"We shall not cease from exploration

And the end of all our exploring

Will be to arrive where we started

And know the place for the first time."

T.S. Eliot

University of Alberta

Native Seed Mixes for Diverse Plant Communities

by

Catherine Dana Bush ©

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Abstract

Ten seed mixes were planted near Vegreville, Alberta in 1994. The seed mixes varied in species richness and functional characteristics. The diversity of the second year plant communities were significantly lower than that of the initial seed mix. Treatments 2, 5, and 7 had the highest density of seeded plants, richness, and percent species composition, but this appeared to be a result of higher seeding rates and/or the growth of individual species. Seed mix diversity had no effect on the species richness or density of weeds. The differences between treatments in canopy and ground cover were all under 10% and were not considered biologically significant.

Many of the species used had not been previously tested for reclamation. Field germination, and the relative size and density of second year plants were compared. Several species show promise for reclamation, in particular *Bromus anomalus, Rumex occidentalis, Oenothera biennis, Achillea millefolium*, and *Penstemon procerus.*

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Table of Contents

List of Tables

List of Figures

Appendices

List of Figures

List of Tables

1 Biodiversity and Ecosystem Function

1.1 Biodiversity

Concern about the loss of biodiversity is assuming greater importance in our decision making, whether it's in forestry, commercial fishing, agriculture, or more recently, reclamation. Biodiversity refers to "the variety and variability among living organisms and the ecological complexes in which they occur" (U.S. Congress 1987). Included in biodiversity are landscape diversity, community diversity, functional diversity, species diversity, species richness, and genetic diversity (Walker 1992). For the purposes of this thesis, biodiversity will refer to species richness unless it is qualified by "genera" or "functional".

The concern over the loss of biodiversity centers on four main arguments; morality, aesthetics, economics, and services (West 1993). Morality is a difficult concept for scientists to deal with for it cannot be easily defined or tested. However, the moral judgments of a society have always affected science. Society's acknowledgment of the rights of the individual has limited science's freedom to experiment with humans, just as acknowledgment of the inherent rights of species and ecosystems to exist will influence the scope and direction of applied ecology and sustainable development.

Like morality, aesthetics are also difficult to define, but its importance is implicitly acknowledged by our society (West 1993). We celebrate natural ecosystems in art and music, we revere them as sources of spiritual renewal, we drive miles to hunt, hike, and play in natural areas, and we struggle to protect them from our own over-use.

Humans directly benefit from the economic value of biodiversity in the form of "Nature's goods"; species, their mass, and their arrangement (Westman 1977). We harvest the species for food, housing, clothing, transportation, medicine, and pleasure.

Less understood are the functions, or "services" that ecosystems provide. A preliminary list of the core terrestrial biogeochemical functions include "primary and secondary productivity, decomposition, nutrient cycling and nutrient accumulation or loss, hydrology, soil development and soil fertility, and disturbance frequency or intensity" (Vitousek and Hooper 1993) - "the functions, in short, that maintain clean air, pure water, a green earth, and a balance of creatures..."(Westman 1977).

Ecologists are now exploring the relationship between diversity and these ecosystem functions. The discussion focuses on two opposite hypotheses: do ecosystems have a number of redundant species with a core of species that fulfill ecological functions (Redundant Species Hypothesis), or are all species cumulatively important (the Rivet Theory)? A great deal of theoretical work has been applied to these questions, although there are few descriptive studies and even fewer field experiments.

Researchers in applied ecology, as the name suggest, focus their work on applications of theory to practical issues. Reclamationists[1], for example, ask which species and how many species are necessary to restore the essential ecosystem functions on damaged sites. Restorationists[2] go further and ask how to restore the predisturbance ecosystem functions and structure. Both reclamationists and restorationists have done important, practical field work but replication and documentation is just gaining momentum. The connection of applied and theoretical perspectives is also attracting increased attention (Hobs and Norton 1996). This thesis is an attempt to bridge part of the gap between theoretical and applied dimensions of reclamation and restoration ecology.

1.1.1 Redundant Species Hypothesis

The proponents of the redundant species hypothesis view species richness as irrelevant; "all that matters is that the biomass of primary producers, consumers,

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[1] Reclamation is the construction of topographic, soil, and plant conditions after disturbance, which may not be identical to the predisturbance site, but which permits the degraded land to function adequately in the ecosystem of which it was a part (Munshower 1993).

[2]Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structure, regional and historical context, and sustainable cultural practices (SER 1996).

decomposers, etc. is maintained, and if it is, the life-support systems of the planet and ecological processes in general will function perfectly well with very few species" (Lawton and Brown 1993; Walker 1992).

On a global and historical scale we have seen that species increase and decrease, migrate and recombine without catastrophic effects (Johnson and Mayeux 1992). The loss of *Castanea dentata* [3] and *Ulmus americana* from the eastern deciduous forest resulted in few reported changes in ecological function. Each species was attacked by a pathogen which killed approximately 80% of the trees. Today, both species continue to exist as understory shrubs or minor canopy components, but they have lost their positions of dominance. In both cases the gaps were rapidly closed by other tree species with no apparent change in ecosystem function: the goods changed, but the services were retained (Johnson and Mayeux 1992; Woodward 1993).

1.1.2 Compensation

Species redundancy, however, may be a function of time. Species may appear to be redundant in the short term, but become important under different ecological conditions. Diverse species can compensate for each other in times of drought stress, water-logging, intense winters, or over grazing. The species abundance may change, but the biomass may stay relatively constant.

Ellenberg (1954, cited in Woodward 1993) grew four grass species, *Arrhenatherum elatius, Dactylis glomerata, Bromus erectus, and Alopecurus pratensis*, in a sandy soil with the water table maintained at different depths. In a dry year, the two deep-rooted species, *Arrhenatherum* and *Dactylis* grew well even with a low water table. In a wet year, *Alopecurus,* a grass which tolerates water-logging, grew well with a high water table, but poorly with a low water table. Ecosystem productivity was almost constant with depth of the water table for any given mixture of three species, except when *Alopecurus* was deleted; removing *Alopecurus* decreased the overall yield and increased the variability. *Alopecurus* acted as a keystone species, but only with a high water table.

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[3] Common names and full scientific names with authorities are found in Appendix Table A-1.

Compensation also occurs on a continental scale. Moore (1988) noted that during the drought of the 1840s, the boundaries of the short grass prairie shifted eastward. The drought adapted species did not move during the drought, but were present as minor species within the tall grass prairie. Under drought conditions the tall grass species were suppressed and the short grass species assumed a more dominant role.

A similar occurrence was observed during the drought of 1987-1988 in Minnesota. Tilman and Downing (1994) found that species-rich plots (up to 25 species) were more drought resistant (the biomass was more resistant to, and recovered more quickly from drought) because they were more likely to contain some drought-resistant species that partially compensated for the decreased growth of other species. Tilman and Downing (1994) noted that "ecosystem resistance to drought is an increasing but nonlinear function of species richness...the progressive loss of species should have progressively greater impacts on ecosystem stability...The greatest dependence of drought resistance on species richness occurred in plots with nine or fewer species."

The 1988 drought also influenced species composition in Yellowstone National Park; diverse communities were more resistant to change than were simpler communities (Frank and McNaughton 1991). Frank and McNaughton (1991) noted that community diversity was strongly influenced by "microsite heterogeneity". They hypothesized that patchy species composition allowed a wider diversity of species to coexist in a given area. These species could then take advantage of changes in climate.

1.1.3 Rivet Hypothesis

This ability of minor species to adjust to and compensate for changes in the ecosystem may be what Ehrlich and Ehrlich (1981) were referring to with their "rivet" hypothesis. In a creative analogy they likened the earth to an airplane, and humans to a "rivet popper"; a mechanic busily removing rivets. "Don't worry." he assures you. "I'm certain the manufacturer made this plane much stronger than it needs to be, so no harm's done. Besides, I've taken lots of rivets from this wing and it hasn't fallen off yet." One interpretation of this theory is that a "progressive loss of species steadily damages ecosystem function" (Lawton and Brown 1993).

The corollary is that reclaimed ecosystems should have the maximum possible number of species.

1.1.4 Keystone Species

We know that some species are more important than others. Paine (1966, 1969) first used the term "keystone" for critical predators in marine communities. The concept has now been extended to competitors, herbivores, predators, mutualists, and ecosystem engineers (Bond 1993; Jones, Lawton and Shachak 1994). Basically, to any species whose activity and abundance determines "the integrity of the community and its unaltered persistence through time..." (Paine 1969). Removal of keystone species "causes massive changes in species composition and other ecosystem attributes" (Jones, Lawton and Shachak 1994). However, keystone species are not easy to recognize. They may be rare, or they may be so common that we don't recognize their role (Krebs 1994).

Debach (1974) reported that in the early 1900s, Australia was plagued with an infestation of *Opuntia inermis* and *O. stricta*. Originally introduced as ornamental plants, *Opuntia* had rendered 60,000,000 acres of rangeland unusable by cattle or people. In 1926 *Cactoblastis cactorum*, the cactus moth, was introduced and by 1935 the *Opuntia* population had collapsed. Today both *Opuntia* and *Cactoblastis* are minor components in the Australian ecosystem. Without knowing the history we would not likely identify *Cactoblastis* as a keystone species.

Keystone species are often herbivores. Three species of *Dipodomys* spp., kangaroo rats, are a keystone guild in the Chihuahuan Desert (Brown and Heske 1990). *Dipodomys* selectively graze on the large seeds of winter annuals and they burrow extensively. Removal of the three species allowed large seeded winter annuals and perennials to increase dramatically, converting the habitat from shrubland to grassland (Brown and Heske 1990).

Ecosystem engineers, like *Dipodomys,* modify abiotic and biotic materials, and in doing so they change the availability of resources to other organisms. Beavers are classic examples, but plants can also act as ecosystem engineers. The growth of trees results in the development of a forest which alters the hydrology, nutrient cycles, and soil stability, as well as humidity, temperature, wind speed, and light levels (Jones, Lawton and Shachak 1994). Not only do the trees provide resources (food and shelter) for other species, but they change the availability of other resources as well.

How do we identify keystone species? Bond (1993) suggests that we examine the competitive abilities of species, and then if they do not dominate the community, identify the agent that is preventing them from reaching dominance. It may be that these species are being controlled by keystone herbivores or pathogens.

1.1.5 Exotic Species

An exotic species (originating in another part of the world) that is not a keystone species in its native ecosystem may become one in a new ecosystem in the absence of predator, herbivore or disease pressures. These species then replace native plant species, changing the goods and services produced by that ecosystem (Vitousek 1986).

Bromus tectorum is an exotic grass that invaded the intermountain west following cultivation and extensive overgrazing in the late 1800s (Mack 1981; Orians 1986). *B. tectorum* is a highly flammable winter annual adapted to both rangeland and cultivated fields. Once established, it significantly alters the fire and grazing regimes. The increase in fire frequency inhibits regrowth of the native, perennial bunchgrass *Agropyron spicatum* and perpetuates the new community (Mack 1981; Orians 1986).

Myrica faya, a leguminous shrub from the Azores and Canary Islands, is invading the islands of Hawaii (Vitousek et al. 1987). *Myrica* establishes on lava flows which are inherently low in nitrogen. Such sites contain no native plants capable of nitrogen-fixing symbiosis, and plant growth is limited by the lack of nitrogen. *Myrica* significantly increases the amount of biologically available nitrogen on these early successional sites. Ecosystem processes are altered, but the influence on the total ecosystem is unknown (Vitousek et al. 1987).

1.1.6 Minimum Numbers

What are the minimum number of species necessary for optimal functioning in an ecosystem? Tilman and Downing (1994) indicate that the effects of biodiversity level off at approximately ten species. Other researchers (cited in Baskin 1994) assert that little productivity is gained by adding more than four or five species to agronomic communities (Swift), and that carbon uptake and productivity probably reach their maxima with approximately ten tropical tree species (Orians). These are tentative numbers; the studies have not been repeated, nor have they been conducted under varying environmental conditions.

Nature's goods and services are supplied by species within ecosystems. The goods and services can be altered by the removal or replacement of species, but we don't know which species are critical, how many species are necessary, or under which environmental circumstances.

1.1.7 Ecological Restoration and Reclamation

What implications does this ecological knowledge have for the restoration of ecosystems? Reclamation and Restoration address ecosystem functions by the use of fast establishing species, and grasses with rhizomatous roots to limit soil erosion. Salt, flood and drought tolerant species are chosen for problem sites. Range managers usually plant long-lived, palatable, and grazing tolerant grasses. Nitrogen fixing species are routinely included, and most mixes include long lived species, although they are not necessarily native in many reclamation projects.

Forestry managers routinely replant dominant tree species, however, native dominant or keystone species are rarely used in prairie or alpine areas. In the northern prairies, native species are commonly replaced by exotic species such as *Bromus inermis* and *Agropyron pectiniforme* or a few rhizomatous grasses and one or two legumes. These species have broad ranges of adaptations and do well in a variety of soil conditions. However, even these robust species may not be adapted to the full range of site variability.

Agropyron pectiniforme has been planted across the prairies of North America for 60 years, and is considered a reliable, drought tolerant forage crop (Gray 1967). However *A. pectiniforme* does not appear to be reproducing itself well in some areas. Four or five years of successive drought in Utah killed thousands of acres of well established *A. pectiniforme* leaving early successional weeds to fill their place (Monsen 1995). Could this disruption of ecosystem function have been avoided by increasing diversity?

1.1.8 Increasing Taxonomic Diversity

Several approaches to encouraging diversity are used in reclamation. Complex mixes increase the likelihood that all microsites will receive seed appropriate to the particular soil conditions. It is hoped that increasing the number of species will ensure that the species critical for ecosystem function will be included. Morgan (1995), a restorationist working on the Canadian tall grass prairie, includes up to 40 native species in each seed mix. In the United States, the 1977 Surface Mine Control and Reclamation Act requires mine operators to "establish...a diverse, effective, and permanent vegetative cover of the same seasonal variety...and capable of self regeneration and plant succession at least equal in extent of cover to the natural vegetation of the native area..." (Allen and Friese 1990; Holechek et al. 1981). This legislation encouraged companies and state departments to use more complex mixes to re-establish the diversity (Allen and Friese 1990; Holechek et al. 1981; Stevens 1995).

Ducks Unlimited uses a technique called sculptured seeding in the rolling prairies. They use several seed boxes with seed mixes designed for crest, midslope and low landscape positions (Jacobson et al. 1994). This ensures that appropriate seed is planted along the soil catena without wasting expensive seed.

Seed can also be separated in time and in vertical or horizontal space to enhance the establishment of rare, expensive, or slow to establish species. The Idaho Fish and Game Association (Stevens 1995) uses a variety of seeding techniques to increase the establishment of species (especially shrubs) that are easily out competed by aggressive grasses. They plant shrubs and other less aggressive species in patches, or alone in the outside row of the seeder. They frequently vary the seeding depth, placing aggressive species deeper and placing slower growing (usually native) species shallower where they will germinate faster. Seeding times may be varied by seeding less competitive species first (DePuit, Coenenberg and Skilbred 1980) or last (Betz 1986), while warm season grasses may benefit from summer planting and irrigation (Samuel and DePuit 1987).

Low seeding rates allows native species to invade from surrounding areas. This is particularly effective in non-weedy areas, where the disturbance is small and adjacent to good quality native prairie. Such disturbances may include oil and gas pipelines, transmission lines, and wellsites (Gerling 1997; Gill Environmental Consulting1996).

1.1.9 Richness

Increasing the seed mix diversity in reclamation is hampered by the cost and availability of native species. Currently the cheapest and most readily available species are from a narrow range of exotic grasses and cultivars of native grasses. Two seed mixes, each with six species, may have the same species richness, but not necessarily the same functional characteristics. For example, one seed mix may have six grasses, all of which are *Agropyrons*, while the other may have three grasses, only one of which is an *Agropyron*, plus a legume, a composite, and a mustard. Although the species richness is the same, the range of functional characteristics is broader in the second mix, and may be more effective in re-establishing basic ecosystem functions.

Even choosing a broader level of taxonomic diversity, such as genera richness, doesn't necessarily translate into functional diversity. In an ecosystem dominated by grasses and *Artemisia tridentata*, the shrub *A. tridentata* acts as a debris and seed trap: establishment of grasses and forbs is enhanced under the protective cover of the shrubs (Allen and Allen 1992). Adding *Artemisia frigida* a low growing forb, to a seed mix would increase the taxonomic diversity but would not fill the same functional role.

1.1.10 Functional Characteristics

Functional diversity refers to those characteristics that "govern the fluxes of energy and materials... and the mechanisms that permit the persistence of an ecosystem through time in a constantly changing environment" (Solbrig 1993). It includes not only the functions necessary for the movement and transformation of energy and matter, but also the functions necessary for the ecosystem to grow and change.

A large number of researchers have attempted to define these functional properties (Westman 1977, 1991; Vitousek 1986; Vitousek and Hooper 1993; Woodward 1993; Solbrig 1993). Vitousek and Hooper (1993) examined the ecosystem biogeochemical processes and stressed that the following were of primary importance: primary and secondary productivity, decomposition, nutrient cycling and nutrient accumulation or loss, hydrology, soil development and soil fertility, and disturbance frequency or intensity.

1.1.11 Functional Groups

Functional groups are classes with similar characteristics or that behave in similar ways (Solbrig 1993). If we could classify all our species into functional groups, then it would simply be a matter of choosing one species from each group and ensuring that all groups are represented. Jackson (1980), analyzed the species composition of the tall grass prairie and concluded that each community had at least one species from each of four functional groups; a warm season grass, a cool season grass, a legume and a composite. He concluded that a "stable" ecosystem should have, at a minimum, these four elements. Tilman, et al. (1997) used five different functional groups to examine the effect of functional diversity on ecosystem process: legumes, C3 and C4 grasses, woody plants and forbs (non nitrogen fixing), while Hooper and Vitousek (1997) used four functional groups: early season annuals, late season annuals, perennial bunchgrasses, and N fixers. Tilman, et al. (1997) concluded that "functional diversity had greater impact on ecosystem process than did species diversity...However, species diversity and functional diversity are correlated...either species or functional diversity may provide a useful gauge of ecosystem functioning."

Solbrig (1993) however, cautions that functional groups are "arbitrary assemblages classified on the basis of similarity criteria set by the ecologist." A plant physiologist might establish groups based on photosynthesis, transpiration, growth, and development. A geneticist might look at genetic recombination, gametogenesis and reproduction. A population biologist might use measures of population growth and regulation, and aspects of life history. A reclamationist might look at establishment, effects on soil erosion, productivity, longevity, palatability, and grazing resistance.

In addition, plants don't necessarily stay in the same functional group. A tree seedling performs a far different function than a mature or a decadent tree. Plants are also highly adaptable and can change their physiological responses and morphology in response to changes in their environment. A species may be actively mycorrhizal in a late successional community, but non-mycorrhizal in an early successional community (Janos 1980). This makes assigning species to functional groups a subjective endeavor.

1.1.12 Individual Functional Characteristics

Researchers have also explored how individual characteristics influence the functions of an ecosystem. The development of alternate forest ecosystems following fires has been explained using life history characteristics such as the movement of propagules, competitiveness, life span and growth patterns, and mortality (Cattelino et al. 1979; Noble and Slatyer 1977). By examining these elements and varying the frequency of disturbance, Cattelino and colleagues described the development of various forest communities in Glacier National Park, Montana. Both Cattelino et al. (1979) and Leps, Osbornová-Kosinová and Rejmánek (1982) emphasized that the behavior of the community is not a function of diversity per se, but of the characteristics of the individual species that make up the community - their dominance, keystone role, life span, reproduction, architecture, and role in energy and nutrient cycling.

Tilman (1997) realized that tests for diversity were easily confounded by the characteristics of the individual species. Using fully randomized seed mixes he accounted for the individual characteristics, isolated the effects of diversity, and demonstrated that increasing diversity resulted in a more stable biomass and more efficient nutrient use in a grassland community. Hooper and Vitousek (1997) examined the effect of the number of functional groups (functional diversity or richness) and the composition of those groups (the individual species) on ecosystem processes. They suggested that "the functional properties of particular species and combinations of species, more than richness per se, control yields and nutrient use...The functional characteristics of the component species in any ecosystem are likely to be at least as important as the number of species for maintaining critical ecosystem process and services."

Not only are the characteristics of the individual species important, but their survival under adverse conditions is a critical factor in the composition of a community. In Cattelino, et al.'s (1979) example, the forest community depended on those species that survived fire (in propagule or vegetative form). Whittaker (1975) says "Communities are in a sense collections of species that have not yet become extinct because their buffering or tolerance of fluctuation has made possible survival of the environmental changes (and biological pressures) they have so far encountered." Ecosystem managers stress that we need to manage *for* variability, not to limit variability (Adams et al. 1994; Hobbs and Norton 1996). It is not the species that survive under stable environmental conditions that determines the health of the ecosystem, but rather the species that survive the rare events. Individual species are the basic elements of a functional community. Some of these species may be redundant, but we don't know which ones, or how many, or under which circumstances they play an important role.

1.2 Research Objectives

The research in chapter 2 helps to understand the characteristics of several species by examining germination, establishment, and growth rates. Chapter 3 provides some insights into how many species, and which ones are important. It provides an evaluation of seed mixes of varying types of diversity (species richness, genera richness, and functional diversity) to determine if the species richness is maintained, and if diversity affects the number and cover of weeds, and the cover, density and species composition of the planted species.

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2 The Germination, Relative Density, Relative Size and Survival of 23 Species

2.1 Introduction

Native species are now commonly used in reclamation, and are frequently required on public lands in Alberta (Special Areas Board et al. 1996) and Saskatchewan (Jorgenson 1997). Recently, native seed has become more available as cultivars, ecovars, and wild collected seed. In addition, there is an increasing amount of information available on their establishment rates and ecological tolerances (Hardy BBT Ltd. 1989; Wark et al. 1994.; Baldridge and Lohmiller 1990; Smreciu 1993; Smreciu, Currah and Toop 1988; Currah, Smreciu and Van Dyk 1983; Thornburg 1979; Gerling et al. 1996; Morgan, Collicutt and Thompson 1995; Nernberg 1994). However, even with the profusion of interest and availability of native seed, there are still significant information gaps for uncommonly used species such as *Bromus anomalus, B. ciliatus, Festuca hallii, F. campestris, Koeleria macrantha, Stipa comata, S. curtiseta,* and most of the forbs. Native species are more variable than agronomic species, (cultivars have been bred to minimize dormancy and within species variability) and less is known about their site requirements, germination, establishment, growth rates, and relative competitiveness, much less their functions in the ecosystem.

Native plants often have variable germination rates. The germination rate of *Festuca hallii* ranges from 20 to 76% (Nernberg 1994), *Achillea millefolium* ranges from 16 to 50%, (59 to 96% with stratification), and *Monarda fistulosa* ranges from 68 to 92% (Smreciu, Currah and Toop 1988). Some of this variability is due to high dormancy rates. Some native species such as *Stipa viridula* have first year germination rates as low as 4%, although cultivars may be as high as 50% (Alberta Agriculture 1981) and pre-treating seeds by scarification or stratification can increase germination to 100% (Nernberg 1994; Smreciu, Currah and Toop 1988). Dormancy also varies between ecotypes and years. The germination rates of *Artemisia tridentata* varies both among subspecies and within subspecies (Meyer, McArthur and Monsen 1987). The germination of *Festuca campestris* varies between years and collection sites (Tannas 1993). Dormancy can be estimated for different ecotypes and combined with percent germination to get a measure of total viable seed (Wark et al. 1994); however, this baseline information is unavailable for most species.

Seed establishment depends on the germination, dormancy, seedling vigour and relative size of the selected species. Some native species have poor seedling vigour. *Agropyron trachycaulum* can bloom in two years, while second year *Festuca hallii* plants consist of 3 or 4 small leaves and may be more susceptible to winter kill or competition. Seedlings that are out-competed in the first year will not be present in the final community. Wark et al. (1994) estimate native seedling establishment at 20 to 25 % of the Pure Live Seed (PLS) seeding rate, but depending on the species, it may be much lower. Here again, the baseline data is unavailable for many species.

To fill these information gaps, I investigated the germination, relative size and density, and survival of some commonly used species and several untested species.

2.2 Objective

To determine the germination, relative density, relative size, and survival of selected native plant species.

2.3 Methods and Materials

2.3.1 Site Location

The research plots are on the Parkland Agricultural Research Initiative (PARI) Conservation Demonstration Farm near Mundare, Alberta, 100 km east of Edmonton (NE and SE quarters of Sec 9, T53, R16, W of the 4th meridian). The study area is in the Central Parkland Natural Subregion (Achuff 1994). Historically, the Central Parkland was a patchwork of *Populus tremuloides* clones and native grassland dominated by *Festuca hallii* with Black and Dark Brown Chernozemic soils (Strong 1992, Achuff 1994). Because of its rich soils and abundant moisture, most of the native grassland has been ploughed for agriculture (Strong 1992).

2.3.2 Climate Data

The 30 year average precipitation (1951 to 1980) is 402.5 mm at the nearest meteorological station at the Vegreville Experimental Farm, 10 km east of the study site (Alberta Agriculture, Food and Rural Development, 1997). The average number of degree days >5°C is 1360, and the 30 year average temperature is 1.4°C (Appendix Table A-2).

In 1994 there was a dry early spring with lower than normal rainfalls in March and April (32 and 14% of the 30 year average), but higher than normal rainfalls in May and June (136 and 137% of the 30 year average) and in August (181% of the 30 year average). The temperatures were slightly warmer in April (by 0.6°C), slightly cooler in June (by 0.9°C), and close to the average for the rest of the growing season.

In 1995, it was drier and cooler than normal, with 87% of the 30 year average precipitation and 1°C cooler. April and June were slightly drier (62 and 35%, respectively) while July and August were wetter (111 and 191%, respectively). The temperatures were cooler by between 1 and 2.8°C in every month except June.

2.3.3 Site Description

The study site was situated in undulating to hummocky terrain with slopes of 2-9%. The soils texture was moderately fine to medium textured, and was predominantly Black Chernozemic (eluviated, and solonetzic) with some depressional areas with Humic Luvic Gleysols, and Black Solodized Solonetz' (Appendix Table A-3).

The research sites were tame pasture for 30 or more years prior to 1993. Remnants of pasture around the sloughs and fence lines were dominated by *Bromus inermis* and *Poa pratensis* with minor amounts of native forbs and wetland species (Appendix Table A-4).

2.3.4 Seedbed Preparation

Glyphosate was applied at a rate of 3.7 L/ha on July 13, 1993 and the turf was broken on August 16 with a heavy breaking disc. Two more passes were made with a lighter disc, in August and November, and once more in the spring. The north pastures (A and B) were disked again and cultivated once before seeding. The south pasture (C) was cultivated, harrowed, and packed before seeding.

Three sites with five blocks were seeded: blocks A1 and A2 at the northeast site, block B3 at the northwest site and blocks C4 and C5 at the south site (Appendix Figures A-2 and A-3). Blocks A1, A2, C4, and C5 were seeded on May 30. A Kohler 8 cone seed drill was used to drill the large seed. Although the seed was de-awned and cleaned, seed mixes containing *Stipa curtiseta* frequently clogged the tubes. A written record was kept of all passes with clogged tubes.

Small seeds of *Achillea millefolium, Erigeron glabellus, Oenothera biennis, Penstemon procerus, Monarda fistulosa, Bouteloua gracilis, Koeleria macrantha, Poa palustris, Oxytropis deflexa,* and *Oxytropis splendens* were mixed with cornmeal and hand broadcast. The small seeds at Mundare B were sown in front of the drill seeder. Due to heavy rains, blocks A1, A2, C4, and C5 were sown on June 6, one week after drill seeding and were not packed due to wet soil conditions. A light wind during seeding carried some seed away from the targeted areas resulting in uneven patches of the lighter seed.

2.3.5 Seed Mix Design

Ten seed mixes (treatments) were planted; two seed mixes provided by industry (NOVA Gas Transmission Ltd. and Ducks Unlimited) and eight seed mixes designed for the diversity research described in Chapter 3. A total of 31 species were planted; four of the species in the industry mixes were non-native (*Agropyron elongatum, Festuca ovina, F. rubra,* and *Medicago sativa*, and the rest were native to the Aspen Parkland (Appendix Figure A-1,Table A-5).

Oxytropis splendens and *O. deflexa* were scarified by lining a jar with sandpaper and shaking the seed until the seed coat was scuffed. *Stipa comata* and *S. curtiseta* were de-awned by rolling them between a corrugated rubber mat and hand held paddles lined with corrugated rubber. Seed was not stratified to avoid too many treatment variables.

The intent of the seeding mix was to have approximately 55 plants per square meter in each treatment at the end of the first growing season. Seeding rates were calculated with Pure Live Seed (PLS) and estimated survival rates. PLS was obtained from the seed certificates for commercial seed, and was estimated for the uncommon native seed. Estimates were based on the weight and germination rates in the literature, and from laboratory research. Survival rates were estimated from published data (Hardy 1989; Wark et al. 1994; Currah, Smreciu and Van Dyk 1983; Thornburg 1979; Gerling et al. 1996; Nernberg 1994). Due to differences in seed size, and inaccurate estimates of germination and survival, the seeding rates varied from a high of 18, 17 and 29 PLS/0.1m^2 for seed mixes 2, 5, and 7 respectively, to a low of 6 PLS/0.1m^2 for seed mix 10.

Scientific nomenclature for plant species follows Moss (1983) with the exception of *Agropyron trachycaulum* and *A. subsecundum* which are considered separate species by the seed industry, and *Festuca campestris* and *F. hallii* (Aiken and Darbyshire 1990). Common names and full scientific names with authorities are included in Appendix Table A-1.

2.3.6 Experimental Design

A completely randomized block design was used, with five blocks consisting of ten treatments (seed mixes) (Appendix Figures A-2, A-3). The blocks were carefully laid out to avoid uneven terrain and depressional areas. Each plot was 9.2 m x 18.3 m. Ten permanent quadrats (0.1 m^2) were established in each plot and marked with four 15 cm nails and washers. The quadrat locations were randomly chosen; however, rows in which the seed drill jammed were avoided.

2.3.7 Field Germination Tests

Thirty seeds of selected species were placed between two pieces of glue impregnated fiberglass-mesh drywall tape. Three replicates of seeded tapes were planted at Site A1 on June 6, 1994. Germination plots were examined in situ weekly and all seedlings were recorded. The seeded tapes were lifted on July 7, 1994, and the seeds were examined under a dissecting microscope to determine the maximum number of germinated seeds, including those whose tops had been eaten or died. All seeds were accounted for. Tests were not done to determine if the presence of the fiberglass tape or glue altered the germination rates.

2.3.8 Vegetation Measurements

Species density and composition were measured in August 1994 and 1995 in the 0.1 m^2 quadrats. Plant density was a direct count of seeded and invaded plants (referred to as weeds). The percent species composition (an estimation of biomass) was estimated visually. Each species, beginning with the dominant species, was estimated as a percent of the total biomass. Total species composition was always 100 for each plot.

Identification was considered accurate to species with the exception of the *Festuca* species in the NOVA mix, and *Agropyron* species in all mixes. Data for *Agropyron trachycaulum* and *A. subsecundum* were combined for analysis.

2.3.9 Soil Measurements and Analyses

On June 24, 1994, three soil cores from each plot were taken, combined and sent to a lab for analysis. Electrical conductivity (EC), sodium adsorption ratio (SAR), Ca, Mg, Na, Organic Carbon, and pH values were obtained for 0 to 15 cm and 30 to 45 cm depths on each plot (Appendix Table A-6) (Carter 1993). This data was collected to provide baseline data for further research at this site.

In July 1995, an electromagnetic inductance meter (EM38) developed by Geonics of Canada was used to measure soil salinity. The EM38 meter provides two soil salinity readings; a horizontal (0-0.6m) and a vertical (0-1.2m), depending on whether the meter is placed on the soil in a horizontal or a vertical position. EM38 readings are dependent on soil moisture, texture and temperature. Readings were converted to dS/m using the equation in McKenzie, Chomistek and Clark (1989). Conversions were based on estimated soil temperature of 5°C, medium textured soils, and <30% available moisture (Walker 1997). [4]One horizontal and one vertical measurement were taken approximately 300 cm east of each quadrat in blocks A1, A2 and B3, and 300 cm north of each quadrat in blocks C4 and C5 (Appendix Table A-7). In addition, extra

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[4] Horizontal mode: $y=0.047x-.0.63$. Vertical mode: $y=0.043x-0.17$. Temperature correction factor for $5^{o}C = 1.6$.

measurements were taken at selected points of high variability (determined by obvious changes in vegetation and soil structure) within each treatment.

2.3.10 Statistical Analyses

Data were analyzed using a General Linear Model (GLM). Data were transformed prior to analyses to minimize the variances and normalize the data. A transformation was chosen if: it did not significantly alter the order of the data, decreased the range of variances, resulted in a residual/predicted plot with a less discernible pattern than that done with untransformed data, and improved the ability of the model to account for the variability in the data (1- (error sum of squares/total sum of squares)).

Percent species composition was re-expressed with an arcsine square-root transformation. Density, relative density (plant density/pure live seeds), and relative size (percent of species composition/plant density) were re-expressed with square root transformations. Variances were improved, but still high following re-expression. Germination data were not transformed.

Relative density (plant density/PLS using field germination rates) is the proportion of the planted seed that actually established. It was calculated as a proportion of the seed planted to account for the differences in seeding rates of the various species. Relative size (percent species composition/plant density) is an estimate of the size of each species based on the proportion of the total biomass contributed by it. The proportion was divided by the number of plants to account for the differences in seeding rate and establishment for the various species. The total mean for relative size was calculated on the actual data points rather than the number of plots, as it was meaningless to average relative sizes of 0. Field germination was used to calculate PLS because laboratory germination rates were not available.

Repeated Measure ANOVAs were done for individual species to compare 1994 and 1995 data. ANOVAs were done on relative size and relative density to compare species. Relative size and relative density were analyzed by ANOVAs with salinity as a random, continuous variable, and block as a fixed, discrete variable. Significance ($p<=0.1$) was determined by Fisher's protected LSD test.

Several species, *Poa palustris, Penstemon procerus,* and *Achillea millefolium* were present in the seed bank, and grew in all treatments whether they were seeded or not. As a result, the relative density appeared significantly higher than the initial seeding rates would indicate. A mean of all treatments which had not been seeded with *P. palustris, P. procerus* and *A. millefolium* was calculated, and subtracted from each data point of all seeded treatments prior to analysis. Negative values were recorded as zeros.

The variation in soil salinity enabled me to test salt resistance for several of the abundant species. Linear regressions were performed on the second year relative densities and sizes against the electrical conductance as measured by the EM38 meter in 1995.

2.4 Results and Discussion

2.4.1 Field Germination

Bromus anomalus had the highest field germination rate at 42%. The next group of species had germination rates between 30 and 40%: *Bromus ciliatus* at 34%, *Poa palustris* at 31%, and *Oxytropis deflexa* at 30%. *Koeleria macrantha, Festuca hallii, Rumex occidentalis, Stipa comata, Oxytropis splendens, Agropyron trachycaulum, and Liatris ligulistylis* all had germination rates between 20 and 30% (Figure 2-1, Table 2-1).

P. procerus' field germination rate was zero, but the germination in the research plots was very high resulting in high relative densities, even after accounting for the natural seed bank. The low field germination may have been due to the presence of glue in the fibreglass tape (P. procerus seedlings are very small and were well embeded in the glue) or they may be very slow to germinate, especially in the absence of stratification (Smreciu, Currah and Toop 1988). *Erigeron glabellus* and *Anemone multifida* had germination and establishment rates of zero, likely as a result of old seed (1984).

Germination rates might have been improved by stratifying seed prior to seeding (Currah, Smreciu and Van Dyk 1983). Smreciu, Currah and Toop (1988) reported that stratification improved the germination rates of *Achillea millefolium* from a range of 16 to 50% for untreated seeds to 59 to 96% for treated seeds.

Currah, Smreciu and Van Dyk (1983) reported that stratification of *P. procerus* improved germination from 4 to 7% to 50 to 96%, although later work by Smreciu, Currah and Toop (1988) reported that stratification simply decreased the time for germination. The germination rates of *Monarda fistulosa* were not significantly improved. Stratification is a useful technique to use for small amounts of seed, when seed is very expensive, for species with very high dormancy rates, or when rapid germination is required.

2.4.2 Relative Density (Density/PLS using Field Germination Rates)

Achillea millefolium and *Penstemon procerus* had the highest second year relative density of any of the trial species, at 3.6 and 2.4, respectively (Figure 2-2, Table 2-2) while *Agropyron trachycaulum/ subsecundum* had a relative density of 1.3. The high relative density may be due to delayed germination, or perhaps may be due to problems encountered during the field germination tests.

Medicago sativa, Festuca rubra, and *Bromus ciliatus,* had relative densities around 1 and were not statistically different from each other or from those species with low relative densities. *Anemone multifida, Bouteloua gracilis, Erigeron glabellus, Stipa comata, S. curtiseta, Oxytropis splendens, Koeleria macrantha,* and *Festuca ovina* had extremely low relative densities, not significantly different than 0.

2.4.3 Plant Density and Survival

There were significantly more plants *of Achillea millefolium, Festuca rubra, Agropyron dasystachyum, A. riparian* and *A. trachycaulum/subsecundum* in 1995 than in 1994 (Figure 2-3, Table 2-3). The second season seedlings *of F. rubra, Agropyron dasystachyum, A. riparian, A. trachycaulum* and *subsecundum, and Achillea millefolium* may actually be rhizomatous shoots rather than seedlings or they may be the result of seed dormancy which prevented all seed from germinating the first year. In the case of *A. millefolium* and *A trachycaulum/subsecundum*, second season germination may have been due to wind blown seed from the surrounding vegetation where both species were prevalent (Appendix Table A-4).

A number of species, *Festuca hallii, Koeleria macrantha, Oenothera biennis, Poa palustris, Rumex occidentalis, Stipa curtiseta*, and *S. viridula*, had fewer seedlings in 1995 than in 1994, indicating a die-off had occurred between survey dates. The winter of 1994/95 was very cold, and the spring in 1995 was cooler and drier than normal, so the die-off may have been due to winterkill or spring drought. *Bouteloua gracilis* and *Stipa comata* were not observed in the quadrats in the second year. *B. gracilis* is a C4 grass that reaches the northern edge of its near the study area, and S. comata only appears in disjunct prairie areas north of the study area (Moss 1983). Their inability to compete in a cool wet year is not, therefore, surprising. *Oxytropis splendens* was present in discrete patches in 1994, but only one plant was recorded in a quadrat in 1995.

2.4.4 Relative Size (Percent Species Composition/Plant Density)

By 1995, the largest plants were *Rumex occidentalis* (16%), *Oenothera biennis* (12%), *Medicago sativa* (10%) and *Oxytropis splendens* (10%) (Figure 2-4, Table 2-4). There was only one *O. splendens* plant by 1995, but this plant accounted for 10% of the species composition in that quadrat. *Agropyron trachycaulum* and *A. subsecundum* (combined), *Bromus anomalus, Poa palustris, Stipa viridula, Bromus ciliatus*, and *Achillea millefolium* each accounted for 5 to 10% of the species composition.

2.4.5 Soil Salinity

The results of the soil analyses showed that soil conditions at the PARI farm were extremely variable (Appendix Table A-6). The soils in blocks A1, A2, and B3 were Orthic and Eluviated Black Chernozems with some Solonetzic Black Chernozems in A2 and B3. The soils in blocks C4 and C5 were highly variable with Solonetzic Black Chernozems, Solodized Solonetz, and Humic Luvic Gleysols (Appendix Table A-3) (Pedocan Land Evaluation Ltd. 1993; Walker 1993). Block C5 had the highest levels of soil salinity, sodium, and SAR with a mean electrical conductivity of 3.43 dS/m(horizontal reading) ranging from 0.9 to 11.8 dS/m in 1995 (horizontal) (Appendix Table A-7). Block C4 EC ranged from 0.2 to 8.7 dS/m (horizontal). Changes in vegetation were evident at 3.4 dS/m. 3 dS/ to 4 dS/m is considered moderately saline while 10 dS/m is very saline (Walker pers. comm.). This variability in salinity significantly affected plant growth and may have been partially responsible for the large influence of the blocks (Appendix Table A-10).

Where salt concentrations were high, several species did relatively well. Linear regressions of the relative densities of *A. millefolium, M. sativa, A. dasystachyum,* and *P. procerus* indicate that they are somewhat resistant to salt during the establishment phase, while *F. hallii* is intolerant to salt. Linear regressions of the relative sizes of A. *trachycaulum/subsecundum* indicate that it is somewhat tolerant to salt, while *A. dasystachyum* and *Oxytropis deflexa* are intolerant. These analyses indicate trends only, as the linear regressions fit the data poorly.

Other species such as *Agropyron smithii and A. elongatum* are reported to be very salt tolerant (Hardy 1989; Wark et al. 1994; Nernberg 1994; Gerling et al. 1996; Abouguendia 1995; Baldridge and Lohmiller 1990); however they did not appear so in this research possibly due to different soil moisture levels during germination and establishment.

2.4.6 Species Summary

The relative density and size of *Agropyron trachycaulum/subsecundum* were very high, indicating that they are successful early successional species and an early maturing, large plant. *Bromus anomalus* had a moderate relative density, and large relative size, due to its fast growth and early maturity; in fact it set seed in the second growing season. *B. anomalus* is reputed to have a high germination rate and short life span (5 to 7 years) (Tannas pers. comm.) and if true, can be considered an early successional species. *Achillea millefolium* and *Penstemon procerus* had high relative densities and medium and low relative sizes, indicating early successional species, but *A. millefolium* is late maturing, and *P. procerus* is relatively small. *P. procerus* also appears to be somewhat salt tolerant during the establishment phase.

Rumex occidentalis and *Oenothera biennis* had moderate relative densities, but very high relative sizes. *R. occidentalis* is a large, broad-leaved plant and is often classified as a weed. The second year size might have been even higher than the 16% recorded in 1995, but heavy, selective spring grazing by deer in blocks C4 and C5 delayed spring growth. *O. biennis* is a biennial with a low rosette of leaves. It was easily out competed, but grew very well in sites with low competition. Both plants have low but broad profiles, providing good ground cover to limit soil erosion. *Oxytropis splendens* had a low and very spotty establishment, but growth was very good for the one plant measured in 1995, and appeared moderate to good for the plants that established outside the permanent quadrats.

Species with high relative densities (around 100%) and high relative sizes (between 7 and 10%) were *Bromus ciliatus* and *Medicago sativa.* These species established well and provided good cover in a short period of time. The majority of the other species varied in relative densities and relative sizes, and could not be statistically distinguished from one another.

Species that had low relative densities, small relative sizes and poor survival were: *Bouteloua gracilis, Erigeron glabellus, Anemone multifida,* (all of which failed to establish), *Festuca ovina, Koeleria macrantha, Oxytropis splendens,* and *Stipa comata. Bouteloua gracilis* is a C4 grass, and is not well adapted to the aspen parkland, but rather to the hot dry summers of the mixed grass prairie. If weather conditions had been hotter and drier it might have persisted. *Erigeron glabellus* and *Anemone multifida* were from old seed collections (1984) which may explain their low germination rates. *Festuca ovina, Koeleria macrantha,* and *Stipa comata* are mid to late successional species and slow to establish.

2.5 Conclusions

I examined the germination, relative density and size, and survival of 23 species. Several of these species show promise for future use in reclamation, in particular, *Bromus anomalus*, and several forbs. *B. anomalus*, *Rumex occidentalis,* and *Oenothera biennis,* could be valuable in the early stages of succession, providing fast growth and good cover. *B. anomalus* may be useful as a short term cover crop, providing erosion control for several years while slower growing species fill in. It's reputed short lifespan of 5-7 years (Tannas 1993) should be confirmed. *R. occidentalis*, with its apparent palatability for deer and its low rosette structure, may be useful for wildlife habitat and erosion control. *O. biennis* may be useful for erosion control in areas where competition is limited. Optimal growing conditions and seeding rates for *O. biennis* should be investigated. *Achillea millefolium* and *Penstemon procerus* appear to be somewhat slower growing, but *A. millefolium's* tolerance to grazing and mowing, and its rhizomatous growth may prove useful in reclamation projects where palatability is not a desired characteristic such as roadside reclamation. *P. procerus* appears to be somewhat salt tolerant and may be useful in saline soils. Further study needs to be done to confirm its tolerance range.

Figure 2-1 Field Germination of Selected Species in 1994

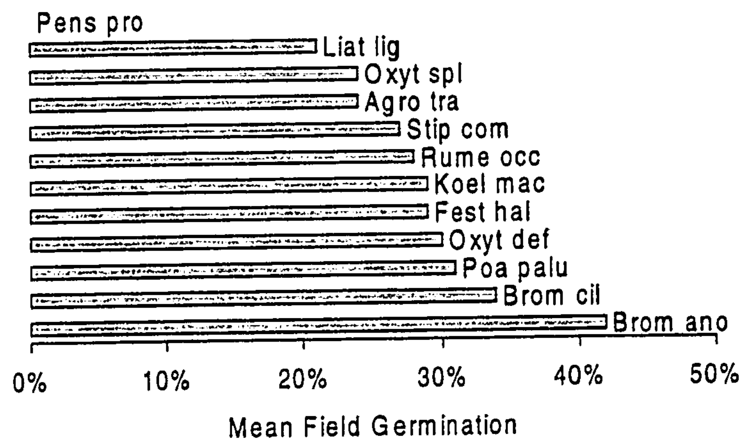

Figure 2-2 Relative Density of Selected Species in 1995

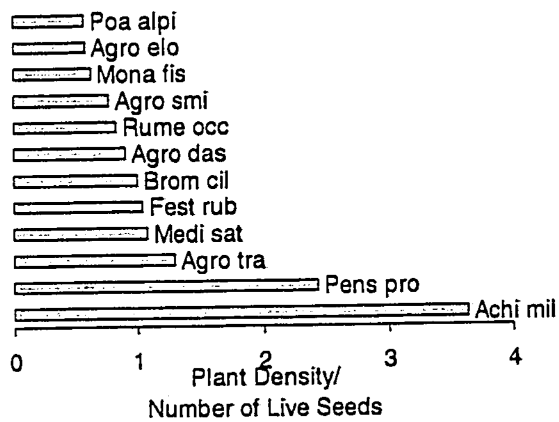

Figure 2-3 Seedling Survival

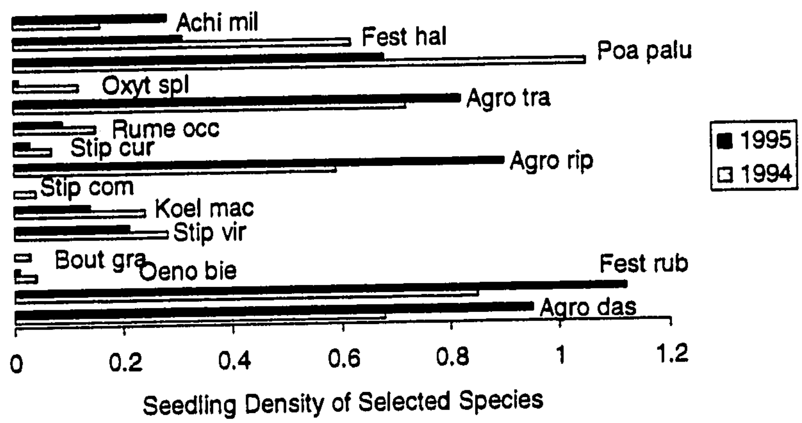

Figure 2-4 Relative Size of Selected Species in 1995

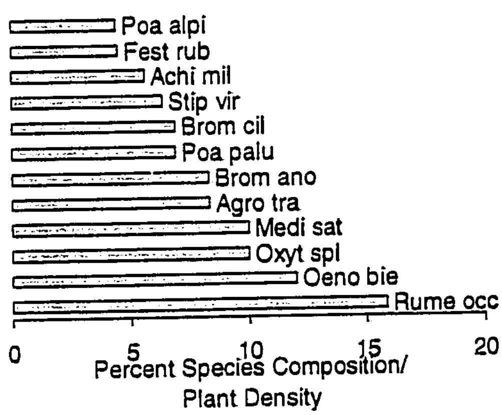

Table 2-1 Field Germination of Selected Species in 1994

	Mean	Sig.	SD
Bromus anomalus	0.42	a	50%
Bromus ciliatus	0.34	ab	48%
Poa palustris	0.31	bc	47%
Oxytropis deflexa	0.30	bc	46%
Festuca hallii	0.29	bcd	46%
Koeleria macrantha	0.29	bcd	46%
Rumex occidentalis	0.28	bcd	45%
Stipa comata	0.27	bcd	44%
Agropyron trachycaulum	0.24	cde	43%
Oxytropis splendens	0.24	cde	43%
Liatris ligulistylus	0.21	def	41%
Agropyron smithii	0.17	efg	37%
Achillea millefolium	0.17	efgh	37%
Oenothera biennis	0.12	fghi	33%
Stipa viridula	0.12	fghi	33%
Astragalus bisulcatus	0.09	ghij	29%
Stipa curtiseta	0.08	hijk	27%
Campanula rotundifolia	0.07	ijk	25%
Calamagrostis inexpansa	0.06	ijk	23%
Aster laevis	0.04	ijk	21%
Erigeron glabellus	0.01	jk	11%
Penstemon procerus	0.00	jk	0%
Anemone multifida	0.00	k	0%

Means within a column followed by different letters are significantly different. P<=0.01.
Field Germination is based on 3 replicates of 30 seeds.
Sig. = significance. SD = standard deviation.

Table 2-2 Relative Density of Seeded Species in 1994 and 1995

		1994			1995		
	N	Mean	Sig.	SD	Mean	Sig.	SD
Achillea millefolium	200	1.79	ab	1.67	3.63	a	3.31
Penstemon procerus	100	3.06	a	4.42	2.42	b	2.74
& A. subsecundum	500	1.07	bc	0.65	1.29	bc	0.80
Medicago sativa	50	0.67	cde	0.96	1.08	bcd	1.30
Festuca rubra	50	0.81	bcd	0.46	1.04	bcd	0.32
Bromus ciliatus	100	0.67	cde	0.65	1.00	bcd	1.92
Agropyron dasystachyum	50	0.52	cde	0.34	0.90	bcd	0.51
Rumex occidentalis	100	1.35	bc	1.36	0.83	cd	1.10
Agropyron smithii	500	0.53	cde	0.45	0.78	cd	0.69
Monarda fistulosa	200	1.13	bc	2.50	0.63	cd	2.28
Agropyron elongatum	50	0.29	de	0.20	0.59	cd	0.61
Poa alpina	50	0.76	bcd	0.76	0.58	cd	0.49
Agropyron riparian	50	0.26	de	0.15	0.57	cd	0.32
Poa palustris	100	0.71	bcde	0.44	0.36	de	0.33
Stipa viridula	200	0.50	cde	0.42	0.35	de	0.33
Oenothera biennis	200	1.03	bc	2.43	0.33	de	1.03
Festuca campestris	50	0.14	de	0.11	0.27	de	0.16
Bromus anomalus	400	0.28	de	0.14	0.25	de	0.14
Oxytropis deflexa	100	0.39	de	0.47	0.22	de	0.43
Festuca hallii	400	0.55	cde	0.38	0.21	de	0.19
Festuca ovina	50	0.25	de	0.24	0.14	def	0.08
Koeleria macrantha	150	0.17	de	0.24	0.10	ef	0.12
Oxytropis splendens	100	0.88	bcd	1.05	0.06	f	0.19
Stipa curtiseta	400	0.02	e	0.04	0.01	f	0.03
Stipa comata	100	0.06	e	0.08	0.00	f	0.00
Bouteloua gracilis	100	0.75	bcde	1.69	0.00	f	0.00
Erigeron glabellus	200	0.00	e		0.00	f	0.00
Anemone multifida	200	0.00	e		0.00	f	0.00

Relative Density = Plant Density/Number of Live Seeds (using field germination rates).
Means within a column followed by different letters are significantly different. P<=0.01.
N = number of quadrats seeded with species x. Sig. = significance. SD = standard deviation.

Table 2-3 Seedling Density and Survival in 1994 and 1995

		Seedling Density 1994		**Seedling Density** 1995		**Survival** Repeated
	N	Mean	SD	Mean	SD	Measure
Bromus ciliatus	100	0.12	0.34	0.13	0.51	p=0.9319
Bromus anomalus	400	0.89	0.85	0.88	0.77	p=0.6911
Penstemon procerus	100	0.46	0.87	0.41	0.81	p=0.5519
Poa alpina	50	0.65	0.89	0.56	0.79	p=0.4657
Medicago sativa	50	0.12	0.38	0.19	0.48	p=0.3066
Festuca campestris	50	0.32	0.51	0.45	0.70	p=0.2895
Monarda fistulosa	200	0.03	0.17	0.01	0.12	p=0.2551
Agropyron intermedium	50	0.12	0.33	0.22	0.44	p=0.1519
Agropyron smithii	500	0.24	0.47	0.28	0.57	p=0.1299
Oxytropis deflexa	100	0.13	0.41	0.08	0.37	p=0.1264
Festuca ovina	50	0.53	0.71	0.35	0.57	p=0.1064
Agropyron dasystachyum	50	0.68	0.72	0.95	0.89	p=0.0973
Festuca rubra	50	0.85	0.94	1.12	0.89	p=0.0967
Oenothera biennis	200	0.04	0.20	0.01	0.10	p=0.0871
Bouteloua gracilis	100	0.03	0.17	0.00	0.00	p=0.0832
Stipa viridula	200	0.28	0.52	0.21	0.46	p=0.0551
Koeleria macrantha	150	0.24	0.57	0.14	0.43	p=0.053
Stipa comata	100	0.04	0.20	0.00	0.00	p=0.0449
Agropyron riparian	50	0.59	0.63	0.90	0.91	p=0.0348
Stipa curtiseta	400	0.07	0.27	0.03	0.20	p=0.0326
Rumex occidentalis	100	0.15	0.40	0.09	0.33	p=0.0147
and subsecundum	500	0.72	0.73	0.82	0.74	p=0.0021
Oxytropis splendens	100	0.12	0.33	0.01	0.00	p=0.0008
Poa palustris	100	1.05	1.02	0.68	0.79	p=0.0002
Festuca hallii	400	0.62	0.84	0.31	0.57	p<=0.0001
Achillea millefolium	200	0.16	0.38	0.28	0.54	p<=0.0001

Survival = the change in the Number of Seedlings (Plant Density) between 1994 and 1995).
A significant increase in seedlings may indicate delayed germination.
A significant decrease in seedlings may be due to winterkill or susceptibility to spring droughts
N = number of quadrats seeded with species x. Sig. = significance. SD = standard deviation.

Table 2-4 Relative Size of Seeded Species in 1994 and 1995

		1994			1995		
	N	Mean	Sig.	SD	Mean	Sig.	SD
Rumex occidentalis	100	24.83	a	14.67	15.83	a	2.46
Oenothera biennis	200	2.71	cdef	4.65	12.00	ab	8.49
Oxytropis splendens	100	0.59	f	0.50	10.00	abc	0.00
Medicago sativa	50	8.07	b	0.38	10.00	bc	7.21
A. subsecundum	500	4.16	cde	5.10	8.35	c	3.93
Bromus anomalus	400	4.69	cd	5.76	8.31	c	4.32
Poa palustris	100	2.25	ef	2.12	6.91	cd	7.25
Bromus ciliatus	100	5.25	bcd	3.86	6.89	cd	6.35
Stipa viridula	200	3.66	cde	3.34	6.35	cd	3.50
Achillea millefolium	200	4.01	cde	3.21	5.62	d	4.59
Festuca rubra	50	3.63	cde	2.35	4.52	de	1.24
Poa alpina	50	2.65	def	0.79	4.44	def	3.84
Agropyron elongatum	50	5.13	bc	2.46	3.67	defg	0.78
Festuca ovina	50	2.55	def	0.51	3.54	defg	2.43
Oxytropis deflexa	100	0.70	f	0.30	3.37	defg	2.49
Stipa curtiseta	400	1.98	ef	1.88	3.36	def	2.57
Koeleria macrantha	150	1.79	ef	2.02	2.78	efg	2.00
Agropyron dasystachyum	50	5.15	bcd	4.53	2.43	efgh	0.71
Agropyron smithii	500	2.90	cdef	2.05	2.34	efgh	1.46
Festuca campestris	50	2.74	cdef	0.97	2.33	efgh	0.66
Agropyron riparian	50	2.68	def	0.65	1.95	fgh	0.45
Festuca hallii	400	0.56	f	0.35	1.79	fgh	1.18
Monarda fistulosa	200	0.74	f	0.80	1.30	gh	1.70
Penstemon procerus	100	0.89	f	0.71	1.23	h	1.01
Anemone multifida		0.00	f	0.00	0.00	h	0.00
Bouteloua gracilis	100	0.80	f	0.99	0.00	h	0.00
Erigeron glabellus	200	0.00	f	0.00	0.00	h	0.00
Stipa comata	100	2.25	ef	1.89	0.00	h	0.00

Relative Size = Percent Species Composition/Plant Density.
Means within a column followed by different letters are significantly different. P<=0.01.
Data was transformed with a square-root transformation.
N = number of quadrats seeded with species x. Sig. = significance. SD = standard deviation.

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3 Biodiversity and the Design of Seed Mixes for use in Reclamation

3.1 Introduction

Biodiversity is a concept that is receiving increasing attention from the public, scientists, and policy makers. Most attention has focused on cataloguing the number and rate of species lost, and the implications of decreasing diversity on medicine and food crops. Little attention has been devoted to the theoretical aspects of restoring biodiversity, such as how many species and which species are needed for a fully functioning, self-sustaining ecosystem.

Most reclamation seed mixes consist of half a dozen grass species (often with several in the same genus) and a legume. The species are chosen to fulfill specific abiotic, social, and biotic functions. Seed mixes typically include species adapted to specific abiotic site conditions such as soil water, slope, texture, pH, organic carbon, precipitation, and evaporation. Social factors generally address the intended land use by including plants that are palatable to livestock or resistant to grazing or mowing. Plants are selected for beauty or rarity, or to provide shelter or food for target wildlife species. The cost and the availability of seed is also a factor. Biotic factors are those characteristics which affect the biological activity in the site. Seed mixes often include aggressive, fast establishing grasses to limit soil erosion and weed invasion, legumes to increase soil fertility, and long-lived species to enhance long term sustainability.

Seed mixes are generally designed to achieve a selection of the above goals with the minimum number of species and lowest cost; biodiversity is usually not considered. However, recent research has indicated that species-rich grassland communities are more resistant to invasion (Tilman 1997, Tilman, Lehman and Thomson 1997) and their biomass and nutrient cycling is more stable during changes in weather (Tilman and El Haddi 1992; Tilman and Downing 1994; Frank and McNaughton 1991; Tilman, Wedin and Knops 1996; Tilman 1996). Further research indicates that functional groups (Tilman, et al. 1997) and functional characteristics (Hooper and Vitousek 1997) are even more significant than diversity in ecosystem processes.

3.1.1 Ecosystem Productivity

A wide diversity of species with different combinations of functional characteristics ensures that critical functions are maintained within the community. In a diverse community, the loss of biomass in one or more species can be compensated for by the increased growth of other species better adapted to the new growing conditions (Naeem et al. 1994; Tilman and Downing 1994; Frank and McNaughton 1991; Tilman 1997). A wide diversity of species and characteristics offers the widest selection of species adapted for all possible ecological conditions at that site; drought, fire, flood, no snow cover, heavy grazing, or all of them together. Functional characteristics such as method and speed of reproduction, phenology, growth, adaptations to environmental conditions, physiology, and ecosystem dynamics (Table 3-1) may all play important roles in ecosystem productivity.

3.1.2 Community Invasibility

It is generally accepted that islands are more easily invaded because of their small number of species (MacArthur and Wilson 1967). Computer modeling by Case (1990) showed that colonization success for invaders decreased with increasing community size and structure. This has recently been verified through field experiments by Tilman (1997) who showed that species rich sites in grassland communities were more resistant to invasion by native species than were less diverse sites. Although invasion was strongly dependent on dispersal, establishment differed significantly among functional groups, favoring legumes over other forbs and grasses. He suggested "that the new species mainly filled previously empty sites".

Tilman's work was based on established communities. Immature or disturbed communities may be more prone to invasion and to the development of different stable communities depending on the species present at establishment (Drake 1991; Westoby, Walker, and Moy-Meir 1989; McCune and Allen 1984; Drake et al. 1993). Robinson, Quinn and Stanton (1995) found that species rich plots in California winter annual grasslands were more susceptible to invasion by *Eschscholzia californica* than were less rich plots. "Plots that were invaded typically featured higher levels of disturbance, as well as lower levels of dominance, both of which were correlated with local species richness...".

Competition experiments involving species grown in monocrops and in pairs provide information on the relative competitiveness of species within mixtures (Baluta and Kenkel 1996; Samuel and DePuit 1987; Nernberg 1994). This information can be used to design balanced seed mixes where aggressive species are present in minor amounts, allowing less competitive species to coexist. Gill Environmental Consulting (1996) recommends that seed mixes designed for the mixed grass prairie should contain no more than 20% rhizomatous wheatgrasses.

Reclamationists express concern that seed mixes containing large proportions of less aggressive seeds will not establish fast enough or densely enough to control soil erosion and weeds. Clark et al. (1997) have data showing that, contrary to current thought, four diverse seed mixes with high proportions of less competitive grasses and forbs had almost twice the establishment of a seed mix consisting of four wheatgrasses (*Agropyron. dasystachyum, A. trachycaulum, A. smithii, and A. subsecundum*) and *Stipa viridula*. More work is needed to test our assumptions that a small selection of fast establishing and broadly adapted species is more competitive or productive than a diverse mix with a balance of slow and fast establishing species.

3.2 Objectives

The objectives of this research were to:

1) Evaluate seed mixes of varying diversity to determine if the seed mix diversity is maintained or altered during the establishment phase of the plant community.

2) Evaluate the effect of diversity on weeds (undesirable invaders).

3) Evaluate the effect of diversity on cover, density, and species composition.

3.3 Methods and Materials

3.3.1 Site Location

The research plots are on the Parkland Agricultural Research Initiative (PARI) Conservation Demonstration Farm near Mundare, Alberta, 100 km east of Edmonton (NE and SE quarters of Sec 9, T53, R16, W of the 4th meridian). The study area is in the Central Parkland Natural Subregion (Achuff 1994).

Historically, the Central Parkland was a patchwork of *Populus tremuloides* clones and native grassland dominated by *Festuca hallii* with Black and Dark Brown Chernozemic soils (Strong 1992, Achuff 1994). Because of its rich soils and abundant moisture, most of the native grassland has been ploughed for agriculture (Strong 1992).

3.3.2 Climate Data

The 30 year average precipitation (1951 to 1980) was 402.5 mm at the nearest meteorological station at the Vegreville Experimental Farm, 10 km east of the study site (Alberta Agriculture, Food and Rural Development 1997). The average number of degree days >5°C was 1360, and the 30 year average temperature was 1.4°C (Appendix Table A-2).

In 1994 there was a dry early spring with lower than normal rainfalls in March and April (32 and 14% of the 30 year average), but higher than normal rainfalls in May and June (136 and 137% of the 30 year average) and in August (181% of the 30 year average). The temperatures were slightly warmer in April (by 0.6°C), slightly cooler in June (by 0.9°C), and close to the average for the rest of the growing season.

In 1995, it was drier and cooler than normal, with 87% of the 30 year average precipitation and 1°C cooler. April and June were slightly drier (62 and 35%, respectively) while July and August were wetter (111 and 191%, respectively). The temperatures were cooler by between 1 and 2.8°C in every month except June.

3.3.3 Site Description

The study site was situated in undulating to hummocky terrain with slopes of 2-9%. The soils texture was moderately fine to medium textured, and was predominantly Black Chernozemic (eluviated, and solonetzic) with some depressional areas with Humic Luvic Gleysols, and Black Solodized Solonetzes (Table A-3).

The research sites were tame pasture for 30 or more years prior to 1993. Remnants of pasture around the sloughs and fence lines were dominated by

Bromus inermis and *Poa pratensis* with minor amounts of native forbs and wetland species (Appendix Table A-4).

3.3.4 Seedbed Preparation

Glyphosate was applied at a rate of 3.7 L/ha on July 13, 1993 and the turf was broken on August 16 with a heavy breaking disc. Two more passes were made with a lighter disc, in August and November, and once more in the spring. The north pastures (A and B) were disked again and cultivated once before seeding. The south pasture (C) was cultivated, harrowed, and packed before seeding.

Three sites with five blocks were seeded: blocks A1 and A2 at the northeast site, block B3 at the northwest site and blocks C4 and C5 at the south site (Appendix Figures A-2 and A-3). Blocks A1, A2, C4, and C5 were seeded on May 30. A Kohler 8 cone seed drill was used to drill the large seed. Although the seed was de-awned and cleaned, seed mixes containing *Stipa curtiseta* frequently clogged the tubes. A written record was kept of all passes with clogged tubes.

Small seeds of *Achillea millefolium, Erigeron glabellus, Oenothera biennis, Penstemon procerus, Monarda fistulosa, Bouteloua gracilis, Koeleria macrantha, Poa palustris, Oxytropis deflexa*, and *Oxytropis splendens* were mixed with cornmeal and hand broadcast. The small seeds at Mundare B were sown in front of the drill seeder. Due to heavy rains, blocks A1, A2, C4, and C5 were sown on June 6, one week after drill seeding and were not packed due to wet soil conditions. A light wind during seeding carried some seed away from the targeted areas resulting in uneven patches of the lighter seed.

3.3.5 Seed Mix Design

Ten seed mixes (treatments) were planted; two seed mixes provided by industry (NOVA Gas Transmission Ltd. and Ducks Unlimited) and eight seed mixes designed for this research (Appendix Figure A-1, Table A-5). The seed mixes were designed to test varying levels and types of diversity. Seed mixes 1 and 6 consisted of six grass species. Seed mixes 2, 3, 4, 6, 7, 8, and 9 had the same core species plus; six grasses (mixes 2 and 7) an increase in the species richness; seven forb species (mixes 3 and 8) an increase in the diversity of characteristics and species richness; and five forbs and two legumes (mixes 4 and 9) a change in the diversity of characteristics. These seed mixes were compared to two industry seed mixes, the standards of the day. Seed mix 5, supplied by NOVA Gas Transmission Ltd., consisted of six grass species and one legume, and seed mix 10, supplied by Ducks Unlimited, consisted of nine grass species. All species are native to the Aspen Parkland. The secondary species were seeded in smaller proportions to reflect their proportion in native plant communities and because of the difficulty in acquiring large quantities of seed of most forbs and many grasses.

Oxytropis splendens and *O. deflexa* were scarified by lining a jar with sandpaper and shaking the seed until the seed coat was scuffed. *Stipa comata* and *S. curtiseta* were de-awned by rolling them between a corrugated rubber mat and hand held paddles with corrugated rubber surfaces. Seed was not stratified to avoid too many treatment variables.

The intent of the seeding mix was to have approximately 55 plants per square meter in each treatment at the end of the first growing season. Seeding rates were calculated with Pure Live Seed (PLS) and estimated survival rates. PLS was obtained from the seed certificates for commercial seed, and was estimated for the uncommon native seed. Estimates were based on the weight and germination rates in the literature, and from laboratory research. Survival rates were estimated from published data (Hardy 1989; Wark et al. 1994; Currah, Smreciu and Van Dyk 1983; Thornburg 1979; Gerling et al. 1996; Nernberg 1994). Due to differences in seed size, and inaccurate estimates of germination and survival, the seeding rates varied from a high of 18, 17 and 29 Pure Live Seeds/0.1m^2 for seed mixes 2, 5, and 7 respectively, to a low of 6 PLS/0.1m^2 for seed mix 10.

Scientific nomenclature for plant species follows Moss 1983 (2nd. edition by Packer) with the exception of *Agropyron trachycaulum* and *A. subsecundum* which are considered separate species by the seed industry, and *Festuca campestris* and *F. hallii* (Aiken and Darbyshire 1990). Common names and full scientific names with authorities are included in Appendix Table A-1.

3.3.6 Experimental Design

A completely randomized block design was used, with five blocks consisting of ten treatments (seed mixes) (Appendix Figures A-2, A-3). The blocks were carefully laid out to avoid uneven terrain and depressional areas. Each plot was 9.2 m x 18.3 m. Ten permanent quadrats (0.1 m^2) were established in each plot and marked with four 15 cm nails and washers. The quadrat locations were randomly chosen; however, rows in which the seed drill clogged were avoided.

3.3.7 Vegetation Measurements

Canopy and ground cover, density, and plant species composition were determined in August 1994 and 1995 in the 0.1 m^2 quadrats. Ground and canopy cover (% bare ground, litter, and live vegetation) were estimated visually and taken as the percent of ground area covered by a vertical projection to the ground surface. Cover estimates always total 100%. Plant density was a direct count of seeded and weeds. Percent species composition was estimated visually as a percent of the total biomass that was contributed by each species. Percentage was estimated for the dominant plants first, minor plants last, and always totaled 100%.

Identification was considered accurate to species with the exception of *Festuca* species in the NOVA mix and *Agropyron* species in all seed mixes. Data for *Agropyron trachycaulum* and *A. subsecundum* were combined for analysis.

3.3.8 Soil Measurements and Analyses

On June 24, 1994, three soil cores from each plot were taken, combined and sent to a lab for analysis. Electrical conductivity (EC), sodium adsorption ratio (SAR), Ca, Mg, Na, Organic Carbon, and pH values were obtained for 0 to 15 cm and 30 to 45 cm depths on each plot (Appendix Table A-6) (Carter 1993). This data was collected to provide baseline data for further research at this site.

In July 1995, an electromagnetic inductance meter (EM38) developed by Geonics of Canada was used to measure soil salinity. The EM38 meter provides two soil salinity readings; a horizontal (0-0.6m) and a vertical (0-1.2m), depending on whether the meter is placed on the soil in a horizontal or a vertical position. EM38 readings are dependent on soil moisture, texture and temperature. Readings were converted to dS/m using the equation in McKenzie, Chomistek and Clark (1989). Conversions were based on estimated soil temperature of 5°C, medium textured soils, and <30% available moisture (Walker 1997). [5]One horizontal and one vertical measurement were taken approximately 300 cm east of each quadrat in blocks A1, A2 and B3, and 300 cm north of each quadrat in blocks C4 and C5 (Appendix Table A-7). In addition, extra measurements were taken at selected points of high variability (determined by obvious changes in vegetation and soil structure) within each treatment.

3.3.9 Statistical Analyses

Data were analyzed using a General Linear Model (GLM). Data were transformed prior to analyses to minimize the variances and normalize the data. A transformation was chosen if it did not alter the order of the data, decreased the range of variances, resulted in a residual/predicted plot with a less discernible pattern than that done with untransformed data, and improved the ability of the model to account for the variability in the data (1- (error sum of squares/total sum of squares)). Measurements expressed in percentages were re-expressed with an arcsine square root transformation. Measurements expressed in simple numbers or proportions were re-expressed with a square root transformation.

Data were analyzed with treatment as a fixed, discrete factor and with block as a random discrete factor. The interaction between treatment and block was more effective in explaining the variation, therefore the chosen model was treatment + block + (treatment * block). Salinity and weeds were analyzed independently for treatment and block. Repeated Measures were done to identify differences between 1994 and 1995. Significance ($p=0.1$) was determined by Fisher's protected LSD test.

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[5] Horizontal mode: $y=0.047x-.0.63$. Vertical mode: $y=0.043x-0.17$. Temperature correction factor for 5°C = 1.6.

3.4 Results

3.4.1 Ground Cover

In the first two years, there was a substantial decrease in bare ground in all treatments, from 71 to 11% (Table 3-2). In 1995, treatments 1, 2, 4, and 10 had the highest amount of bare ground, while treatments 5 and 9 had the lowest amount (Figure 3-1). Litter provided the bulk of the ground cover in the second year, increasing from 20 to 74%, but with no significant differences among treatments. Live vegetation only increased from 9 to 15% in the second year. Although treatment 4 had the highest live vegetation in 1995, it was also extremely variable, and therefore not significantly different from the other treatments.

3.4.2 Canopy Cover

Canopy cover exhibited a similar pattern to ground cover, with bare ground decreasing slightly and litter increasing between 1994 and 1995 (Table 3-3). There was a small, but biologically insignificant difference (5%) among treatments for bare ground (Figure 3-2). Litter increased from 5 to 15% in the second year; treatments 2, 7, and 8 had the highest amounts of litter in 1995. There was a slight but statistically insignificant decrease in live vegetation in the second year.

3.4.3 Percent Seeded Species in the Species Composition

A clear pattern was evident in the percentage of seeded plants in the total species composition (Figure 3-3, Table 3-4). The proportion of the total biomass that was contributed by the seeded species increased from 15% in 1994 to 28% in 1995 reflecting moderate but continued growth. This was in spite of a significant decrease in the proportion of seeded plants, from 0.23 to 0.11 (Figure 3-4) , indicating that although there were comparatively fewer plants, the seeded plants were more robust in 1995. Treatments 2, 7 (and 5 in 1994) had the greatest percentage both years, although the difference was not significant in 1994.

3.4.4 Density and Richness of the Seeded Species

The diversity of the first and second year communities was significantly lower than that of the initial seed mixes (Figure 3-5, Table 3-4). There were no significant changes in the seeded richness or density between 1994 and 1995 indicating that the established plants over-wintered well although there was some loss in certain species (see chapter 2). The highest richness and proportion of seeded plants in 1995 was in treatments 2, 5, and 7.

3.4.5 Soil Salinity

The results of the soil analyses showed that soil conditions at the PARI farm were extremely variable (Appendix Table A-6). The soils in blocks A1, A2, and B3 were Orthic and Eluviated Black Chernozems with some Solonetzic Black Chernozems in A2 and B3. The soils in blocks C4 and C5 were highly variable with Solonetzic Black Chernozems, Solodized Solonetz, and Humic Luvic Gleysols (Appendix Table A-3) (Pedocan Land Evaluation Ltd. 1993; Walker 1993). Block C5 had the highest levels of soil salinity, sodium, and SAR with a mean electrical conductivity of 3.43 dS/m(horizontal reading) ranging from 0.9 to 11.8 dS/m in 1995 (horizontal) (Appendix Table A-7). Block C4 EC ranged from 0.2 to 8.7 dS/m (horizontal). Changes in vegetation were evident at 3.4 dS/m. Soil is considered moderately saline at 3 dS/ to 4 dS/m while 10 dS/m is very saline (Walker 1997). This variability in salinity significantly affected plant growth and may have been partially responsible for the large influence of the blocks (Appendix Table A-10)

3.4.6 Density and Richness of Weed Species

The weed richness (number of weed species) in each treatment was unchanged between 1994 and 1995 (Figure 3-6, Table 3-5) and there was no difference among the treatments. However, this does not reflect the shift in density or species between the two years. In 1994 two treatments; 6 and 9, had the highest number of weeds. This was not a result of seed mix diversity, as treatment 6 had 6 species, while treatment 9 had 13 species. In 1995 there were no differences between plots.

The number of weeds changed dramatically between 1994 and 1995. In 1994 the mean number of weeds was $17/0.1m^2$, while in 1995 the mean number of weeds was $110/0.1m^2$ with an extremely high variance among treatments. The spring of 1995 was dry and few seeds germinated until after heavy July rains. Data collection began two weeks after the rain, just as a flush of weeds germinated. Some plots had as high as 1000 weed seedlings in $0.1\ m^2$, however, they rarely comprised more than 10% of the total species composition.

3.4.7 Weeds and Their Effects on Community Composition

In both 1994 and 1995, several *weeds (Chenopodium album, Crepis tectorum, Bromus inermis, Polygonum convolvulus*, and *Potentilla norvegica* in 1994, and *Agrostis scabra, Bromus inermis, Cirsium arvense, Poa pratensis*, and *Potentilla norvegica* in 1995) varied significantly among blocks, obscuring treatment differences (Appendix Table A-10).

Some of these weeds had a significant effect on the establishment of the seeded species. In 1994 several plots in block C4 had such a high canopy cover of *Polygonum convolvulus*, an aggressively spreading decumbent annual, that many of the seeded species were eliminated by midsummer. In 1995 *P. convolvulus* was replaced by the slower growing *Artemisia frigida*, a native perennial. The seeded species that survived 1994, grew without any competition in the early spring of 1995 and by midsummer their stature and vigour exceeded those in any other plots. As a result, the number of seeded plants and seeded richness were lowest in block C4 in 1994 and 1995, but the percentage of seeded species in the total species composition was moderately high.

Cirsium arvense was a serious problem in blocks A1, A2 and to a lesser extent, B3 and C4. *Cirsium arvense* is designated as a noxious weed in Alberta (Alberta Government 1990) and as such, control is legally required. In addition, because of its perennial, aggressive nature, it was unlikely to be out-competed by the native species, and could potentially dominate the site if left unchecked. Several methods of control were attempted (wick applications of Glyphosate, hand-pulling, hand-cutting), however, because of difficulties with staff and time, only some thistles were pulled prior to data collection contributing to the variability in results.

3.5 Discussion

3.5.1 Site Variability

The soil types, salinity, and number and species of weeds on the PARI farm were extremely variable. This variability meant that the blocks were more significant than treatments and the treatment*block interactions for all measures of ground cover, canopy litter, canopy live vegetation, % species composition, weed richness, and weed density (Appendix Table A-10). The only measure in which treatment was more significant than block was canopy bare ground, however I could find no correlation with diversity or with seeding rate.

3.5.2 Immaturity of the Plant Community

The immaturity of the plant community limits the conclusions of this research to the effects of early successional species. Fast growing species such as *Agropyron trachycaulum, A. subsecundum, Bromus anomalus,* and *Rumex occidentalis* had more influence on the structure and species composition of the community because of their sheer size. Slower growing species such as *Festuca hallii* or *Penstemon procerus* will not exert a similar effect for several years if at all. Stevens (1995) states that three or four years is too short a time line to follow a reclamation project. He has seen examples where native fescues out-competed *Agropyron pectiniforme* and *Elymus junceus* twenty five or thirty years after planting. We need to establish long-term research projects where we can follow the community succession of various seed mixes, and various planting years before we can predict the long-term outcomes.

3.5.3 Characteristics of Individual Species

This research attempted to compare seed mixes with varying levels of diversity. Because the core species were the same in 8 of the 10 seed mixes, the research addressed the additive value of diversity rather than diversity per se. This design assumes that the species that make up the core grass mix do not unduly influence the community composition, and in this case, it is clearly untrue. The growth characteristics of the individual species, especially those in the core mix, and the proportions in which they were seeded had significant effects on the community composition.

The ability of individual species to influence the cover, productivity and richness of a community is well documented (Tilman, et al 1997; Hooper and Vitousek 1997; Gill Environmental Consulting, 1996; Wilson 1989). In this research, species with a high relative density (RD) and a high relative size (RS), such as *Agropyron trachycaulum* (RD = 1.29, RS = 8.35, 1995) or *Medicago sativa* (RD = 1.08, RS = 10, 1995) contributed more to the cover, density, and species composition than did slower growing species such as *Stipa curtiseta* (D = 0.10, RS = 4.27). In addition, treatments 2, 5, and 7 had proportionally more seeds of *Agropyron trachycaulum* and *A. subsecundum* which resulted in high plant density and percent species composition.

3.5.4 Number of Seeds

Each seed mix was designed to have approximately 55 live plants at the end of the first growing season (with the exception of treatments 5 and 10 which were seeded at the recommended industry rate). Once the field germination rate was calculated, it became apparent that the estimates of germination and establishment rates were inaccurate. The result was that treatments 2, 7, and 5 (Table A-5).had significantly higher live seed numbers than the other treatments. Further analyses indicated that the higher seed numbers were primarily responsible for the higher total species composition and number of seeded plants in these three treatments. Increasing the seeding rate commonly results in an increase in productivity and (Stevenson, Bullock and Ward 1995; Depuit and Coenenberg 1979), but further increases may result in a decrease in productivity and diversity (Stevenson, Bullock and Ward 1995; Launchbaugh and Owensby 1979; Walker 1995).

3.6 Conclusion

The diversity of the first and second year plant communities was significantly lower than that of the initial seed mix, however there was no significant difference between 1994 and 1995. There were significant differences in the loss of certain species. *Achillea millefolium, Festuca rubra, Agropyron dasystachyum, A. riparian A. trachycaulum* and *A. subsecundum* increased between 1994 and 1995, while *Festuca hallii, Koeleria macrantha, Oenothera biennis, Poa palustris, Rumex occidentalis, Stipa curtiseta, S. viridula, Bouteloua gracilis and Stipa comata* had fewer seedlings in 1995 (chapter 2).

Treatments 2, 5, and 7 had the highest density of seeded plants, richness, and percent species composition in both years, but this appears to be a result of higher seeding rates and/or the growth of individual species. Seed mix diversity had no effect on the diversity of weeds (richness), or on the number of weeds. The differences between treatments in canopy and ground cover were all under 10% and were not considered biologically significant.

The soil types, salinity, and number and species of weeds on the PARI farm were extremely variable. This variability meant that the difference among blocks was stronger or equivalent to the difference among treatments for all measures except for canopy bare ground.

The results show that the seeding rate, the influence of individual species, and the variable site conditions were more significant than species diversity in the development of the second year community.

Figure 3-1 Ground Cover in 1995

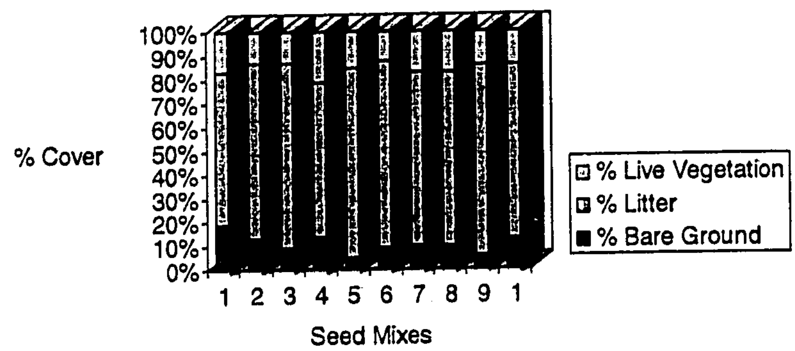
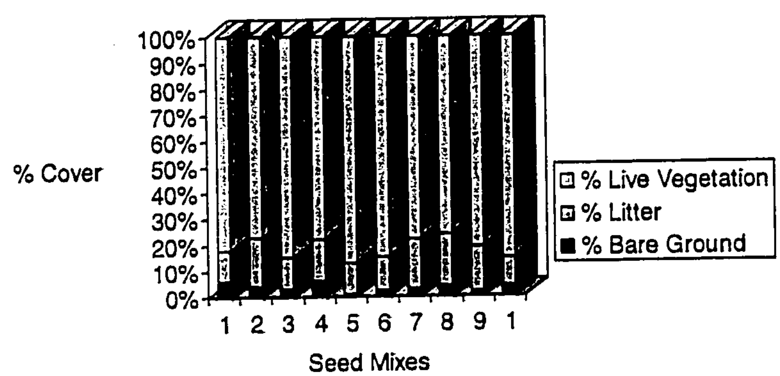


Figure 3-2 Canopy Cover in 1995



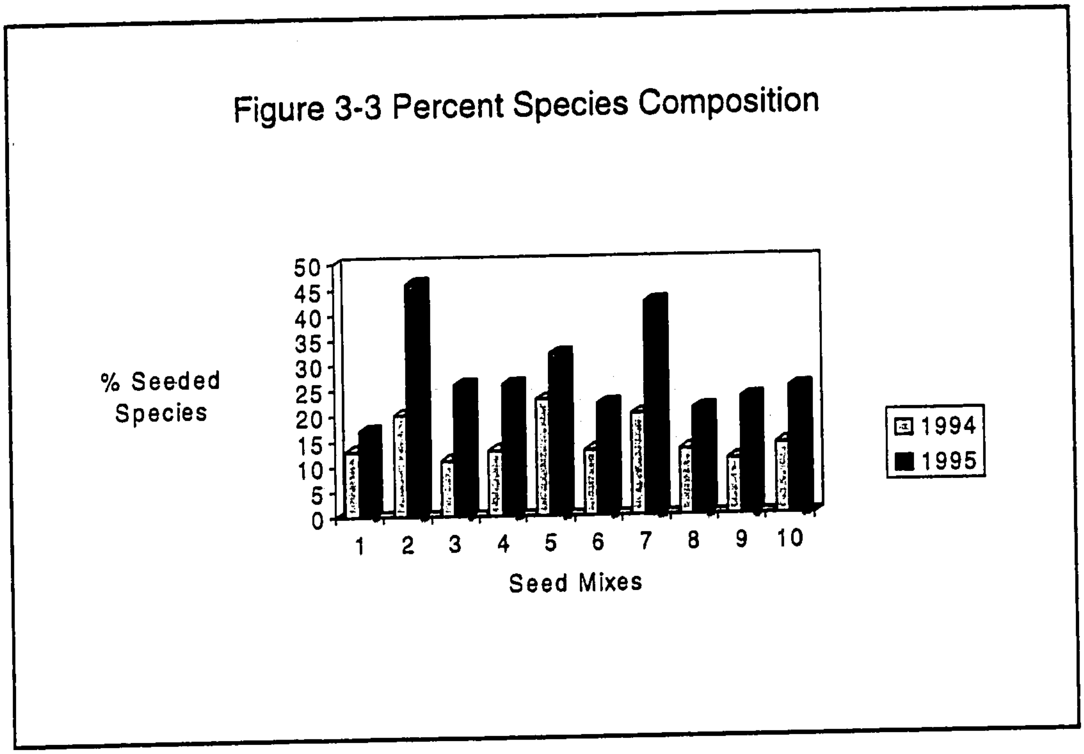


Figure 3-3 Percent Species Composition
% Seeded Species
50
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10
Seed Mixes
1994
1995

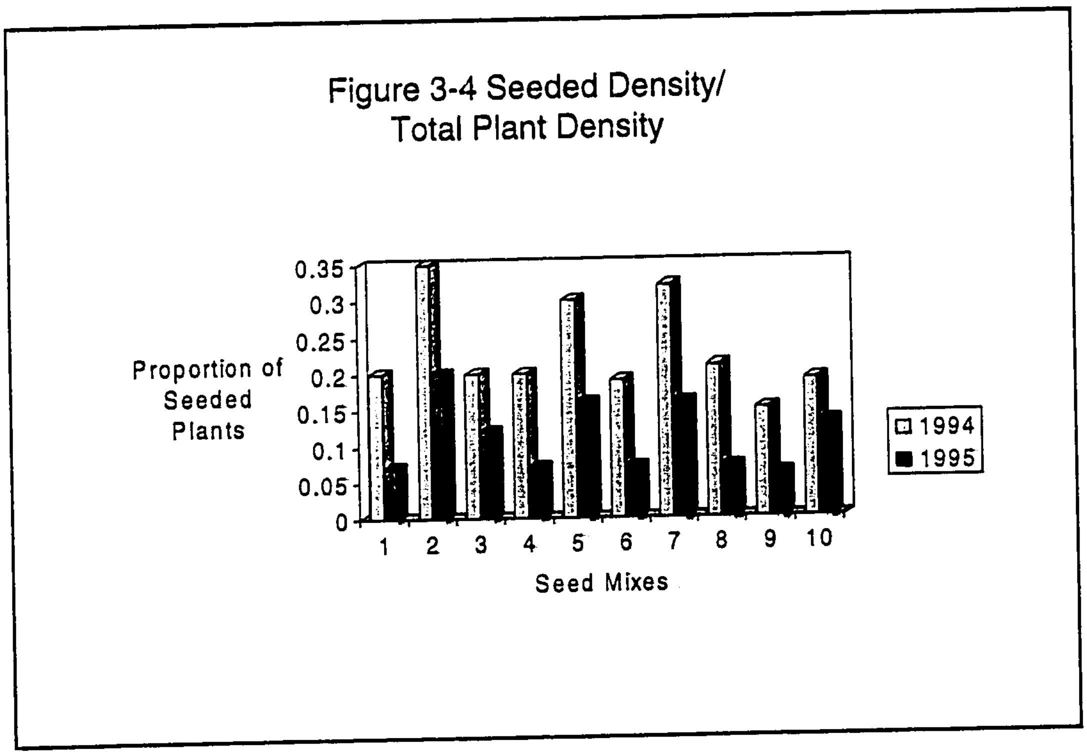


Figure 3-4 Seeded Density/ Total Plant Density
Proportion of Seeded Plants
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10
Seed Mixes
1994
1995

Figure 3-5 Density and Richness of Seeded Species in 1995

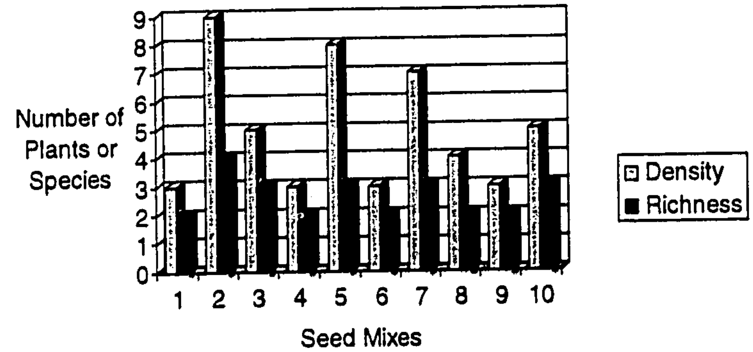


Figure 3-6 Density and Richness of Weed Species

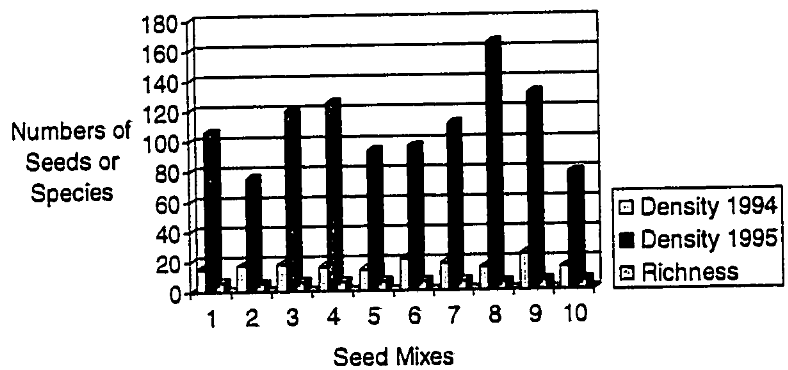


Table 3-1 Functional Characteristics of Species Used in Reclamation

Reproduction

Seed size

Dormancy

Seed longevity

Number of seed produced

Vegetative reproduction

Growth rate

Phenology

Early season flowering

Late season flowering

Early leaf growth

Late season leaf growth

Environmental Conditions

Precipitation range

Soil texture

Soil moisture

Salt tolerant

pH tolerant (acid or base)

Shade tolerant

Fire tolerant

Grazing tolerant

Physiology

N fixing (rhizobial or actinorrhizal)

P fixing (mycorrhizal)

C3, C4 or CAM

Low nutrient tolerant

High nutrient tolerant

Growth Form

Root or underground shoot type

Leaf type

Stem type

Height

Width (cover)

Perennial (short or long lived)

Biennial

Annual

Grass

Forb

Legume

Shrub

Tree

Macrophyte

Evergreen

Litter production

Ecosystem Dynamics

Rare species

Controllers

Keystones

Competitive in early seral stages

Competitive in late seral stages

Table 3-2 Ground Cover (% Bare Ground, Litter, and Live Vegetation) in 1994 and 1995

1994 Trt	% Bare Ground Mean	Sig.	SD	% Litter Mean	Sig.	SD	% Live Vegetation Mean	Sig.	SD
1	70	b	14	21	x	13	9	bcd	5
2	70	b	16	21	x	12	9	bcd	5
3	72	ab	11	19	x	9	9	abcd	5
4	67	b	13	22	x	10	10	ab	7
5	77	a	6	15	x	5	7	cd	3
6	67	b	16	23	x	13	13	a	17
7	72	ab	13	19	x	9	9	abc	5
8	69	b	14	21	x	10	10	ab	6
9	68	b	13	21	x	12	10	ab	4
10	78	a	6	15	x	4	7	d	3
Mean	71	p=0.0503	13	20	p=0.2894	11	9	p=0.0558	7

1995 Trt	% Bare Ground Mean	Sig.	SD	% Litter Mean	Sig.	SD	% Live Vegetation Mean	Sig.	SD
1	19	a	17	64	x	22	17	x	12
2	13	ab	16	74	x	16	13	x	9
3	9	bc	13	78	x	15	13	x	7
4	14	ab	18	65	x	26	21	x	21
5	5	c	4	80	x	8	15	x	7
6	9	bc	11	78	x	12	12	x	6
7	10	bc	11	74	x	18	17	x	12
8	10	bc	13	74	x	15	17	x	11
9	6	c	8	80	x	11	14	x	10
10	13	ab	14	73	x	17	14	x	8
Mean	11	p=.0143	14	74	p=0.3045	18	15	p=0.867	11
Repeated Measure	p<=0.0001			p<=0.0001			p=0.009		
Treatment Repeat	p=0.1423			p=0.5661			p=0.7518		

Means within a column followed by different letters are significantly different.p<=0.01.
Significance was determined with an arcsine square-root transformation.
Displayed data is untransformed.
SD = standard deviation. Sig. = significance.

Table 3-3 Canopy Cover (% Bare Ground, Litter, and Live Vegetation) in 1994 and 1995

1994	% Bare Ground			% Litter			% Live Vegetation		
Trt	Mean	Sig.	SD	Mean	Sig.	SD	Mean	Sig	SD
1	14	a	16	6	x	7	80	de	21
2	6	bc	7	5	x	7	89	abcd	12
3	8	ab	11	4	x	5	86	abcde	19
4	11	ab	14	7	x	10	82	cde	21
5	3	c	5	2	x	2	95	a	6
6	10	ab	14	7	x	9	80	e	24
7	10	ab	15	5	x	5	85	bcde	18
8	6	bc	8	4	x	8	90	ab	14
9	12	a	14	7	x	7	81	de	18
10	6	bc	10	3	x	3	91	abc	12
Mean	9	p=0.0845	12	5	p=0.1392	7	86	p=0.05	18

1995	% Bare Ground			% Litter			% Live Vegetation		
Trt	Mean	Sig.	SD	Mean	Sig.	SD	Mean	Sig	SD
1	6	ab	9	12	b	10	83	ab	15
2	4	abcd	9	19	a	14	77	b	16
3	3	cde	7	12	b	11	84	a	14
4	6	a	11	16	ab	14	77	b	17
5	1	e	2	12	b	12	87	a	13
6	2	cde	3	13	b	14	84	a	15
7	3	cde	4	19	a	13	78	b	15
8	4	bcde	7	20	a	16	76	b	19
9	2	de	4	17	ab	14	81	ab	15
10	4	abc	6	11	b	8	85	a	12
Mean	4	p=0.024	7	15	p=0.0518	13	81	p=0.0921	15
Repeated Measure		p=0.0563			p=0.0048			p=0.1901	
Treatment Repeat		p=0.0669			p=0.0462			p=0.1018	

Means within a column followed by different letters are significantly different. p <= 0.01

Significance was determined with an arcsine square-root transformation.

Displayed data is untransformed.

SD = standard deviation. Sig. = significance.

Table 3-4 Species Composition, Proportion of Seeded Plants, and Seeded Density in 1994 and 1995

1994	% Spp. Comp.			Seeded Density/ Total Plant Density			Seeded Density		
Trt	Mean	Sig.	SD	Mean	Sig.	SD	Mean	Sig.	SD
1	13	x	15	0.2	bc	0.2	4	b	5
2	20	x	18	0.35	a	0.2	9	a	7
3	11	x	14	0.2	bc	0.2	5	b	6
4	13	x	20	0.2	bc	0.2	4	b	4
5	23	x	21	0.3	ab	0.2	7	b	8
6	13	x	13	0.19	bc	0.2	5	b	5
7	20	x	17	0.32	a	0.2	9	a	5
8	13	x	18	0.21	bc	0.2	5	b	5
9	11	x	12	0.15	c	0.1	4	b	5
10	14	x	18	0.19	bc	0.2	3	b	3
Mean	15	p=.2190	17	0.23	p=.0165	0.19	5.5	p=.0092	5.8

1995	% Spp. Comp.			Seeded Density/ Total Plant Density			Seeded Density		
Trt	Mean	Sig.	SD	Mean	Sig.	SD	Mean	Sig.	SD
1	17	d	19	0.07	c	0.1	3	d	3
2	46	a	23	0.2	a	0.2	9	a	5
3	26	cd	24	0.12	bc	0.2	5	c	4
4	26	cd	26	0.07	c	0.1	3	d	3
5	32	bc	20	0.16	ab	0.2	8	a	6
6	22	d	25	0.07	c	0.1	3	d	3
7	42	ab	22	0.16	ab	0.2	7	ab	4
8	21	cd	19	0.07	c	0.1	4	cd	4
9	23	cd	21	0.06	c	0.1	3	cd	3
10	25	cd	19	0.13	b	0.1	5	bc	4
Mean	28	p=0.0026	23	0.11	p=0.0001	0.12	5	p<=0.0001	4
Repeated Measure	p=0.0173			p=0.0241			p=0.7427		
By Treatment	p=0.0177			p=0.0009			p=0.0004		

Means within a column followed by different letters are significantly different. p<=0.01.
Seeded Density/Total Plant Density: Significance was determined with a square-root transform
% Species Composition: Significance was determined with arcsine square-root transformation.
Displayed data is untransformed.
SD = standard deviation. Sig. = significance.

Table 3-5 Species Richness, and Weed Density and Richness in 1994 and 1995

1994	Seeded Richness			Weed Richness			Weed Density		
Trt	Mean	Sig.	SD	Mean	Sig.	SD	Mean	Sig.	SD
1	2	c	2	6	x	2	15	cd	11
2	3	a	2	6	x	3	17	bcd	11
3	3	bc	2	6	x	2	18	bcd	11
4	2	c	2	5	x	2	16	bcd	11
5	3	ab	2	6	x	2	14	d	11
6	2	bc	1	7	x	2	21	ab	14
7	4	a	2	6	x	2	18	abc	9
8	2	bc	2	5	x	2	15	bcd	7
9	2	bc	2	7	x	2	24	a	13
10	2	bc	1	6	x	3	15	cd	9
Mean	2.5	p=0.0251	1.8	6	p=0.1377	2.5	17	p=0.0532	11

1995	Seeded Richness			Weed Richness			Weed Density		
Trt	Mean	Sig.	SD	Mean	Sig.	SD	Mean	Sig.	SD
1	2	de	2	6	x	2	106	x	160
2	4	a	2	5	x	2	75	x	79
3	3	cd	2	6	x	2	120	x	142
4	2	de	1	6	x	2	125	x	144
5	3	ab	2	6	x	2	93	x	109
6	2	e	1	6	x	2	96	x	91
7	3	ab	1	6	x	2	111	x	123
8	2	cd	1	5	x	2	164	x	153
9	2	cde	1	6	x	1	131	x	141
10	3	bc	1	6	x	2	78	x	72
Mean	3	p<=0.0001	2	6	p=0.6923	2	110	p=0.2628	127
Repeated Measure		p=0.6312			p=0.8329			p=0.0330	
By Treatment		p=0.0008			p=0.4384			p=0.2081	

Means within a column followed by different letters are significantly different. p <= 0.01.
Displayed data is untransformed.
SD = standard deviation. Sig. = significance.

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4 Synthesis

4.1 Discussion

4.1.1 The Effects of Species Diversity and Functional Diversity on Community Development

This research project was designed to examine the effects of species diversity and functional diversity on cover, density, species composition, and weed invasion, by limiting the species pool through planned seed mixes. To do this, I designed ten seed mixes with varying numbers of species, varying abundances, and varying functional characteristics.

I attempted to correlate the results with various measures of diversity and heterogeneity (Magurran 1988). I could find no effect of diversity on cover, density, species composition, or weed invasion. This research does not support the hypothesis that diverse plant communities have better cover or are more resistant to weed invasion, nor does it refute it. It does emphasize the importance of other factors, particularly site heterogeneity, seeding rates, and the influence of the individual species on the development of a community.

The following factors influenced the development of the community:

1) The influence of individual species was very strong. Some species such as *Agropyron trachycaulum* and *A. subsecundum* were extremely well adapted and competitive, while others such as *Bouteloua gracilis* were not well adapted for the site, and did not establish. In addition, *A. trachycaulum* and *A. subsecundum* were seeded in higher proportions in treatments 2, 5, and 7, giving them a greater advantage.

2) The strength of community interactions such as competition may be important in the diversity of a community and its resistance to weed invasion. In this case, competitive weeds present in the first year had an enormous effect. *Polygonum convolvulus* altered the community by out-competing most seeded species in the first year. By the second year, *P. convolvulus* had virtually disappeared, and the seed plants that had survived grew with little competition.

By mid season they were extremely large, and the spaces between were filled with a large number of *Artemisia frigida*. The effect of the competition was to significantly alter the species composition in several treatments within one block.

3) The history of community development, including the order that species enter a community, and their proportions, appears to be a critical factor in the composition of a community. The effect of *Polygonum convolvulus* was evident in the second year even though *P. convolvulus* was no longer present.

4) The total number of seeds varied significantly among the treatments. The proportion of seeds of each species, and the number of total seeds in each mix had a significant effect on the results. The seed mixes with the greatest number of seeds (2, 5, and 7) had the greatest percent species composition, seeded density, seeded density/total density, and seeded richness.

5) The site was extremely variable. The soil types, salinity, and weeds were so variable, that the blocks, and the treatment*block interactions were both more significant than the treatments alone.

6) The distribution of *Cirsium arvense* varied among treatments and blocks. Control measures such as Glyphosate applications, cutting, and pulling can be considered disturbances, and were not uniform among the treatments or blocks.

The cumulative result of these factors is that the research was not able to detect treatment differences that may have been due to diversity. However, we learned a great deal about what contributes to community diversity, and how to control the factors in future research.

4.1.2 Factors Influencing Community Diversity

As I wrote this paper, it became evident that the diversity of a community depends on a number of interrelated factors (Figure 4-1).

1) Regional species pool. The regional species pool dictates which species and how many species are available to migrate into a site (Tilman 1997*b*; Cornell and Lawton 1992; and MacArthur and Wilson 1967). In restoration projects it includes the seeded species and those species present in the seed bank, and surrounding landscape. It appears that many communities are not saturated

(Tilman 1997*b*; Cornell and Lawton 1992) and most reclamation mixes have so few species that they do not come close to saturation.

2) Individual species. Individual species are the building blocks of a community. The characteristics of each species; their establishment and growth rates, their competitive ability, and their tolerances to site conditions and disturbance, affect the species composition, structure and the function of the whole community. Aggressive species may dominate a community preventing less competitive species coexisting (Wilson 1989; Gill Environmental Consulting 1996; Romo and Grilz 1990) and certain functional characteristics may be more significant than others (Tilman, et al. 1997; Hooper and Vitousek 1997).

3) Community interactions. Close interactions between species do occur, especially between herbivores and producers, parasites and hosts, and pollinators and flowers, and between competitors (Tilman 1997*a*; Schoener 1983, 1985; Connell 1983*a*, 1983*b*; Sih et al. 1986).

4) Community assembly. The history of community assembly such as the order that species join a community, and the proportion of individuals in each immigration wave can significantly alter the composition of the mature community (Drake et al. 1993; Drake 1991).

5) Site heterogeneity. Variable sites provide more habitats for more species, and may act as refugia where less competitive species can coexist with dominant species (Frank and McNaughton 1991).

6) Disturbance: Disturbance can also provide more niche space for species, by altering the dominance of competitive species, and by opening up new microsites for additional species. Grime (1987) hypothesized that communities that experience moderate disturbance are the most diverse.

These factors may significantly affect the composition of the developing community. The net result is that what we seed is not necessarily what we get. Researchers must account for these factors by controlling for them, or by adding sufficient replicates to account for them. Those people planning restoration projects must accept that a reclamation failure is not necessarily the fault of the seed mix, and must allow for these other factors and be prepared to re-seed.

4.1.3 Recommendations for Future Research

To isolate the effects of species richness the following factors must be considered:

1) Regional Species Pool: Vary the size of the species pool by testing several levels of species diversity, with a significant difference in the number of species in each one.

2) Individual Species: Randomize the species in the seed mixes so that each level of diversity is not influenced by the effects of individual species. Increase the number of replicates to compensate for the increased variability.

3) Community Interactions: Ensure that the weeds have been well controlled before seeding. Two years of mechanical or chemical fallow may be necessary.

4) Community Assembly: Use the same number of live seeds (PLS) in each seed mix. Unfortunately, this means that seeds with a high dormancy, and seeds that are slow or difficult to establish will be under-represented in the seed mix. Using establishment rates will give you a better estimate of the number plants to establish, however the data is not available for most native plants.

Obtain PLS values for all species prior to calculating the seeding rates to provide baseline data that can be compared to other published work. PLS does not adequately account for dormancy, but it is a reasonable baseline.

5) Site Heterogeneity: Choose a site with uniform soil condition, or increase the replicates to account for the variability.

6) Disturbance: Ensure that disturbances are as uniform as possible. If weed control is required, do it in all blocks and treatments to eliminate another source of variability.

4.1.4 Recommendations for Designing Seed Mixes for Reclamation or Restoration

Seed mixes used for restoring native plant communities should use a wider diversity of species and functional characteristics than are currently being employed. Ideally if we understood more about the characteristics of individual species we could manipulate their presence and proportions in seed mixes to account for the major functional characteristics such as competitive interactions, growth rates, size, germination and establishment, Nitrogen fixing, nutrient uptake, and metabolic pathways (C3 and C4 grasses). However, given the lack of details on most native plants, it is easier to simply select plants from several broad functional groups, or to increase the number of species in the hopes that the important species/characteristics are included. Common sense says that we should do all three:

1) Increase the species diversity.

2) Include species from many functional groups (for example C4 and C3 grasses, legumes, woody species, and forbs) (Tilman, et al. 1997).

3) Select species and proportions based on all available information including field experience, anecdotal information, and research.

4.2 Conclusions

The second year community in this research project was influenced by several factors in addition to the species pool: the individual species, community interactions, history, site variability, and disturbance. In particular, the site conditions, seeding rate, and individual species had a significant effect on the species composition, density, and richness. Recent research indicates that although species diversity is a significant factor in ecosystem processes (Tilman 1977; Tilman and Downing 1994; Frank and McNaughton 1991; Tilman, et al. 1997; Hooper and Vitousek 1997), the functional characteristics of the individuals species appear to be more significant (Tilman, et al. 1997; Hooper and Vitousek 1997). This appears to be the case in this research, where the proportions and growth characteristics *of Agropyron trachycaulum* and *A. subsecundum* had a disproportionate influence on the community composition.

The effects of individual species on community composition appears to support the Redundant Species Hypothesis, that not all species are critical to the functioning of the ecosystem, and that some species are more important than others. It does not, however, refute the Rivet Hypothesis, that each species is important in maintaining the function of the ecosystem, for neither this research, nor most other diversity research (with the exception of Frank and McNaughton 1991; Tilman and Downing 1994) examines the effects of individual species during changing climatic conditions or management practices. In addition, the short time length of the project limits the conclusion: long-term studies that follow the abundance and species composition of individual species under different conditions needs to be done to further examine these hypotheses.

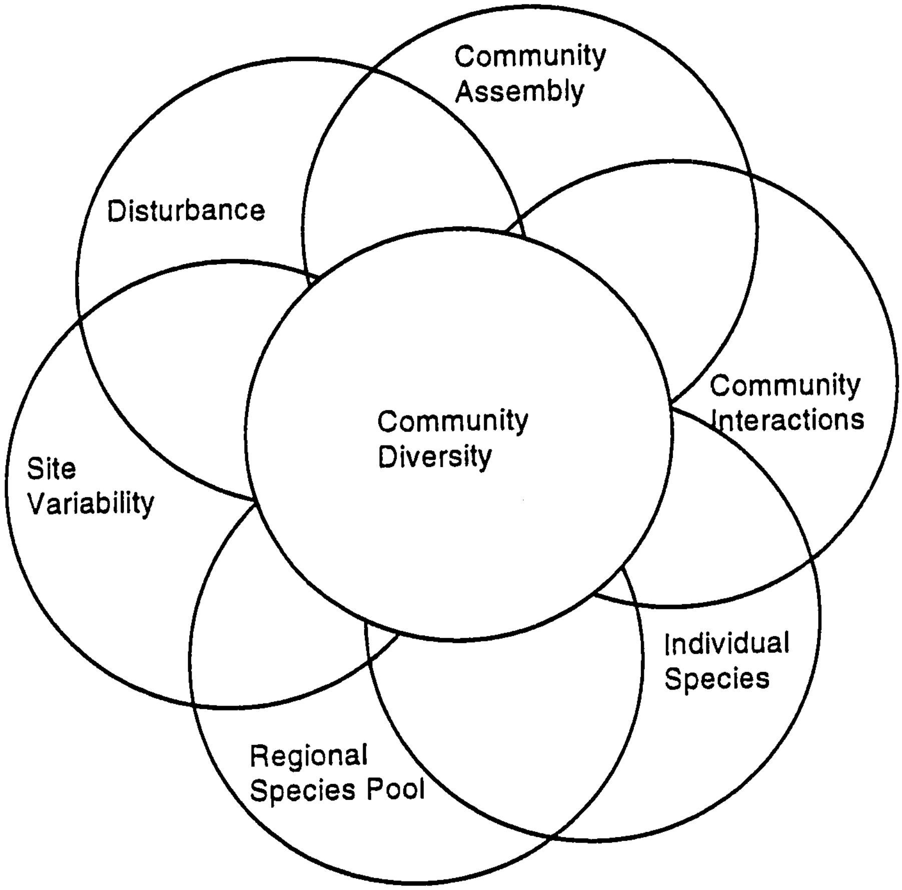

Figure 4-1 Factors Influencing Community Diversity

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Appendices

Figure A-1 Species and Functional Diversity in Each Treatment

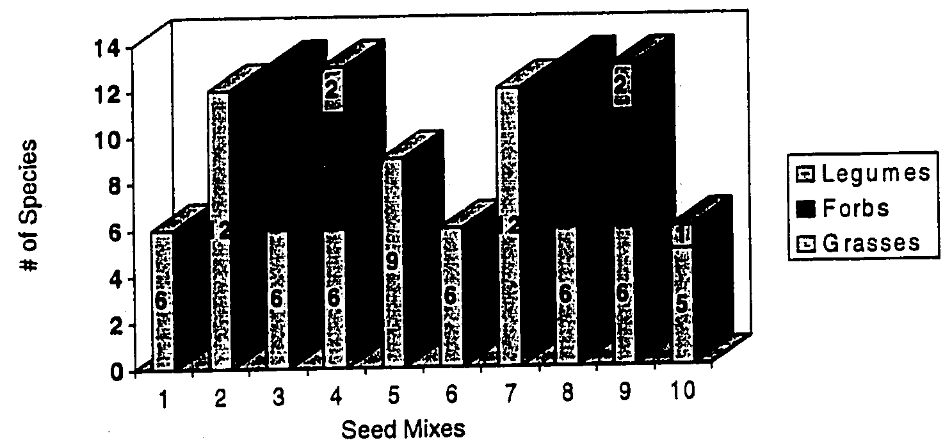


Figure A-2 Plot Layouts in Blocks A1, A2 and B3

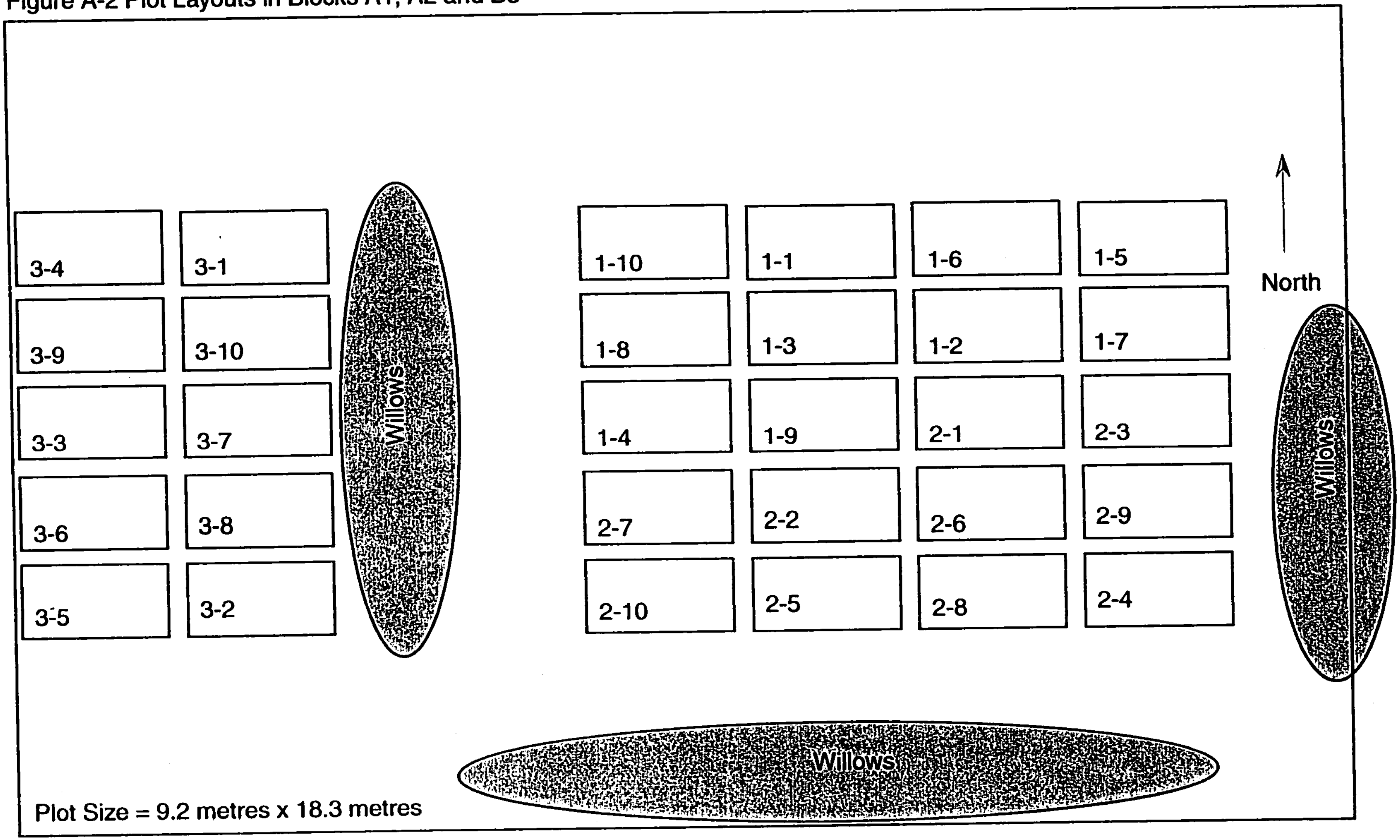
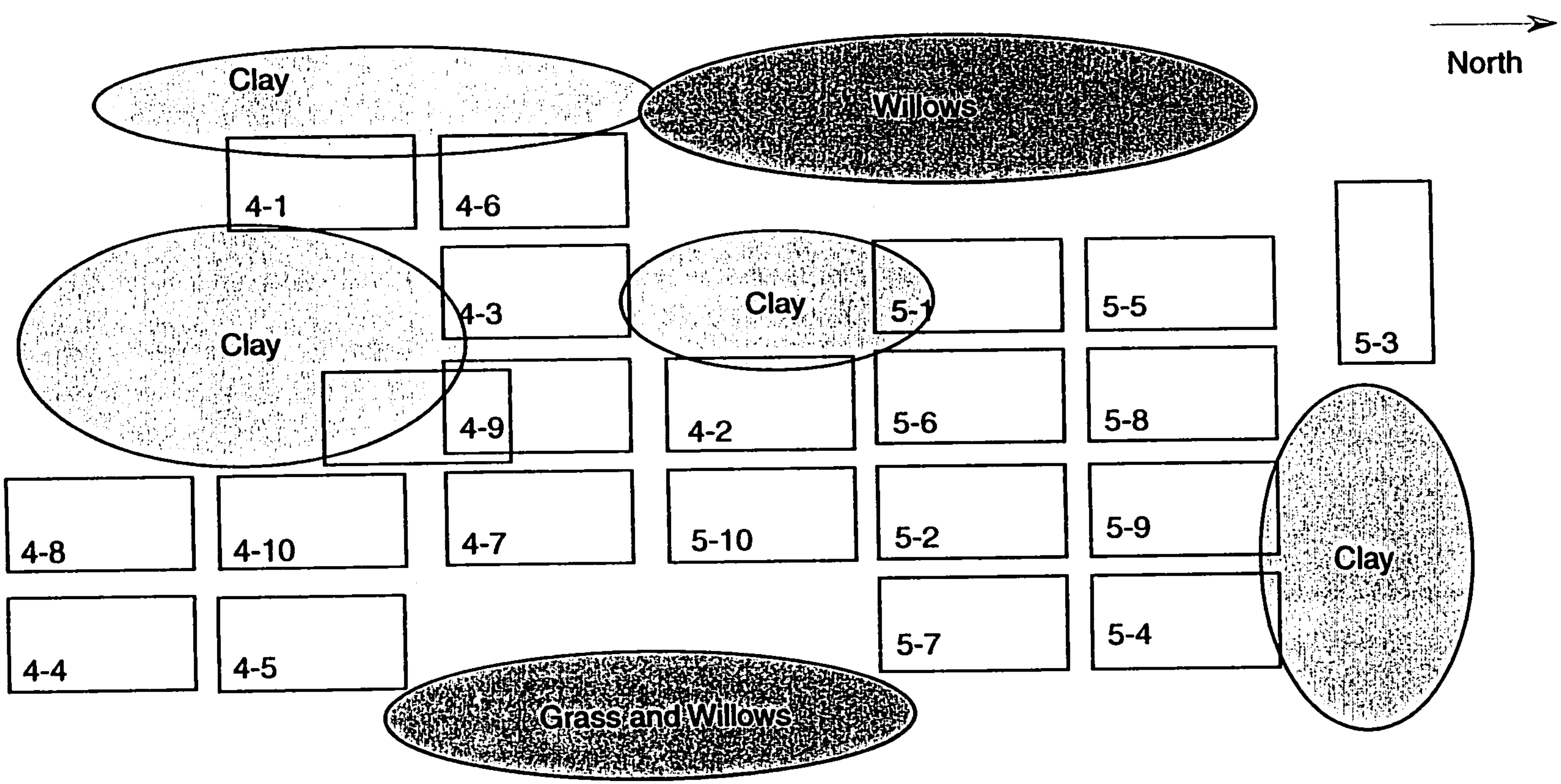


Figure A-3 Plot Layouts in Blocks C4 and C5.



Plot Size = 9.2 metres x 18.3 metres

Table A-1 Scientific and Common Names of Cited Species

Scientific Names	Common Names
Achillea millefolium L.	*yarrow*
Agropyron dasystachyum (Hook.) Scribn.	*northern wheatgrass*
Agropyron intermedium (Host) Beauv.	*tall wheatgrass*
Agropyron pectiniforme R.& S.	*crested wheatgrass*
Agropyron riparian	*streambank wheatgrass*
Agropyron smithii Rydb.	*western wheatgrass*
Agropyron spicatum (Pursh) Scribn. and Smith	*bluebunch wheatgrass*
Agropyron subsecundum	*awned wheatgrass*
Agropyron trachycaulum (Link) Malte	*slender wheatgrass*
Agrostis scabra Willd.	*rough hair grass*
Alopecurus pratensis L.	*meadow foxtail*
Anemone multifida Poir.	*cut-leaved anemone*
Arrhenatherum elatius	
Artemisia frigida Willd.	*pasture sagewort*
Artemisia tridentata Nutt.	*big sagebrush*
Aster laevis L.	*smooth aster*
Astragalus bisulcatus (Hook.) A. Gray	*two-grooved milk vetch*
Bouteloua gracilis (HBK.) Lag.	*blue grama*
Bromus anomalus Rupr. ex Fourn.	*nodding brome*
Bromus ciliatus L.	*fringed brome*
Bromus erectus Huds.	*upright brome*
Bromus inermis (Leyss.)	*awnless brome*
Bromus tectorum L.	*downy brome*
Cactoblastis cactorum Berg.	*cactus moth*
Calamagrostis inexpansa A. Gray	*marsh reedgrass*
Campanula rotundifolia L.	*harebell*
Castanea dentata (Marsh.) Borkh.	*American chestnut*
Chenopodium album L.	*lamb's-quarters*
Cirsium arvense (L.) Scop.	*Canada thistle*
Crepis tectorum L.	*hawk's-beard*
Dactylis glomerata L.	*orchard grass*
Dipodomys spp.	*kangaroo rats*
Elymus junceus Fisch.	*Russian wild rye*

Erigeron glabellus Nutt.	*fleabane*
Eschscholzia californica Cham	*California poppy*
Festuca campestris	*foothills rough fescue*
Festuca hallii (Vasey) Piper	*plains rough fescue*
Festuca ovina L.	*sheep fescue*
Festuca rubra L.	*creeping red fescue*
Koeleria macrantha (Ledeb.) J.A Schultes	*June grass*
Liatris ligulistylis (A. Nels.) K Schum.	*blazing star*
Medicago sativa L.	*alfalfa*
Monarda fistulosa L.	*bergamot*
Myrica faya	
Oenothera biennis L.	*yellow evening primrose*
Opuntia inermis	*prickly pear cactus*
Opuntia stricta	*prickly pear cactus*
Oxytropis deflexa (Pall.) DC.	*reflexed locoweed*
Oxytropis splendens Dougl. ex Hook.	*showy locoweed*
Penstemon procerus Dougl. ex. Grah.	*smooth blue beardtongue*
Poa alpinus L.	*alpine bluegrass*
Poa pratensis L.	*Kentucky bluegrass*
Polygonum convolvulus L.	*wild buckwheat*
Populus tremuloides Michx.	*trembling aspen*
Potentilla norvegica L.	*rough cinquefoil*
Rumex occidentalis S. Wats.	*western dock*
Stipa comata Trin. & Rupr.	*spear grass*
Stipa curtiseta (A.S. Hitchc.) Barkworth	*western porcupine grass*
Stipa viridula Trin.	*green needle grass*
Ulmus americana L.	*American elm*

Table A-2 Climate Data for the Study Site: 1994, 1995, and the 30 Year Average (1951 to 1980)

	Mean temp. (C)			Total Precip. (mm)			Degree Days >5		
Month	1995	1994	30 year	1995	1994	30 year	1995	1994	30 year
April	2	4	3.4	10	2.2	15.9	4	-	42
May	9.2	10.6	10.4	40.2	52	38.3	136	-	172
June	14.4	13.5	14.4	25.4	100.3	72.9	283	-	282
July	15.2	16.3	16.2	92.2	71.9	83.2	317	-	347
August	12.6	15.4	15.2	116.8	111.2	61.3	169	-	101
Mean	0.4	-	1.4	348.6	-	402.5	1164	-	1360

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Table A-3 Description of Soil Series

Mundare A **HBBV10/3u4h** **Hobbema-Beaver Hills**

Parent Material and Landform:

Discontinuous, moderately fine to medium textured, FLLC-GLLC veneer overlying moderately fine texture till.

Undulating to hummocky. Slopes 2-9%

Major Soils: HBMzz (O.BL) 20-40%

BVH (O. BL) 20-30%

JVExtaa/JVEaa (HU.LG) 20-30%

SZ group (NRM, STExt, CMO,TFD) 15-25%

Minor Soils: POK/POKzz (E.BL/O.BL) 5%

Remarks: Undulating to hummocky moraine with a thin, discontinuous, fluviolacustrine or glaciolacustrine veneer. Commonly, till soils (BVH) occur on the hilltops and may have thin A horizons; veneer soils (HBNzz) occur on the side slopes; and wet soils (mainly HU.LG, some O.HG) occupy lower slopes and depressions. Solonetzic and like soils (NRM, STExt, CMO) occur randomly on mid slope to hilltop positions, usually where salts (i.e. gypsum) are near the surface. Wet soils (mainly HU.LG) occupy depressions and channels.

Hobbema (HBM) Thick Black Eluviated Black Chernozemic

zz = Atypical subgroup

Notes: These soils are developed on silty clay loam grading to silt loam texture veneers with clay loam till occurring about 30 to 70 cm below the surface. In cultivated areas, the AE horizon is usually incorporated into the plow layer (AP Horizon). These soils are associated with stream channels.

Beaverhills (BVH) Thick Black Orthic Black Chernozemic

Notes: Clay loam textured till. High water table in spring.

Mundare B **AGNR3/3u** **Angus Ridge-Norma**

Parent Material and Landform:

Moderately fine textured till.

Undulating to hummocky. Slopes 2-5%

Major Soils: AGSsc (E.BL) 20-30%

NRMsc (SZ.BL) 20-30%

JVExtaa/JVEaa (HU.LG) 20-30%

Gleyed saline/carbonated soils 10-20%

Minor Soils: TFD/CMO (BL.SO/BL.SS) 5-15%

BVH (O.BL) 5%

HBM/STExt (E.BL/SZ.BL) 5%

Remarks: Undulating moraine with only minor veneer. The major soils commonly have saline subsoil (sc modifier) and occur on mid slopes and hilltops. Gleyed Rego Blacks and related soils with carbonated and/or re-salinized mid to upper sola are common on lower slopes. Recharge gleysols (HU.LG) occupy most depressions.

Angus Ridge AGS Thick Black Eluviated Black Chernozemic

sc = saline subsoil

Notes: Developed on clay loam textured till. This soil is very good for agriculture. Cultivation may have incorporated the AE horizon into the plow layer.

Norma (NRM) Thick Black Solonetzic Black Chernozemic

sc = saline subsoil

Notes: The B horizon has weak solonetzic tendencies. The lower subsoil is saline and sodic. Seasonally high water table is present in spring.

Jarvie (JVE) Dark Gray-Gray Humic Luvic Gleysol

xt = till at 30-99 cm

aa = not modal SCA

Notes: Soils are wet all year and as a result, exposed faces are unstable. Seasonally high water table is present all year.

Mundare C **CMNR2/3uh** **Camrose-Norma**

Parent Material & Landform:
Moderately fine textured till.
Undulating to hummocky. Slopes 2-5%
Major Soils: CMOta (BL.SS) 30-40%
NRM (SZ.BL) 20-30%
JVExtaa/JVEaa (HU.LG) 15-25%
Minor Soils: ARM/STExt (BL.SS/SZ.BL) 5-15%
TFD (BL.SO) 5-15%
BVH/AGS (O.BL/E.BL) 5%

Remarks: Undulating to hummocky moraine. Commonly, Solonetzic Blacks (NRM) occur on the hilltops, Solodized Solonetz (CMO) occur on mid to lower slopes and bench-like areas, and wet soils (mainly HU.LG) occupy depressional segments of the landscape. Solods (TFD) are common inclusions, occurring from hilltops to midslopes. Veneer soils (FLLC or GLLC over till) are also common inclusions.

Camrose (CMO) Thick Black, Black Solodized Solonetz
ta = thin A
Notes: The BNT horizon is undesirable. Separation of topsoil from subsoil is difficult unless an AE horizon is present. The lower subsoil is saline and sodic. Seasonally high water table is present in spring.

Norma (NRM) Thick Black, Solonetzic Black Chernozemic
sc = saline subsoil
Notes: The B horizon has weak solonetzic tendencies. The lower subsoil is saline and sodic. Seasonally high water table is present in spring.

Jarvie (JVE) Dark Gray-Gray, Humic Luvic Gleysol
xt = till at 30-99 cm
aa = not modal SCA

Notes: Soils are wet all year and as a result, exposed faces are unstable. Seasonally high water table is present all year.

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Table A-4 Species Found in Area Surrounding Research Sites

Scientific Names	Common Names	
Mundare A and B		
Achillea millefolium L.	yarrow	N
Agropyron repens (L.) Beauv.	quack grass	* I
Agropyron trachycaulum (Link) Malte	slender wheatgrass	N
Agrostis scabra Willd.	hair grass	N
Aster hesperius A.Gray	western willow aster	N
Aster spp.	aster	N
Astragalus dasyglottis Fisch. Ex. DC.	purple milkvetch	N
Beckmannia syzigachne (Steud.) Fern.	slough grass	N
Bromus inermis Leyss.	smooth brome grass	I
Calamagrostis inexpansa A. Gray	northern reed grass	N
Campanula rotundifolia L.	harebell	N
Carex rostrata Stokes	beaked sedge	N
Epilobium ciliatum spp. ciliatum Raf.	fringed willowherb	N
Festuca rubra L.	creeping red fescue	I/N
Galeopsis tetrahit L.	hemp nettle	I
Gentianella spp.	gentian	N
Geum aleppicum Jacq.	yellow avens	N
Glyceria grandis S. Wats. *ex* A. Gray	fowl manna grass	N
Medicago sativa L.	alfalfa	I
Melilotus alba Desr.	white sweet clover	I
Mentha arvensis L.	wild mint	N
Penstemon procerus Dougl. Ex Grah.	smooth blue beard tongue	N
Plantago major L.	broad-leaved plantain	I
Poa palustris L.	fowl bluegrass	N
Poa pratensis L.	Kentucky bluegrass	I/N
Polygonum persicaria L.	lady's-thumb	I
Potentilla anserina L.	silverweed	N
Rosa acicularis Lindl.	prickly rose	N
Salix bebbiana Sarg.	beaked willow	N
Salix discolor Muhl.	pussy willow	N
Salix petiolaris J.E. Smith	basket willow	N
Salix planifolia Pursh	flat leaved willow	N

Sium suave Walt.	water parsnip	N
Sonchus uliginosus Bieb.	perennial sow thistle	N
Thermopsis rhombifolia (Nutt.) Richards.	buffalo bean	N
Trifolium hybridum L.	alsike clover	I
Vicia americana Muhl.	American vetch	N
Mundare C		
Agropyron pectiniforme R. & S.	crested wheatgrass	I
Agropyron smithii Rydb.	western wheatgrass	N
Amelanchier alnifolia Nutt.	saskatoon	N
Androsace septentrionalis L.	fairy candelabra	N
Artemisia absinthium L.	wormwood, absinthe	I
Artemisia frigida Willd.	pasture sagewort	N
Artemisia ludoviciana Nutt.	prairie sagewort	N
Beckmannia syzigachne (Steud.) Fern.	slough grass	N
Bromus biebersteinii	meadow brome	I
Bromus inermis Leyss.	smooth brome	I
Calamagrostis inexpansa A. Gray	northern reed grass	N
Campanula rotundifolia L.	harebell	N
Carex spp.	sedge	N
Cerastium arvense L.	mouse-ear chickweed	N
Comandra umbellata (L.) Nutt.	pale comandra	N
Corylus cornuta Nutt.	beaked hazelnut	N
Draba nemorosa L.	annual whitlow-grass	N
Festuca rubra L.	creeping red fescue	I/N
Fragaria virginiana Duchesne	wild strawberry	N
Galium boreale L.	northern bedstraw	N
Geum aleppicum Jacq.	yellow avens	N
Glyceria grandis S. Wats. *ex* A. Gray	manna grass	N
Penstemon procerus Dougl. Ex Grah.	smooth blue beards tongue	N
Poa pratensis L.	Kentucky bluegrass	I/N
Potentilla gracilis Dougl. ex Hook.	graceful cinquefoil	N
Potentilla norvegica L.	rough cinquefoil	N
Ranunculus rhomboideus Goldie	prairie buttercup	N
Ribes inerme Rydb.	wild gooseberry	N
Rosa acicularis Lindl.	prickly rose	N
Salix bebbiana Sarg.	beaked willow	N

Salix discolor Muhl.	pussy willow	N
Salix petiolaris J.E. Smith	basket willow	N
Salix planifolia Pursh	flat-leaved willow	N
Symphoricarpos albus (L.) Blake	snowberry	N
Taraxacum officinale Weber	dandelion	I
Thalictrum spp.	meadow rue	N
Thermopsis rhombifolia (Nutt.) Richards.	buffalo bean	N
Thlaspi arvense L.	stinkweed	I
Trifolium hybridum L.	alsike clover	I
Vicia americana Muhl.	American vetch	N
Viola adunca J.E. Smith	early blue violet	N

* N = Native   I = Introduced.

Table A-5 Seed Mixes: PLS/ 0.1m^2 based on Field Germination Rates

Seed Mix #	1	2	3	4	5	6	7	8	9	10
Species	.	**Grass**	**Forbs**	**Legume**	**Mix**	.	**Grass**	**Forbs**	**Legume**	**Mix**
Festuca halli	1.87	1.38	1.38	1.38		2.90	2.40	2.39	2.40	
trachycaulum and A.	1.47	1.98	1.08	1.08	1.94	1.07	1.57	0.67	0.68	0.56
Bromus anomalus	5.79	4.22	4.22	4.22		7.32	5.81	5.79	5.81	
Stipa curtiseta	5.18	3.79	3.81	3.79		3.79	2.37	2.37	2.37	
Agropyron smithii	0.63	0.43	0.44	0.43	0.88	0.46	0.27	0.28	0.27	1.31
Bouteloua gracilis		0.04					0.02			
Bromus ciliatus		0.30					0.15			
Koeleria macrantha		1.61			1.61		2.41			
Poa palustris		2.53					3.67			
Stipa comata		1.28					0.63			
Stipa viridula		0.51			0.45		0.76			1.15
Achillea millefolium			0.16	0.11				0.06	0.06	
Erigeron glabellus			0.00	0.00				0.00	0.00	
Anemone multifida			0.00	0.00				0.00	0.00	
Monarda fistulosa			0.04	0.04				0.02	0.02	
Oenothera biennis			0.03	0.03				0.03	0.03	
Penstemon procerus			0.28					0.40		
Rumex occidentalis			0.15					0.11		
Oxytropis splendens				0.17					0.26	
Oxytropis deflexa				0.65					0.32	
Agropyron riparian					2.85					
Festuca ovina					3.18					
Festuca rubra					1.94					
Festuca campestris					2.50					
Poa alpina					1.58					
Agropyron dasystachyum										1.86
Agropyron elongatum										0.41
Medicago sativa										0.24
Total PLS/0.1m^2	14.94	18.07	11.59	11.90	16.93	15.54	20.06	12.12	12.22	5.53

Note: based on field germination r: PLS = germination from field tests * purity. Germination rate for Erigeron and Anemone is 0%.
No germination rates for Bouteloua, or Monarda, therefore entered 2%; Germination rate for Penstemon is 0%, therefore entered 10%.

Table A-6 Soil Characteristics by Block and Treatment in 1994

Soil Depth 0-15 cm														
Trt	Ca mg/kg	SD	Mg mg/kg	SD	Na mg/kg	SD	Carbon	SD	EC ds/m	SD	SAR	SD	pH	SD
1	59.6	28.6	17.8	6.5	48	80.3	4.9	0.9	1	0.3	3	6	5.9	0.3
2	53.8	29.9	17.2	6.9	54.6	68.4	4.8	1.8	1	0.2	3	4	6.2	0.5
3	60.5	39.4	18.7	9.9	47.5	55.3	4.7	0.7	1	0.1	3	5	5.8	0.7
4	79.7	39.4	20.5	7.1	23.3	34.1	4.7	1.2	1	0.2	1	1	6.4	0.8
5	73.5	26.9	25.2	6.2	51.3	85.4	5.5	1	1	0.4	2	4	5.8	0.5
6	78.8	53.2	27.2	14.9	55.1	52.8	5	0.5	1	0.5	2	2	6	0.7
7	69.9	41.7	18.2	6.6	30.6	46.7	3.9	1.7	1	0.3	2	5	6.3	0.6
8	70.6	25.6	23.3	10.1	24.4	25.3	4.9	2.4	1	0.5	1	1	6.2	0.8
9	68.1	47.5	21.2	8.6	53.2	53.2	4.8	0.6	1	(0.30	3	3	6	0.8
10	70.6	19.5	17.6	3.3	12.3	12.1	4.7	1.5	1	0.1	0	0	6.4	0.5
Mean	69	34	21	8	40	53	4.8	1.3	1	0.32	2	3	6.1	0.62
Block	Ca mg/kg	SD	Mg mg/kg	SD	Na mg/kg	SD	Carbon	SD	EC ds/m	SD	SAR	SD	pH	SD
1	91.9	36.6	24.6	11.4	13.7	15.9	5.3	0.5	1.1	0.4	0.4	0.3	6	0.5
2	79	28.3	25.4	5.4	17.9	8.6	5.4	1	0.9	0.1	0.6	0.2	6.4	0.5
3	78.7	25.4	20.8	4.4	7	1.4	5.5	0.6	0.9	0.1	0.2	0.1	6.2	0.3
4	57.8	26.2	17.7	5	48.9	55.7	3.7	1.3	1.1	0.2	2.4	3	6.1	0.9
5	35.1	24.9	14.9	9.7	112.7	56.7	4	1.6	1.4	0.4	6.6	4.2	5.8	0.7
Mean	69	34	21	8	40	53	4.8	1.3	1	0.32	2	3	6.1	0.62
Soil Depth 30-45 cm														
Block	Ca mg/kg	SD	Mg mg/kg	SD	Na mg/kg	SD	Carbon	SD	EC ds/m	SD	SAR	SD	pH	SD
1	71.0	75.6	27.8	22.2	95.7	110.4	1.8	1.0	1.7	1.2	4.3	5.4	6.9	0.6
2	154.1	90.3	129.6	96.2	304.3	225.8	1.5	0.6	4.4	2.5	6.0	2.9	7.6	0.1
3	43.7	40.2	16.8	16.5	31.8	25.8	1.1	0.7	1.0	0.8	1.6	0.7	7.3	0.5
4	49.7	51.5	28.5	44.7	278.2	477.5	1.1	1.2	2.3	2.9	7.8	9.6	6.8	0.7
5	107.1	108.5	71.3	78.9	822.1	668.4	0.6	0.4	5.6	4.2	20.1	11.2	7.4	0.7

SD = significant difference, O. - organic.

Table A-7 Electrical Conductance as Measured by EM38 Meter in 1995

Trt	EM38 reading	dS/m	Horizontal	dS/m
1	40.00	2.60	25.05	1.25
2	40.85	2.65	25.33	1.25
3	41.26	2.65	25.59	1.33
4	41.57	2.90	25.84	1.33
5	41.89	2.90	26.01	1.33
6	42.29	2.90	26.33	1.33
7	42.55	2.70	26.43	1.33
8	42.98	2.70	26.80	1.40
9	43.62	1.32	27.23	1.40
10	43.80	1.32	27.40	1.40
Block	**EM38 reading**	**dS/m**	**Horizontal**	**dS/m**
A1	38.92	2.70	23.43	1.10
A2	62.37	4.10	38.94	2.30
B3	45.39	2.90	26.92	1.40
C4	53.53	3.50	32.90	1.85
C5	78.74	5.26	53.63	3.43

* Conversion for vertical mode: $y = 0.043x - 0.17$. Temperature correction = 1.6

** Conversion for horizontal mode: $y = 0.047x - 0.63$. Temperature correction = 1.6

Soil temperature was estimated at 5°C, soil moisture <30%, texture = medium.

(Mackenzie, Chomistek and Clark, 1989; Walker 1998)

Table A-8 Weeds Present in Research Plots

Scientific Names	Common Names
1994	
Achillea sibirica Ledeb.	Siberian yarrow
Amaranthus retroflexus L.	red root pigweed
Androsace septentrionalis L.	fairy candelabra
Artemisia absinthe L.	absinthe
Artemisia ludoviciana Nutt.	prairie sagewort
Avena fatua L.	wild oats
Axyris amaranthoides L.	Russian pigweed
Barbarea spp.	winter cress
Beckmannia syzigachne (Steud.) Fern.	slough grass
Bromus inermis Leyss.	smooth brome
Campanula rotundifolia L.	harebell
Capsella bursa-pastoris (L.) Medic	shepherd's purse
Chenopodium album L.	lamb's quarters
Chenopodium gigantospermum Aellen	maple-leaved goosefoot
Chenopodium salinum Standl.	oak-leaved goosefoot
Cirsium arvense (L). Scop.	Canada thistle
Collomia linearis Nutt.	collomia
Conringia orientalis (L.) Dum.	hare's-ear mustard
Crepis tectorum L.	narrow-leaved hawksbeard
Descurainia pinnata (Walt.) Britt.	green tansy mustard
Descurainia richardsonii (Sweet) O.E. Shulz	gray tansy mustard
Descurainia sophia (L.) Webb	flixweed
Draba nemorosa L.	draba
Epilobium ciliatum Raf.	
Equisetum arvense L.	horse-tails
Erucastrum gallicum (Willd.) Shulz	dog mustard
Erysimum cheiranthoides L.	wormseed mustard
Geranium bicknellii Britt.	Bicknell's geranium
Geum triflorum Pursh	3-flowered avens
Gnaphalium uliginosum L.	cudweed
Hordeum jubatum L.	foxtail barley
Lappula squarrosa (Retz.) Dumort.	blue-bur

Lathyrus ochroleucus Hook.	white pea vine
Lepidium densiflorum Schrad.	common peppergrass
Linaria vulgaris Hill	toadflax
Matricaria perforata Merat	scentless chamomile
Mentha arvensis L.	wild mint
Monolepsis nuttalliana (Schultes) Greene	spear-leaved goosefoot
Neslia paniculata (L.) Desv.	ball mustard
Plantago major L.	plantain
Poa compressa L.	Canada bluegrass
Poa pratensis L.	Kentucky bluegrass
Polygonum arenastrum Jord. ex Bor.	prostrate knotweed
Polygonum convolvulus L.	buckwheat
Polygonum lapathifolium L.	smartweed
Populus spp.	poplar
Potentilla norvegica L.	rough cinquefoil
Salsola kali L.	Russian thistle
Senecio vulgaris L.	common groundsel
Silene noctiflora L.	night-flowering catchfly
Silene pratensis (Rafn) Godron & Gren.	white cockle (*Lychnis alba*)
Solanum triflorum Nutt.	wild tomato
Sonchus arvensis L.	perennial sow thistle
Sonchus uliginosus Bieb.	perennial sow thistle
Spergula arvensis L.	corn spurry
Stellaria media (L.) Cyrill.	chickweed
Tanacetum vulgare L.	tansy
Taraxacum officinale Weber	dandelion
Thlaspi arvense L.	stinkweed
Trifolium hybridum L.	Alsike clover
Trifolium pratense L.	red clover
Trifolium repens L.	white clover
Triticum aestivum L.	common wheat
Veronica persica Poir.	veronica
Vicia americana Muhl.	wild vetch
1995 additions	
Scleranthus annuus L.	knawel
Artemisia biennis Willd.	biennial sagewort
Artemisia frigida Willd.	prairie sagewort

Table A-9 Glossary

Canopy Cover: (% Bare Ground, % Litter, and % Live Vegetation). A percent of the ground area covered by a vertical projection to the ground surface. Canopy cover was estimated visually and always totaled 100%.

Cultivar: Cultivated variety ...rigidly selected for uniformity of agronomic characteristics (Ducks Unlimited Canada, 1995).

Diversity: Diversity refers to the number of species (richness), unless it is qualified by "genera" (number of genera) or "functional" (number of functional characteristics).

Ecological Restoration: Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity ecological processes and structures, regional and historical context, and sustainable cultural practices. (SER 1996)

Ecovar: a plant variety that is developed with equal emphasis placed on maintenance of a broad genetic base and agronomic characteristics. It differs from a "cultivar"...in that a broader range of the genetic potential of the species is retained....will yield seed that is closer to its native origin than are the cultivars currently in use (Ducks Unlimited Canada, 1995).

Field Germination: the percentage of seeds that germinated in field trials. Three replicates of thirty seeds were tested between June 6 and July 7 at block A1.

Functional Characteristics: "Those characteristics that govern the fluxes of energy and materials...and the mechanisms that permit the persistence of an ecosystem through time in a constantly changing environment" (Solbrig 1993). Functional characteristics include primary and secondary productivity, decomposition, nutrient cycling and nutrient accumulation or loss, hydrology, soil development and soil fertility, and disturbance frequency or intensity (Vitousek and Hooper (1993).

Functional Groups: Classes with similar characteristics or that behave in similar ways (Solbrig 1993). Tilman recognized five different functional groups: legumes, C3 and C4 grasses, weedy plants, and forbs (non N-fixing) (Tilman, et al. 1997).

Ground Cover: (% Bare Ground, % Litter, and % Live Vegetation). A percent of the ground area covered by litter or live vegetation at ground level. Ground cover was estimated visually and always totaled 100%.

Native Species: those that occurred naturally in an area at the time of settlement and were not brought in from other areas of the county or other continents (Morgan et al. 1995).

Percent Species Composition: Percent species composition was estimated visually as a percent of the total biomass that was contributed by each species. Percentage was estimated for the dominant plants first, minor plants last, and always totaled 100%.

Plant Density: a direct count of seeded plants and weeds.

Pure Live Seed: An estimate of the amount of live seed in a seed lot.
PLS =(Pure seed * Germination)/100

Reclamation: the construction of topographic, soil, and plant conditions after disturbance, which may not be identical to the predisturbance site, but which permits the degraded land to function adequately in the ecosystem of which it was a part (Munshower 1993).

Relative Density: (Density/PLS using Field Germination Rates). The proportion of the planted seed that actually established. Relative density accounts for the differences in seeding rates of the various species.

Relative Size: (Percent Species Composition/Plant Density). Relative size is an estimate of the size of each species based on the proportion of the total biomass contributed by one species divided by the number of plants. This accounts for differences in seeding rate and establishment of the various species.

Richness: The number of species.

Seeded Plants: Those plants included in the specific seed mixes.

Survival: a comparison of the plant density between 1994 and 1995. A significant difference in the values indicates an increase in numbers due to delayed germination, or rhizome production, while a decrease in numbers indicates a die-off due to winter-kill or spring drought.

Weeds: for the purpose of this study, weeds include any plant not intentionally seeded. It includes native species that were present in the seed bank, non-native species that are generally considered to be weeds such as *Polygonum convolvulus*, and aggressive agronomic species such as *Bromus anomalus.*

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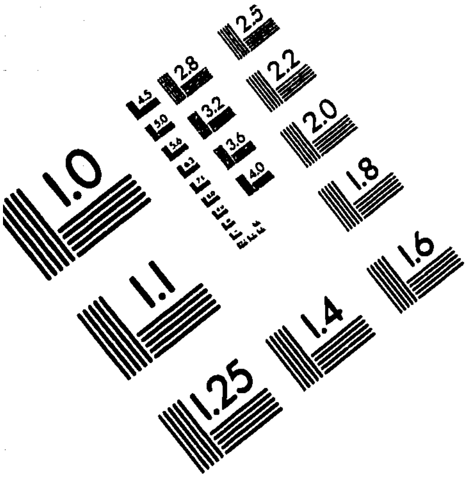
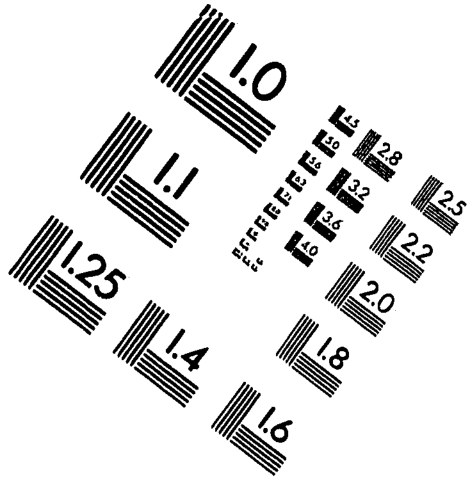
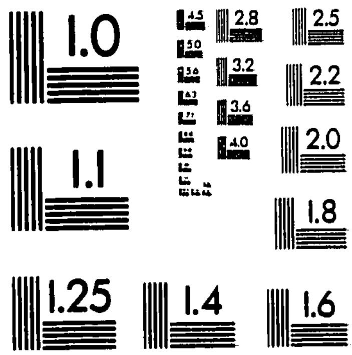
Table A-10 Probability of Block and Treatment Effects on Cover, Species Composition, Density and Richness

1995	**Ground Cover**			**Canopy Cover**		
	Bare Ground	Litter	Live Vegetation	Bare Ground	Litter	Live Vegetation
Block	p=0.0008	p<=0.0001	p<=0.0001	p=0.358	p<=0.0001	p<=0.0001
Treatment	p=0.0143	p=0.3045	p=0.867	p=0.024	p=0.0518	p=0.092
1995	**% Spp. Comp.**	**Seeded Density/ Total Density**	**Seeded Density**	**Seeded Richness**	**Weed Richness**	**Weed Density**
Block	p<=0.0001	p<=0.0001	p<=0.0001	p<=0.0001	p<=0.0001	p<=0.0001
Treatment	p=0.0026	p=0.0001	p<=0.0001	p<=0.0001	p=0.692	p=0.2626

IMAGE EVALUATION TEST TARGET (QA-3)







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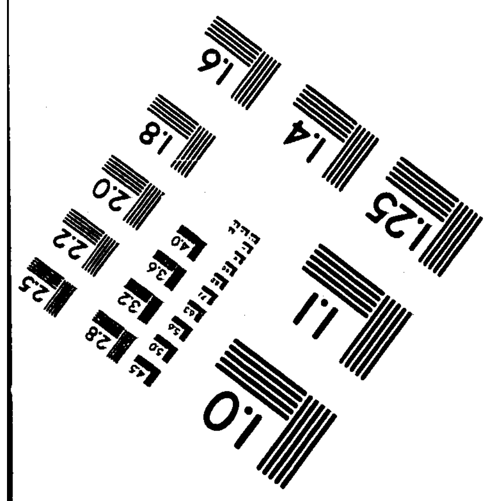

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