukey multiple comparison test confirms that the average cover of 28% achieved by *Festuca* under the fertilized 6000 PLS/m^2 treatment combination is significantly greater than all other seeding densities or fertilizer treatment combinations.

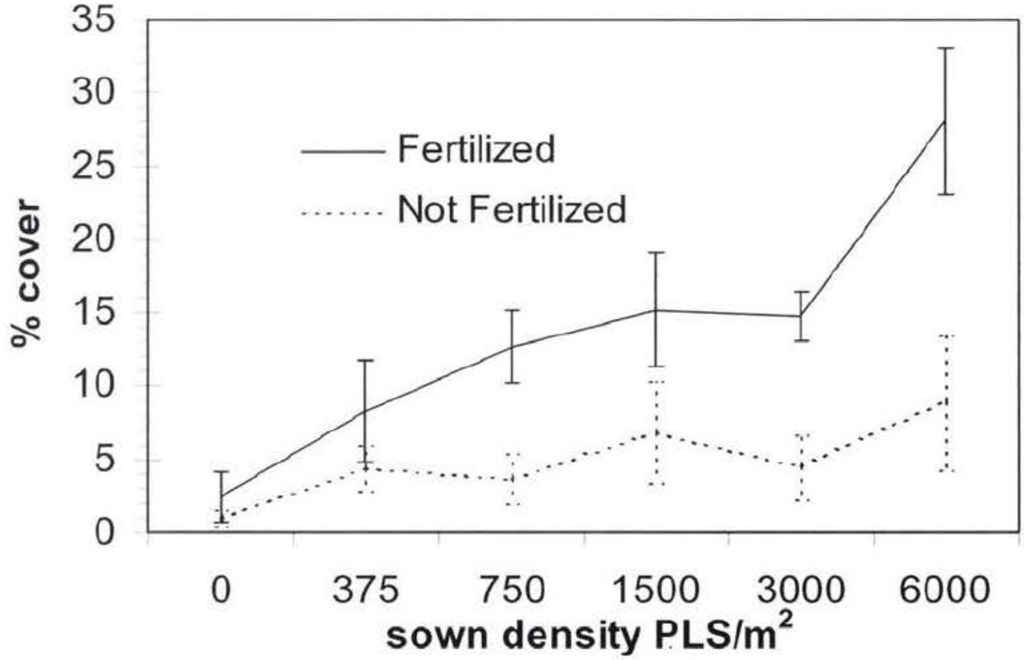


Figure 9. Year 2 mean cover (± S.E.M.) of *Festuca occidentalis* in response to fertilization x density treatments, summarized for all six locations and season of seeding treatments, n=36.

It is possible that superior performance by one species might only occur at the expense of another. To look for such a trend, *Elymus glaucus, Festuca occidentalis, Achillea millefolium* and *Lupinus polyphyllus* were tested in pairwise combinations to test for species association or avoidance in the same quadrats. Results reveal that there were no significant negative associations in any of the density x fertilizer treatments, but there were several significant positive correlations ($p=0.05$). Year 1 data suggest that all four of these species tended to grow equally well or equally poorly in any given quadrat. Year 2 data revealed the same positive significant relationships between *Festuca occidentalis, Achillea millefolium* and *Elymus glaucus* but not *Lupinus polyphyllus.* Year 1 values ranged from $r=+0.32$ to $r=+$

0.71; Year 2 values ranged from r=+0.33 to+ 0.89 (where the closer the r value to 1.0, the more consistent the association).

4.5 Exotic plant cover

Exotic plants encountered in this study include a variety of weeds and escaped agronomic grasses and legumes (Table 20). The most common exotic agronomic species found growing in the plots were *Agrostis stolonifera* L (redtop bentgrass) Poaceae, *Festuca rubra* L. (red fescue) Poaceae, *Phleum pratense*, L. (timothy) Poaceae, *Trifolium hybridum* L.(alsike clover) Fabaceae, and *Trifolium repens* L. (white clover) Fabaceae. The most common exotic weed species were *Cerastium fontanum* Baumg. (=*C. vulgatum* L., mouse-eared chickweed) Caryophyllaceae, *Sonchus arvensus* L (sow thistle) Asteraceae and *Taraxacum officinale* G.H.Weber *ex* Wiggers (common dandelion) Asteraceae.

Table 20. Presence (1) or absence (0) of exotic species at all six test locations.

	Location					
Exotic Species	Chapman	Francois	McKendrick	Nass	Ptarmigan	Viewmount
Agropyron repens	1	0	0	0	0	1
Agrostis stolonifera	1	1	1	0	1	0
Arabis glabra	0	1	0	0	0	0
Barbarea vulgaris	0	0	0	0	0	1
Capsella bursa-pastoris	0	1	0	0	0	1
Cerastium fontanum	0	1	1	1	0	1
Chenopodium album	0	0	0	0	0	1
Chrysanthemum leucanthemum	0	0	1	0	0	0
Cirsium arvense	0	0	0	0	0	1
Cirsium vulgare	0	0	0	0	0	1
Crepis tectorum	0	0	0	0	0	1
Dianthus armeria	0	0	0	0	0	1
Festuca rubra	1	1	1	1	1	1
Galeopsis tetrahit	0	0	0	0	0	1
Matricaria matricariodes	0	1	0	0	1	1
Phleum pratense	1	1	1	0	0	1
Plantago major	0	0	0	0	1	1

Table 20. (continued)						
Poa pratensis	0	1	0	0	0	1
Poa annua	0	0	1	0	1	0
Polygonum convolvulus	0	0	0	0	0	1
Polygonum persicaria	0	0	0	0	0	1
Potentilla norvegica	0	0	0	0	0	1
Ranunculus acris	0	1	0	0	0	1
Rumex acetosella	0	0	1	0	0	1
Senecio vulgaris	0	0	0	0	0	1
Sonchus arvensis	1	1	1	0	1	1
Stellaria media	0	1	0	0	0	0
Taraxacum officinale	1	1	1	0	1	1
Thlaspi arvense	1	0	0	0	0	1
Trifolium hybridum	1	0	1	1	0	1
Trifolium repens	1	1	1	0	0	1
Trifolium sp.	0	1	1	0	1	0
Unknown Brassicaceae	0	0	0	1	0	0

4.5.1 Effect of seeding density on exotic plant cover

In general, exotic plants were less abundant where more native seed had been sown. In addition, exotic plant cover was less in Year 2 than in Year 1 on these sown plots, whereas it remained unchanged in the control plots (Figure 10). In Year 1, exotic cover responses to the density treatments were not significant ($F_{5,55}$=0.38, p=0.8614). In Year 2, on the other hand, mean cover of exotic species varied significantly among density treatments ($F_{5,55}$ = 4.20, p= 0.0026), with higher weed cover at the lower seeding densities. Average values of Year 2 mean exotic cover ranged from 3% to 12%, with the control plots (0 PLS/m^2) yielding the highest mean cover of exotic species (Figure 10). A Tukey multiple comparison test on Year 2 exotic cover data revealed significantly less cover (than in the control treatment) but only at seeding densities of 3000 and 6000 PLS/m^2. None of the 375, 750 or 1500 PLS/m^2 treatments were significantly different from each other with respect to exotic cover, but all produced less exotic cover than was found in the control plots (0 PLS/m^2).

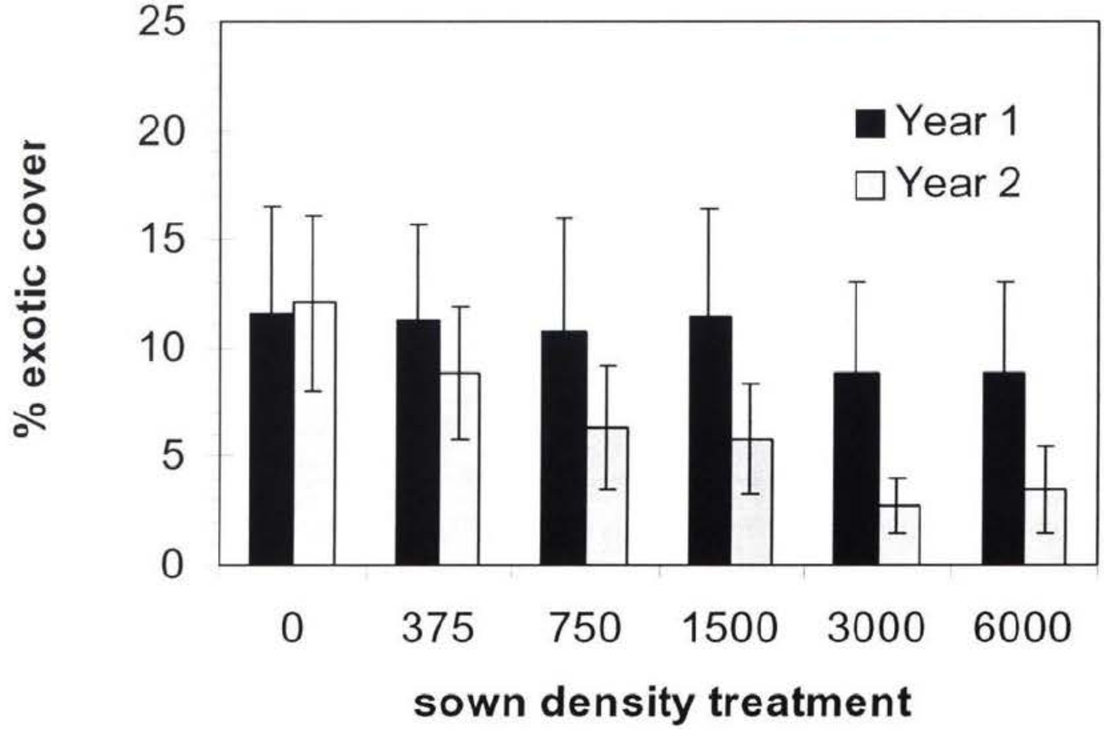


Figure 10. Mean (± S.E.M.) cover of exotic species in response to density treatments, summarized for all six locations, both fertilization treatments and both seasons of sowing, n=24.

To better explore the negative association between sown species cover and exotic cover, a regression analysis was performed to test the effect of actual plant density on exotic cover in individual sample quadrats. Because sample plots were large (6.25 m^2) and clumps of plants could be found growing within each plot, this analysis was conducted at the level of individual sample quadrats (0.25 m^2) where weeds and native plants would be more directly interacting. When including quadrats from all sites, the negative relationships between exotic cover and sown species cover in either Year 1 or Year 2 were highly significant ($p=0.0001$) but very unpredictable ($r^2=0.0357$ in Year 1, $r^2=0.0534$ in Year 2) (Table 21). The high p value and the low r^2 value suggested high variability between sites. Because of visible variability in the level of weed infestation among the sites, it was hypothesized that any potential effect would only act at sites with high weed densities. The regression was therefore repeated on a site by site basis. Results were significant at the Viewmount Road site (p=0.0001, r^2=0.2216), Francois Lake (p=0.0201, r^2=0.0746) and at McKendrick Pass (p=0.0018, r^2=0.1308), but not at the other three locations (Table 21).

Table 21. Results of linear regression analysis relating exotic cover to plant density.

Location	Year	p	r^2	intercept	Slope
All	1	0.0001	0.0357	14.136291	-0.016079
Chapman	1	0.3591	0.0120	0.524353	-0.000356
Francois	1	0.0398	0.0590	3.398911	-0.004780
McKendrick	1	0.0482	0.0546	3.587263	-0.003936
Nisga'a	1	0.8347	0.0006	0.401105	-0.000211
Ptarmigan	1	0.5147	0.0061	0.072665	-0.000059
Viewmount	1	0.0579	0.0504	61.342048	-0.031824
All	2	0.0001	0.0534	9.953951	-0.016859
Chapman	2	0.0763	0.0442	1.671205	-0.005141
Francois	2	0.0201	0.0746	3.495899	-0.006494
McKendrick	2	0.0018	0.1308	3.616444	-0.005789
Nisga'a	2	0.1713	0.0266	3.288659	-0.005303
Ptarmigan	2	0.1205	0.0341	0.360738	-0.000721
Viewmount	2	0.0001	0.2216	44.099710	-0.088244

n=72 quadrats for each individual location in each year.
n=432 quadrats for all locations combined.

This negatively sloped relationship is shown in Figure 11 for the Francois and Viewmount sites. It is most pronounced at the Viewmount site, which had 44% cover of exotic species where there were no sown species growing (at the y-intercept of the line in Figure11).

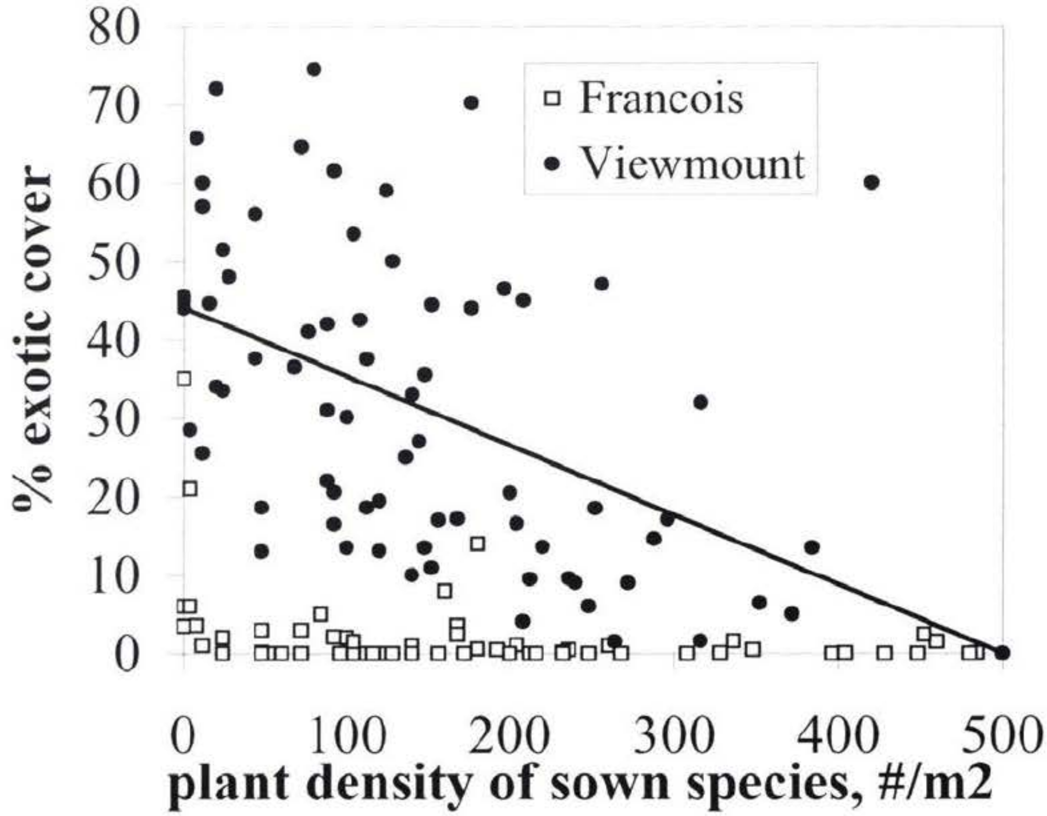


Figure 11. Individual quadrat measurements of exotic plant cover (%) in Year 2 as related to actual density of sown plants counted in the same quadrats; n=72 for each location (3 quadrhats in each plot, 12 plots in the spring-sown sub-block and 12 plots in the fall-sown sub-block).

4.5.2 Effect of fertilizer treatments on exotic plant cover

The fertilizer treatment promoted weed growth in the first year but not in the second year. Across all sites, density treatments and sowing seasons, mean cover of exotic plants varied significantly by fertilizer treatments only in Year 1 ($F_{1,55} = 7.84$, p= 0.0070). In Year 1, fertilized plots achieved a mean exotic cover of 12.8% compared to 8.1% in non-fertilized plots (Figure 12). In Year 2, $F_{1,55} = 0.57$, p = 0.4544; fertilized plots then averaged 7.0% exotic cover compared to 6.0% in non-fertilized plots.

(lodgepole pine) Pinaceae. The *Pinus contorta* was often a planted species, especially at the Chapman, Francois and Nass sites, so this species was excluded from the analysis described below. The most common shrub encountered was *Rubus parviflorus* Nutt. (thimbleberry) Rosaceae. Herbaceous species commonly found were *Epilobium angustifolium* L., (fireweed) Onagraceae, *Hieracium albiflorum* Hook., (white-flowered hawkweed) Asteraceae, *Anaphalis margaritacea* (L). Benth. & Hook., (pearly everlasting) Asteraceae, *Aster* sp. (wild asters) Asteraceae, *Agrostis scabra* Wild. (hair bentgrass) Poaceae, and *Vicia americana* Muhl. *ex.* Willd. (American vetch) Fabaceae.

Table 22. Presence (1) and absence (0) of unsown native species at all six test locations.

	Location					
Native Species	Chapman	Francois	McKendrick	Nass	Ptarmigan	Viewmount
Abies lasiocarpa	1	0	1	0	0	0
Agoseris glauca	1	0	1	0	0	0
Agrostis exarata	0	0	1	0	0	0
Agrostis scabra	0	1	1	0	1	0
Agrostis sp.	0	1	1	0	0	0
Alnus sinuata	0	0	1	1	0	0
Alnus sp.	0	1	0	0	0	0
Amelanchier alnifolia	0	0	0	0	0	1
Anaphalis margaritacea	1	1	1	1	0	0
Arabis holboellii	0	0	0	0	0	1
Aralia nudicaulis	0	0	0	0	1	0
Arctostaphylos uva-ursi	0	1	0	0	0	0
Arnica cordifolia	0	0	0	0	1	0
Aster ciliolatus	0	1	0	0	0	0
Aster conspicuus	0	1	0	0	1	0
Aster foliaceous	0	0	0	0	0	1
Aster sp.	0	1	1	0	1	0
Betula papyrifera	0	1	0	0	1	0
Bromus ciliatus	0	1	0	0	0	0
Bromus sp.	0	0	0	0	1	0
Carex mertensii	0	0	1	0	0	0
Carex sp.	0	1	1	0	0	0
Chenopodium capitatum	0	0	0	0	1	1
Cinna latifolia	0	0	0	0	1	0
Deschampsia caespitosa	0	0	0	0	1	0
Elymus trachycaulus	0	1	0	0	0	0
Epilobium angustifolium	1	1	1	1	1	1
Epilobium ciliatum	0	1	0	0	1	0
Epilobium latifolium	0	0	1	0	0	0

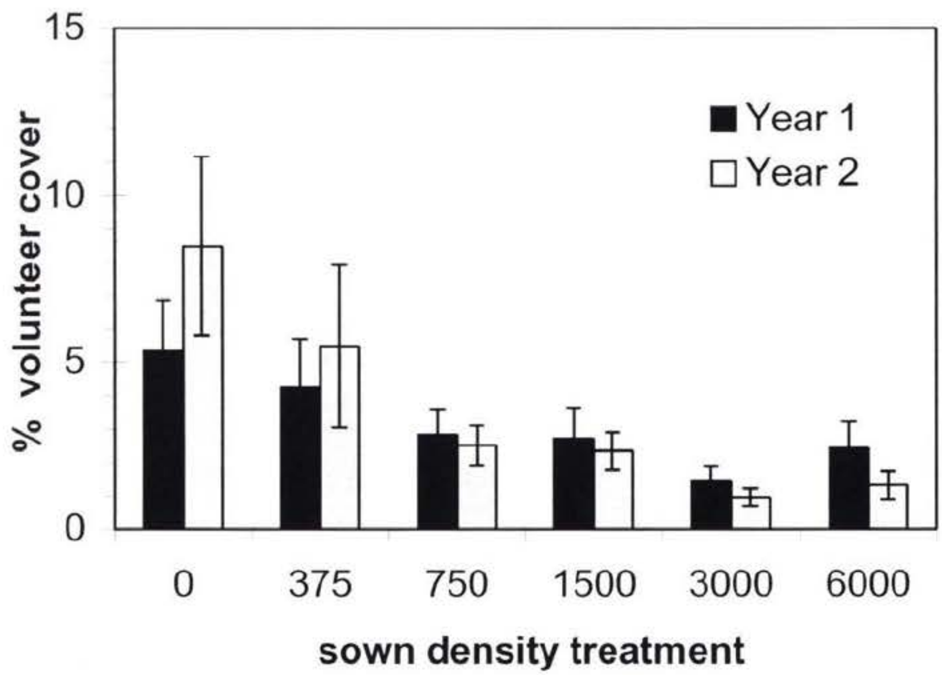
Table 22. (continued)

Epilobium sp.	1	0	1	0	0	0
Erigeron acris	0	0	1	0	0	0
Festuca idahoensis	0	1	0	0	0	0
Festuca sp.	0	0	1	0	0	0
Fragaria virginiana	0	1	0	0	0	1
Galium boreale	0	0	1	0	1	0
Galium triflorum	0	0	1	0	0	0
Geranium sp.	0	0	0	0	1	0
Glyceria borealis	0	0	0	0	1	0
Glyceria sp.	0	0	0	0	1	0
Hieraceum albiflorum	1	1	1	1	0	1
Hieracium gracile	0	1	0	0	1	0
Hieraceum sp.	1	1	1	0	1	1
Juncus bufonius	0	0	1	0	0	1
Lathyrus ochroleucus	0	1	0	0	1	0
Lathyrus sp.	0	0	0	0	1	0
Melampyrum lineare	0	0	0	1	0	0
Petasites palmatus	0	0	0	0	1	0
Picea glauca	1	1	1	1	0	0
*Pinus contorta**	1	1	1	1	0	0
Poa alpina	0	0	0	0	1	0
Polemonium pulcherrimum	0	1	0	0	0	0
Populus trichocarpa	1	1	1	1	1	0
Rhinanthus minor	0	1	0	0	0	0
Rosa acicularis	0	1	0	0	1	0
Rubus idaeous	0	0	0	0	1	0
Rubus parviflorus	0	1	1	0	1	0
Salix sp.	0	0	1	0	1	0
Spiraea pyramidata	0	1	0	0	0	0
Symphoricarpos albus	0	0	0	0	1	0
Thalictrum occidentale	0	0	0	0	1	0
Thalictrum sp.	0	0	0	0	1	0
Trisetum cernuum	0	0	1	0	0	0
Trisetum spicatum	0	1	0	0	0	0
Veronica americana	0	0	0	0	0	1
Veronica sp.	0	0	0	0	0	1
Vicia americana	0	1	0	0	1	1
Viola glabrella	0	1	0	0	0	0

*Most of the *Pinus contorta* seedlings were planted but not as part of this experiment.

4.6.1 Effect of seeding density on native volunteer plant cover

In general, volunteer native species were less abundant where more seed had been sown (Figure 13). At low seeding density treatments of 0 and 375 PLS/m^2, mean cover of volunteer native plants was greater in Year 2 than in Year 1. In all other treatments, however, mean cover declined in the second year. In Year 1, cover response of volunteer native species to the density treatments was not significant ($F_{5,55}$=1.99, p=0.0946). In Year 2, on the other hand, mean cover of volunteer native species varied significantly among density treatments ($F_{5,55}$ = 3.65, p= 0.0063), with a decrease in volunteer cover as density increased (Figure 13). Average values of Year 2 mean cover ranged from 1% to 9%, with the control (0 PLS/m^2) plots yielding the highest mean cover of volunteer native species (Figure 13).



Figdure 13. Mean (± S.E.M.) cover of native volunteer species in response to density treatments, summarized for all six locations, both fertilization treatments and both seasons of sowing, n=24.

A Tukey test on Year 2 volunteer native cover data revealed significantly less cover (than in the control treatment) only at densities of 3000 and 6000 PLS/m^2. None of the 375, 750 or 1500 PLS/m^2 treatments were significantly different from each other, but all produced less volunteer cover than was found in the control plots (0 PLS/m^2). These are the same trends as noted for treatment effects on exotic plant species (Section 4.4.1).

4.6.2 Effect of other treatments on volunteer native plant cover

There were no significant effects of fertilization, the season of seeding, or any treatment interactions on volunteer native cover. In Year 1, p values ranged from 0.09 (for density, season of seeding, and fertilizer x season of seeding effects) to 0.95 for fertilizer treatment. In Year 2, p values ranged from 0.23 to 0.96.

4.7 Chapter summary

This experiment induced a series of highly significant results in response to sowing density and fertilizer treatments. High seeding densities successfully generated higher plant cover, and fertilization further enhanced the overall cover at all densities. Individual species differed somewhat in their response to treatments. The season of seeding was generally not significant but it was occasionally significant in interaction with other treatments. However, generally treatment interactions were not significant. The interpretation and implications of these responses are discussed further in Chapter 5.

Chapter 5 Discussion

5.0 Introduction

The results of this research provide support for many of the hypotheses presented in Chapter 1 (Section 1.7), but some of the hypotheses were not supported. Specifically, the results reported in Chapter 4 suggest that:

- H1: High initial seeding densities do provide superior coverage.
- H2: Densities $\leq$ 1500 PLS/m2 did not achieve high cover in the first year after planting but by the second year cover at these densities was comparable to densities sown at 3000 PLS/m^2.
- H3: The application of the fertilizer increases the overall cover of plants, at all sowing densities.
- H4: In both Year 1 and Year 2, looking strictly at treatment means, higher cover of sown species was achieved in several low sowing density treatments with fertilizer than in higher density treatments without fertilizer (Table 14, Table 15).
- H5: Fall seeding can result in higher levels of seedling emergence in the first growing season, especially in the fertilized plots (Table 13), though this does not necessarily translate into high levels of cover (Table 19).
- H6: There was generally lower exotic species cover at the higher sown densities, especially in Year 2.
- H7: Fertilizer increased the cover of exotics at the lowest densities, especially in Year 1.

Soil analysis results at all six sites confirm that the plots were relatively homogenous in that all were deficient in nitrogen (Table 9). The climate and weather data also reveal that these sites are similar in that they are generally characterized by cold winters and cool temperatures during the growing season (Table 10).

One overall conclusion to be taken from this experiment is that, with the addition of fertilizer, native seed can provide cover as high as 62%. Assuming that the six research sites are typical of many degraded sites found in northern British Columbia, therefore, one can confidently conclude that a mixture of native plant species can be used successfully for revegetation purposes to provide effective cover on degraded sites throughout much of northern B.C.

5.1 Plant density and seedling emergence

5.1.1 Plant density

As expected, the plant density of sown species increased as seed density increased. The explanation for this is straightforward: when there were more seeds available and there was still space available for new seedlings to establish, they did so. Presumably plant density remained low enough even at 6000 PLS/m^2 that natural self-thinning (density dependent mortality) did not occur at the seed germination stage. By the second year, as plants grew larger, mean plant density consistently declined in all treatments at sown densities of 3000 and 6000 PLS/m^2. In contrast, plant density continued to increase slightly at 375 PLS/m^2 (Tables 11 and 12). As plants grew, they began to interfere with each other, presumably because there was insufficient growing space at the higher densities.

At densities of 750 and 1500 PLS/m^2, year-to-year trends in mean plant density were not consistent in the fertilized and unfertilized and fall- versus spring-sown treatments (Table 11 and 12). There were declines in mean plant density (count) under some treatment combinations and increases in others. Based on the variability of the count data at these intermediate seeding densities, an optimum plant density had not yet been confirmed so recommendations for an optimally efficient seeding density based on these results would be premature.

More seeds germinated in the fall plots than in the spring plots in the first year. This pattern may have developed because fall-sown seed was in the ground and ready to grow as soon as conditions were suitable for germination the next year, and would therefore have had a chance to germinate before the spring plots were even sown. Perhaps the slight differences in the number of plants became more accentuated (through the death of weak seedlings), because by the end of the second growing season, plant densities in the fall-sown plots were significantly greater than those in the spring-sown plots. The relatively high success of fall seeding agrees with Brown and Chamber's (1990) recommendation that at high elevation sites (similar in many respects to the northern climate tested here), seeds should be sown in the fall. It must be noted, though, that perhaps the fall-sown counts were higher during the first growing season because sites were drier than the 30 year norm at all sites but Wisteria in the spring and drier at all sites than the 30 year norm in the summer of that year (Table 10). Spring-sown seed may not have experienced sufficient moisture for a normal rate of germination to occur. Or seeds may have germinated but seedlings were not well enough established to survive the summer drought. If insufficient moisture led to poor germination rates and/or seedling survival, then the warning offered by Schwab (1991) and Kennedy (1992) to sow in the fall should be heeded.

5.1.2 Seedling emergence

Overall seedling emergence (as defined in Section 1.8) of sown species after the first year's growth averaged 281 seedlings per square metre, which is 16% of the estimated number of PLS sown (Table 13). This percentage may seem low, but is consistent with Bazzaz's (1986) observation that the percentage of seeds that germinates in nature is typically less than germination determined under laboratory conditions. However, since all plots were monitored only once, late in the growing season, these emergence numbers likely underestimate successful germination because some seeds may have germinated but then died before monitoring occurred.

The patterns of emergence exhibited by individual species emergence are interesting but they can also be misleading. A glance at individual species emergence (Table 13) would suggest that only *Elymus glaucus, Lupinus polyphyllus* and *Festuca occidentalis* seem worthy of consideration for use in a revegetation mix because only these three species had emergence rates over 25%. The emergence rates of *Achillea millefolium* (8.5%) and *Geum macrophyllum* (6.5%) are similar. Based on emergence results alone, it might be tempting to make a decision to exclude (or include) them both from a mix. These emergence data, however, do not take plant size into account, an important factor when considering what species should be included in a mix. Although *Achillea millefolium* had low emergence, it established good cover and consistently went to seed by the end of the second growing season. On this basis, despite its low emergence rate, it would seem to be a valuable addition to a seed mix. *Geum macrophyllum*, on the other hand, rarely went to seed and cover establishment was low, usually <3% (Table 18). It would therefore not be a useful addition to a seed mix to be used under the conditions reported here.

Carex aenea had very low germination rates, emergence and cover production at all sites under all treatment combinations. This was a disappointing result because this species is reported to grow well on degraded sites (MacKinnon et al. 1992). Based on germination tests in the lab and the time to first germination in a greenhouse (Burton and Burton 2001), it was considered a slow but reliable germinator that would fill the role of a "slow germinator," thus providing the balance of fast and slow germinators discussed in Section 3.3

Why *Carex aenea* performed so poorly in this experiment is unknown. According to Hurd and Shaw (1991), one reason most *Carex* species have received relatively little study is because of their taxonomic complexity. It is generally considered that *Carex* species generally do not establish well from seed (Ceska 1999) but out-planting nursery-grown plugs can provide a reliable means of establishment (Martin and Uhler 1939 *fide* Hurd and Shaw 1991, Burton and Burton 2001). However, restoration with seedlings is time consuming and usually too expensive to consider as an alternative to seeding, especially on a large scale. *Carex pennsylvanica* is a similar upland sedge species, reported to grow well in openings in oak (*Quercus* spp.) and pitch pine (*Pinus rigida* P.Mill.) forests on acidic soils, particularly after fire (Forman 2003). Other *Carex* species apparently respond well to stratification under laboratory test conditions (Hurd and Shaw 1991). However, it is unknown whether *Carex aenea* establishes better after fire. Also, stratification did not increase germination rates in lab tests conducted by Symbios Research and Restoration (Burton and Burton 2001). Despite its low success in this study, since *Carex* species can be found growing under a variety of disturbed conditions, the potential of *Carex aenea* to grow on degraded sites remains promising. More studies need to be undertaken to understand the ecology of this species to discover a successful protocol for germination and establishment from seed.

Geum macrophyllum also exhibited poor emergence and cover establishment in this experiment, however, this response is not surprising. Although *Geum* occurs on degraded sites (along roadsides, trails and in clearings, at a range of elevations), it grows most frequently in stable moist sites (Mackinnon et al. 1992, Beaudry et al. 1999). Since *Geum* is a moisture-loving species, its poor performance in this study may have been, in part, the result of the dry growing conditions experienced during the first growing season (Table 10). *Geum macrophyllum* can still be considered for inclusion in a seed mix of native species on wet sites because its germination rate is good (69 to 95% under lab conditions) and it spreads by rhizomes under the right conditions (MacKinnon et al. 1992, Burton and Burton 2001). The lack of a significant response by *Geum macrophyllum* to the addition of a complete fertilizer (Table 19), however, may call into question Klinka et al.'s (1989) assertion that this is a nitrogen-loving species.

5.2 Sown plant cover

Statistical analysis shows that the seeding density and fertilizer treatments had a significant effect on plant cover, but season of seeding did not. It is not surprising that fertilizer had a positive effect. When judiciously applied, fertilizer enhances plant growth, especially on degraded sites (Hollowell and Tysdal 1948, McKell 1982, McCaughey and Simons 1996, Bulmer 1998). Likewise, common sense suggests that increasing the density of sown species will result in increased cover, until all available space is taken up. Even though the density of plants in plots sown to 3000 or 6000 PLS/m^2 declined from Year 1 to Year 2 (Section 5.1.1), the cover in all treatments still generally increased in the second year. Though plants were getting bigger they still came nowhere near to occupying the 100% growing space; the highest mean cover was only 62% (Table 15). The inability to achieve higher total cover may be because these perennial plants sown in this experiment had not yet achieved their full stature after only two growing seasons. On the other hand, 100% cover may never be achievable on these degraded sites, or with this species mix, perhaps due to below-ground competition for moisture and nutrients.

5.2.1 Density treatments and sown cover

The seed density treatment yielding the highest cover (62% in Year 2) was 6000 PLS/m^2 in the fertilized spring plots (Table 15). At lower densities of 750, 1500 and 3000 PLS/m^2, mean cover ranged from 33% to 45% in the fertilized plots in both seasons of seeding.

So is 45% enough sufficient for a level site, or is 62% cover (or more) needed? There are few specific recommendations in the literature for minimum acceptable cover when revegetating bare degraded sites on level terrain. For the establishment of seasonal cover and conservation purposes, including erosion control, soil moisture management and weed control, the U.S.Department of Agriculture Field Office in Connecticut suggests that a combined canopy and surface cover of at least 60% is necessary (Anonymous 2001). A cover of 20% to 30% plant residue is said to reduce erosion by 50% on agricultural sites (Dickey et al. 1986). On mine sites in Australia, it is believed that a cover of 50% will reduce soil loss to very low levels, whereas at other sites at least 70% cover is necessary

(Grigg 2001). Apparently these different recommendations for mine sites can be explained by the known interaction between slope and plant cover. Bugg et al. (1997) suggest that the 25% cover achieved in their roadside native and non-native grass monoculture trials is adequate for cover on roadsides and other rights of way in the Sacramento Valley of central California.

If 20 to 30% cover is adequate to control erosion and conserve moisture on degraded roadsides and other level sites, then the cover of 33 to 45% achieved in the fertilized plots at densities of 750 and 3000 PLS/m^2 can be considered more than adequate. These treatments are close to the range of densities (250 to 2000 PLS/m^2) recommended by Hardy BBT (1989) and Schwab (1991) but they are higher than densities (150 to 500+ PLS/m^2) recommended by Hammermeister (1998). On the other hand, if one considers that a plant cover >60 % is necessary for conservation purposes (Anonymous 2001), then only the 6000 PLS/m^2 density with the addition of fertilizer appears capable of achieving this goal in northern B.C., using the mixture of plant species (Table 15) tested in this thesis.

The 70 to 80% cover recommended by Carr (1980) and Grigg (2001) for erosion control on slopes was never achieved. Using such high densities of pure native seed would not be practical since the seed is expensive and in short supply. Therefore, to achieve >60%, a practical solution is to include agronomic annuals like *Secale cereale* L. (cereal rye), *Lolium multiflorum* Lam. (annual ryegrass) or "ReGreen™", a sterile cross between *Triticum aestivum* L. x *Elymus trachycaulus* (Glen 1992, *fide* Sexton 1995) in the native mix may to control erosion until native species have a chance to establish.

There were different responses to treatment and treatment interactions by individual species. For example, in Year 1, *Achillea millefolium* had developed a similar amount of cover at densities of 750 PLS/m^2 and above, whereas *Lupinus polyphyllus*, *Festuca occidentalis* and *Elymus glaucus* had similar cover at densities of 1500 PLS/m^2 and above (Table 18).

The cover of several species was significantly correlated. There was a positive correlation of cover values between species for *Elymus glaucus, Festuca occidentalis, Achillea millefolium* and *Lupinus polyphyllus* in both Year 1 and Year 2 year in both the fertilized and non-fertilized plots, at all densities. This correlation was not as strong in Year 2. In Year 1, the species appeared to grow well together and one species did not significantly inhibit the growth of the other (Section 4.3.1). By Year 2, however, there were far fewer significantly positive relationships in the fertilized plots, whereas there were the same number in the unfertilized plots. The trend to fewer positive interactions in the fertilized plots suggest that competitive interactions between the species were beginning to develop as the plants in the fertilized plots grew bigger. Presumably as plants of some species continue to grow bigger, they will out-compete the smaller plants of other species. Such interspecific competition would be consistent with "alien thinning" as described by Harper (1977) in Section 2.1. This trend is not unexpected, as the mix contained species with different sizes and other morphological characteristics, so asymmetrical competition can be expected to develop (Wedin and Tilman 1993).

5.2.2 Fertilizer and sown cover

Fertilization studies have created some conflicting perceptions regarding the use of fertilizer (Section 2.5). For example, fertilizer is widely used on agricultural crops for enhanced productivity, even on fertile soils (Brady 1974). Generally speaking, application of a broad-spectrum fertilizer is recommended for roadside revegetation (Dyrness 1975, Carr 1980, Anonymous 1997, Bulmer 1998). Fertilizer is also recommended for tree seedling establishment in forestry where brush competition is not a problem (Kimmins 1993, Bulmer 1998) and for reclamation purposes on industrial disturbances (Green et al. 1992), especially where topsoil has been removed. On the other hand, fertilizer applications are not usually recommended for grassland restoration where introduced species frequently occur in the flora and may sometimes dominate the seed bank. The growth of exotic species is especially associated with nutrient-rich soils (Huenneke et al. 1990, Wilson and Tilman 1991). Because of a history of breeding or natural selection for response to nutrient enrichment, exotic species (both agronomic species and weeds) tend to overwhelm the native plant community on rich sites. In fact, in some tallgrass prairie restoration projects, a technique of soil impoverishment is even recommended to inhibit exotic growth (Morgan et al. 1995).

In research with native species, studies indicate that fertilizer is important for some species, but other studies have indicated that the use of fertilizer does not enhance cover (Maslen and Kershaw 1989). Fertilizer is not generally recommended for legume establishment either, because it is believed that legumes cannot compete with grasses responding to the increased nitrogen (Dyrness 1975) or because high nitrogen inhibits the growth of nitrogen-fixing nodules (Ziemkiewicz 1985).

Fertilizer increased the overall cover of native species in this experiment, so its application can be recommended for use with native plant revegetation in northern B.C. Three of the four top performing species (*Elymus glaucus*, *Festuca occidentalis* and *Achillea millefolium*) responded with an increase in cover in fertilized plots in both Year 1 and Year 2 (Table 19).

Only *Lupinus polyphyllus* responded negatively to the addition of fertilizer. There was an overall tendency to higher cover of *Lupinus polyphyllus* in the non-fertilized plots in both years. By Year 2, there was higher cover in 8 out of the 10 sown treatments in the unfertilized plots. Although the relationships between fertilizer treatments and *Lupinus* cover were not significant, significance was almost reached in Year 2 ($p=0.47$ in Year 1, $p = 0.07$ in Year 2). If this trend continues, into Year 3 the apparently negative effect of fertilizer on this species may become significant. This negative response of *Lupinus polyphyllus* to fertilization does not mean that the species should be excluded from a seed mix if fertilizer is used. *Lupinus* did establish and went to seed in the fertilized plots. In the long run, it may well be important to include *Lupinus* or another legume in a seed mix. As this nitrogen-fixing perennial continues to grow, and the applied fertilizer dissipates, *Lupinus* plants could provide nitrogen and growth enhancement to all vegetation in the future.

Even though *Lupinus polyphyllus* is a nitrogen-fixing species, the cover response achieved in the unfertilized plots suggest that it cannot be used in place of fertilizer. The marginal improvement in *Lupinus* cover achieved in sown non-fertilized plots (a 1.3% difference by Year 2) cannot compensate for the dramatic cover increase of all sown species (16% difference by Year 2) found in the sown fertilized plots, compared to the unfertilized plots. Overall, it is important to remember that sown species in the fertilized plots, at all densities, established better cover than in the unfertilized plots. Also, by the second year of the experiment, all sown species had produced seed in fertilized plots, whereas fewer species produced seed in the non-fertilized plots. This seed production is important because it helps establish a self-sustaining stand, which can presumably maintain cover and resist invasion by exotics.

Due to some of the undesirable impacts of fertilizer, especially on grasslands and legumes (Section 2.5), and the relatively limited information regarding its value for restoration, the use of fertilizer for restoration is frequently discouraged. However, the results reported in this thesis suggest this caution is unwarranted on highly degraded sites. Fertilizer effects were always highly significant, although they were stronger in Year 1 than in Year 2, and its use did not significantly increase the growth of exotic species (Section 4.5.2). It is possible that even more pronounced effects might have been achieved if a range of fertilizer application rates had been tested. Perhaps the same effect could have been achieved with less than that used for this work (295 kg/ha) or perhaps higher cover could have been achieved if more fertilizer had been used. If fertilizer is going to be used for revegetation purpose, current recommendations suggest that fertilization can be effective for anywhere from three to seven years (Dyrness 1975, Walker and Harrison 1984, Ziemkiewicz 1985, Schwab 1991).

5.2.3 Season of seeding and sown cover

Of the three main treatments tested, the season of seeding was the only main factor that did not produce significant results in cover. Seeding season as a treatment has not yet been widely tested. As with fertilizer research, much of the literature about this topic has focused on grassland restoration. In grassland restoration it is generally recommended that cool-season species (which includes all those tested here) should be sown in the early spring for best results (Gerling et al. 1996, Pahl and Smrecieu 1999, Smith and Smith 2000). For other habitats, recall that Schwab (1991) recommends fall seeding to avoid summer drought in the Pacific Northwest, and Brown and Chambers (1990) recommend fall seeding at high elevations, in order to take advantage of optimum growing conditions as soon as they occur on these difficult to reach sites.

At first glance, the improved germination and higher number of plants associated with fall seeding in this experiment (Section 5.1.1) seem to support Schwab's (1991) strategy. However, fall sowing does not necessarily translate to better growth and higher cover.

Results for sown cover show that fall seeding and spring seeding are equally effective for cover production. Fall seeding was conducted under cool conditions late in the season, and seed presumably over-wintered under the snow in a dormant condition. In the cold climate characteristic of these sites, soils warm slowly, so the conditions required for germination likely didn't occur until late in the spring. The benefit of fall seeding would therefore not be so great as in milder climates. The results of this research are more in line with the recommendations of Kennedy (1992), who says that either early spring or fall seeding is acceptable, depending on site moisture regime.

Flexibility in seeding time is an important factor. It provides managers with more options when using native plants. For example if a seed mix contains seed that will benefit from stratification, fall seeding would be more appropriate because it imitates natural re-seeding and stratification can occur naturally during the winter (Anonymous 2002). However if the site to be seeded has a weed problem, spring seeding may be more appropriate because it allows weed control with herbicides to be initiated before seeds are sown (Anonymous 2002).

Very little effect of the season of seeding was noted on the cover of individual species (Table 19). However, in both Year 1 and Year 2, *Geum macrophyllum*, exhibited greater mean cover in fall-seeded plots compared to the spring-seeded plots. Although the results were not significant, as discussed in Section 5.1.2, the trend may exist because *Geum macrophyllum* has greater moisture requirements than any of the other species used in the mix. It may have been able to take advantage of the fall sowing to germinate and establish early in the spring when the soil was moist, before spring seeding was even done.

A similar trend of greater mean cover in fall-sown plots was also noted for *Lupinus polyphyllus*, particularly in Year 2 (Table 19). This trend is probably related to the fact that fall-sown seed had a longer time to grow in the first year, and plants of this species are naturally slow to mature. In Year 1, most lupine plants were still small compared to the *Elymus glaucus*, *Festuca occidentalis* and *Achillea millefolium* plants, and compared to their size in Year 2.

5.2.4 Treatment interactions on sown cover

There were no significant treatment interactions on the cover of sown species, when looking at the species mix as a whole. However, there were some significant interactions for individual species. For example, there was significantly higher cover of *Elymus glaucus* in the spring-sown plots at densities ≥3000 PLS/m^2 (Section 4.3.1) than under other density x season of seeding combinations. At these higher densities (3000 and 6000 PLS/m^2), this result appears to contradict the recommendations of Archibald et al. (2000) and Maslovat (2001), who say fall sowing is preferred for this species. However their recommendations are based on studies conducted at mild coastal sites in the Pacific Northwest, rather than sites with a continental climate as found in the northern interior of B.C. Fall-sown seeds on the Pacific Coast germinate and acquire sufficient stature before the onslaught of cold weather, and freezing winter temperatures are not so severe as to cause mortality. Fall sowing is also recommended on the coast because cool fall temperatures inhibit the germination of many local weed species, but not the germination of *Elymus glaucus* (Archibald et al 2000). On the Prairies, winter dieback of grass seedlings frequently occurs (Agriculture Canada 1991).

In the interaction between fertilizer and sowing density, *Festuca occidentalis* exhibited significantly greater cover at the highest densities in both years. The biggest increase in cover (from 15% to 28%) occurred between sown densities of 3000 and 6000 PLS/m^2 (Figure 9). The reasons for this pattern may be related to the occurrence of larger plants of other species and the influence of shading. Even when fully mature, *Festuca occidentalis* is a small plant in comparison to *Elymus glaucus, Lupinus polyphyllus* and some *Achillea millefolium* individuals (Section 3.3.1). It likely benefited from the high density x fertilizer treatments because of its small stature. There was higher cover of big plants growing in the most densely sown fertilized plots, where the abundance of large plants may have offered the smaller *Festuca occidentalis* protection from desiccation or even insect pests. In severe habitats such as barren volcanic ash, it has been demonstrated that there is a benefit for seedlings to establish in the presence of other plants that provide shade, protection and nitrogen inputs (Wood and del Moral 1987).

5.3 Exotic species cover response

The exotic species present at all sites did not overwhelm the developing plant association (Figure 10). Exotic species grew strongly in the first year but by the second year the cover of exotics began to decline while cover of sown native species continued to increase. Exotic species consisted primarily of perennial weeds such as *Sonchus arvensis* and *Taraxacum officinale*, agronomic grasses such as *Agrostis stolonifera* and *Phleum* *pratense* and legumes of the *Trifolium* genus. At the Viewmount site there were several annual weeds such as *Cerastium fontanum*, *Chenopodium album* and *Thlaspi arvense*, due to previous agricultural activity (Table 20).

5.3.1 Density treatments and exotic cover

The cover of exotic species significantly decreased with higher sown densities of native species, but only in Year 2 (Figure 10). This same effect may not have occurred in Year 1 because the native seedlings were likely not big enough to compete effectively against exotic species. This result is exciting because it means that plant density can effectively be used to limit invasion by exotic species. This confirms the validity of recommendations by Townley-Smith and Wright (1993) and Stevenson and Wright (1996) to sow more heavily on weedy sites.

Many studies have examined the relationship between species diversity and the establishment of exotic plants (Tilman 1997, Palmer and Maurer 1997, Levine and D'Antonio 1999). Few have investigated the relationship between plant density and exotic species invasion (Lavorel et al. 1999, Von Holle 2003). In a greenhouse study, Lavorel et al. (1999) did find that there was a significant reduction of invasive species related to an increase in plant density. The results achieved in this thesis are similar. Such results are important because they suggest that high seeding densities can constrain the growth of exotic plants. The fact that these results were achieved with a mixture of native species is also exciting, since native plants are not typically considered competitive with exotic agronomics and weeds (Darroch 1994). Clearly more studies related to the effect of plant density on exotic species establishment are needed to further explore these important results.

There were clearly more weeds at the Viewmount site, where weed cover in individual quadrats was as high as 80%. At all other sites, cover in individual quadrats never exceeded 40% (Figure 11). It is possible that the significant results noted above were unduly weighted by the high weed cover at that one site. To address this possibility, an ANOVA testing treatment effects on exotic plant cover was conducted with the exclusion of the Viewmount data. Notably, the overall density and fertilizer effects were still significant. The Tukey test excluding the Viewmount data revealed that seeding densities from 750 to 6000 PLS/m^2 help control exotic species. By comparison, the Tukey analysis that including Viewmount data revealed that a sown density of at least 3000 PLS/m^2 was required for significant exotic control. These results suggest that different seeding densities can be used for weed control in different situations. On agricultural and other previously weedy sites, with large exotic seedbanks, seeding densities over 3000 PLS/m^2 are required, but only 750 PLS/m^2 of sown native plants are needed for significant weed reduction on less weedy sites (such as forest landings and roadsides).

More specific results were obtained through regression analysis conducted at each location (Table 21 and Figure 11). Results revealed that significant relationships between exotic plant cover and sown density were achieved only at locations or in years where exotic cover was >3.3% (as given by the 'intercept' column in Table 21). The greater the cover of weeds in unseeded plots, the more significant the trend, and the tighter the relationship (denoted by the 'p' and 'r^2' columns, respectively, in Table 21). This result suggests that even if there is a high cover of weeds, native plants can not only establish successfully, but they help to reduce the dominance of exotic plants, if sown at sufficient densities.

5.3.2 Fertilizer treatments and exotic cover

Exotic cover increased significantly in the first year with the application of fertilizer, but that benefit appeared to wear off by the second year when exotic cover was similar in both the fertilized and unfertilized plots. The higher cover of exotics in the fertilized plot in Year 1 is consistent with the reluctance of some restorationists to use fertilizer in restoration projects (Huenneke et aul. 1990, Wilson and Tilman 1991, Morgan et al. 1995). Fertilizer enhances the growth of weedy and agronomic seedlings from the seedbank because they are nutrient loving species (Huenneke et al. 1990, Wilson and Tilman 1991). In this study, these species did not benefit from fertilizer after the first growing season, whereas the beneficial effects of fertilizer on sown species persisted for at least two years (Section 4.3.3). Consequently, it would seem worthwhile to use fertilizer for restoration with native plants, regardless of the temporary increase of exotic species cover.

5.4 Volunteer native cover

Woody and non-woody native plant species in addition to those sown in the experiment appeared in almost all plots. Tree species included common native conifer seedlings and saplings such as *Picea glauca* and *Pinus contorta.* Of these, a few *Pinus contorta* had reached heights >0.5 m by the end of Year 2, simply because these species were planted after disturbance on two or three of the sites, and were present in a few control plots. Deciduous trees were represented mostly by tiny *Alnus* sp. and *Populus trichocarpa* seedlings. Common shrub species encountered were *Amelanciar alnifolia*, *Rubus* and *Salix* spp. at the seedling stage. The herbaceous species tended to be weedy natives like *Hieraceum*, *Epilobium* and *Aster* spp. (Section 4.6, Table 22).

5.4.1 Native volunteers and sown cover

Volunteer native species accounted for only 3.2% mean cover in Year 1 (Table 14) and 3.5% mean cover in Year 2 (Table 15). Closer examination of these tables shows that there was generally a higher cover of native volunteers in the control plots than in the manipulated plots. The highest mean volunteer cover, 13.2%, was achieved in the non-fertilized fall plot in Year 2 (Table 15). There was also a statistically significant effect of the density treatments on the cover of native volunteer plants, where the cover of native volunteers declined significantly by Year 2 at sown densities of 3000 and 6000 PLS/m^2 (Section 4.6.1, Figure 13). These results are similar to the results obtained for exotic species (Section 4.5.1, Figure 10).

This significant decline of native volunteer cover at high sown densities is an issue in the context of restoration. It is often desirable that when revegetating degraded sites with native seed, the cover achieved by sown natives should not negatively affect naturally occurring native species. Therefore, from the perspective of naturally occurring natives species, sowing densities of this seed mixture $\geq$3000 PLS/m^2 should be avoided, except where necessary for cover establishment on slopes or other sites where erosion levels may be high. Note that seeding densities of 375 to 3000 PLS/m^2 are able to suppress weed growth (so long as weed infestation is not so severe; Section 5.3.1), so it should be possible to significantly inhibit weed growth without inhibiting native plant succession.

5.5 Revising the seed mix

Because none of the seeding treatments achieved the desired levels of 70 or 80% cover, it seems worth exploring what treatments might be required to achieve various cover levels. Only one level of fertilization was tested in this experiment, and seasons other than spring or fall are unlikely to be better, so it is not possible to refine the fertilization or seasonal treatment based on the results obtained in this experiment. There is, however, a general trend of increasing cover with increasing density of seed sown (Section 4.3.2), so seeding rates greater than 6000 PLS/m^2 should result in desired cover levels. While acknowledging that it is not prudent to extrapolate beyond the data, it is nonetheless useful and interesting to speculate on what seed densities might be required to achieve fixed levels of cover. Assuming a linear extension of the relationship, the results of all treatment combinations were therefore extrapolated using linear regression to determine what density of seeding would be needed to achieve cover ranging from 40 to 80% (Table 23). Regressions were not forced through 0 because there was some cover of the sown species even in the control plots (i.e., there was no incidence of 0% cover). This cover in the control was either the result of seed from the density treatments migrating to the control plots or the natural occurrence of these native species on the site.

Results of the regression show that even to achieve a minimum cover of 40% (Section 5.2.1), the most successful treatment (fertilized, fall seeding) requires an application of 2,584 PLS/m^2 (Table 23). To achieve the 70% cover recommended for erosion control (Section 5.2.1), the most effective treatment for reaching that objective with the least amount of seed (fertilized, spring seeding) would require 6,380 PLS/m^2 (Table 23, Figure 14). As discussed earlier, these densities are often too high to be implemented in operational revegetation programs because of the high cost and limited availability of native seed. Figure 14 portrays the relationships for spring-seeded plots in Year 2 specified in Table 23. It graphically demonstrates that densities much higher than those tested in this experiment would be needed to reliably achieve 70 or 80% cover, especially if fertilizer is not used.

Table 23. Linear regressions of sown cover, as related to seeding density, with resulting equations solved for a series of desired cover levels.

			Regression Results				Densities to sow (PLSm^2)				
Year	Season	Fert.*	p	r^2	intercept	slope	40%	50%	60%	70%	80%
1	fall	F	0.0005	0.3031	19.221429	0.005262	3949	5849	7750	9650	11550
1	fall	NF	0.0001	0.3761	6.161111	0.003446	9820	12722	15624	18526	21427
1	spring	F	0.0011	0.2710	13.606349	0.007759	3402	4691	5979	7268	8557
1	spring	NF	0.0024	0.2408	3.611905	0.003233	11255	14348	17441	20535	23628
2	fall	F	0.0037	0.2223	24.844762	0.005864	2584	4290	5995	7700	9406
2	fall	NF	0.2684	0.0359	18.708254	0.002303	9245	13587	17930	22272	26614
2	spring	F	0.0001	0.4030	17.565429	0.008218	2730	3947	5164	6380	7597
2	spring	NF	0.0173	0.1555	9.578730	0.004754	6399	8503	10606	12710	14813

- F=fertilized at 295 kg/ha 18-18-18; NF=no fertilizer applied.

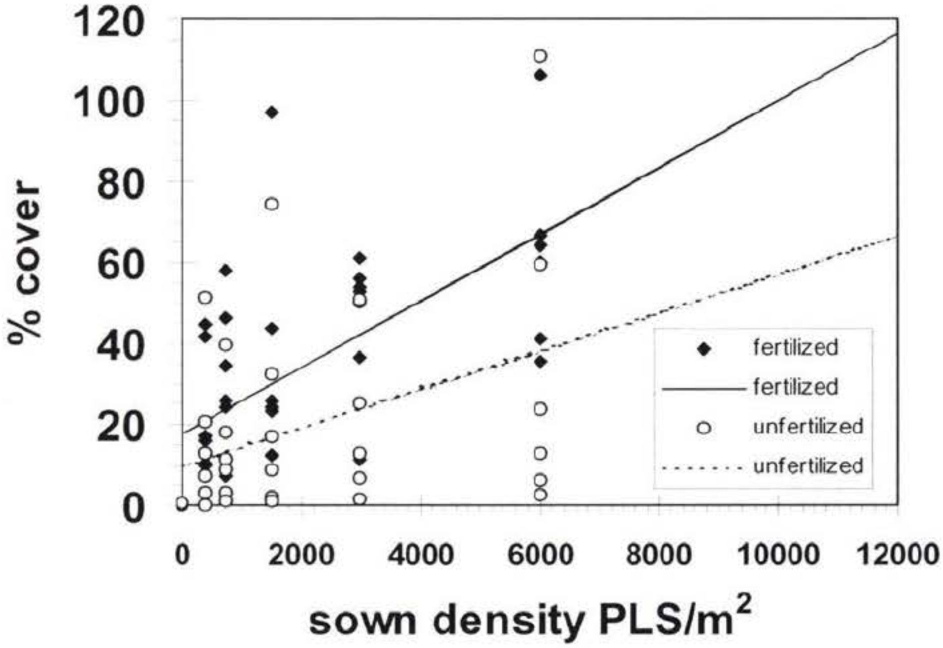


Figure 14. Year 2 sown cover and regression lines (see Table 22) derived for fertilized and unfertilized spring-seeded plots.

Because *Carex aenea* and *Geum macrophyllum* established so poorly in this experiment, it is also interesting to speculate on how different the recommended seeding rates would be if these two species were excluded from the seed mix. If *Carex aenea* and *Geum macrophyllum* seeds are not included in the PLS count in the seed mixture, the density treatments were, in effect, 36% less than the densities named for use in this experiment. For example, the treatment of 375 PLS/m^2 reduces to 240 PLS/m^2, if only the four most successful species are considered in the seed mix and its analysis. The poorly germinating *Carex* and *Geum* provided so little cover that they, in effect, acted as filler in the seed mix. Ignoring the contribution of those two species to sown cover results in a loss of <4% cover in any treatment.

A regression analysis excluding these two species from the mix was conducted, to derive new cover versus seed density relationships, and to see how recommended seeding densities would differ as a result (Table 24). The results show that only 4,210 PLS/m^2 are needed to achieve 70% cover in the most successful treatment (fertilized, spring seeding), while only 1,825 PLS/m^2 are needed to achieve 40% cover with the same treatment (Table 24).

Table 24. Linear regressions of cover generated by the sum of the four top performing species, and seeding Densities required to generate a series of desired cover levels. Contrast with results of existing seed mix (shown in Table 23).

			Regression Results				Densities to sow (PLSm^2)				
Year	Season	Fert.*	p	r^2	intercept	slope	40%	50%	60%	70%	80%
1	fall	F	0.0006	0.2989	18.091270	0.007983	2744	3997	5250	6502	7755
1	fall	NF	0.0001	0.3835	5.494444	0.005067	6810	8783	10757	12731	14704
1	spring	F	0.0012	0.2701	13.306349	0.012081	2210	3037	3865	4693	5521
1	spring	NF	0.0024	0.2410	3.547619	0.005009	7277	9274	11270	13267	15263
2	fall	F	0.0049	0.2101	22.975079	0.008241	2066	3279	4493	5706	6920
2	fall	NF	0.3013	0.0314	16.716349	0.002918	7979	11406	14833	18260	21687
2	spring	F	0.0001	0.3942	17.046032	0.012578	1825	2620	3415	4210	5005
2	spring	NF	0.0210	0.1469	9.353016	0.007011	4371	5798	7224	8650	10077

* F=fertilized at 295 kg/ha 18-18-18; NF=no fertilizer applied.

5.6 Chapter summary

This experiment provided innovative additions to a small but growing body of research on the use of native plant seed for revegetating degraded sites. It is logical that putting more seeds into a plot will result in higher numbers of germinating plants, and (ultimately) higher cover. It also is logical that the use of fertilizer will enhance the growth of these plants. However, as a result of this work, information regarding the effects of seeding density and the use of fertilizer for a particular suite of native plant species in a northern climate are now more refined. Some information on the best season for sowing on disturbed sites and the use of native species can be found in the literature but it is sparse. Similarly, the various interactions tested between seeding density, fertilizer, and season of seeding have also been largely untested, even in the literature of basic ecology. The research described in this thesis offers strong evidence that high levels of the sown native species suppressed the cover of exotic species, and that the use of fertilizer does not have a lasting effect on the growth of exotic plants. Overall, the results presented throughout this work enhance and expand a somewhat impoverished area of basic and applied research.

Chapter 6 Conclusions and Recommendations

6.0 Summary of results

This study demonstrated the following critical points concerning revegetation with native plants in the cold temperate climate of northern British Columbia:

- Native plant species can germinate and establish from seed on degraded sites;
- Seeding density is an important consideration when revegetating degraded land;
- Of the six species evaluated, *Elymus glaucus*, *Festuca occidentalis*, *Achillea millefolium* and *Lupinus polyphyllus* showed reliable response and are recommended for general use;
- *Carex aenea* did not establish well from seed, even when evaluated over two years;
- Seeding in either spring or fall both produce satisfactory seedling emergence and cover production in the northern interior of British Columbia;
- Higher seeding densities successfully inhibited the growth of exotic species on weedy sites;
- Fertilizer enhances the growth of native plant seed on degraded sites;
- Fertilizer increases the growth of exotic species in the first year, but in the second year the benefit of fertilizer to exotic species appears to decline.

6.1 General considerations

The results of this study in the northern interior of British Columbia have important implications for our understanding of basic plant ecology, and for practical application at the local and global level. These results provide guidance in developing seed mixes and prescribing seeding densities on sites typically degraded by logging and other industrial and agricultural activities. Assuming that there are reliable supplies of native seed, seeding at densities ranging from 350 to 6000 PLS/m^2, with a single addition of fertilizer, will provide from 23 to 62% cover, depending on the site conditions and seeding density (Table 15). In addition, high sown densities of seed will exert some control on the growth of unwanted exotic species, as suggested by the decline in exotic cover at the Viewmount site.

6.2 Recommendations

6.2.1 Revegetation guidelines

Several recommendations for revegetating degraded sites with native seed can be made based on the results of this experiment. Brackets indicate densities based on the revised seeding mix discussed in Section 5.5.

- Seeding densities as low as 375 PLS/m^2 (240 PLS/m^2) will produce cover similar to densities up to 3000 PLS/m^2 (1920 PLS/m^2) after two growing seasons. Therefore, if the need to establish vegetation is not urgent, then lower densities may be used. Final determination of density should be based on site and microsite factors.
- To obtain 70% cover on steep slopes and other erosion-prone areas a seeding density of 9650 PLS/m^2 (sown in the fall with fertilizer) is recommended. Based on the revised seeding mix a density of 4693 PLS/m^2 (sown in the spring with fertilizer) will provide the same cover.
- If the need to establish cover is not urgent, a seeding density of 2730 PLS/m2 (sown in the spring with fertilizer) will provide up to 40% cover after two growing

seasons. Using the revised seeding mix, this density may be reduced to 1825 PLS/m^2 (sown in the spring with fertilizer).

- Where exotic plants are expected to be problematic, seeding densities $\geq$3000 PLS/m^2 (1920 to 3840 PLS/m^2) are recommended as a method of weed control.
- Fertilizer should be used when establishing native plants from seed on degraded sites. A single application of fertilizer at the time of sowing can be beneficial for at least two years.
- The presence of exotic species should not deter the use of fertilizer. The benefit of fertilizer to exotic growth will likely decline by the second year.
- Season of seeding does not affect cover establishment in cold northern climates. For convenience, on remote sites or those with a heavy snowpack, fall seeding may be preferable because such locations are difficult to access until late in the spring.

6.2.2 Suggestions for further research

Clearly there is a need for more research on the species used in this experiment, as well as on additional native species and native seed mixes in general. There are many gaps in our knowledge with regard to the biology, ecology and management of native species, especially in relation to their use for revegetation purposes.

Further topics in need of research, stemming from this experiment, include:

- Evaluation of density-dependent mortality and other trends, following the analysis of the third year of monitoring;
- Evaluation of long-term trends in community composition, especially in relation to the effect of seeding density treatments on the growth of exotic species;

- Refining a mixture of native species that can be used for revegetation purposes;
- Testing a variety of fertilization rates to see if native cover can be enhanced with less than the 295 kg/ha tested here, and whether significantly more cover can be generated with more fertilizer;
- At the same time, testing a variety of fertilization rates to see how exotic cover is affected;
- Testing a variety of fertilizer treatments in combination with a variety of density treatments, including some greater than the 6000 PLS/m^2 tested here, to see if >80% cover (desirable for steep-sloped sites) can be generated by some combination of treatments;
- Research regarding the ecology of the genus *Carex* in general and *Carex aenea* specifically including the propagation of *Carex* species from seed.
- Why germination under field conditions is so low.

6.3 Overall conclusion

It must be remembered when doing any type of revegetation work, that all sites are unique in some respect, and prescriptions must take site differences into account. Providing cover to control erosion and achieve soil moisture stability are important reasons for establishing vegetation on degraded sites (Brown and Johnston 1980, Anonymous 2001), but they are not the only reasons. If they were, then the use of agronomic species would be perfectly acceptable, and even encouraged since these species germinate well, establish rapid vegetation cover, are drought resistant and readily available (Looman and Heinrichs 1973). Aesthetic appeal, wildlife management (Forman 2003), and the maintenance of biodiversity and ecosystem function are also important goals for revegetation projects (Bradshaw 1990, Woodley et al. 1993, Anonymous 2001). Therefore, in order to establish successful vegetation cover with native species, site-specific seed mixes and seeding densities need to be developed, depending on site and microsite factors. Information regarding site location, geological factors, soil conditions and history need to be considered before any revegetation project begins. Once these factors have been taken into account, then the important results from this work can provide useful guidelines for revegetating degraded sites with native seed.

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Appendix 1. Data collection form

Seeding Density Trials Location __________________________ Date ____________

Measured by: ____________________ Plot No./Treatment

	Sample 1		Sample 2		Sample 3	
	x=_____m	y=_____m	x=_____m	y=_____m	x=_____m	y=_____m
Seeded Species	count	cover	count	cover	count	cover
Achillea millefolium						
Carex aenea						
Elymus glaucus						
Festuca occidentalis						
Geum macrophylum						
Lupinus polyphyllus						
Native invaders						
Agrostis scabra						
Aster sp.						
Betula papyifera						
Calamagrostis canadensis						
Collinsia parviflora						
Epilobium angustifolium						
Epilobium ciliatum						
Equisetum arvense						
Hieracium albiflorum						
Picea glauca x engelmanii (spruce)						
Populus trichocarpa (cottonwood)						
Rosa acicularis (wild rose)						
Salix sp.						
Exotics						
Agropyron repens (quackgrass)						
Agrostis stolonifera (redtop bentgrass)						
Capsella bursa-pastoris (shep's purse)						
Cerastium fontanum (mouse-ear chick)						
Chrysanthemum leucocephalum (daisy)						
Chenopodium album (lamb's quarters)						
Cirsium vulgare (bull thistle)						
Dactylis glomerata (orchard grass)						
Festuca rubra (cr. red fescue)						
Galeopsis tetrahit (hemp nettle)						
Phleum pratense (timothy)						
Poa pratensis (Kentucky bluegrass)						
Polygonum convolvulus (buckwheat						
Sonchus arvensis (sow thistle)						
Taraxacum officinale (dandelion)						
Thlaspi arvense (stinkweed)						
Trifolium sp.						
Ground Cover / Physical features						
moss						
stones/wood						
erosional rills						
litter (leaves, etc)						

Appendix 2. Analysis of variance model employed for most hypothesis testing.

This example uses Year 2 total sown cover as the response (dependent) variable.

Source of Variation	d.f.	Error Term for F test	Anova SS	Mean Square	F Value	p Value
Main plot effects:						
Location n=6	(n-1) = 5	(replicates; not tested)				
Density d=6	(d-1) = 5	Location x density x fertilizer	24286.75	4857.35	15.53	0.0001
Fertilizer f=2	(f-1) = 1	Location x density x fertilizer	6922.98	6922.98	22.13	0.0001
Season[a] s=2	(s-1) = 1	Location x season	453.74	453.74	1.65	0.2551
Interaction terms:						
Density x fertilizer	(d-1)(f-1) =5	Location x density x fertilizer	2285.26	457.05	1.46	0.2174
Density x season	(d-1)(s-1) = 5	Location x density x fertilizer x season	1114.63	222.93	1.64	0.1647
Fertilizer x season	(f-1)(s-1) = 1	Location x density x fertilizer x season	24.88	24.88	0.18	0.6704
Density x fertilizer x season	(d-1)(f-1)(s-1) = 5	Location x density x fertilizer x season	218.40	43.68	0.32	0.8980
Error terms:						
Location x Density x Fertilizer	(n-1)(df-1) = 55					
Location x Density x Fertilizer x Season	(n-1)(df-1)(s-1) = 55					

[a] denotes season of sowing

x=interactions of all possible combinations

Error terms=sources of natural variability not attributable to treatments

F= ratio of treatment mean square to the error mean square, or what proportion of variability is due to variability among treatment groups

A high F value denotes a strong treatment effect

p=the probabiliy of getting a higher F value solely by chance; unless that chance is less than 5% (p=0.05), we traditionally do not say there was a significant treatment effect.

Appendix 3a: Percent cover of vascular plant species in year 2 at Viewmount.

	Fall Sown												Spring Sown											
	Fertilized						Non Fertilized						Fertilized						Non Fertilized					
Sown species	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000
Achillea millefolium	0.0	8.3	6.7	18.3	31.7	12.8	0.0	16.7	11.0	4.5	30.0	16.7	0.0	7.3	14.0	11.3	17.3	27.7	0.0	3.2	10.0	15.5	29.3	24.0
Carex aenea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elymus glaucus	1.7	2.3	8.2	3.7	5.2	8.7	0.0	6.0	3.5	1.3	5.5	21.0	0.0	0.5	0.5	2.3	5.8	4.2	0.0	1.2	1.7	1.2	2.5	1.3
Festuca occidentalis	4.5	0.5	14.2	10.8	6.3	13.8	3.8	5.8	3.5	11.3	1.7	12.7	0.3	6.7	8.5	2.8	21.7	22.3	0.3	8.2	2.7	1.2	14.7	11.7
Geum macrophyllum	0.0	8.3	14.7	4.2	19.3	31.0	0.0	15.0	20.0	15.5	15.3	26.0	0.2	2.3	1.0	5.8	4.2	5.5	0.0	0.3	2.8	5.8	1.5	10.3
Lupinus polyphyllus	0.0	0.0	0.0	7.0	1.7	1.7	0.0	0.0	11.7	1.7	11.7	12.2	0.0	0.0	0.3	0.8	4.7	4.5	0.0	0.0	0.8	8.8	2.7	12.3
Native Volunteers																								
Epilobium angustifolium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Epilobium ciliatum	0.2	0.7	3.3	0.0	+	0.2	1.2	0.0	1.3	0.3	0.0	0.0	1.3	0.5	0.9	1.7	+	0.4	2.2	0.7	0.5	2.0	0.2	0.0
Fragaria virginiana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.8	0.0	0.0	0.0
Hieracium albiflorum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hieracium sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Veronica americana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.5	0.3	0.0	0.0
Unknown dicot	1.5	0.1	0.3	+	0.2	0.6	0.1	0.7	0.2	0.1	0.2	0.0	0.5	0.1	0.1	0.2	0.1	0.5	1.0	0.2	0.5	1.3	0.2	0.1
Exotic species																								
Agropyron repens	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	8.3	5.0	0.0	0.0
Capsella bursa-pastoris	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	+	0.0	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.5
Cerastium vulgatum	0.0	35.0	2.6	12.8	7.5	23.3	16.7	17.3	36.7	1.0	7.0	2.8	0.0	0.0	0.8	2.7	0.0	1.8	0.2	0.3	2.2	4.3	0.3	0.0
Chenopodium album	0.0	0.0	1.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.7	0.3	0.2	0.0	3.3	0.0	0.0
Circium arvense	0.0	0.0	12.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
Circium vulgare	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.0
Crepis tectorum	0.0	0.0	1.6	0.0	0.0	0.0	1.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	3.3	0.0	2.0	12.3	11.6	2.7	8.3	1.2	0.0
*Dactylis glomerata**	0.0	0.0	0.0	0.0	0.0	0.8	22.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dianthus armeria	14.3	21.7	8.5	12.8	3.5	16.5	0.0	14.5	0.0	19.0	3.3	1.8	16.7	7.8	0.8	3.3	0.8	0.8	7.7	4.5	2.0	7.7	0.0	1.3
*Festuca rubra**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
Galeopsis tetrahit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Plantago major	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Poa pratensis**	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polygonum convolvulus	0.9	2.0	1.2	0.9	0.1	1.0	1.8	0.4	1.8	0.2	+	+	5.3	1.3	1.2	1.5	0.7	1.2	7.7	4.0	7.5	2.8	1.0	0.9
Potentilla norvegica	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rumex acetosella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0
Sonchus arvensis	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taraxacum officinale	6.8	2.7	3.8	0.2	0.2	2.2	1.3	5.0	4.5	3.8	0.5	0.2	4.0	9.7	7.2	8.5	2.2	4.0	6.0	8.3	10.5	7.7	4.0	3.0
Thaspi arvense	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	+	0.0
*Trifolium hybridum**	15.0	6.8	9.0	3.0	3.8	2.5	9.2	0.0	1.7	5.3	2.7	1.0	2.0	2.2	4.3	7.5	0.7	2.8	3.8	3.8	5.7	4.5	3.3	1.2
*Trifolium repens**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	4.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0

Appendix 3b: Percent cover of vascular plant species in year 2 at Francois Lake

	Fall Sown												Spring Sown											
	Fertilized						Non Fertilized						Fertilized						Non Fertilized					
Sown species	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000
Achillea millefolium	6.0	2.8	6.4	1.8	7.7	4.7	3.3	3.2	1.5	1.0	0.7	5.3	0.7	0.8	1.5	0.4	10.7	10.2	0.0	0.7	0.8	0.5	1.3	3.0
Carex aenea	0.0	0.5	0.2	0.0	0.0	0.0	+	+	0.0	+	0.0	0.0	0.0	1.5	0.3	0.1	0.2	0.0	+	0.0	+	0.0	0.1	0.2
Elymus glaucus	8.3	5.7	7.0	16.7	16.7	10.0	2.7	4.5	3.8	1.7	4.2	4.3	0.0	5.0	8.7	11.7	4.2	8.8	0.5	3.5	7.7	1.0	5.7	4.7
Festuca occidentalis	0.5	2.3	17.3	10.5	8.0	20.0	0.7	1.3	2.8	5.0	1.0	0.8	0.0	5.7	23.3	12.3	25.7	46.7	+	3.0	2.3	0.4	2.3	4.3
Geum macrophyllum	0.0	+	1.2	2.3	0.2	0.2	1.0	0.2	0.3	0.2	0.2	0.2	0.0	+	0.1	+	0.0	0.2	0.0	+	0.4	0.0	0.0	0.1
Lupinus polyphyllus	0.0	0.2	+	0.3	0.2	+	0.0	0.0	+	0.0	0.9	0.0	0.0	3.0	0.7	1.2	15.0	0.8	0.0	0.0	0.2	0.3	3.5	0.3
Native Volunteers																								
Agrostis scabra	0.7	0.0	1.7	0.0	0.0	0.0	1.2	1.2	0.5	0.0	0.0	1.2	1.3	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0
Alnus sp.	0.0	0.0	0.2	0.1	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arctostaphylos uva-ursi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aster conspicuus	0.7	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carex sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium angustifolium	0.2	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium ciliatum	0.1	0.4	0.0	0.1	+	+	0.7	0.4	0.4	0.2	0.0	+	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Festuca idahoensis	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fragaria virginiana	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+
Hieracium albiflorum	6.0	0.0	1.3	1.0	1.4	0.3	2.7	1.8	0.0	0.5	0.2	0.2	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+
Hieracium sp.	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lathyrus ochreleucus	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinus contorta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.7	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Populus trichocarpa	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rhinanthus minor	1.2	0.7	2.2	1.5	1.0	1.2	1.2	0.0	0.0	0.2	1.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spirea pyrimidata	0.0	0.0	0.8	2.8	0.0	0.0	0.0	0.0	0.0	0.2	+	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Trisetum spicatum	0.5	1.0	0.0	0.0	0.0	0.2	+	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0
Vicia americana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Unkown dicot	0.0	0.1	+	0.4	0.1	0.1	+	+	0.1	0.1	+	0.1	0.0	0.1	0.1	0.1	+	0.0	0.0	0.0	0.0	0.0	+	0.0
Exotic species																								
Agrostis stolonifera	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cerastium vulgatum	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dactylis glomerata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Festuca rubra**	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Matricaria matricariodes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Phleum pratense**	0.3	2.3	0.0	0.0	+	0.0	1.2	0.2	0.0	0.0	0.1	0.2	20.3	0.0	0.1	0.0	0.3	+	2.0	0.5	0.0	0.0	0.2	0.0
*Poa pratensis**	0.0	2.7	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stellaria media	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taraxacum officinale	0.0	1.7	+	0.4	1.8	0.2	0.0	1.0	0.0	+	+	0.5	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
*Trifolium repens**	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0

Appendix 3d: Percent cover of vascular plant species in year 2 at Chapman Rd.

	Fall Sown												Spring Sown											
	Fertilized						Non Fertilized						Fertilized						Non Fertilized					
Sown Species	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000
Achillea millefolium	0.0	1.8	2.5	0.3	1.2	2.2	0.0	1.3	1.3	0.7	0.1	0.7	+	11.7	2.7	4.3	4.2	12.2	0.0	0.1	+	+	1.5	0.9
Carex aenea	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.0
Elymus glaucus	0.0	5.0	7.8	4.7	8.0	15.7	0.8	3.0	2.0	2.2	1.0	1.5	0.0	21.0	14.0	14.0	17.7	20.3	0.0	1.2	2.5	6.7	3.2	3.8
Festuca occidentalis	0.0	7.2	6.7	10.0	13.3	10.7	0.2	0.9	0.2	0.5	0.2	0.8	0.0	5.7	5.0	5.0	13.3	16.3	0.0	0.3	0.4	1.9	0.6	1.0
Geum macrophyllum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Lupinus polyphyllus	0.0	5.7	5.0	2.2	2.3	3.7	0.0	4.8	2.7	9.0	6.7	7.0	0.0	3.2	4.0	0.4	1.3	11.0	0.0	1.0	0.2	0.4	1.0	0.6
Native Volunteers																								
Anaphalis margaritacea	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium angustifolium	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium sp.	0.4	0.0	0.0	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	+	0.0	0.0
Hieracium albaflorum	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hieracium sp.	8.8	1.4	0.0	0.3	0.0	0.0	2.2	0.0	0.3	0.3	0.2	0.0	1.3	+	0.2	0.0	0.0	0.0	0.0	+	0.4	0.0	0.0	0.0
Unknown dicot	0.0	0.0	0.0	0.0	0.0	+	0.5	0.0	0.0	+	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
Exotic species																								
*Festuca rubra**	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Phleum pratense**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Taraxacum officinale	+	0.2	0.0	+	0.0	+	0.2	2.4	0.2	+	0.0	0.0	0.9	+	0.5	+	0.0	+	0.1	0.0	+	+	+	0.0
*Trifolium repens**	+	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	13.4	0.0	0.0	0.0	0.0	0.0

* = domesticated cultivars

+ = present but <0.1% cover

Appendix 3e: Percent cover of vascular plant species in year 2 at McKendrick Pass.

	Fall Sown												Spring Sown											
	Fertilized						Non Fertilized						Fertilized						Non Fertilized					
Sown Species	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000
Achillea millefolium	0.0	4.7	1.2	3.7	3.5	4.4	0.0	0.7	+	0.1	0.4	0.2	+	2.0	4.4	3.7	6.5	3.2	0.0	1.3	0.1	0.7	0.4	1.8
Carex aenea	0.0	+	+	+	0.0	0.0	+	0.0	0.0	+	0.0	0.0	0.0	0.2	0.0	0.0	0.0	+	0.0	0.0	0.1	0.0	0.0	0.1
Elymus glaucus	2.0	5.0	1.2	6.2	6.8	10.0	0.5	0.2	0.5	0.1	1.0	2.0	0.0	1.7	25.7	17.7	25.0	9.3	0.0	6.3	3.8	6.2	8.3	9.3
Festuca occidentalis	0.0	4.5	9.0	20.7	15.0	21.7	+	0.7	0.4	0.7	4.4	1.2	0.0	3.5	7.3	16.7	11.0	14.3	0.2	4.0	+	2.5	1.2	1.5
Geum macrophyllum	0.0	0.8	1.3	0.4	0.2	0.5	0.0	0.3	+	0.1	0.1	0.1	0.0	0.2	0.5	0.2	0.2	0.1	0.0	0.1	0.1	+	0.1	0.2
Lupinus polyphyllus	0.0	11.3	22.7	19.0	25.0	25.0	0.0	20.7	28.3	22.3	22.3	32.7	0.0	3.0	8.5	5.3	10.0	14.0	0.0	8.8	4.8	7.3	15.0	10.7
Native Volunteers																								
Abies lasiocarpa	0.1	0.0	0.1	+	+	0.0	0.1	0.0	0.1	0.0	0.2	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agrostis scabra	10.5	0.0	0.8	0.0	0.0	0.0	0.5	0.2	0.0	0.2	0.7	0.7	5.7	2.7	2.7	1.7	0.3	0.2	1.3	0.0	0.0	0.0	0.2	0.3
Agrostis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus sinuata	1.0	+	0.1	+	0.0	0.0	1.9	0.1	0.0	0.2	0.2	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anaphalis margaritacea	1.3	1.8	0.2	+	0.0	0.0	1.7	+	0.0	+	0.0	0.0	0.4	+	0.2	0.3	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
Aster sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carex sp.	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium angustifolium	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium ciliatum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0
Epilobium latifolium	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Erigeron acris	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Festuca sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Galium boreale	0.0	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hieracium sp.	0.5	1.7	0.1	+	0.0	0.8	0.9	0.0	0.0	0.0	0.0	0.1	0.0	+	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0
Juncus bufonius	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.3	0.3	+	0.0	0.0	+	0.0	0.0	0.0	0.0
Picea glauca	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
Tricetum cernuum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.3	0.3	0.0	0.3	0.2	0.0	0.0	0.0	0.0
Unknown dicot	0.0	0.0	0.0	0.0	0.0	0.2	+	0.2	+	0.1	0.0	+	0.1	0.1	0.0	0.2	+	0.0	+	0.1	0.2	0.1	0.1	+
Unknown grass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	*	2.2	0.0	0.0	*	0.0	0.0
Exotic species																								
Cerastium vulgatum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	+
Chrysanthemum leucanthemum	0.7	0.0	0.2	0.0	0.0	0.0	0.8	0.2	0.0	0.0	0.0	0.0	8.7	0.2	2.6	0.3	0.0	0.0	3.3	0.0	0.4	0.2	0.0	0.3
*Festuca rubra**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Festuca sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
*Phleum pratense**	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	+	0.5	0.0	+	0.0	0.3	0.0	0.0	0.0	+	0.5
Rumex acetosella	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Taraxacum officinale	0.3	5.2	+	0.0	0.0	0.0	1.7	0.0	+	0.0	0.0	+	+	8.6	0.5	0.8	+	0.0	3.0	0.3	0.2	0.4	0.0	0.5
Trifolium sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* = domesticated cultivars

+ = present but <0.1% cover

Appendix 3f: Percent cover of vascular plant species in year 2 at Nass Valley.

	Fall Sown												Spring Sown											
	Fertilized						Non Fertilized						Fertilized						Non Fertilized					
Sown Species	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000	0	375	750	1500	3000	6000
Achillea millefolium	0.3	0.0	0.0	2.7	4.2	5.8	0.0	0.5	0.2	0.3	0.2	0.0	0.0	0.3	+	0.5	0.2	2.8	0.0	0.0	0.2	0.0	0.0	+
Carex aenea	0.0	0.0	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0	+	0.0	0.0	1.2	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.2	+	0.1
Elymus glaucus	0.0	0.5	5.8	3.8	4.5	4.0	0.0	1.5	0.0	2.3	0.7	0.7	0.0	3.3	1.7	1.8	2.0	12.7	0.0	0.2	0.7	0.5	1.3	2.5
Festuca occidentalis	2.8	1.3	14.5	8.8	13.3	38.3	0.0	0.1	0.0	1.2	0.0	+	0.0	4.7	5.3	10.0	8.8	18.3	+	0.0	0.2	0.2	0.0	0.9
Geum macrophyllum	0.0	0.0	0.0	0.2	0.0	+	0.0	0.2	0.0	0.4	0.0	0.0	0.0	+	+	0.0	+	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Lupinus polyphyllus	0.0	0.0	0.3	1.7	+	5.7	0.0	+	0.0	3.3	0.2	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Native Volunteers																								
Anaphalis margaritacea	0.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium angustifolium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hieraceum albaflorum	0.4	0.2	0.0	0.5	0.4	0.2	+	2.3	0.5	9.0	0.7	0.0	11.0	0.4	4.4	2.0	0.8	5.8	2.6	0.7	0.5	2.7	0.6	0.2
Pinus contorta	0.0	0.0	4.0	18.7	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Populus trico carpa	0.0	0.0	+	4.3	0.0	+	+	+	+	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	+	0.2	0.0	+	0.1	0.1
Unknown dicot	0.1	0.1	0.2	+	0.1	+	+	+	0.1	0.1	+	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+	+	0.1	0.0
Exotic species																								
Festuca rubra*	12.0	28.3	3.3	0.0	3.7	0.0	0.0	0.8	0.4	2.8	0.0	0.3	3.2	1.3	0.5	0.2	0.4	0.5	0.0	0.0	0.7	1.2	0.0	0.0
Russian rocket crucifer	+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trifolium hybridum*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0	0.0

* = domesticated cultivars

+ = present but <0.1% cover

Vita

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1995-date: Partner, Symbios Research and Restoration, Smithers, B.C.
- field botanist, environmental consultant, research technician, workshop co-ordinator, personnel and project manager
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1992-1995 (part-time and summers): Research Assistant, Department of Forest Sciences, University of British Columbia, Vancouver, B.C.
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1992-1995: Elementary Teacher, K-2, Vancouver School Board, Osler, Henderson, and University Hill Elementary Schools, Vancouver, B.C.
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1982-1989: Medical Receptionist, Gabriola Medical Clinic, Gabriola Island, B.C.

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2002: The Edward Bassett Family Bursary, University of Victoria
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