Native Shrub-Steppe Restoration at the Yakima Training Center, Yakima, Washington

by

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INTRODUCTION

This thesis focuses on the restoration of two rangeland sites which have been nearly denuded of vegetation. The two sites, located at the Yakima Training Center (YTC), Yakima, Washington, were utilized as a bivouac camp and a machinery depot for the U.S. Army. Due to these military activities, the sites were nearly denuded of vegetation and in need of restoration. The current method of revegetation used by the U.S. Army on disturbed sites involves the broadcasting or drilling of *Agropyron cristatum* (crested wheatgrass) seeds, a non-native plant species of little value to wildlife. *Agropyron cristatum* can be easily introduced to degraded rangeland sites and can be established during droughty conditions. The YTC utilizes these characteristics of *A. cristatum* to quickly establish a vegetational ground cover on sites that have been denuded in order to reduce or eliminate the potential for soil erosion. The direction of this research was to find an alternate means of revegetation which utilized native instead of non-native species for disturbed sites in the shrub-steppe community of the YTC. A new method of revegetation may provide a more useful habitat to wildlife as well as establish sufficient vegetational ground cover.

Staff wildlife biologists for the U.S. Army have recorded a steady decline in the numbers of Sage Grouse (*Centrocercus urophasianus*) at the YTC. The decline in Sage Grouse is speculated to be a direct effect of the reseeding of *A. cristatum* by the U.S. Army in damaged training areas. Stands of *A. cristatum* do not provide adequate habitat for grouse and other wildlife species such as deer and elk. Therefore, finding a new method of reseeding which utilizes native species more suitable for wildlife use is important, and subsequently is the driving concern behind this research.

Due to the difficult nature of establishing native species by seed in arid regions, I also compared the natural successional development of the sites over a period of two growing seasons. Finally, I compared the vegetational composition of the two sites to their own neighboring communities and to an undisturbed, stable reference shrub-steppe community in order to determine community similarities and differences.

The steppe community of eastern Washington consists of nine plant associations which are referred to as a mosaic of zones within the Columbia Plateau. Each zone reflects climatic differences which influence the competitive balances between community dominants (Daubenmire 1969a). The *Artemisia tridentata* - *Agropyron spicatum* association (*Artr - Agsp* ; big sagebrush and bluebunch wheatgrass) is one of the nine zones found in the Columbia Basin of eastern Washington. It is within this zone that my research plots are found.

The *Artr - Agsp* zone is one of the most extensive plant associations in the steppe community of Washington. In undisturbed areas, *Artemisia tridentata* is the principle shrub component and *Agropyron spicatum* is the principle grass component. *Stipa comata* (Needle-And-Thread), *Stipa thurberiana* (Thurber's needlegrass), *Poa cusickii* (Cusick's bluegrass), and *Sitanion hystrix* (bottlebrush squirreltail) may also be present, however, their combined coverage typically does not surpass that of *Agropyron* species. This zone is found between 1,230 and 1,850 meters (4,000 and 6,000 feet) in elevation and typically consists of shallow to moderately deep soils. The Cascade mountain range lies to the west of the Columbia Plateau, casting its rainshadow effect upon the regions to its east (Daubenmire 1969a). It is this effect that causes this plant association to lie within the 30 to 46 centimeters (12 to 18 inches) precipitation zone (Mueggler and Stewart 1980).

The dominant shrub typically covers between 5 and 25 percent of undisturbed or only slightly disturbed sites (Daubenmire 1969a, Mueggler and Stewart 1980), however, there can be a wide distribution of shrub cover found throughout areas of this zone. Within the *Artr - Agsp* zone, shrub cover increases as grass and forb cover decreases (McLendon and Redente 1990). Here, most large shrub species depend on permanent moisture supplies within the deeper subsoil horizons. Grass species, in contrast, have a highly developed root system in the upper few inches of the soil to absorb as much moisture as possible. Their network of roots at the soil surface captures great amounts of moisture before it can penetrate deeper into the soil to support an abundance of shrubs. Therefore, often in areas of high grass cover, there is low shrub cover.

The Columbia Plateau has endured widespread disturbance. Cattle grazing was first introduced to the area in 1834, however it was not until the 1880's that it became a strong contributor to the degradation of the natural condition of the local habitats (Daubenmire 1969a). Native species of the region are unable to endure heavy use such as grazing and typically require decades to recover from severe damage (Tueller 1973, McLendon and Redente 1990, Samuel and Hart 1994).

Seedlings of many steppe species have difficulty becoming established due to the aridity of the environment, which leads to high levels of competition among the existing vegetation and emerging seedlings for the limited water resources. There are many opportunistic rangeland species, however, that thrive in arid regions and on disturbed sites. These species are able to invade a site, establish themselves, and begin to competitively exclude other plant species from establishment. These include *Bromus tectorum* (cheatgrass), an annual non-native weed, and other perennial grasses, such as *A. cristatum*, which effectively remove the limited moisture and nutrient resources of the upper soil horizons, allowing them to dominate certain landscapes (McLean and Tisdale 1972, Young and Evans 1973, Cline et al. 1977, Allen and Knight 1984). Thier dominance is so absolute that in nearly all cases where they become established, few other species, native or non-native, are able to colonize in its presence.

Autumn is generally the suggested season for planting most steppe species (Monsen and Christensen 1975). This allows the seeds to undergo a freezing period during the winter so they are prepared to germinate in the spring. Successful establishment of steppe species by seeders requires the preparation of a proper seedbed prior to seeding and the elimination of weedy species competition. Weedy species should be eliminated for at least two growing seasons following seeding of the desired species, especially if the desired species is a shrub (Holmgren and Basile 1959, Plummer et al. 1968, Monsen and Christensen 1975).

Seeding has the greatest potential for restoration in steppe areas where desirable native vegetation does not exist. Seeding should help to increase the percentage cover of the desired species as well as possibly destroy an inferior quality of vegetation in the process (Cairns Jr. 1985, Aronson et al. 1993a, Aronson et al. 1993b). In areas which receive less than 20 centimeters (9 inches) of precipitation per year, it is much more difficult to achieve successful seedings (Heady 1975). In addition to low precipitation, varying amounts of precipitation from year to year can also lead to irregular germination success, especially if those varying amounts are also low.

Objectives

The objectives of this study were to:

1. Compare the germination success of two shrub-steppe seed mixes,
2. Compare species establishment between areas that were either cultivated or not cultivated prior to rangeland reseeding methods,
3. Identify and define plant successional development over two growing seasons following rangeland reseeding,
4. Compare species composition among reseeded sites, their neighboring communities, and an undisturbed, shrub-steppe community to predict how quickly a degraded shrub-steppe site may recover after being reseeding.

CURRENT STATE OF THE PRACTICE OF ARID-LAND RESTORATION

The limited amount of rainfall in arid regions makes plant establishment very difficult for those plants which are not physiologically and morphologically adapted to such an environment. Weedy species are phenologically adapted to avoid extreme conditions such as low precipitation and therefore establish and dominate new areas quite readily in response to occasional rainfall events. Native plant communities in arid regions, in contrast, require many years to develop (McLean and Tisdale 1972, Monsen and Christensen 1975, Jackson et al. 1992, Samual and Hart 1994, Gabbert et al. 1995, McArthur et al. 1995).

Aridland environments can be strenuous environments, experiencing natural disturbances such as high wind velocities, low precipitation, and high ground temperatures. In the case of my study sites, the selected areas have also been affected by human interaction. To aid in the rehabilitation of disturbed aridland sites, many factors must be understood prior to any restorative activities. The following review of aridland restoration techniques includes information beyond the scope of this study, and is meant to give an overiew of current practices.

Seed Germination and Establishment

Seeds allow plants to seek out favorable future environments. The seed is a highly complex package of nutrients, embryonic plant material, and a protective outer seed coat from which the primary plant body emerges (McDonough 1977).

The germinative process occurs in four stages: (1) imbibition - the uptake of water largely by the protein components of the seed through a cracked seed coat; (2) hydration and activation of informational and synthetic mechanisms - nucleic acids and enzymes; (3) cell enlargement and cell division; and (4) visible germination - growth of the root through the coat (McDonough 1977, Young and Evans 1986).

Species respond differently to environmental cues such as soil moisture or temperature when preparing for germination. In an arid environment, vulnerability to moisture stress greatly influences germination success (Abbott et al. 1995). Many species produce seeds that respond to the first rains of the growing season by initiating their germination cycle. Once the germination cycle has begun, the seedling needs to have soil water available to maintain growth and survive. Often species produce seeds that only respond to the early spring moisture and then fall victim to a prolonged period of aridity which sometimes occurs prior to the onset of the first consistent rains of the year. A seed is not always penalized for its early germination cycle. Early germination in an environment that is stressed for soil moisture may give that species an advantage over other later-germinating species provided it is adapted to a reduced moisture environment throughout the remainder of the growing season. Early spring soil moisture in arid environments may be the only available moisture for the majority of the growing season. Species that produce seeds early and late in the same growing season tend to be favored in a variety of environments, including arid lands (Abbott et al. 1995).

Premature germination near the end of the growing season often leads to the failure of some species. Seeds commonly fall from their host plant in autumn and lie on the soil's surface or in subsurface soil horizons throughout the winter months, awaiting spring germination cues (Young et al. 1994). Should suitable environmental conditions occur in autumn, even if it is for a short period of time, some seeds may begin to germinate. An autumn germination is often detrimental to the germinating seed in latitudes which experience very cold winters.

Premature germination during autumn months typically is controlled by the seed's natural timing device. Many seeds require a prolonged cold period before they able to germinate. Cold temperatures help to compromise the integrity of the seed's protective coat and allow oxygen and water to penetrate the interior, a requirement for germination. Without this period of cold, many seeds will continue to lie dormant during the following growing season, even with near perfect growing conditions (Caldwell 1979, Young and Evans 1986).

Scarification of the seed coat may also be necessary for germination. This involves a mechanical action to crack the seed coat. Most commonly, scarification is achieved naturally when a seed is washed down a river bed. The action of being washed over rocks or pebbles tends to weaken the seed coat and eventually causes it to crack, thus allowing oxygen and water to enter the seed. Diurnal temperature alterations, light, gibberellins, cytokinins, potassium nitrate, ethylene, and carbon dioxide may also affect the time at which the seed embryo will end its dormancy period and continue with its later growth stages (McDonough 1977).

Seeds harvested from a different climatic region than where they are planted tend to be less successful than native seeds. The environmental cues that trigger germination of the seed collected from another region may be quite different than for the same species of another region. Seed collections of *Artemisia tridentata* (big sagebrush), *Chrysothamnus nauseosus* (rubber rabbitbrush), *Purshia tridentata* (antelope bitterbrush), *Penstemon eatonii* (firecracker penstemon), and *Penstemon palmeri* (Palmer penstemon) taken from areas with warm winter climates and replanted to endure a winter under snowpack germinated more quickly under snowpack than did seeds taken from areas with cold winter climates (Meyer 1990). The seeds collected from the warm-winter climate germinated prematurely while still under snow, committing themselves to germination exposure prior to proper spring conditions and leaving them more vulnerable to freezing, desiccation, and attack from fungal pathogens (Deitschman 1974, Young and Evans 1986, Meyer 1990).

<u>Dormancy</u>

Dormancy is the period of time during a seed's existence when its own growth is physiologically stalled during the embryonic development stage (McDonough 1977, Young and Evans 1986, Young and Ross 1992). This stalling of development often involves gibberellins and cytokinins (growth hormones) being inhibited by abcissic acid

(ABA). In the absence of ABA, gibberellins initiate germination by causing the elongation of root stock.

A seed in dormancy is characterized by its ability to endure dehydration of the protoplasts of the embryo as well as by the maturation of its protective outer seed coat. A seed is still living while in dormancy, but often described as quiescent (McDonough 1977). Dormancy is typically ended when favorable environmental conditions occur. Germination of the seeds of many species occurs synchronously and rapidly across a wide range of temperatures and moistures. In other cases, species germinate intermittently over an extended period of time. The latter case may allow for the species to survive in an environment of less predictability due to the spread of germination over time. The seeds of a species that germinate all at once may be subjected to widespread destruction from a single catastrophic event.

A prolonged cold period, termed stratification, is required of many seed species to trigger the mobilization of nutrients within the seed in order to end its dormancy. *Artemisia tridentata* subsp. *vaseyana* terminates its seed dormancy stage more readily following a 50-day stratification treatment than without the treatment (Deitschman 1974, McDonough 1977).

Light plays a key role in the termination of dormancy for many species. *Artemisia tridentata* responds to radiation stimuli. The stimuli must meet seed requirements for length of transmission, intensity, or wavelength. If a seed is buried too deeply within the soil surface to experience direct or indirect sunlight, often it will remain dormant until conditions change so that its light requirements can be met (McDonough 1977, McGinnies 1984, Young and Evans 1986, Stutz and Buchanan 1990, Young et al. 1994). Some weed species may remain dormant for years. When a fallow field is plowed, churning many buried seeds to the surface, tremendous germination may take place due to the previously buried seed having their light requirement fulfilled.

Temperature can influence the dormancy period of a seed. The optimal temperature for the initiation of germination often depends on the length of time the seed spends at optimal temperatures. Indirectly, the temperatures at which the seeds are responding are linked to other existing environmental conditions such as soil moisture, humidity, length of day, or nutrient availability (Young and Evans 1986, Young and Ross 1992, Sullivan 1980, McDonough 1977).

Germination is possible at temperatures slightly below freezing (Harniss and McDonough 1975, Harniss and McDonough 1976). The metabolic rate within the seed during germination increases as temperature increases, therefore, although cooler temperatures may still trigger germination, there is a much slower growth rate and success rate. For small seeds characterized by high vigor, higher temperatures are more critical than for larger seeds (McGinnies 1984, Leishman and Westoby 1994).

Different seed species begin germinating at different temperatures. This allows them to emerge from their dormant state during the time of year that best suits their environmental needs. Seeds that are best prepared to begin germination during the summer will typically require higher temperatures to trigger germination, while other seeds require much lower temperatures in order to begin germination during spring or fall conditions. Seeds may not always respond to temperature cues, therefore some species will have seeds germinating throughout the year (McDonough 1977).

The condition of the seed coat can influence dormancy. In some species, the seed coat is impermeable to air and water, which are necessary for continued growth following dormancy; the coat needs to be opened to allow these and other nutrients to enter. With other species, the seed coat is already permeable to air and water, and while these can pass freely in to the seed embryo, the seed will not terminate its dormancy period until other environmental requirements are satisfied. These may include potassium nitrate, ethylene, and carbon dioxide, all of which are found within the soil medium. Each of these chemical compounds are either increased or decreased in concentration within the soil as other environmental conditions vary. It is these chemical constituents, however, that trigger the embryo of the seed to terminate dormancy (Young and Evans 1986, McDonough 1977).

Germination

As a seed is hydrated by soil moisture (imbibition), the seed's own metabolic activity begins to intensify. Greater availability of moisture within the growing medium allows the seed to germinate at increasing rates until an optimum level is reached. Should the available water decrease to below minimum requirements of the seed during the early stages of germination, the germination process can actually reverse itself. This is not always to the detriment of the seed. Some species, such as *Agropyron cristatum* , benefit by wet-dry cycling during the initial stages of germination provided the cycles are not too extensive in time, drying is not too rapid, or temperatures are not too high. Should wet-dry cycling occur beyond the first stages of enzyme synthesis however, irreversible injury most likely will occur (McDonough 1977).

In lab and field experiments, A. T. Bleak and W. Keller (1974) found that 5 of 6 species of rangeland grass seeds which were exposed to a single wet-dry cycle imbibed at 17˚C (63˚F) (sufficient for incipient germination), then, if air-dried prior to sowing, emerged more rapidly than if untreated. This is thought to be caused by an advancement of pregerminative processes due to the pre-exposure to droughy conditions (McDonough 1977, Abbott et al. 1995).

Another factor that plays a role in the germination success of a seed is its seed-soil pore contact ability. A seed's size, surface/volume ratio, shape, or presence of mucilage-forming tissue affect the seed's relationship with its growing medium (McDonough 1977, McGinnies 1984). Water-absorbing coatings applied to the seed coat prior to sowing may enhance the seed's ability to absorb soil moisture, thus increasing the germination and emergence rate. Such coatings would consist of proteins, starch, or cellulose (in order of effectiveness), each exhibiting high capacities for water uptake (McDonough 1977).

Air-dry storage (afterripening) can improve to the germination rate of certain seed species. Recently harvested seed may germinate at lower rates than seeds that have been air-dried. The optimum air-drying temperature for most species ranges from 15˚ to 20˚C

(59˚ to 68˚F) while the time of storage required can range from weeks to years (Young and Evans 1986, Beckstead et al. 1995).

Fungi are ubiquitous in soil and effect seed germination. Decomposition of seeds due to fungal infection occurrs most readily from early autumn to mid-spring (Crist and Friese 1993). Decomposition rates can be significantly higher under snowpack (winter) than during dry summer conditions and may explain why lower seed survival results during this time of year.

Vesicular-arbuscular mycorrhizal (VAM) fungi have been found to play an important role in succession of rangeland systems. Rangeland plants, particularly shrub species, hosting VAM fungi generally have improved water relations. Non-mycorrhizal weedy species attempting to establish in an area already inhabited by species with VAM are rarely competitive (Goodwin 1992).

A prominent shrub-steppe granivore, *Pogonomyrmex occidentalis* (western harvester ant), when choosing seeds to transport back to its nest, distinguishes between fungal-infected seeds and non-infected seeds (Crist and Friese 1993). This rate of non-infected seed removal by the ants was nearly twice that of the infected seed. This type of animal interaction can dramatically skew germination rates.

Seed size can provide an advantage to seedlings attempting to establish in low soil moisture conditions. Larger seeds have a higher emergence and survival rate than small seeds in most conditions. The difference between the survival rates of large and small seeds diminishes under increasingly dry conditions (Leishman and Westoby 1994).

In addition, large seed size generally produces larger seedlings, which are typically more robust than those seedlings established from smaller seeds (Jordan 1983, Young and Evans 1986, Kitchen and Monsen 1994). A larger seedling is less vulnerable to being dislodged from the soil by impact of rainfall, surface water erosion, or wind. In droughy conditions, larger seeds have the advantage over smaller seeds because of their initial placement within the surface soil. A larger seed will begin to grow its roots from a deeper depth than a smaller seed provided both seeds are buried at sufficient germination depths for their species. As the surface soil begins to dry following a premature rain event, the seedling establishing from a larger seed will sooner have a root tip deeper in the soil than a seedling establishing from a smaller seed (McGinnies 1984, Leishman and Westoby 1994). The seedling established from a smaller seed would be more vulnerable to water stress than the other.

Establishment

Soil moisture and temperature apparently contribute more towards the distribution patterns of aridland species than do the chemical constituents of the soil or its profile characteristics (Daubenmire 1969a, Daubenmire 1972). Annual precipitation, and indirectly soil water potential, seem to play a very significant role in the establishment of shrub as well as grass and forb species (Campbell and Harris 1977, Nelson and Tiernan 1983, Briedé and McKell 1992). In arid and semi-arid environments, two consecutive years of above average precipitation provide good moisture conditions for seed establishment (Jackson et al. 1992, Slayback et al. 1995). Readily available soil moisture within the rooting depth of most aridland plants will largely determine the success or failure of individuals. The establishment of an aridland species from seed can be successful with low soil moisture levels near the surface of the seedbed if soil moisture at depth is sufficient for growth and development. This can create a mosaic pattern of establishment (Briedé and McKell 1992). *Artemisia tridentata* and *Pursia tridentata* are both large aridland shrubs that are believed to significantly increase soil moisture levels directly below their canopies by shading the ground beneath them (cooling of soil surface) and by reducing ground-level wind (reducing evaporation from soil surface). Because these plant species cover approximately 20% of the ground surface in their communities, their existence helps to determine the placement of such species as the late-maturing *Poa pratensis* (Daubenmire 1969a, Daubenmire 1975a, Daubenmire 1975b). *Bromus tectorum*, on the other hand, prefers soils that dry deeply and are not found as prominently beneath the canopy cover of the larger shrubs.

Competition

In arid and semi-arid regions, available soil moisture levels during the growing season are affected by warmer air temperatures and low precipitation amounts. These characteristics affect the transpiration rates of the rangeland plants. With limited available water, all plants attempt to uptake moisture as necessary for optimal photosynthetic and metabolic activity. This is not always possible, creating potential competition for moisture between species (Reichenberger and Pyke 1990, Goodwin 1992, Sheley 1994).

Direct Effects

Plant individuals respond differently to the presence of other individuals. The survival and growth characteristics of shrub seedlings located near to adult shrub individuals typically are significantly lower than seedlings located further from adult shrubs. Few naturally occurring shrub seedlings as well as some naturally occurring annuals emerge under the canopies of mature plants. In addition, when the mature plant canopy is removed, the numbers and biomass of the annuals increase as a direct result of the lessening of competition. *Bromus tectorum* (cheatgrass) is a non-native, weedy annual that responds favorably to the removal of a shrub canopy. Once *B. tectorum* invades and successfully dominates a site, it typically remains the dominant annual for three to five years (Holmgren and Basile 1959).

In arid and semi-arid environments, climatic conditions may become extremely variable throughout a year or across years. This type of varying condition may be expected to foster a situation where the size of plant populations would be forced to decrease in some years to levels below which competition would no longer exist (Fowler 1986). This phenomenon occurs in some water-limited grasslands, where perennial grass populations were reduced by droughty conditions thus nearly eliminating density-dependent effects between the remaining species. The opposite also occurs. In an arid or semi-arid environment, a year of greater than normal precipitation and lower than normal air temperatures may cause many plant populations to increase in biomass and density in greater amounts than otherwise expected (Slayback et al. 1995). Should that year be followed by a more droughty year than normal, those newly established plant individuals will be forced into fierce competition for the remaining resources (Fowler 1986, Reichenberger and Pyke 1990).

Both of these scenarios do occur and support two different arguments for competition in arid or semi-arid conditions. The dilemma with these findings is that most of the experimental studies concerning competition in this type of an environment are short term and last less than five years. Aridland restoration utilizing direct seeding may yield highly variable results because of the unpredictability of the weather during seed germination, and because of competition (Fowler 1986, Briedé and McKell 1992).

Broadly defined, competition among plant individuals is not limited to a single growth stage. Competition may affect survival, growth, or reproduction (Reichenberger and Pyke 1990, Fowler 1986).

The importance of competition can often be gauged by the abundance of roots in the surface soil (Fowler 1986, Reichenberger and Pyke 1990). Perennials occupy rooting zones that are both wider and deeper than those of annuals, and perennials can occupy different depths of the soil. Woody plants tend to root more deeply than grasses, and it is this type of rooting separation that allows many plant species to coexist, competing for resources in different strata of the soil medium.

Belowground gaps in rooting may play an important role in the seedling survival of perennials in arid or semi-arid environments. Establishment of perennials may be enhanced with a soil disturbance that would create a surface gap in the rooting zone that would provide an environment of reduced competition. This type of disturbance would determine the relative abundances of species in these dry communities in much the same way a forest canopy gap would determine the relative abundances in mesic communities (Reichenberger and Pyke 1990).

Seeding Technology

The shrub-steppe of eastern Washington has been managed largely for grazing purposes, and until only recently, grazing was a major activity at the research sites evaluated in this study. Management for grazing often includes sagebrush removal by surface scarification (chain dragging or plowing), chemical spraying, cutting, or burning (Mueggler and Stewart 1980). These treatments may be applied several times a year. These treatments remove the less palatable plant species, often shrubs, in order to favor growth of grasses and forbs which are more desirable for livestock.

Such management requires the removal of the unwanted, established species followed by reseeding with desirable grasses and forbs. Prior to any reseeding or rehabilitation of arid rangelands, numerous factors that affect seeding success must be taken into consideration. The use of native species must not be attempted without first determining from where their seeds have been harvested and whether that location matches the environmental conditions of the site to be reseeded. Soil conditions are critical to a seedling's success, including whether there is enough soil moisture, if suitable soil temperatures will be reached, and if soil bulk density meet the needs of the species to be used (Plummer et al. 1968). Ideal seeding depth, which is related to seed size, must be known for each species to be planted. Seedling vigor characteristics and the removal of plant competition should also be considered for each species (Laycock 1982, Kitchen and Monsen 1994). The local topography must also be considered in terms of the type of equipment planned to be used.

Rangeland Drilling

The rangeland drill is a piece of equipment towed like a trailer behind a farm tractor and powered by that tractor's PTO (Power Take-Off) shaft or by the rotation of the drill's wheeled axle. The rangeland drill is designed to distribute seeds in furrows or drills. It is constructed of thick steel framing carried by steel rimmed rubber tires (Figure 1). On the frame of this trailer sit two seed-boxes which hold the seed that is to be dispersed. The boxes are agitated by steel rods, forcing seeds to escape the boxes through an adjustable orifice. The seeds slide down through rubber hoses to be deposited just behind heavy disks which open the soil into the shallow furrows (
Figure **2**) (Larson 1980).

Broadcast and Aerial Seeding

Broadcast seeding is far less machinery-intensive, but is also very inefficient compared to drill seeding (Laycock 1982, Young and Ross 1992, Young et al. 1994). Because it is an inexpensive and relatively non-technical operation, broadcast seeding is regularly used in reseeding degraded aridland sites such as abandoned mine sites.

Broadcast seeding is not hampered by extremely rough or rocky terrain and therefore has some advantages in those situations (McArthur et al. 1987). Such terrain would be impossible to reseed with a drill, but would still offer plenty of suitable sites (safesites) for seeds to germinate (Vallentine 1989, Young 1990). It is these types of non-uniform terrain sites that offer the highest success for broadcast seeding (Jha and Singh 1992, Young and Ross 1992).

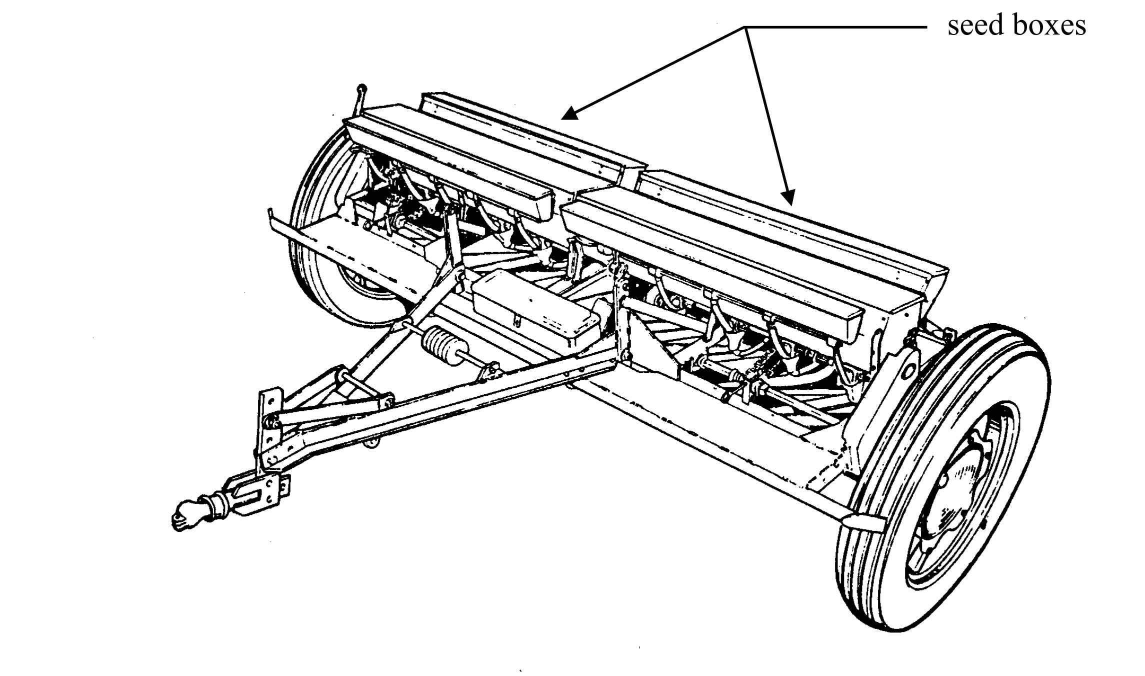

Figure 1. Standard rangeland drill (front view) (Larson 1980).

Seeding rates using broadcast seeding can vary widely (Vallentine 1989). Heavy rates of seeding may produce thicker stands earlier for some species, however within 10 years of seeding, usually no observable differences are found between areas seeded at different densities (Laycock 1982, Hirsch and Nilson 1990). Unless care is taken, the expenditure of 40 to 80 seeds per square foot can accidentally occur with a small-seeded species when far fewer seeds are actually needed. In some *Artemisia tridentata* zones, one perennial grass species established per square foot is a fully stocked stand (Young and Ross 1992).

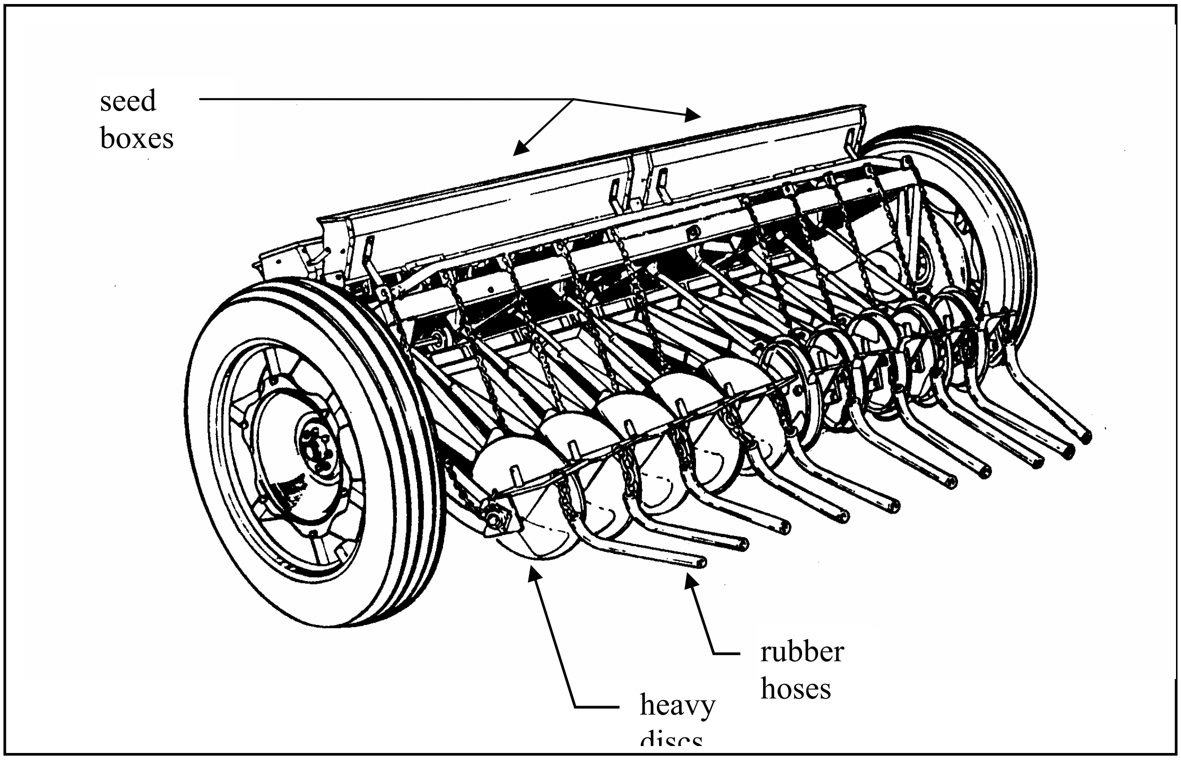

Figure 2. Standard rangeland drill (rear view) (Larson 1980).

In any type of seeding including broadcast seeding, a light soil cover over the dispersed seeds should be achieved to ensure the successful germination of those seeds (Blaisdell et al. 1982). Attempts to broadcast seeds of native dominant, perennial grasses onto untilled, depleted rangeland have generally failed (Vallentine 1989).

Aerial seeding, a specialized broadcasting method which utilizes a helicopter and suspended bucket, can also be used for seeding. On days where there are light winds (less than 10 miles per hour), proper seed distribution can be achieved. This method is most often utilized for reseeding treacherous terrain or areas of large acreage.

Hydro-seeding

Hydro-seeding is a major method of industrial revegetation in the United States. Hydro-seeding provides a seedbed environment conducive to germination after a seed and fiber mixture is applied. A slurry of water, mulch, and seed is pumped from a mixing container and sprayed over the landscape of the area to be reseeded. The mixture includes the moisture and nutrients needed to initiate and maintain germinating seedlings (Young and Ross 1992). A criticism of hydro-seeding is that the equipment often destroy a large portion of the seed as they pass through the pumps.

Hydro-seeding is often very effective in mesic environments which can allow for fast growth rates (Anderson 1990). When seed is applied by hydro-seeding, the seeds are placed on the soil surface along with a protective mulch covering and sufficient moisture for germination at that moment. If the seeds are placed on a dry soil at the time of application or if dry conditions occur following hydro-seeding, seed germination will have very little chance to proceed. In aridlands, supplemental irrigation, which can become labor intensive and costly, is sometimes required in order to maintain survival of newly established seedlings. Hydro-seeding is often attempted late in the growing season in an attempt to decrease the time between seeding and the first precipitation events (Anderson 1990).

<u>Imprint Seeding</u>

A land imprinter is an effective implement for producing micro-depressions in the soil to improve water infiltration. An imprinter is pulled behind a farm tractor like a trailer. It is comprised of a solid drum which is designed with many shallow protrusions on the skin of the drum that, when rolled across the landscape, press indentations into the soil. It is these indentations that create sites for the seeds.

The results of seeding with the use of a land imprinter has shown good results in the Southwestern Unites States, where much of the precipitation occurs as intense summer rains (McGinnies 1984). In the northern sagebrush-bunchgrass zones, where over one-half of the precipitation falls as snow and spring rain and most seeds are fall planted, imprinting has not been used as successful.

Some soils are too loose to be successfully seeded by use of a rangeland drill or by broadcast seeding. In these cases, cultipacking (the intentional compaction of soil surface) is often required to achieve the degree of soil firmness needed for optimum control of seed depth at the time of planting as well as improving the water holding capacity of the soil surface. This will ultimately improve capillary transfer of water to seeds in areas of subsurface moisture as well as improve the seed-to-soil contact area. An imprinter can act as a cultipacker where loose soils are found.

<u>Seeding Mixtures</u>

Aridland plant communities often consist of dominant species in each of the major life forms; shrubs, perennial, grasses, and broadleaf herbaceous species. During droughty conditions typical of aridlands or during excessive stress from immoderate grazing practices, one or more species may enjoy a competitive advantage (Reichenberger and Pyke 1990, Young and Ross 1992). Most of the communities found in aridland conditions are identified by a singe dominant species in each existing life form (grass/shrub/forb). Generally, aridland environments experience a limited potential for plant growth due to limited moisture.

A successful rehabilitation seeding in an aridland environment needs only to contain three species; a perennial grass, a shrub, and a broad leafed herbaceous species (Young and Ross 1992). Based on their competitive characteristics, the most important species to establish is a perennial grass, followed by the establishment of a long-lived shrub. To add diversity, the establishment of one or more perennial broad-leaved herbaceous species can be beneficial.

In order to select the most effective species to be included in a reseeding mix, an understanding of how certain species will balance each others' needs is needed. These needs may include the ability of a species to fix nitrogen, the potential addition of nutrients to the soil through litter fall (higher protein content of another species), or the casting of a shadow by a taller shrub species. These types of relationships must be looked for and incorporated into the selection of seeds for a particular mix (Harper 1987).

There are difficulties, however, with using many species in seeding mixtures. More time and effort are typically associated with the collection and preparation of multiple seed species for restoration efforts. Different seed species most often require different seeding depths and rates, requirement which can be difficult to satisfy. In arid or semi-arid environments, there may not be many species that are well suited for seeding (Heady 1975, Harper 1987), however on areas where heavy animal use, former cultivation, or fire has completely eliminated vegetation cover, seeding may be the only practical reclamation means (Holmgren and Basile 1959, Heady 1975).

Weed Suppression and Management

Weed control and revegetation of degraded sites are two of the most challenging tasks facing land managers (Young 1983). Weed control techniques must be specifically matched to each site. All areas are affected by ecological processes, and because of this, partially controlled plant populations respond dynamically and can return to or exceed original population densities following disturbance. It therefore becomes highly desirable to select and control weedy plants and foster an environment that will allow more desirable species to establish and suppress potential invasion of those weedy plants.

Rangeland weed control treatments are designed and utilized to temporarily alter the current plant community succession. It is during this alteration, which is usually short lived, that revegetation measures are administered (Young 1983).

Chemical Use

Herbicide use for selective weed control is often used in arid rangeland environments (Evans et al. 1983, Vallentine 1983, Young 1983). Physiologically-selective herbicides are very rare. Selectivity is usually based on broad differences in growth form, such as grass versus broadleaf or differences in phenology.

The physical and chemical characteristics of herbicides can be used to selectively control certain weedy species (Evans et al. 1983). As an example, atrazine ($C_8H_{14}ClN_5$), a commercial preemergence herbicide, has been used to control cheatgrass that is growing in concert with wheatgrasses (Mississippi State University 1996, Waffle 1996). The relatively shallow rooted seedlings of cheatgrass can be controlled by atrazine (Young 1983). Wheatgrasses are susceptible to the herbicide atrazine, but because atrazine has a very low solubility in water, it does not leach deeply into the soil before it is biodegraded and therefore is not absorbed by the deeper roots of the perennial grasses.

Chemically controlling certain weedy species, then leaving the treated area fallow for a period of time, may also help to alter the growing environment in ways that will benefit desired plant species. If an area is left fallow, the physical nature of the seedbed may change as the amount of litter accumulation on the soil surface is reduced (Vallentine 1983, Young 1983). A reduction of litter accumulation may begin to limit the ability of cheatgrass seeds to germinate. By removing the cheatgrass component of a community, a competitive annual grass will no longer reduce much of the natural resources that are needed by other desirable species to survive (Evans et al. 1983).

Foliar and soil active herbicides can be applied as broadcast sprays either on the leaves of the plant, to be translocated from the leaves to the rest of the plant, or on the soil surface to be absorbed by the roots of the plant (Evans 1983, Vallentine 1983).

Foliar-applied herbicides are often applied at a time which takes advantage of the phenology of the target species, typically applied during the active growth period in late spring. Soil active herbicides require some precipitation to leach the herbicide into the rooting depths of the soil and are thus applied in the fall.

Many herbicides are becoming less effective in controlling their respective weedy species. The evolution of herbicide-resistant biotypes has been documented for greater than 100 weed species (Liebman and Dyck 1993).

Prescribed Burning

Prescribed burning can control vegetation (R. P. Young 1983). Much of the appeal of prescribed burning derives from the view of fire as a natural component of range ecosystems.

Two aspects of fire effects on vegetation need to be considered. These include direct effects, which consist of heat damage to individual plants, and indirect effects, such as how fire affects post-burn community development by altering stand composition and structure. Fire can kill certain plants, such as cheatgrass, and therefore reduce competition with emerging seedlings of reseeded species. Fire also can release resources, such as nutrients and light, to those plants that survive the burn and to the new plants that will emerge during the post-burn (Daubenmire 1969b, Young 1982, Tausch et al. 1993, Pacioretty et al. 1995).

Trees, shrubs and some perennial forbs have meristematic areas elevated on aerial stems, terminal and lateral buds. These are extremely sensitive to fire and can be severely damaged quite easily. Once damaged, the plant must rely on seedling establishment to rebound unless some lower portion of the stem still has a viable dormant bud that was not damaged by the fire or there are viable adventitious buds of the stems or roots (Cook and Stubbendieck 1986). Most grasses and forbs have growing points variously insulated from heat injury because they are located below the soil surface. The degrees of damage sustained by these types of species are proportional to the intensity and duration of the fire that affects their meristematic tissues. Post-burn regrowth is by way of undamaged meristematic tissue for these plants. Most herbaceous plants will survive a fire in this manner. Rhizomatous species are also very effective at surviving fires due to the insulation of their growing points by the soil. Annual grasses, such as cheatgrass, may suffer reduced densities the year after a burn due to the lack of favorable microsites for germination or they may rapidly re-invade the site following burning (R. P. Young 1983).

Grazing

Grazing management is the manipulation of livestock grazing to accomplish a desired result (Laycock 1983). Grazing management include fencing needs, water development, seeding, brush control, fertilizing, salt distribution, and intensified animal husbandry (Laycock 1983). Grazing management can be aimed at improving range conditions with careful study of the desired species, their phenological characteristics, how they respond to grazing pressures during each annual season, and annual re-seeding.

If a grazing management plan does not take into consideration these types of ecosystem issues, the successful rehabilitation of an area may be limited.

Grazing can affect the vegetational composition of a community (Young 1959). Studies have shown that there is more ground cover (live foliage and litter) on the grazed plots when sampled after being grazed for more than 4 decades (Laycock 1983). When analyzing vegetational cover only, no clear trends seem apparent between grazed and ungrazed areas. Apparently, the rates of succession of both grazed and ungrazed areas over time are similar. In opposition to these statements, there are many other studies that show how exclosure areas set up on grazed rangelands have much higher growth rates and cover percentages over a period of three to four decades compared to a continuously grazed rangeland site. For example, a 20-acre exclosure was established in 1939 and basal cover by species was recorded (Laycock 1983). After resampling in 1979, an increase in cover of over 60% was recorded; Thurber's needlegrass increased in cover over 700%, squirreltail increased nearly 300%, and the cover of Sandberg bluegrass stayed about the same. Perennial forb cover increased by 85%, while annual forbs decreased.

Long periods of time (three to four decades minimum) are required for significant vegetational changes to occure in rangelands and are relative to the conditions of the soil, climatic conditions, competing species, and available seed source. In addition, more time is required for a site to progress from a poor to fair condition than from a fair to good condition (S. Young 1958, McLean and Tisdale 1972, Herbel et al. 1973).

Mechanical Removal

Mechanical treatments aimed at the removal of certain rangeland species must be specifically matched to the selected community. There are many options for mechanical removal of rangeland plants depending on the level of effort and the condition of the landscape to be achieved (Barrow and Havstad 1993, Davis 1982, Young 1982, Youtie 1995). A majority of these methods were first designed for the removal of rangeland shrubs, such as sagebrush, in order to develop prime grazing areas.

Root Plows

Usually used in relatively deep soils which are free of rock, the root plow is aimed at killing sprouting roots of shrubs which cannot be killed with a standard plow because of the lack of depth of plowing. The blades are drawn laterally through the soil, cutting and uprooting all species. They are successful at removing sagebrush and mesquite in the southwest and Intermountain area as well as juniper in the Intermountain West. Root plows also tend to destroy desirable herbs and shrubs in the process.

Brush Rake

The brush rake is quite limited on rangeland settings due to its ineffectiveness at removing younger, more flexible plants. The rake is dragged across the surface of the landscape, pulling up older woody brush material such as sagebrush. This type of mechanical removal process has not been proven very successful on a wide scale or on landscapes dominated by small forbs.

Dixie or Pipe Harrow

This is an attachment that is drawn behind a farm tractor that consists of parallel poles, running lengthwise in the direction of pull by the tractor, which have spikes attached to them in order to be pulled through the soil. These are most effective for covering broadcast seed or in areas of post-burn that are very rocky, which restrict the use of larger equipment. Again, this type of equipment is largely used for controlling brush densities.

Rail Drags

A configuration of sharpened rails, either in a ∇ or in a Δ behind the tractor, are dragged along the soil surface in order to cut to the ground any species stiff enough not to slide under the cutting blade edge of the rails. Young plants are typically left alive due to their flexibility. This type of method is primarily aimed at controlling woody species.

Brush Beating

Brush beating involves a series of hammers or flails that are attached to a spinning, horizontal shaft, raised above the ground surface by a trailered (wheeled) frame. The shaft is powered by the tractor's PTO shaft, hydraulically, or by separate engines. The hammers are spun around the shaft, beating down on the standing plant material that are taller than 3 inches. This type of method leaves the soil surface untouched and causes little damage to the understory species. This type of treatment is aimed at reducing brush densities, however stands generally recover in less than five years unless additional measures such as fire or herbicides are employed.

Rotary Mower

A rotary mower is much like a very large lawn mower, except that it is powered by the PTO shaft of a farming tractor and is pulled behind the tractor like a trailer. Very large rotating blades are attached to vertical shafts and cut all vegetation that is taller than a few inches. It is very effective at killing large, non-sprouting shrubs and reducing any contacted vegetative material to litter. Depending on the objective of its use, the rotary mower may be considered a useful tool when brush control is required for less than 5 years, but not for long-term control. It is also limited by rocky terrain.

Surface Soil Plows

There are several types of available plows; moldboard plows, wheatland plows, tandem disk plows, and brushland plows. They all attempt to cultivate the surface horizons of the soil, cutting and burying the live plant material. The different types of plows are designed for different types of terrain.

Plowing following the establishment of cheatgrass is effective weed control to allow the establishment of perennials. This is usually a spring operation unless unusual fall germination occurs. The longer that cheatgrass dominates a site, the greater the seedbank of dormant seeds and the more difficult the seed is to control (Young and Ross 1992).

Anchor Chains

Chains have been designed to be pulled behind tractors. Generally, chain links weighing 90 pounds or more are connected in line. The ends of the chain are attached to the rear of two tractors and the chain is dragged behind them along the soil surface, forming a U shape. The chain virtually scrapes the surface free of vegetation. If more of a rough scarification of the surface is wanted, sharpened steel rods can be welded to the individual links which are to help pierce and churn the soil surface as the links scrape the surface clean.

If the soil surface is very rocky or is comprised of thick, undesirable shrubs, two tracked caterpillar tractors can be used simultaneously, each with one end of the chain attached to it. The two tractors than can maneuver side by side across the landscape pulling the one chain behind them.

Others' Research Successes in Seeding and Habitat Dynamics

Loss of *Artemisia tridentata* and the shrub-steppe of eastern Washington and Oregon has increased as development of open rangelands has become more prevalent. Frequent attempts at restoring the shrub-steppe habitat of these two states as well as other regions are also becoming more prevalent.

Loss of sage grouse (*Centrocercus urophasianus* subsp. *phaios*) habitat has stimulated research into shrub-steppe restoration. Approximately 35 miles southeast from the research sites used in this study, another project involving the restoration of shrub-steppe habitat took place in 1993 (on the Arid Lands Ecology [ALE] Reserve).

The sage grouse populations in the shrub-steppe of both Washington and Oregon have been declining as the contiguous stands of sagebrush, important to grouse lekking and brooding, have declined. Concerns about their status in Washington have prompted efforts to identify areas where habitat restoration and/or species reintroductions may be feasible (Downs et al. 1995).

In 1981 and 1984, massive wildfires removed *Artemisia tridentata* from large areas in eastern Washington. One of the shrub-steppe areas most effected was on the Hanford Site, ten miles from the YTC and just north of the Tri-Cities area. These wildfires were expected to hinder the reproduction of local sage grouse populations for many generations to come.

Since these wildfires, native bunchgrasses have dominated the areas where big sagebrush stands were removed by the fire. The recolonization by big sagebrush of the burned areas has been extremely slow. It was the slow recolonization characteristic of the big sagebrush that spurred the questions of whether artificial seed dispersal would successfully increase their re-establishment and whether some method aimed at the reduction of existing herbaceous species would be needed to improve seedling establishment.

Seeding trials were conducted on undisturbed soil surfaces, mechanically disturbed soil surfaces, and herbicide-treated surfaces. Seeds were collected from remnant *Artemisia tridentata* plants at the perimeter of the wildfires in early December 1992, air dried and refrigerated for 30 days, then broadcast seeded in late February 1993.

On the sites involving an herbicide treatment, Roundup (active ingredient 18% glyphosate) was used. The plots were sampled in August 1993 by counting the number of *Artemisia tridentata* seedlings and determining the condition of the forbs and grasses both around the original parent plants and within the seeded plots. Reducing the competition by use of herbicide in conjunction with being located under the dripline of a parent *A. tridentata* plant appeared to create the most successful growing medium of the three treatments. Mechanical disturbance did not greatly enhance the germination of *A. tridentata* seedlings, however the density of perennial forb seedlings was nearly twice that found in the control and herbicide-treated plots which were associated with the parent plants. The increase in forb seedlings beneath the parent plants may be attributable to the shading and wind protection by the parent plant as well as fairly fertile soils created by shrub litterfall.

Overall, very few big sagebrush seedlings established on any of the study plots. The low levels of germination and establishment of the seeds collected in December 1992 was speculated to be the result of adverse climatic conditions during the previous growing season. Between March and September of 1992, the maximum air temperatures were warmer than in previous years and the average air temperatures were the highest recorded since 1945 even though the precipitation was normal for the year.

In a separate study, seedlings of three subspecies of big sagebrush, *Artemisia tridentata* (*tridentata, vaseyana,* and *wyomingensis*) were subjected to 10 weeks in a growth chamber at a specified temperature regime, below-average, average, and above-average conditions of their native late spring to early summer season. All subspecies at all three temperature regimes were able to successfully establish. The above-average and average temperatures demonstrated a slightly higher growth rate of the seedlings, thus the results of this study suggest that year-to-year temperature variations are not critical in the determination of successful re-establishment in these subspecies (Harniss and McDonough 1975, Harniss and McDonough 1976).

Following an August wildfire on the sagebrush/grass/juniper benchlands adjacent to Pocatello, Idaho, a study involving the seeding of exotic cheatgrasses and forbs by use of a rangeland drill was conducted (Ratzlaff and Anderson 1995). The wildfire swept the area during the summer of 1987 and reseeding was accomplished in November of that same year. Prior to the reseeding, plots within the burned area were designated as controls, left unseeded and undisturbed.

Plant density was greater in the unseeded areas than seeded areas for both 1988 and 1989. Grass species constituted approximately 75% of the plants in the seeded areas, forbs contributed approximately 25%, and shrubs were rare, contributing 0.03% of the total density. Within the unseeded areas, grass species constituted approximately 88% of the plants, forbs contributed approximately 12%, and shrubs were still fairly rare, contributing 0.07% of the total density (Ratzlaff and Anderson 1995).

Conclusions drawn from this study were that the seeding effort produced results counter to the objectives of the rehabilitation plan by impeding post-fire recovery of vegetation, increasing the amount of bare ground and potential for erosion. These results emphasize the need to continue to research and develop reseeding technologies that produce acceptable success rates (Ratzlaff and Anderson 1995).

In another study, mulch applied to the soil surface at the time of seeding actually reduced the rates of establishment among grass seedlings in an arid or semi-arid environment (Belnap and Sharpe 1995). Apparently, certain grass seedlings which are typically found in very sandy soils prematurely germinate due to the effect of the mulch on the soil surface. Normally, surface water in a sandy soil passes through the soil horizons fairly rapidly compared to other smaller textured soils, but water was held in the surface soil with the mulch material for a longer than normal period of time. The seeds of *Stipa comata* (Needle-N-Thread) and *Oryzopsis hymenoides* (Indian ricegrass) can inadvertently germinate at an inappropriate time of the year. Seedlings concentrate their roots in the surface soils to absorb the existing water instead of deploying its roots to the deeper soils (Belnap and Sharpe 1995, Winkel et al. 1995).

In a sagebrush-steppe region of southeastern Idaho, a 12-year study was begun in 1976 to measure the successional patterns that develop following four types of soil disturbances (McLendon and Redente 1990). The disturbance treatments consisted of 1) mechanical removal of vegetation with minimal disturbance to the surface soil horizons, 2) mechanical removal of vegetation where the surface soil was scarified to a depth of 30 cm, 3) removal of surface and subsurface soil horizons to a depth of 1 m, mixed, and then replaced, and 4) removal of the upper 2 m of soil which was then turned upside down and replaced leaving the original lower soil layer on the surface and the original surface layer buried.

The successional dynamics of the study plots during the initial period of data collection (1979-1980) followed a pattern directly related to the extent of disturbance. Greater disturbance fostered the greatest amount of annual-dominated establishment while, in areas with the least amount of disturbance, perennials established and became dominant.

During the 12 years following the initial disturbance, the plots with the least amount of disturbance became and remained dominated by perennial grasses. The plots which were administered more of a disturbance were dominated by annuals for the first four to five years before including any shrub (*Artemisia tridentata*) recruitment. McLendon and Redente (1990) feel that it is not possible on the basis of a 12-year study to predict how a plant community will ultimately develop, however they do believe that given a long enough period of time two distinct community types will form. These community types are grassland habitat and shrub habitat.

A comparison study involving soil water use between a sagebrush-bunchgrass community and a cheatgrass community indicates that the two communities may be able to establish in the presence of each other and still flourish (Cline et al. 1977). In 1974, a community of sagebrush-bunchgrass in the ALE Reserve of south-central Washington was analyzed for water use at different soil depths from the surface, down to 1.8 meters. The same was done for a 30-year-old cheatgrass sward.

The amount of water utilized by each community was significantly different, 15 cm for the sagebrush-bunchgrass community and 8 cm for the cheatgrass community. Their respective water supplies ultimately came from different soil depths. While plant growth was arrested in the cheatgrass community with the onset of summer, the sagebrush-bunchgrass community was able to exploit moisture from further down in the soil horizons with their root system. The use of deeper moisture by the sagebrush-bunchgrass community proceeded to utilize nearly all of the available moisture, leaving very little soil moisture at the end of the summer months.

This study supports the idea that the invasion of deep-rooted perennial plants into a cheatgrass sward may be enhanced by years of above-average precipitation. The precipitation may allow the establishment of deep-rooted plants, offering them a season to extend their rooting system below 0.5 m where there would be relatively little root competition by cheatgrass and an abundance of soil moisture. Until above-average precipitation with normal air temperatures occurs, hope for the reclamation of established cheatgrass communities is dim (Cline et al. 1977).

In another field study dealing with succession in sagebrush, three sites in Wyoming were disked and sampled for vegetation densities (Allen and Knight 1984). During the first three years of the study, weedy species were recorded as colonizing the sites and dominating the cover. In the sites with high weed cover and densities, native species had reduced cover, density, and richness per unit area. Three years after the disking treatment, invasive weeds were much less common, and in many plots, native perennial species that normally dominate later successional stages were just beginning to emerge at low levels. This slow rate of establishment by the perennial species suggests the presence of high weed cover retards the establishment of other species. This competitive nature of the weedy species is often attributed to (1) their effective seed dispersal mechanisms, (2) often deeper rooting systems which deplete soil moisture to the detriment of associated native species, and (3) temporal resource partitioning, where the weedy species maximize their seasonal growth either earlier or later in the growing season than the native species.

Ultimately, rangeland managers must attempt to understand a very complex set of environmental and species characteristics. Aside from all of the decisions that must be made, a rangeland manager cannot predict annual weather conditions, and can only use restoration efforts most appropriate for the environmental conditions. If attempts are unsuccessful one year, attempts should again be made until favorable climatic conditions demonstrate whether the restoration treatments were successful. If a droughty year follows a seeding effort, reseeding should be attempted if possible. Reseeding should be done as soon as the selected seed species begin to no be longer viable, which in the case of many native shrub-steppe species is only one to three years. It is only after a year with above-average rainfall and high naturally occurring germination rate that a decision to change the seeding method or seedmix should be made.

STUDY AREA

Shrub-Steppe of Eastern Washington

Shrub-steppe refers to plant communities which consist of one or more layers of perennial grass with a conspicuous but discontinuous over-story layer of shrubs (Dobler and Eby 1990). This definition was first stated by Rexford Daubenmire circa 1970. Daubenmire found that, in Washington state, this type of plant community was most commonly found to include several *Artemisia tridentata* (big sagebrush) and bunchgrass populations, although other plant species combinations were also identified.

Steppe vegetation came into existence in the Palouse area (high plains semidesert of eastern Washington, northern Idaho, and eastern Oregon) after the Pliocene Epoch (Daubenmire 1993). It was during the Pliocene Epoch that the Cascade mountains were being formed by volcanic layers accumulating upon volcanic layers. As the mountains became high enough, their existence began to disrupt the previous course of moisture-laden air masses moving easterly from the coast. A rainshadow effect began to take place east of the Cascade mountains. As eastern Washington became more arid, the few xerophytes that had existed in selected microsites such as shallow soiled sites or exposed ridges, were able to spread out and inhabit more territory. Gradually, mesic plant communities developed into more arid types of communities.

During the 1840's, as European settlers moved west across the shrub-steppe, many individuals began to convert sagebrush stands, which were typically considered wastelands, into fertile agricultural areas. At that time, little value was placed upon wildlife concerns. The grasslands of Whitman County were the first to be converted from shrublands to productive agricultural lands. In 1893, the World's Fair Commission of the

State of Washington wrote:

> "Eastern Washington is the great wheat granary of the Pacific coast, its peculiar volcanic soil being adapted to the most marvelous extent to the production of all cereals. Every succeeding year adds to the already extensive wheat area of Eastern Washington, and the time is not far distant when the great sage-brush plains will be as one vast field of waving grain."

LANDSAT analysis reveals that there were at least 10.4 million acres of shrub-steppe prior to European settlement (Dobler and Eby 1990). Very few areas remain unaffected by development of some sort. In 1990, it was estimated that 40% of the original shrub-steppe of eastern Washington and Oregon still remained (Dobler and Eby 1990, West 1983) (Figure 3). Grant County, Washington, which once contained the largest number of acres of shrub-steppe, now retains only 35% of its original habitat condition. Most of the more recent conversions from shrub-steppe to something less native has largely been due to irrigated agriculture.

Today, there remain few large contiguous blocks of functioning shrub-steppe. Yakima County currently contains the largest contiguous block of shrub steppe in the state

of Washington at 58% of the original acreage, primarily as a result of Federal control. The Yakima Training Center, controlled by the U.S. Army, and the Yakima Indian Reservation are two of the largest contributors to the county's shrub-steppe habitat (Dobler and Eby 1990). The Hanford Site of adjacent Benton County, controlled by the U.S. Department of Energy, maintains another large contiguous block of shrub-steppe habitat. Of the remaining shrub-steppe habitat that is owned by private citizens, a majority of it is found on

rocky sites or steep slopes where agricultural activities are not practical. Much of this land is found in the Scablands of eastern Washington where the soils are shallow and rock

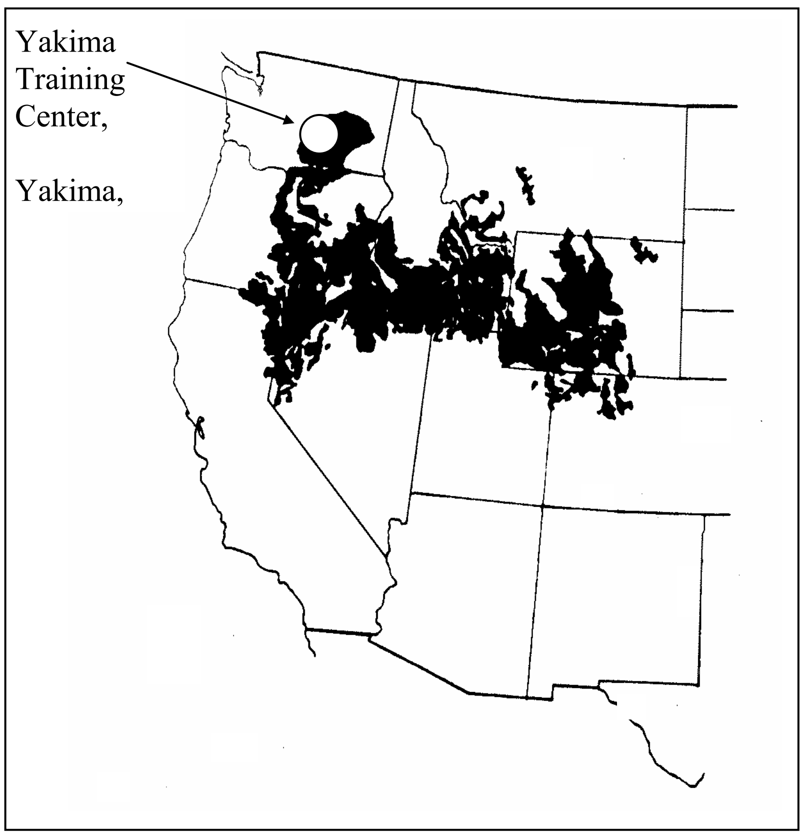

Figure 3. Map of existing western Intermountain sagebrush steppe habitat (Eby 1990).

outcrops are prominent (Figure 4).

Regardless of the type of disturbance or lack of disturbance, there remains no more than a rare fragment of pristine shrub-steppe in the state of Washington. Cattle and sheep grazing, accidental introduction of exotic weeds, and Federal programs which were designed to encourage ranchers to remove sagebrush plants from the landscape in order to foster better growth of grasses has all but eliminated one of the most extensive types of habitats of the state of Washington (Sullivan 1980, Dobler and Eby 1990).

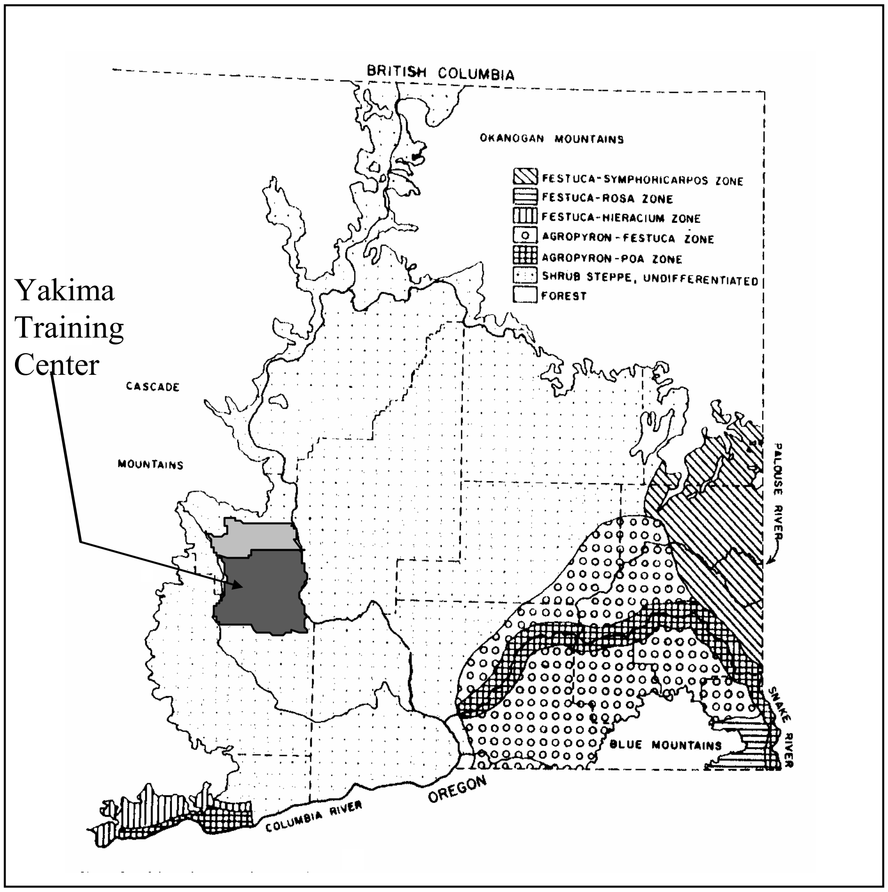

Figure 4. Map showing the distribution of zonal grassland types, including shrub-steppe, within a part of the Palouse prairie located in the eastern portion of the state of Washington (Dobler and Eby 1990).

In 1990, the Washington State Department of Wildlife had identified over 100 wildlife species which utilize shrub-steppe habitat, and of those identified, many are heavily dependent upon its successful existence for their own species survival (Dobler and Eby 1990, Downs et al. 1995). Not all wildlife species suffer a substantial loss with the removal of shrub-steppe vegetation. Irrigated and dryland agriculture has increased the number of waterfowl and exotic game birds in previously shrub-steppe regions. Important shrub-steppe wildlife species such as the sage grouse (*Centrocercus urophasianus*), sharp-tailed grouse (*Pedioecetes phasianellus*), and pygmy rabbit (*Brachylagus idahoensis*), however, cannot survive without substantial areas of high-quality or stable shrub-steppe habitat (Dobler and Eby 1990). There is and will always remain motivation to protect shrub-steppe: the provision of habitat for wildlife.

Western Columbia Plateau

The study sites are located on the western portion of the Columbia Plateau (also known as the Columbia Basin) and are characterized by varied relief with numerous alternating valleys and ridges, perennial and ephemeral creeks, and an underlying basalt bedrock. Much of the region where the study sites are located include basalt cliffs, such as those found along the Columbia River. Elevations above sea level can range from 150 meters to over 1,200 meters. Soil textures are typically clay loam or silt clay loam. Soil parent materials are generally colluvial or alluvial deposits.

The area of research is in a shrub-steppe or steppe region (Daubenmire 1969a) and is characterized by the *Artemisia tridentata* /*Agropyron spicatum* (bluebunch wheatgrass) association (Franklin and Dyrness 1969). The region is dominated by shrubs such as *Artemisia tridentata*, *Chrysothamnus nauseosus* (rubber rabbitbrush), and *Sarcobatus vermiculatus* (greasewood), bunchgrasses such as *Agropyron spicatum*, *Festuca idahoensis* (Idaho fescue), and *Elymus cinereus* (basin wildrye), and annuals such as

Bromus tectorum (cheatgrass). Riparian sites, springs, and drainages often have forbs, shrubs, shrubby trees, and few tall trees. These trees mostly include *Populus trichocarpa* (black cottonwood), *Betula occidentalis* (water birch), *Populus tremuloides* (quaking aspen), and *Salix* sp. (willow). *Juniperus scopulorum* (Rocky Mountain juniper), *Ulmus pumila* (Siberian elm), *Prunus virginiana* (western chokecherry), *Crataegus douglasii* (black hawthorn), and *Pinus ponderosa* (ponderosa pine) may also occur. Because of regionally droughty conditions, few naturally occurring trees exist other than in riparian and spring sites.

The Yakima Valley, in the west-southwest region of the Columbia Plateau, has a mild and dry climate (Daubenmire 1993). The Cascade and Rocky mountains contribute to the presence of both maritime and continental climates. As a result, the area has dry, hot

summers and cool winters with light snowfall. It is during the winter months that the maritime influence is strongest. Prevailing westerlies are strong and steady. During the summer, conversely, afternoons are hot, but due to the dry air, temperatures fall rapidly upon sunset producing cool evenings with minimum temperatures in the 10's˚C (50's˚F) (CLIMVIS 1996).

The Yakima Valley lies in the rainshadow of the Cascade mountains. It is this rainshadow effect that limits the annual precipitation in the area. No rainfall is often recorded for the months of July or August (Table 1).

Table 1. Average temperature and rainfall levels recorded at the Yakima Air Station, Yakima, Washington (CLIMVIS 1996).

Average Annual Climate			
	Recorded High	Recorded Low	Recorded Precipitation
January 1:	11˚C (52˚F)	7˚C (44˚F)	0.08 cm (0.03")
July 1:	27˚C (80˚F)	6˚C (43˚F)	0.00 cm (0.00")

Occasionally, when a mass of cold polar air moves south from Canada into the continental interior, east of the Rocky mountains, and begins to build in volume, the cold air will spill westward of the Rocky mountains and into eastern Washington. This event can drop air temperatures of the shrub-steppe region as low as -45˚C (-43˚F) (Daubenmire 1993).

Snowfall is also limited. On average, the Yakima Valley receives an annual snowfall total of 51-64 centimeters (20-25 inches). During December of 1964 , a record setting 36 centimeters (14 inches) of snowfall was recorded for a 24-hour period while a record setting snow depth of 56 centimeters (22 inches) was also recorded that same month (CLIMVIS 1996).

During the summer months, 85% of the days have full sun, while during the winter months, 32% of the days experience sunshine. The Yakima Valley averages 270 days of sunshine each year and an average annual precipitation of 20 centimeters (eight inches). The average length of the growing season is 195 days. Also, on average, the last day of expected freezing is May 13th, while the first is October 1st. Temperatures below 0˚C (32˚F) are infrequent during the period of May 8th to September 23rd (CLIMVIS 1996).

A review of annual precipitation measurements recorded at the Yakima Air Terminal, Yakima, Washington, details the past rainfall trends (Figure 5). The years of 1961, 1968, 1983, and 1995 demonstrated the highest annual rainfall levels for the past 15 years. Between these years, precipitation was typically much lower, often categorized as droughty. The year of 1994 (first growing season) was a year of below-average rainfall.

A review of daily drought severity index measurements (Palmer Drought Severity Index) recorded at various weather stations within the Yakima valley, indicates that every year between 1987 and 1995, with the exception of 1993, suffered a drought (Figure 6). The Palmer Drought Severity Index depicts prolonged periods (in terms of months to years) of abnormal dryness or wetness (Cornell University 1996). The index responds very slowly to the weekly climatic changes and reflects more long-term moisture, runoff,

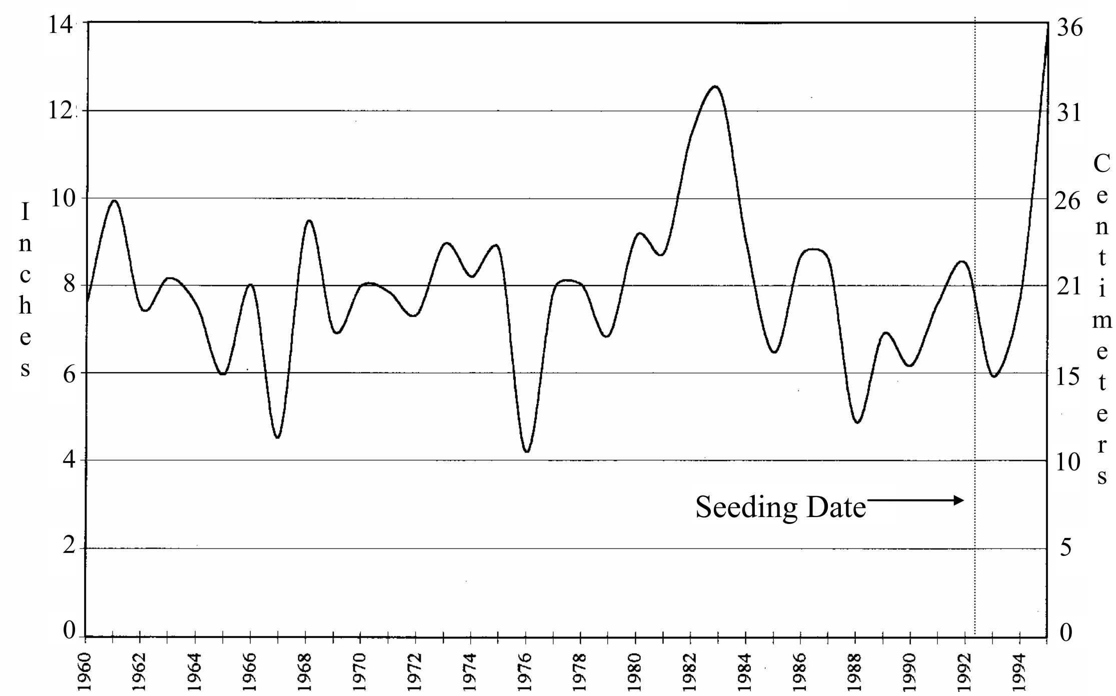

Figure 5. Annual precipitation totals, 1960 - 1995. Measurements were recorded daily at the Yakima Air Terminal, Yakima, Washington (CLIMVIS 1996).

recharge and deep percolation, as well as evaporation (Guttman 1996). The Palmer Drought Severity Index is used primarily as a measure of drought for measured regions. An index value of -4.0 is defined as extreme drought.

Records show that, since 1985, the Yakima Valley area has been experiencing drought conditions, and in the two years between 1985 and 1995 that were not considered drought years, the drought index did not rise significantly. In the year following reseeding measures associated with this research, a drought severity index of -4.1 was measured.

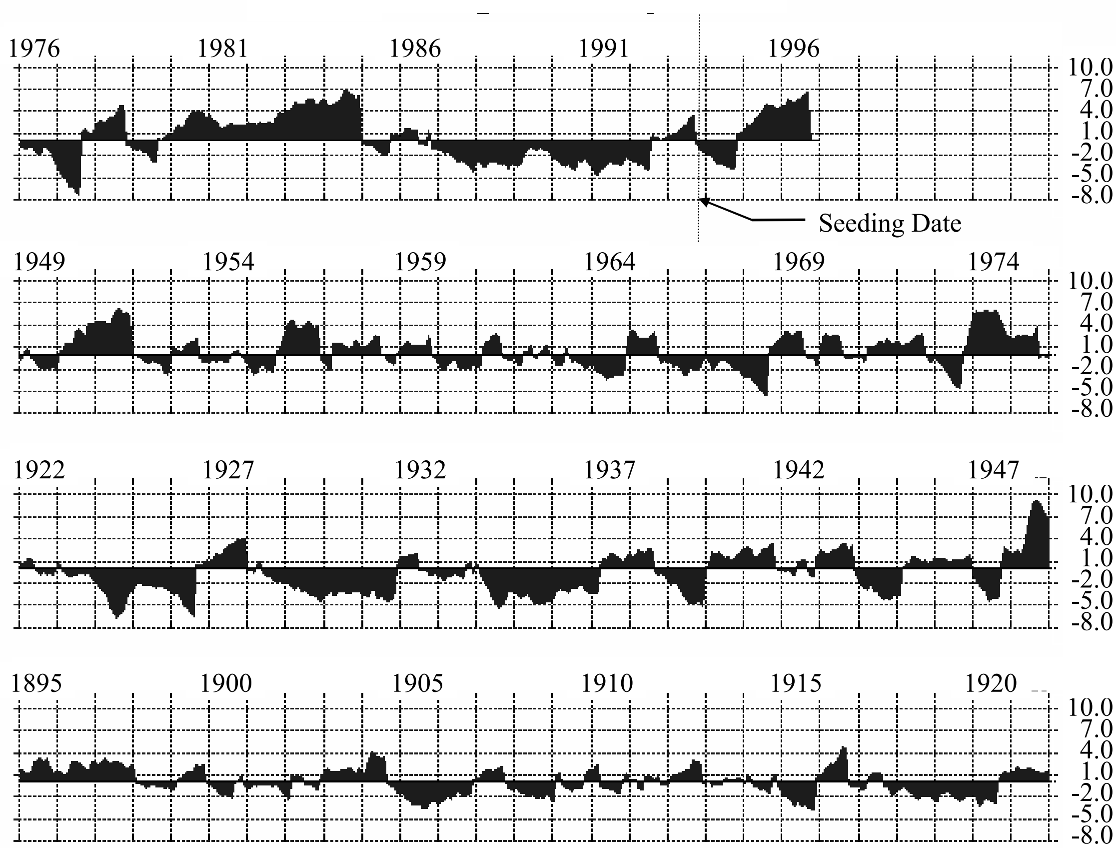

Figure 6. Palmer drought severity index, 1895-1996 (monthly averages); Division 08 (Yakima Valley), Washington (CLIMVIS 1996).

Yakima Training Center

The study sites are located within the boundaries of the Yakima Training Center (YTC). The YTC is a military subinstallation of Fort Lewis owned in fee simple by the U.S. Army. The YTC is located in the south-central part of the state of Washington (Figure 7). It is bordered on the east by the Columbia River, on the south by private lands, and on the west by Interstate 82. A northern expansion area (recently acquired) extends the YTC's northern boundary to Interstate 90.

The over 121,400-hectare (>300,000 acres) facility is used year-round for military maneuvers and weapons training, primarily by Active Army, U.S. Army Reserve (USAR), U.S. Air Force, and Washington National Guard units. The YTC is also utilized by the

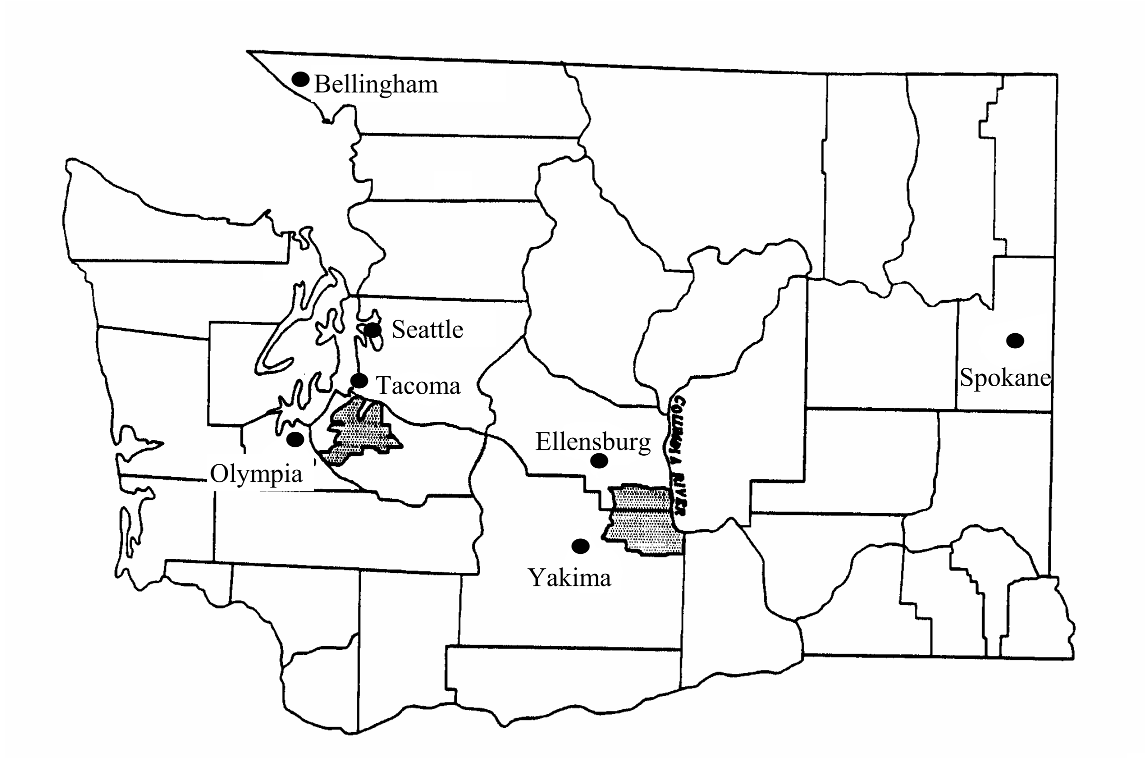

Figure 7. Fort Lewis and Yakima Training Center, State of Washington.

Navy, Marines, Coast Guard, and foreign forces for military training, and by law enforcement personnel (U.S. Army 1989).

A variety of military activities take place year-round at the YTC. Firing activities by military tanks and aircraft in the Multi-Purpose Range Complex (MPRC) are particularly common. A central impact zone is used for live artillery and airborne weapons firing and

explosive ordnance demolitions. Many other smaller firing ranges within the YTC are used for small arms and automatic weapons training. Numerous roads and open terrain

allows widespread troop movements, maneuvers, and soldier air drops. Some open rangelands
were grazed until mid-1995 (for a total of approximately 60 years) by livestock while many of the riparian areas were used by the livestock as water sources. Sport hunting for wildlife still occurs on the YTC.

TA2C and DS3

Both TA2C and DS3 were chosen as study sites due to their similar topographic and disturbance characteristics. They have been mostly undisturbed following the initial seeding and through two growing seasons.

TA2C is 0.89 hectares (2.2 acres) in size and is located on a seven percent slope (Range 2C; UTM coordinate #030-909). It is a southeast-facing alluvial fan. The soil series found within this study plot area is Manastash-Durtash (taxinomically defined as a typic camborthid soil), five to 10 percent slopes (SCS 1993). As confirmed with a soil excavation pit located near the center of the study site, the soil is primarily sandy loam to a depth of 23 centimeters (nine inches) (See Appendix B for full soil description). The soil is
considered moderately deep to hardpan, however, large cobbles were found between 23 and 43 centimeters (nine and 17 inches). The soil is well drained. The permeability of the

soil is moderately to high, and has a moderate to very low available water holding capacity. The potential rooting depth for this soil series is restricted by hardpan generally between 38 and 64 centimeters (15 and 25 inches).

The colors of the soil ranged from light brownish to very dark grayish brown (Munsell 1990). The clay content in the soil ranged from two to three percent. The structure of the soil throughout the profile was massive. The consistence was loose or friable at most depths, and when wet, remained non-sticky and non-plastic. Fine roots were common in the top five centimeters (two inches) of the soil profile and dwindled to few very fine roots at a depth of 15 centimeters (six inches).

At the time of reseeding, the site had been nearly entirely denuded of vegetation. This site had been used as a bivouac site and as a training activity gathering point. These activities involved either setting up of short-term living arrangements such as tents and/or camouflaged vehicle parking areas, or involved using the area as a rendezvous point for training vehicles. The native vegetation on this site had been trampled and the soils compacted. Other areas in the same region, and in areas of the TA2C site, have been seeded with *Agropyron cristatum* sometime prior to the reseeding efforts associated with this research. The established *A. cristatum* has since been disturbed by military activities, thus nearly removing all of the surface vegetation. There were however trace amounts (less than one percent mean cover) of *Bromus tectorum*, *Lepidium perfoliatum* (clasping peppergrass), *Sisymbrium altissimum* (tumblemustard), young *Artemisia* *tridentata*, *Chrysothamnus nauseosus*, *Agropyron cristatum* , *Agropyron spicatum*, and *Salsola kali* (Russian thistle) found on the TA2C site prior to seeding.

DS3 is 1.9 hectares (4.6 acres) in size and is located on a four to five percent slope (Range 7; UTM coordinate #039-758). It is also a southeast-facing alluvial fan. The soil series found within this study plot area is Selah silt loam (taxinomically defined as a lithic camborthid soil), two to five percent slopes (SCS 1993). The soil is primarily silt loam to a depth of 36 centimeters (14 inches) (See Appendix B for full soil description). The soil is considered moderately deep to hardpan, which is found at 36 centimeters (14 inches). The soil is well drained. The permeability of the soil is moderately slow, and has a high available water holding capacity.

The colors of the soil ranged from light olive brown to dark grayish brown (Munsell 1990). The clay content in the soil ranged from a high of four percent to a low of two percent. The structure of the soil throughout the profile was massive. The consistence was loose or soft at most depths, and when wet, remained non-sticky and non-plastic. Fine roots were common in the top three inches of the soil profile and dwindled to few very fine roots at a depth of 36 centimeters (14 inches).

At the time of reseeding, the site had been nearly entirely denuded of vegetation. This site had been used as a training activity gathering point. The native vegetation on this site had been trampled and the soils compacted. The soil surface had been essentially scraped clean of vegetation by all of the military activity prior to the reseeding measures involved in this research. There were trace amounts (less than one percent mean cover) of *Salsola kali*, *Bromus tectorum*, *Lepidium perfoliatum*, *Agropyron cristatum*, *Sisymbrium altissimum*, *Centaurea diffusa* (knapweed), and *Chrysothamnus nauseosus*.

METHODS AND MATERIALS

Experimental Design

On December 2-3, 1993, the two heavily disturbed rangeland sites (TA2C and DS3) received two treatments (two seed mixes and cultivation/non-cultivation) in hopes of rehabilitating native species composition prior to the expected establishment of non-native, weedy species. This combination of treatments created a two-factor design. This particular date for seeding was chosen for its climatic condition. At the time of seeding, fall-like conditions still existed. This date was the latest time in the year that those conditions still existed prior to the onset of winter and freezing ground temperatures.

Comparisons of species composition and mean percent cover were to be made between the treatments after the first and second growing seasons. In addition, descriptive comparisons were to be made between each of the two site's neighboring communities and a single stable shrub-steppe community. The two neighboring communities have not been recently disturbed but both have suffered some sort of disturbance in the past. Each of the two reseeded sites were sampled at regular intervals along a set of transects which spanned each treatment group. The neighboring and stable communities were sampled using a randomized grid selection instead of transects.

The experimental design allowed for comparisons to be made between treatments. Due to the lack of treatment replication, pseudoreplication of data would exist if statistical comparisons were made between individual sites or between the neighboring and stable, shrub-steppe communities. In this case, only descriptive analyses can be applied. To determine whether the reseeded sites were established by species similar to their neighboring sites or to the stable, shrub-steppe site, species composition of the three reference sites were compared to the reseeded sites.

Treatments

Two different seed mixes, two seedbed preparations, and one type of planting technique was used. The combination of treatments was administered to both disturbed sites. Each of the two sites were divided into four treatment areas; 1A, 1B, 2A, 2B. Areas 1A and 2A were drill seeded only. Areas 1B and 2B were cultivated prior to being drill seeded (Figure 8).

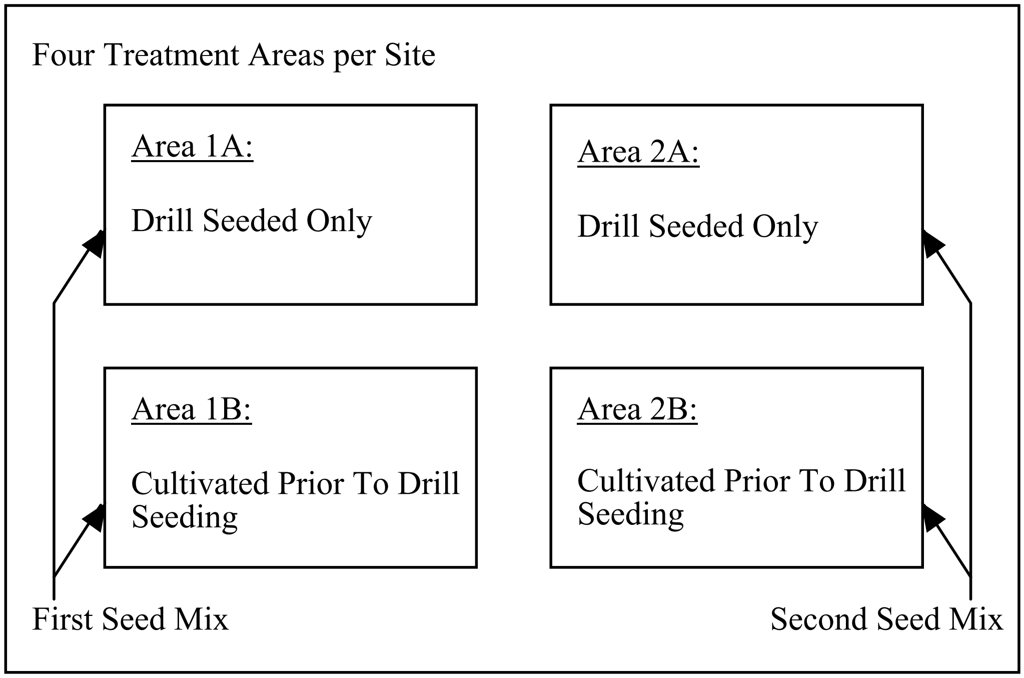

Figure 8. Four treatment areas used at each site.

Drill Seeding

All four plots at each of the two sites were drill seeded using a 2.74-meter (9-ft.) wide rangeland drill and a two-wheel drive Massy Ferguson tractor. The drill seeder consisted of 12 top-loaded seed dispersal boxes which were mechanically agitated as the seeder was pulled across the landscape. Each seed dispersal box was equipped with an adjustable seeding rate control valve allowing for a specific seeding rate. The seeds were dropped into shallow furrows created by the seeder's 12, 90.7-kilogram (200-pound), 81-centimeter (32-inch) diameter rolling discs. The seeder was pulled by the tractor in a direction parallel to the contours of the slight hillslopes upon which the sites were located.

Forward of the seed dispersal boxes were 18, 25-centimeter (10-inch) diameter, light soil cultivating discs. These discs were positioned at a 35˚ angle from the direction of travel in order to lightly cultivate the soil to a maximum depth of five centimeters (two inches) ahead of the seeder.

In order to calibrate the seeding rate of the rangeland drill, the seed dispersal tubes (which transport the seeds from the seed dispersal boxes to the newly created furrows) were detached and replaced with a waterproof tarp. The tarp was attached directly beneath the seed dispersal boxes. One of the two seed mixes was poured into each of the 12 seed dispersal boxes. The seeding rate control valve was set at an appropriate setting for the specific seed mix; approximately 19 kilograms/hectare (17 pounds/acre) for each seed mix. Five trials of 0.8 kilometers (0.5 miles) each were made. Following each run, the expelled seeds which were collected into the attached tarp were weighed on a precalibrated scale to determine how much seed was dispersed. The seeding rate control valve was adjusted following each of the five runs until the desired rate of seeding per hectare was consistently found and recorded. This calibration method was used for each of the two seed mixes.

In order to lightly cover the exposed seeds which were dropped into the created furrows with soil, a light scarification of the soil surface was administered. This covering of the seeds was accomplished by dragging eight aluminum pipes behind the drill seeder.

These pipes were attached to the rear of the seeder by medium grade chain links. As the drill seeder was pulled along the landscape, the loose aluminum pipes scraped the soil surface to lightly cover the exposed seeds.

Soil Cultivation

At each of the two sites, areas 1B and 2B were cultivated prior to being drill seeded. The cultivator, pulled by a Ford 6600 farming tractor, was a standard orchard disc with a hydraulic lift system for accurate depth control. The set depth of the cultivator was no greater than 13 centimeters (five inches). The surface soil was cultivated in a direction parallel to the contours of the slight hillslopes at which the sites were located. This direction of soil cultivation was chosen in order to reduce any potential erosion from spring snowmelt or precipitation that might tend to follow a downhill groove in the soil, and, over time, could create larger rills. The direction of drill seeding matches that of the soil cultivation for the same reason. The cultivator and Ford farming tractor was acquired and operated by a local Yakima, Washington rancher.

Seed Mixes

Two different seed mixes were used at each of the two sites. At the DS3 site, plots 1A and 1B were planted with seed mix #001 (Table 2). Plots 2A and 2B were planted with seed mix #002. At the TA2C site, plots 1A and 1B were planted with seed mix #002 and plots 2A and 2B were planted with seed mix #001 (see Figure 8).

Seed mix #001 is composed of five native species while seed mix #002 is composed of ten native species. All five species found within seed mix #001 are also found within seed mix #002. Each species found in the two mixes was independently tested for the percentage of seed by weight, percentage of pure seed, percentage of successfully germinated seeds, seed origin, and test date.

Table 2. Seed Mixes.

Seed Mix[1] (kg/ha)	Species		Life Form	% Seed[2] (by weight)	% Pure Seed[3]	% Germination[4]	State of Seed Origin	Test Date
#001 (19)	Sandberg Bluegrass	*Poa sandbergii*	grass	15	6.13	79	UT	11/93
	Secar Bluebunch Wheatgrass	*Agropyron spicatum*	grass	25	53.92	94	WA	10/93
	Western Yarrow	*Achillea millefolium*	forb	15	1.61	95	CO	5/93
	Wyeth Buckwheat	*Eriogonum heracleoides*	forb	15	8.23	79	ID	10/93
	Wyoming Big Sagebrush	*Artemisia tridentata* subsp. *wyomingensis*	shrub	30	5.25	87	MT	7/93
#002 (19)	Basin Big Sagebrush	*Artemisia tridentata* subsp. *tridentata*	shrub	10	0.70	95	CO	5/93
	Basin Wildrye	*Elymus cinereus*	grass	5	8.60	95	UT	7/93
	Indian Ricegrass	*Oryzopsis hymenoides*	grass	5	7.94	91	UT	10/93
	Needle-N-Thread	*Stipa comata*	grass	5	6.54	89	WA	5/93
	Sandberg Bluegrass	*Poa sandbergii*	grass	10	21.60	94	WA	10/93
	Secar Bluebunch Wheatgrass	*Agropyron spicatum*	grass	15	28.39	18	UT	7/93
	Tailcup Lupine	*Lupinus caudatus*	forb	10	2.34	87	MT	7/93
	Western Yarrow	*Achillea millefolium*	forb	10	2.72	79	UT	11/93
	Wyeth Buckwheat	*Eriogonum heracleoides*	forb	10	3.64	79	ID	10/93
	Wyoming Big Sagebrush	*Artemisia tridentata* subsp. *wyomingensis*	shrub	20	0.92	82	UT	11/93

[1]Seeds supplied by Stevenson Intermountain Seed; Box 2 Ephriam, UT 84627
[2]% Seed (by weight) refers to the percentage of each species in seed mix.
[3]% Pure Seed refers to the percentage of actual seed numbers in comparison to the other species.
[4]% Germination refers to the percentage of seeds for each species that is viable.

The richness of (number of) species for these two mixes were determined by U.S. Army's Department of Environmental and Natural Resources shrubs, grasses, and forbs.

Sampling Design

Treatment Sites

Within each treatment area of the two reseeded sites, two transects were laid out parallel to the topographic contours of the site with 122-meter (400-feet) vinyl measuring tapes, each equally spaced between themselves and the area boundaries of the site (Figure 9). Each transect was marked at the ends and center with 18-inch steel rebar. Beginning from the eastern end of each transect, sampling quadrats were located every 25 feet. Each quadrat was positioned parallel (lengthwise) to the transect line, always with its northeastern corner on the specified tape location (Figure 10).

A plexiglas Daubenmire frame was designed for use as a portable sampling quadrat. The finished inside dimensions of the frame measured 20 by 50 centimeters (7.8 by 19.5 inches). These dimensions are the smallest sample size that consistently show reproducible statistics for most species of herbs and shrubs in the community under study (Daubenmire 1969a). Sections of the outer rim of the quadrat were painted to help determine percentages of area within the frame (Figure 11).

Baseline Sites

Three baseline sites were chosen for vegetation sampling. Two sites were adjacent to the two reseeded sites (each adjacent to the reseeded site that they neighbor).

The third site (Range 2B; UTM coordinate #055-813) was a representative stable shrub-steppe community located within the YTC boundary but not near either of the reseeded sites. This site is considered stable because it has not suffered from military disturbances and

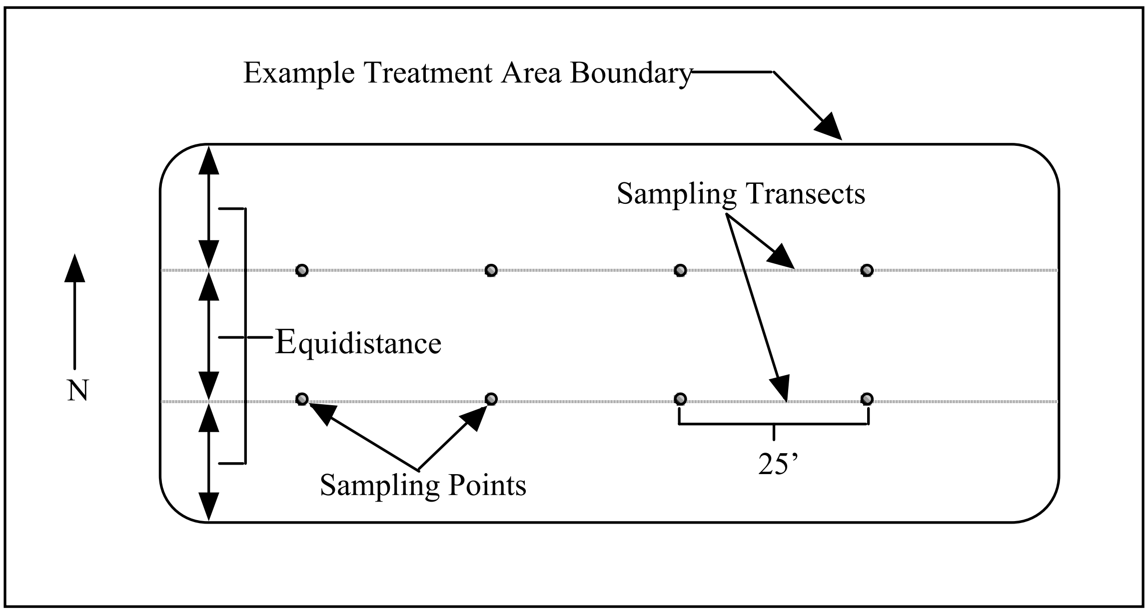

Figure 9. Transect and sampling-point positioning within a treatment area.

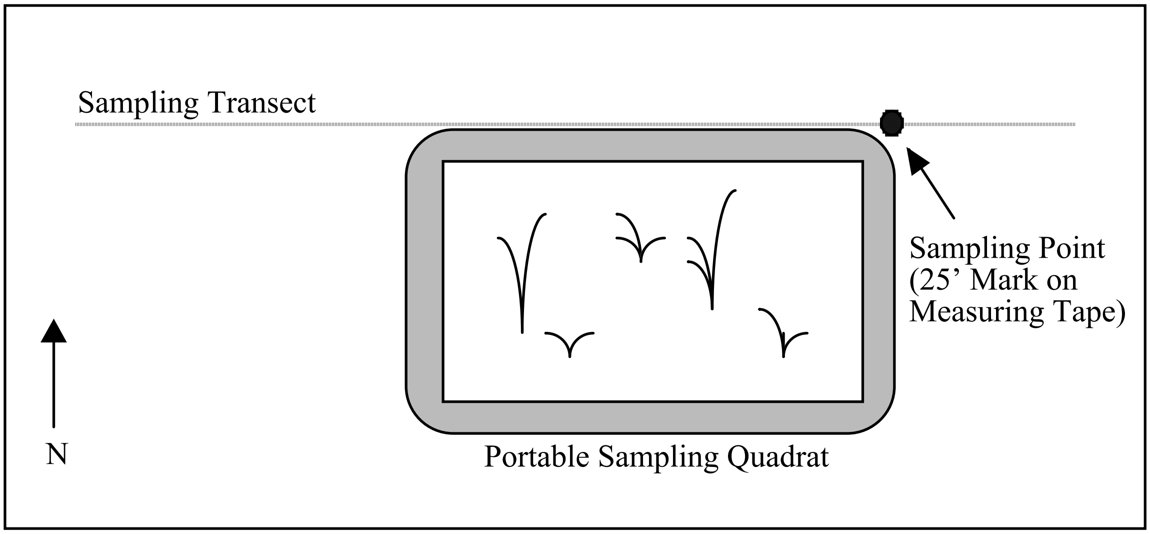

Figure 10. Display of how the quadrat frame is positioned along the transect.

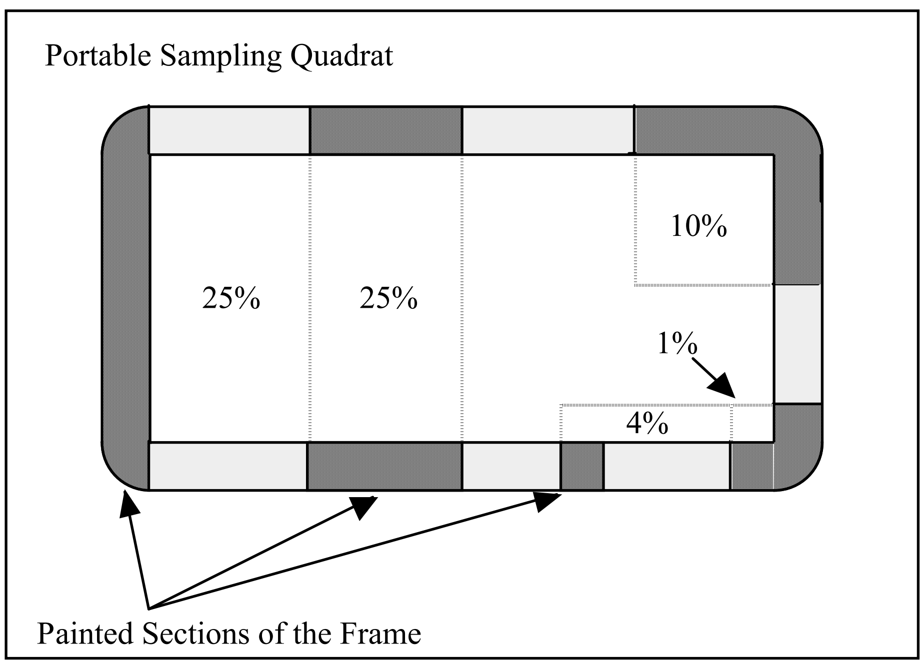

Figure 11. The painted design of the portable sampling quadrat.

has developed an exemplary shrub-steppe community. It is the plant composition and percent cover of this stable community that is the goal for the treatment sites. The corners of a 100 by 100 ft. grid were established and marked with 18-inch steel rebar within these three baseline sites. The grid was established in agreement with the four major compass headings. Random numbers were used to each sampling point. The first number represented the distance east from the northwest corner of the grid; the starting point (Figure 12). The second number represented the distance south from the first directional point. Distances east and south were accomplished in 10 foot increments. Twenty sampling points were created and measured for similar vegetation data as collected at the reseeded sites. The portable sampling quadrat was used to collect

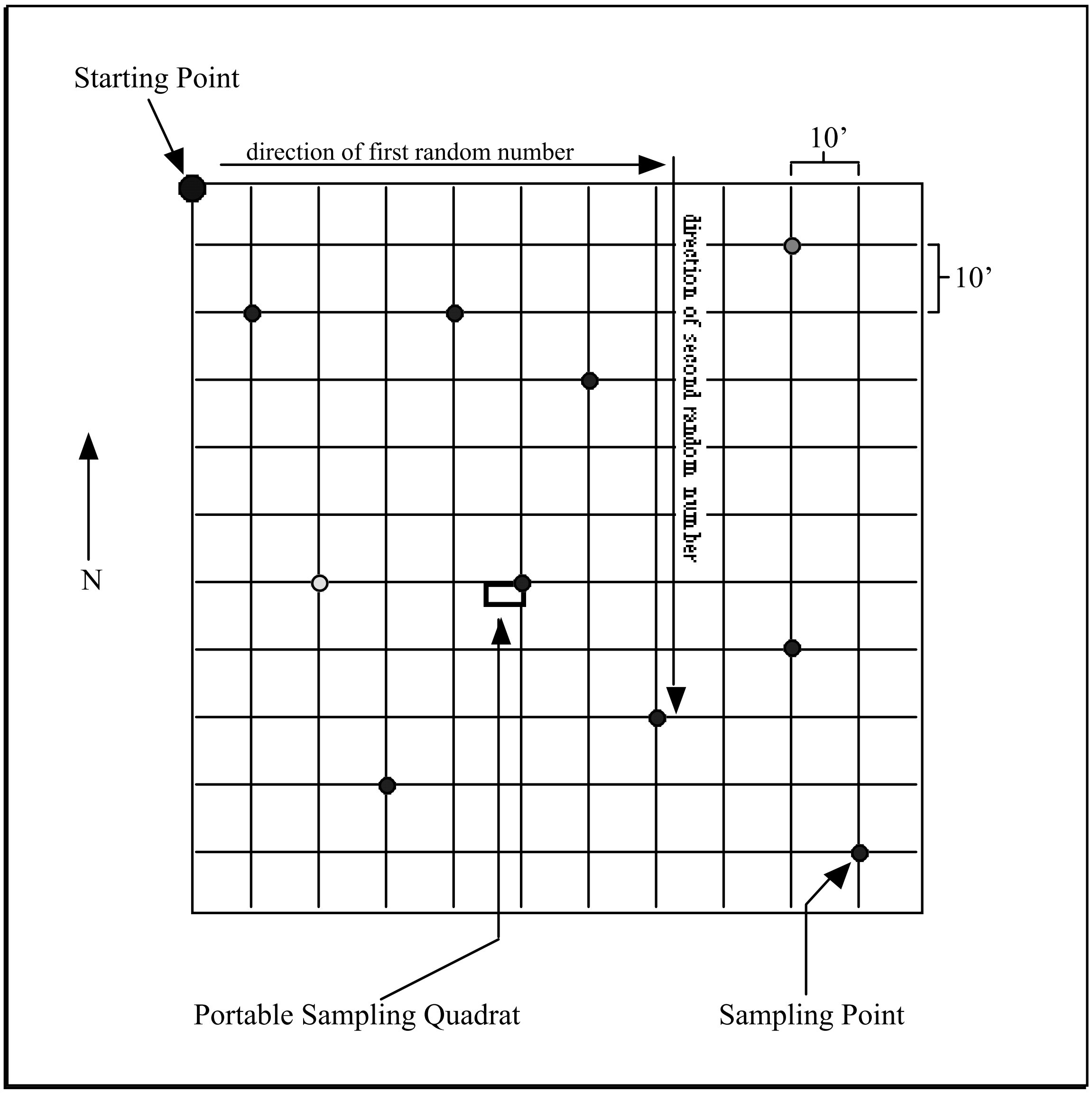

Figure 12. Randomized sampling grid.

the vegetation data. Each quadrat was positioned lengthwise from east to west, always with its northeastern corner on the specified grid location.

Plant Species Data Collection

Data were collected during four sampling efforts. The reseeded sites were sampled in April and June of 1994 and in June of 1995. The baseline sites were sampled in September of 1995.

Within each portable sampling quadrat, percent ground cover, density, and maximum height were recorded for each species. Values of percent cover were recorded in one percent increments between the values of zero and five percent and in five percent increments between the values of five and one hundred percent. If the percent cover value was less than one percent, “trace” was recorded for the species. Density was determined by counting the number of individuals of each species within the quadrat. The height of the tallest individual for each species was also recorded. Where an individual species was unidentifiable, its life form was recorded as unknown grass, forb, or shrub.

Data Analysis

SPSS 6.0.1. and Microsoft Excel® were used for statistical analyses. One-way analysis-of-variances (ANOVA) were used to show significant differences between cultivation treatments, either by year (1994 and 1995) or by species type (native/non-native species only and perennial/annual species only) for June 1995. Four replications (two per site; e.g., 1A and 2A treatment groups) were used for each treatment ANOVA (n = 8). Significance levels were set at 0.05 for all ANOVA's. Simple bar graphs were created to help explain these statistical differences as well as to show the community composition of the reseeded sites, neighboring sites, and the stable, shrub-steppe site. TWINSPAN and DECORANA were used in analyzing and in displaying the collected vegetation data in two-way classification dendrograms and two-dimensional ordination scatterplots (Hill 1979a, Hill 1979b).

TWINSPAN is a cluster analysis program which involves a method of data analysis (correspondence [reciprocal averaging] algorithm) aimed at classifying or clustering similar groups of data (Ecosurvey® 1982). The TWINSPAN program hierarchically clusters the sampling quadrats using a divisive strategy. It first separates the sampling quadrats into two groups based on their similarities, and then further separates each of those groups. Certain species are identified as indicators of one of the two originally created groups (entire sample of quadrats divided into two smaller groups). These indicator species are selected based on their presence in only certain quadrats instead of being common to a majority of the quadrats. They are weighted differently within the algorithm to help determine the similarities between quadrats . Ultimately, a dendrogram (hierarchical tree) is created, graphically displaying groups of quadrats based on their similarities.

DECORANA is a detrended correspondence analysis which involves an eigenanalysis ordination technique based on reciprocal averaging (Hill 1979a). The program analyzes the percent cover data recorded for each quadrat and graphically groups them on three axes based on their similarities (Ecosurvey® 1982). Each axis represents some environmental gradient or treatment difference which affects the percent cover data for each quadrat. Eigenvalues are assigned to each axis. The absolute value of eigenvalues range from 0.00 to 1.00, with 1.00 representing the greatest amount of information that can be derived from that axis. Axes which have eigenvalues of less than 0.50 do not clearly indicate strong environmental gradients. When two of the three axes are combined to create a two dimensional scatterplot, individual quadrats can be graphically displayed in a manner

where their spatial proximity to each other within the scatterplot is a direct relationship to their similarities.

RESULTS AND DISCUSSION

Seeding Treatment Results

The two seed mixes that were drill seeded at each of the two sites did not germinate. The lack of germination is attributed in part to the below-average precipitation of 1994. The Yakima Air Terminal, Yakima, Washington recorded an annual total precipitation of 6 inches and the Palmer Drought Severity Index for division 08 (Yakima Valley, Washington) indicates a measure of -4.1 (-4.0 is defined as extreme drought) (CLIMVIS 1996). Due to the lack of germination by the seed mixes, no analyses have been calculated for this treatment.

Species Composition and Percent Cover of Sampled Sites

Research Sites

Species composition, mean percent cover values, and their variances have been calculated and graphed for the three dates upon which the seeded sites were sampled. The first sampling date was at the beginning of the first growing season following the seeding treatments. The greatest richness of species was recorded during this sampling date. Twenty four species were identified within the seeded sites (Table 3, Figure 13). Ten of the 24 species were non-native, annual, weedy species. One species was a non-native, perennial, weedy species while five were native, perennial, weedy species. One species was a non-native, perennial, grass species while five were native, perennial, grass species. Two species were native, perennial, shrub species. For this sampling date, the amount of bare ground was the highest of the three sampling dates at 62%.

The second sampling date was in the middle of the first growing season following the seeding treatments. The species richness decreased during this sampling date as

Table 3. List of species types and abundances found at the reseeded sites for April, 1994.

Species Type			Number of Species
Non-Native,	Annual,	Weedy	10
Non-Native,	Perennial,	Weedy	1
Native,	Perennial,	Weedy	5
Non-Native,	Perennial,	Grass	1
Native,	Perennial,	Grass	5
Native,	Perennial,	Shrub	2
		Total:	24

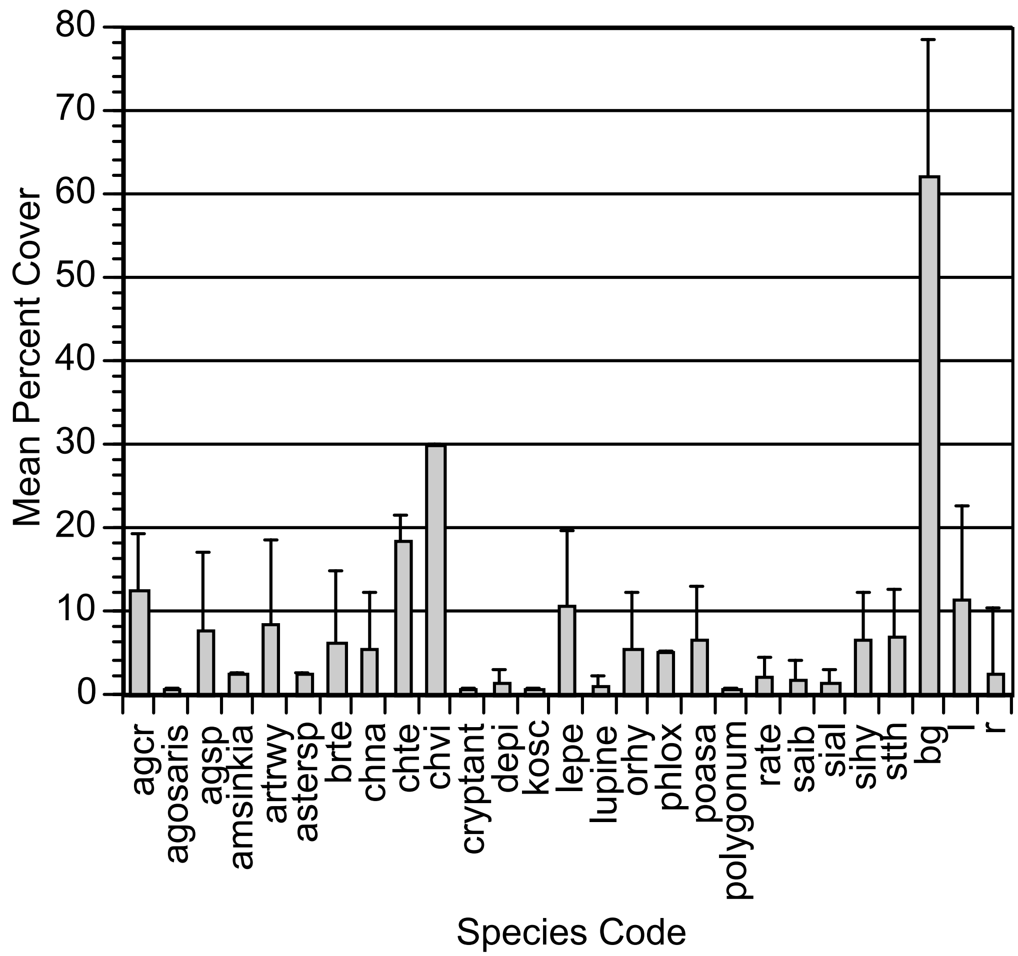

Figure 13. Species composition of seeded sites for April, 1994. (+1 standard error indicated by error bars)

compared to the first sampling date. Fourteen species were identified within the seeded sites (Table 4, Figure 14). Seven of the 14 species were non-native, annual, weedy species. No non-native, perennial, weedy species were found while only one native, perennial, weedy species was found. The one identified non-native, perennial, grass species was the same species as the previous sampling date. Three of the species were native, perennial, grass species. The same two species as were found in the previous sampling date were native, perennial, shrub species. For this sampling date, bare ground was 61%.

The third and final sampling date was in the middle of the second growing season following the seeding treatments. The species richness increased slightly during this sampling date as compared to the second sampling date. Eighteen species were identified within the seeded sites (Table 5, Figure 15). Eight of the 18 species were non-native, annual, weedy species. One non-native, perennial, weedy species was found and one native, perennial, weedy species was found. The one identified non-native, perennial, grass species (*Agropyron cristatum*)was found on the previous two sampling dates. Five of the species were native, perennial, grass species. The same two species as were found in the previous sampling date were native, perennial, shrub species. For this sampling date, bare ground was much lower at 34%.

The one non-native, perennial, grass species that was found across all three sampling dates was *A. cristatum* (crested wheatgrass). It is this species that the U.S. Army currently reseeds damaged training areas at the YTC. The two native shrub species found across all three sampling dates were *Artemisia tridentata* (big sagebrush) and *Chrysothamnus nauseosus* (gray rabbit-brush). The *A. tridentata* is found in both of the neighboring community sites as well as the stable shrub-steppe site while *C. nauseosus* is not found in either of the neighboring communities or the stable shrub-steppe site.

Table 4. List of species types and abundances found at the reseeded sites for June, 1994.

Species Type	Number of Species	Change from Previous Sampling Date

Non-Native,	Annual,	Weedy	7	↓ 3
Non-Native,	Perennial,	Weedy	0	↓ 1
Native,	Perennial,	Weedy	1	↓ 4
Non-Native,	Perennial,	Grass	1	no ∴
Native,	Perennial,	Grass	3	↓ 2
Native,	Perennial,	Shrub	2	no ∴
		Total:	14	↓ 10

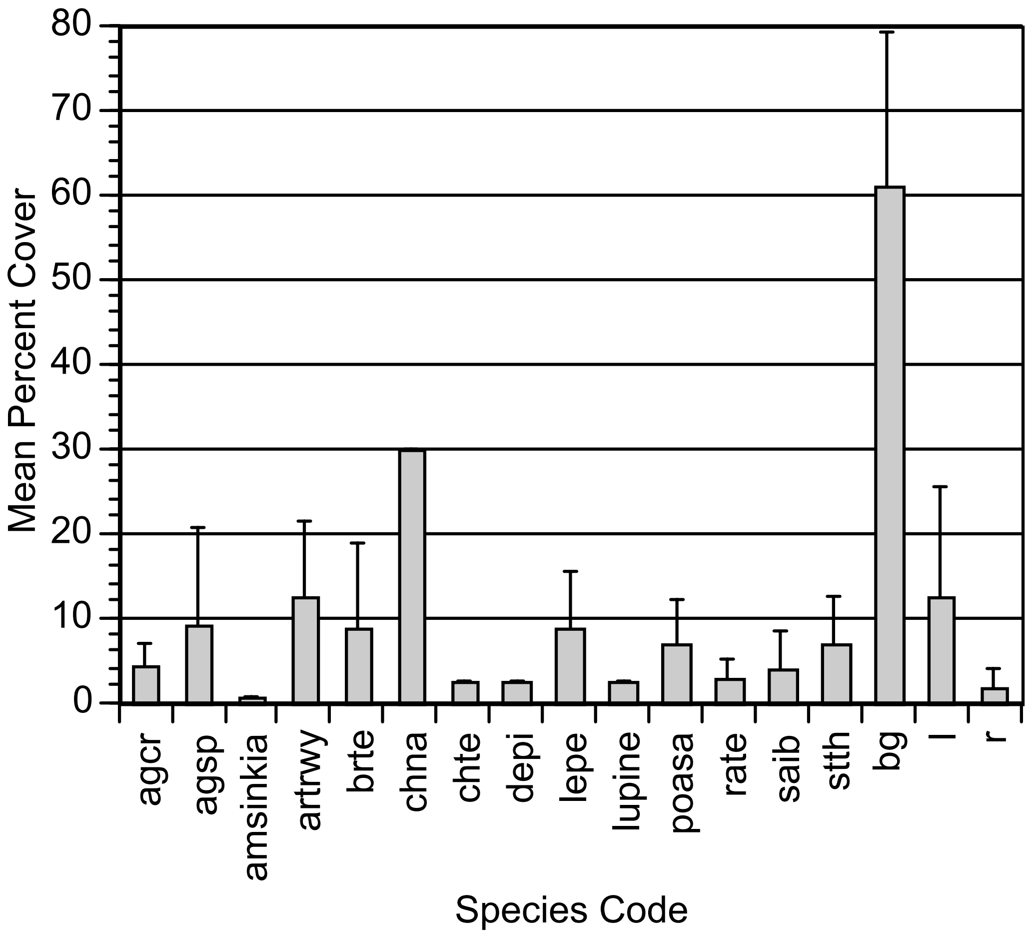

Figure 14. Species composition of seeded sites for June, 1994. (+1 standard error indicated by error bars)

Table 5. List of species types and abundances found at the reseeded sites for June, 1995.

Species Type			Number of Species	Change from Previous Sampling Date
Non-Native,	Annual,	Weedy Species	8	↑ 1
Non-Native,	Perennial,	Weedy Species	1	no ∴
Native,	Perennial,	Weedy Species	1	no ∴
Non-Native,	Perennial,	Grass Species	1	no ∴
Native,	Perennial,	Grass Species	5	↑ 2
Native,	Perennial,	Shrub Species	2	no ∴
		Total:	17	↑ 3

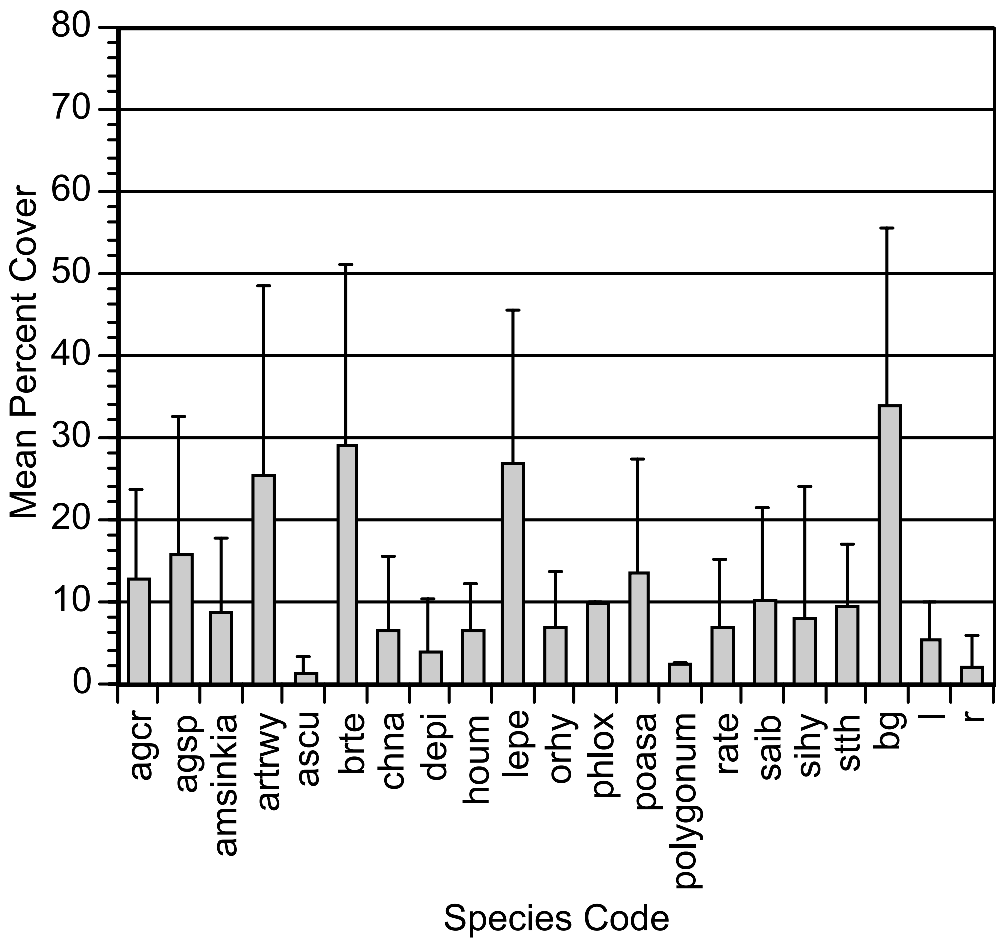

Figure 15. Species composition of seeded sites for June, 1995. (+1 standard error indicated by error bars)

<u>Neighboring Community Sites</u>

The only sampling date for these sites was at the end of the second growing season following the seeding treatments. The species richness of the neighboring communities was less than the last sampling date for the seeded sites. Eleven and 13 species were recorded independently within the two neighboring communities as compared to the 18 species found within the seeded sites during the last sampling date.

Eleven species were recorded for the community neighboring TA2C (Table 6, Figure 16). Five of the 11 species were non-native, annual, weedy species. No non-native, perennial, weedy species were found and no native, perennial, weedy species were

found. One species was a non-native, perennial, grass species while four were native, perennial, grass species. One species was a native, perennial, shrub species. At this neighboring community, bare ground was 51%.

Thirteen species were recorded for the community neighboring DS3 (Table 7, Figure 17). Five of the 13 species were non-native, annual, weedy species. No non-native, perennial, weedy species were found. Two native, perennial, weedy species were found. One species was a non-native, perennial, grass species while four were native, perennial, grass species. Two species were native, perennial, shrub species. At this neighboring community, bare ground was 51%.

Of the four native, perennial, grass species that were identified at each of the two neighboring communities, three of them were found at both sites. They are *Agropyron spicatum* (bluebunch wheatgrass), *Poa sandbergii* (Sandberg bluegrass), and *Stipa* *comata* (Needle-and-Thread). *Agropyron spicatum* and *P. sandbergii* are both species that were found in the stable, shrub-steppe community as well.

Table 6. List of species types and abundances found at the neighboring site to TA2C for September, 1995.

Species Type			Number of Species
Non-Native,	Annual,	Weedy	5
Non-Native,	Perennial,	Weedy	0
Native,	Perennial,	Weedy	0
Non-Native,	Perennial,	Grass	1
Native,	Perennial,	Grass	4
Native,	Perennial,	Shrub	1
		Total:	11

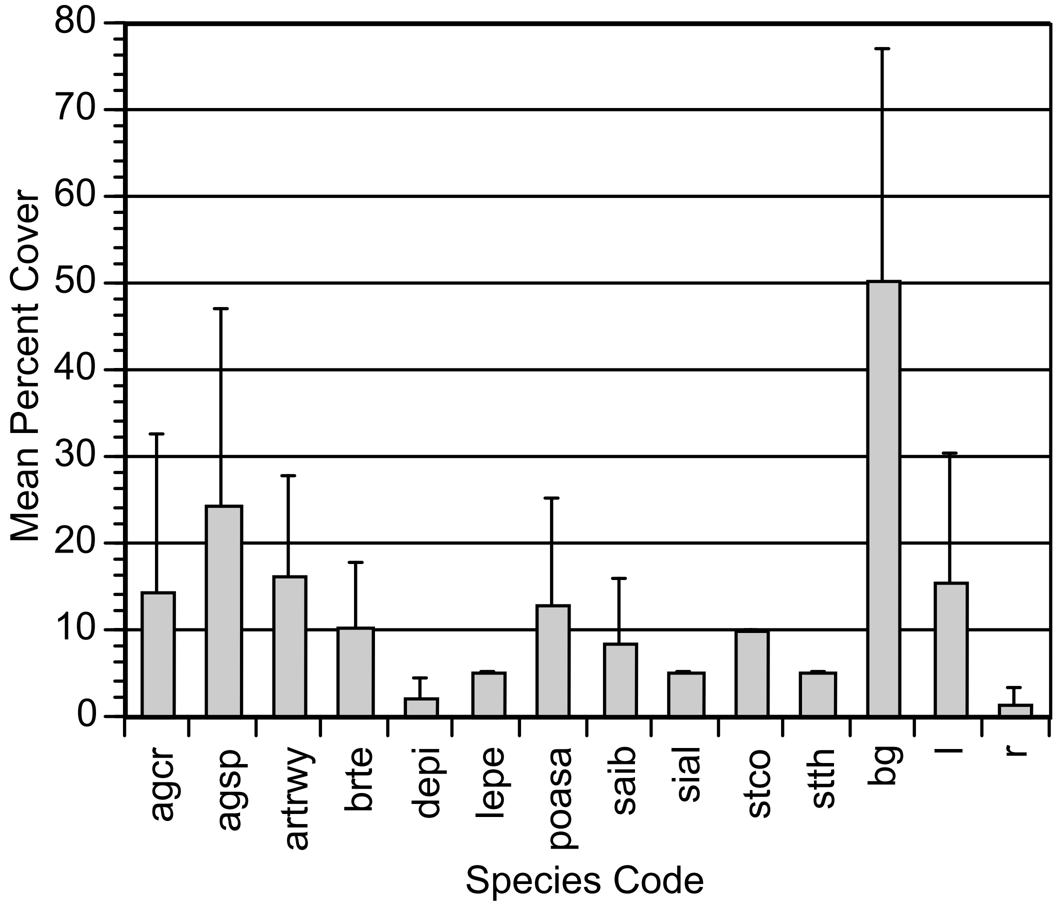

Figure 16. Species composition of the neighboring community to TA2C. (+1 standard error indicated by error bars)

Table 7. List of species types and abundances found at the neighboring site to DS3 for September, 1995.

Species Type			Number of Species
Non-Native,	Annual,	Weedy	5
Non-Native,	Perennial,	Weedy	0
Native,	Perennial,	Weedy	2
Non-Native,	Perennial,	Grass	1
Native,	Perennial,	Grass	4
Native,	Perennial,	Shrub	1
		Total:	13

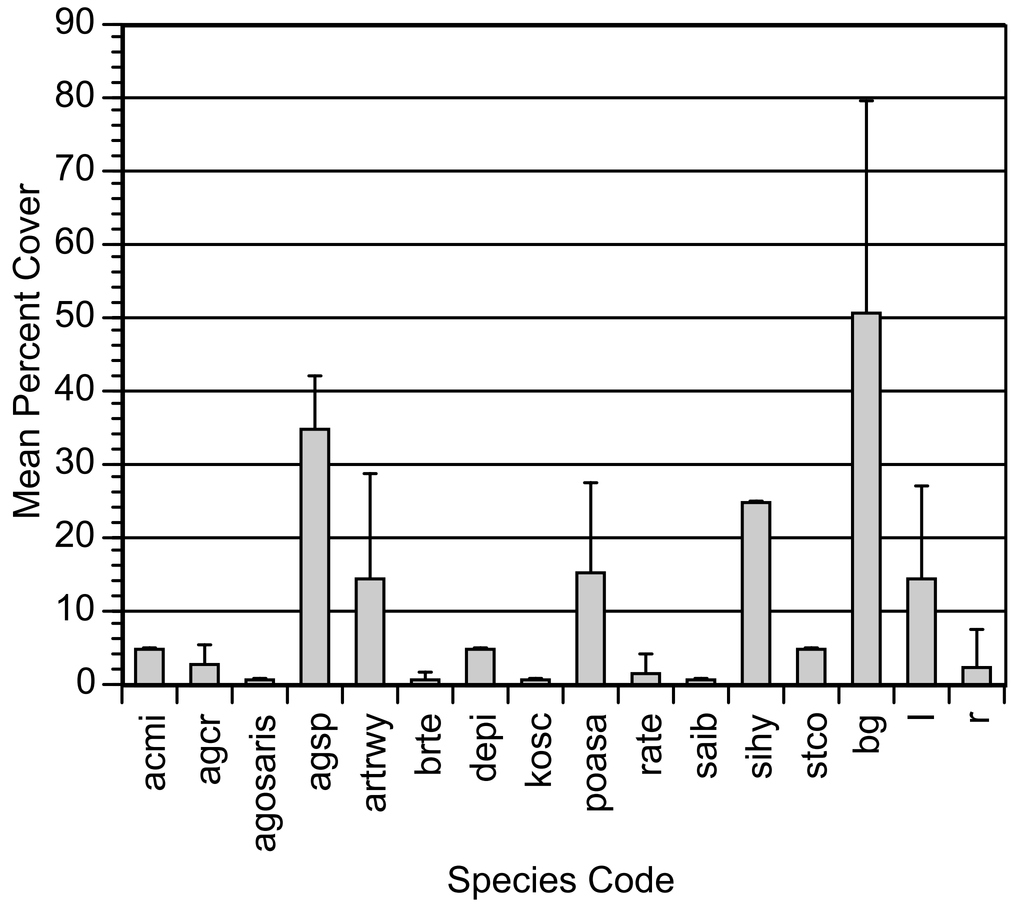

Figure 17. Species composition of the neighboring community to DS3. (+1 standard error indicated by error bars)

<u>Stable Shrub-Steppe Community Site</u>

The only sampling date was at the end of the second growing season following the seeding treatments. The species richness of the stable, shrub-steppe community was less than the last sampling date for the seeded sites. Six species were recorded for this shrub-steppe site as compared to the 18 species found within the seeded sites during the last sampling date (Table 8, Figure 18). Two of the six species were non-native, annual, weedy species. No non-native, perennial, weedy species were found while one native, perennial, weedy species was found. No non-native, perennial, grass species were found while two native, perennial, grass species were found. One species was a native, perennial, shrub species. At this neighboring community, bare ground was 28%.

This community is dominated by *Agropyron spicatum* and *Artemisia tridentata* , a grass and shrub species. This community also has a combined mean percent cover of 48% for bare ground and litter. In addition, the fact that only two non-native, annual, weedy species were recorded may be attributed to the lateness of the growing season, a time when a majority of the annual species are not present in an arid environment.

Cultivation Treatment Results

Analysis of Variance Comparisons

Six analyses-of-variance were calculated for a selected set of data using two treatment levels (cultivation and non-cultivation) prior to drill seeding. Mean percent cover was compared between treatment levels for both June of 1994 and 1995. For June 1995, mean percent cover was compared between treatment levels for perennial species only, annual species only, native species only, and non-native species only.

For the June 1994 data, there was not a significant difference in mean percent cover between cultivation and non-cultivation treatments (Figure 19). The non-cultivated sites

Table 8. List of species and abundances found at the stable, shrub-steppe site for September, 1995.

Species Type			Number of Species
Non-Native,	Annual,	Weedy	2
Non-Native,	Perennial,	Weedy	0
Native,	Perennial,	Weedy	1
Non-Native,	Perennial,	Grass	0
Native,	Perennial,	Grass	2
Native,	Perennial,	Shrub	1
		Total:	6

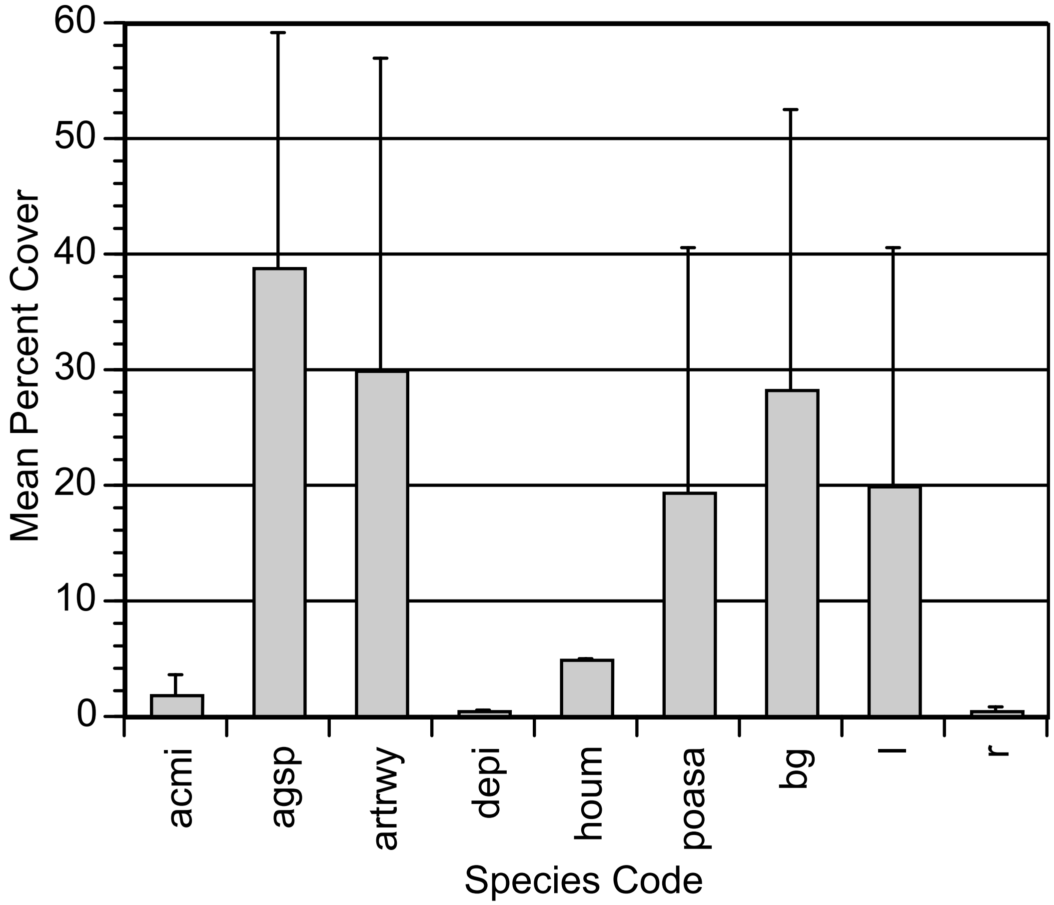

Figure 18. Species composition of the stable, shrub-steppe community for September 1995. (+1 standard error indicated by error bars)

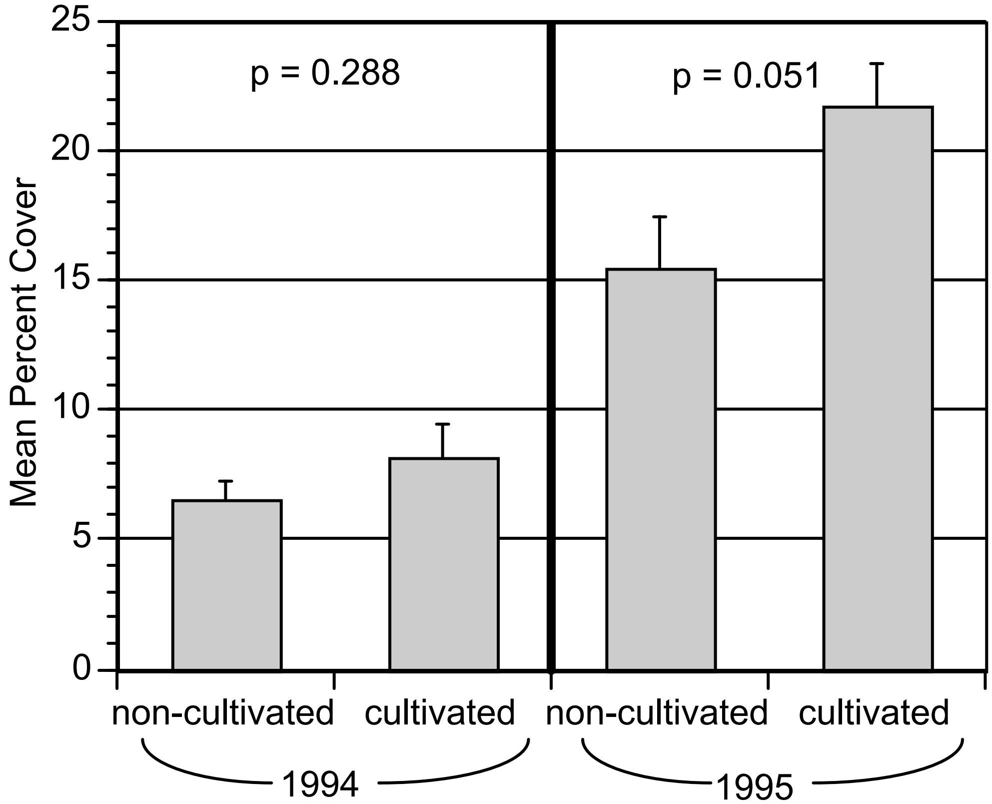

Figure 19. Treatment comparisons (ANOVA) for 1994 and 1995. (+1 standard error indicated by error bars)

had a mean percent cover of 6.5% while the cultivated sites had a mean percent cover of 8.1%. For the June 1995 data, there was nearly a significant difference (p = 0.051) in mean percent cover between the two treatment levels (Figure 19). The non-cultivated sites had a mean percent cover of 15.4% while the cultivated sites had a mean percent cover of 21.5%, a trend that was evident but also not significantly different the previous year.

Comparisons were made between treatment levels for four selected species types for the June 1995 data. The mean percent cover for perennial species only were compared

between treatment levels (Figure 20). No significant difference was found. The non-cultivated sites had a mean percent cover of 17.5% while the cultivated sites had a mean percent cover of 25.7%. The mean percent cover of annual species only was also compared between treatment levels (Figure 20). A significant difference (p = 0.025) was found to exist. Annual species found within the non-cultivated sites had a mean percent cover of 13.9% while the cultivated sites had a mean percent cover of 6.8%. The overall trend between non-cultivated and cultivated sites is reversed for perennial and annual species. Although no statistically significant difference was found and therefore substantial conclusions should not be drawn from it, the mean percent cover of perennials species were lower in the non-cultivated than the cultivated sites. The opposite was true for the annual species.

The mean percent cover for native species only were compared between treatment levels (Figure 21). A significant difference (p = 0.021) was found to exist. The non-cultivated sites had a mean percent cover of 12.2% while the cultivated sites had a mean percent cover of 2.6%. The mean percent cover of non-native species only were also compared between treatment levels (Figure 21). A significant difference was nearly found (p = 0.052). The non-native species found within the non-cultivated sites had a mean percent cover of 16.1% while the cultivated sites had a mean percent cover of

24.5%. The overall trend between non-cultivated and cultivated sites is also reversed for native and non-native species. For native species, the greatest mean percent cover was found in the

non-cultivated sites while the opposite was true for the non-native species. Because a statistically significant difference was not quite found between the treatment levels of the non-native species only, care should be taken when drawing conclusions from the data.

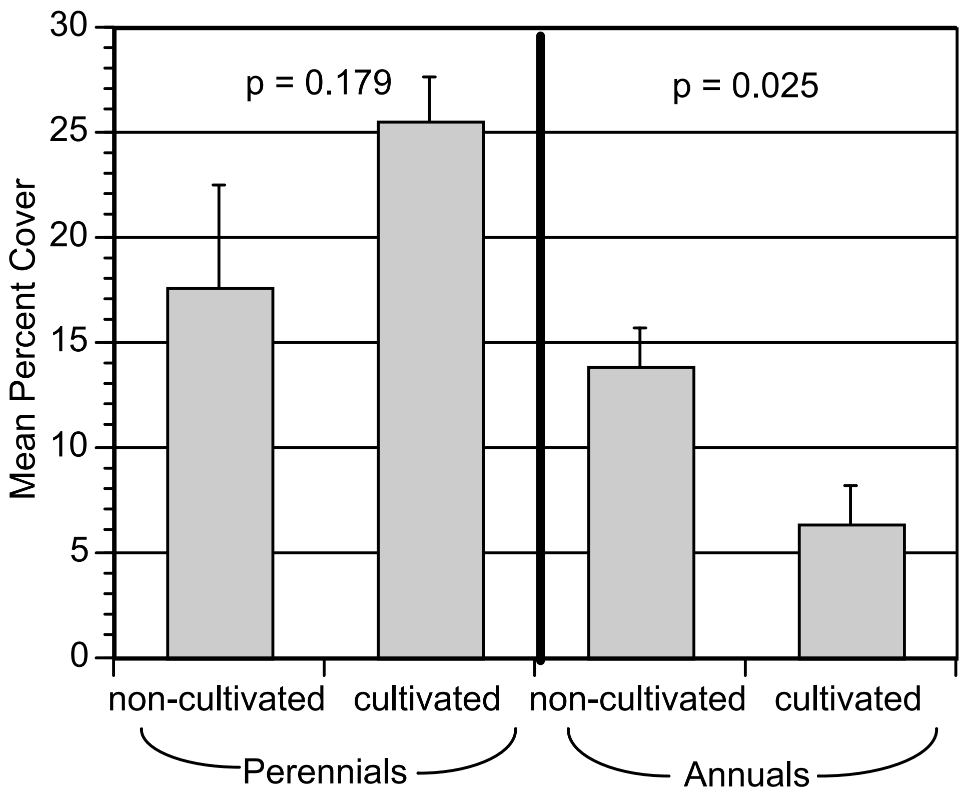

Figure 20. 1995 treatment comparisons (ANOVA) by perennial and annual species.
(+1 standard error indicated by error bars)

Comparisons were made between the culitvation and non-cultivated sites for each of the two seeded sites independently (Appendix C). Statistical analyses could not be applied to these comparisons and therefore are for reference only.

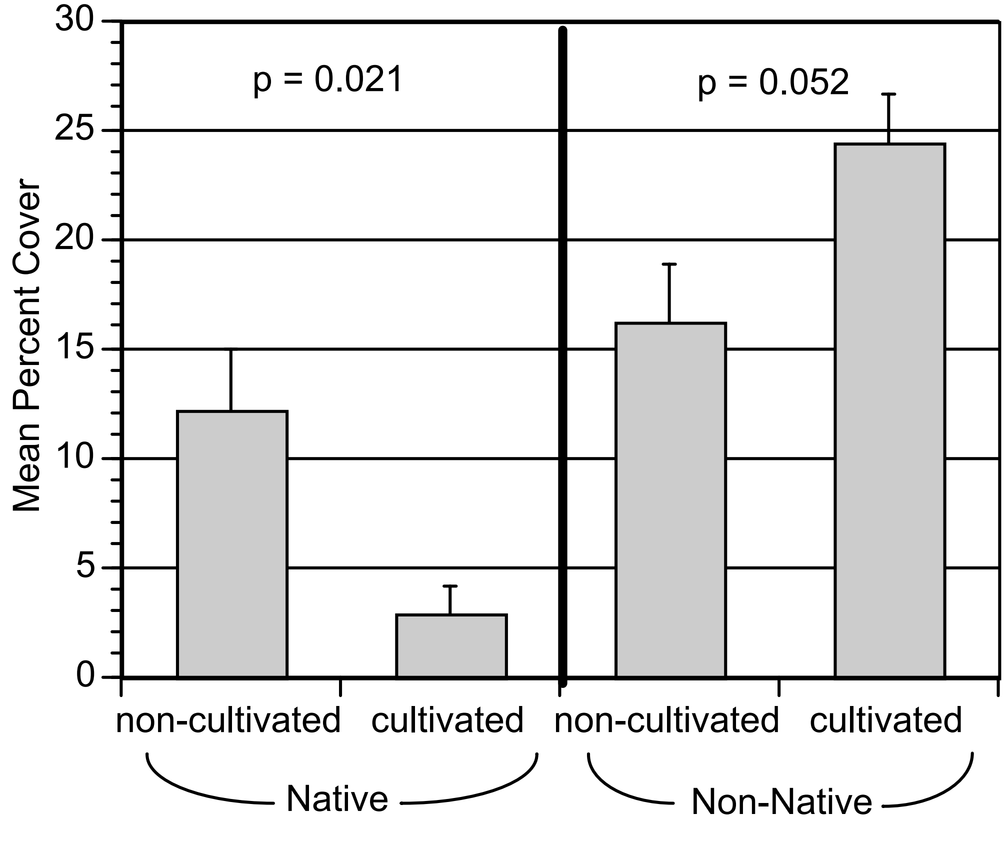

Figure 21. 1995 treatment comparisons (ANOVA) by native and non-native species.
(+1 standard error indicated by error bars)

TWINSPAN and DECORANA

TWINSPAN Output

Three classification dendrograms were created, displaying groupings of randomly sampled quadrats based on the cultivation treatment. This was completed for both sites for each sampling date.

Randomly sampled quadrats for April 1994 are clustered in a dendrogram in Figure 22. For this sampling date, no clear clustering trend is evident in regards to the individual treatment groups. A very low eigenvalue (0.158) is associated with the first level of division into Groups 2 and 3. The low eigenvalue indicates very little difference between these first two groups. Group 2 is largely characterized by the presence of *Poa sandbergii* (native perennial grass) and litter while Group 3 is characterized by the presence of

Chorispora tennella (non-native annual weed). At the second level of division, Group 2 is divided into Groups 4 and 5. A low eigenvalue (0.192) is associated with the division. Group 4 is characerized by the presence of *Agropyron cristatum* (non-native perennial grass; normally seeded throughout the YTC) and *Bromus tectorum* (non-native annual weed). Group 5 is characerized by the presence of *Agropyron spicatum* (native perennial grass), *Ranunculus testiculatus* (non-native annual weed), *P. sandbergii* , and *Lepidium perfoliatum* (non-native annual weed).

At the second level of division, Group 3 is divided into Groups 6 and 7. A low eigenvalue (0.227) is associated with the division. The eigenvalue of this division is slightly higher than the other divisions indicating a slightly greater difference between Groups 6 and 7 than between other divided groups. Group 6 is characerized by the presence of *C. tennella*, *P. sandbergii* , *Salsola kali* (non-native annual weed), and *L. perfoliatum* . Group 7 is characerized by the presence of *A. cristatum* , litter, and *B. tectorum* .

Groups 4, 5, 6, and 7 have been divided further into more sub-groups, but lower level divisions tend to find smaller and smaller differences between groups. Because the eigenvalues of the first two division levels are low and therefore do not indicate much difference between the Groups 2-7, no further levels of division are discussed.

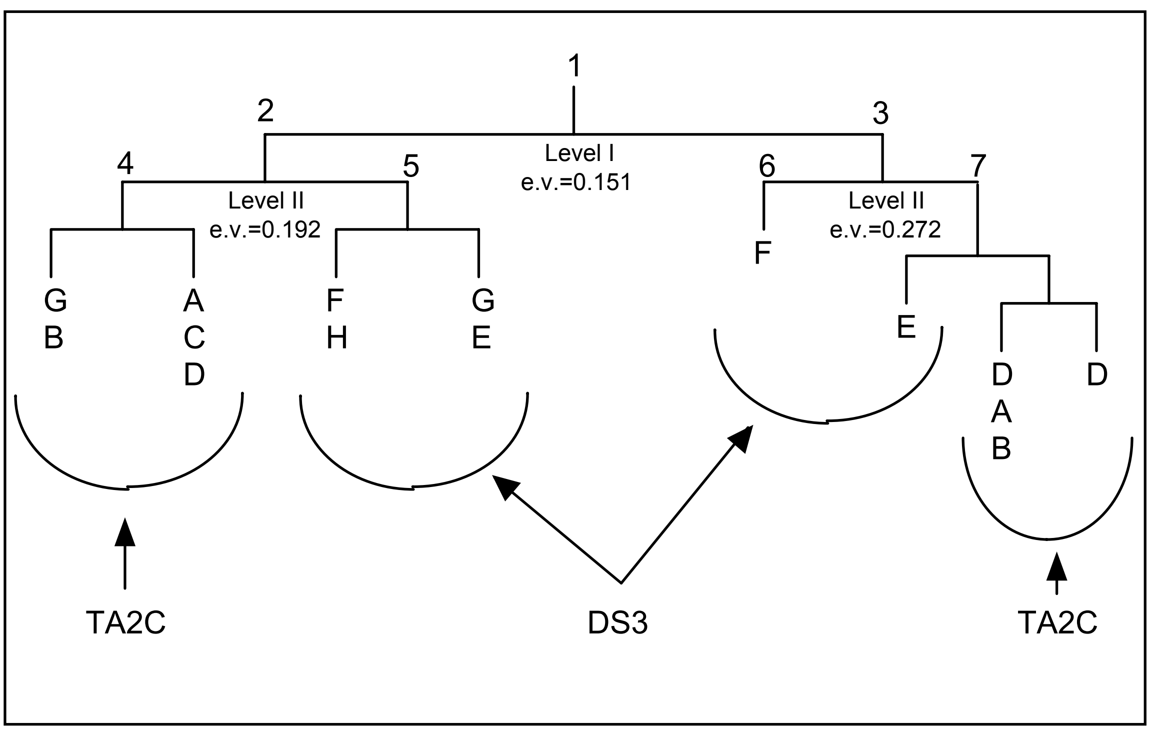

Figure 22. Clustering dendrogram of treatment plots for April 1994. A = Site TA2C, Non-cultivated, Seedmix #002; B = Site TA2C, Cultivated, Seedmix #002, C = Site TA2C, Non-cultivated, Seedmix #001; D = Site TA2C, Cultivated, Seedmix #001; E = Site DS3, Non-cultivated, Seedmix #001; F = Site DS3, Cultivated, Seedmix #001, G = Site DS3, Non-cultivated, Seedmix #002; H = Site DS3, Cultivated, Seedmix #002.

The divided groups were largely characterized by non-native perennial weeds. Because both reseeded sites are represented in Groups 2 and 3, the two sites can be assumed to be similar. No difference in cultivation treatments are shown.

Randomly sampled quadrats for June 1994 are clustered in a dendrogram in Figure 23. This dendrogram indicates a slight clustering of data between cultivation treatments (right side of dendrogram), however there are low eigenvalues associated with the division and therefore a distinction between the treatments cannot be made to any substantial degree. A very low eigenvalue (0.175) is associated with the first level of division into Groups 2 and 3. The low eigenvalue, as with the previous sampling date's dendrogram, indicates very little difference between these first two groups. Overall, very little information is learned from either of the groups due to the few species (determined by the TWINSPAN program) that help to characterize each group. Group 2 is characerized by the presence of *L. perfoliatum, P. sandbergii,* and *R. testiculatus* while Group 3 is characerized by the presence of *A. cristatum, B. tectorum,* and *S. kali.* At the second level of division, Group 2 is divided into Groups 4 and 5. A low eigenvalue

(0.173) is associated with the division. Group 4 is characerized by the presence of *P. sandbergii* and litter. Group 5 is characerized by the presence of *R. testiculatus* and *S. kali.*

At the second level of division, Group 3 is divided into Groups 6 and 7. A low eigenvalue (0.124) is associated with the division. Group 6 is characerized by the presence of *A. spicatum, S. kali, R. testiculatus, B. tectorum,* and *L. perfoliatum* . Group 7 is characerized by the presence of *A. cristatum* . The eigenvalue of this division and the division associated with Groups 4 and 5 are slightly lower than the eigenvalue associated with Level I. This indicates that the amount of information that could be learned from further level divisions will be low.

The divided groups were evenly characterized by non-native perennial weeds. A slight difference in cultivation treatments are shown, but because the eigenvalue associated with the Level III division is so low (0.140), no strong conclusions can be made between the sampling date and cultivation treatments . A slight division appears evident between reseeded sites, but because of the low eigenvalue associated with the division, the characteristic differences between the groups (Groups 2 and 3) are too low to define.

Randomly sampled quadrats for June 1995 are clustered in a dendrogram in Figure 24. This dendrogram indicates a clustering of data between cultivation treatments (left side

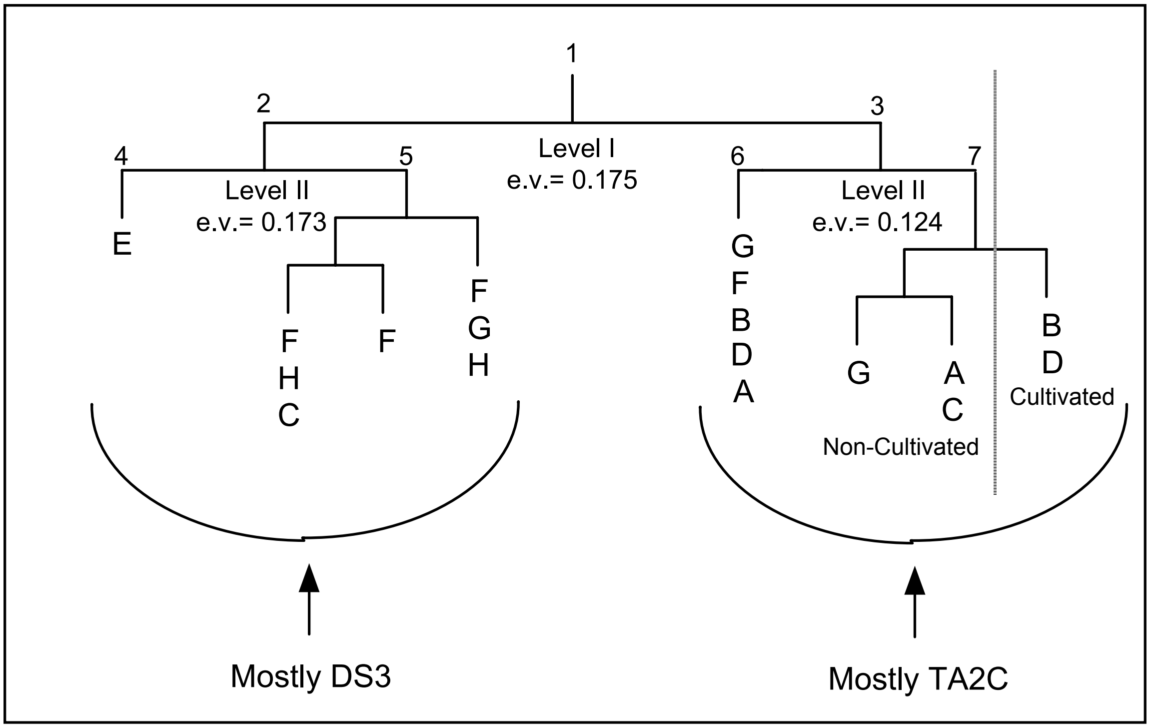

Figure 23. Clustering dendrogram of treatment plots for June 1994. A = Site TA2C, Non-cultivated, Seedmix #002; B = Site TA2C, Cultivated, Seedmix #002, C = Site TA2C, Non-cultivated, Seedmix #001; D = Site TA2C, Cultivated, Seedmix #001; E = Site DS3, Non-cultivated, Seedmix #001; F = Site DS3, Cultivated, Seedmix #001, G = Site DS3, Non-cultivated, Seedmix #002; H = Site DS3, Cultivated, Seedmix #002.

of dendrogram), however there are low eigenvalues associated with the division and therefore care should be taken when making a distinction between the treatments. A moderately low eigenvalue (0.314) is associated with the first level of division into Groups 2 and 3. The low eigenvalue, as with the previous sampling date's dendrogram, indicates little difference between these first two groups. Group 2 is characerized by the presence of *A. spicatum, P. sandbergii, L. perfoliatum* , and *R. testiculatus* while Group

3 is characerized by the presence of *A. cristatum* and *S. kali.* At the second level of division, Group 2 is divided into Groups 4 and 5. A low eigenvalue (0.189) is associated with the division. Group 4 is characerized by the presence of *A. spicatum, P. sandbergii* and *Artemisia tridentata* (native perennial shrub). Group 5 is characerized by the presence of *R. testiculatus, B. tectorum,* and *L. perfoliatum.*

At the second level of division, Group 3 is divided into Groups 6 and 7. A low eigenvalue (0.180) is associated with the division. Group 6 is characterized by the presence of *S. kali* . Group 7 is characterized by the presence of *P. sandbergii* . The eigenvalue of this division and the division associated with Groups 4 and 5 are low and nearly identical to the eigenvalues associated with the same group divisions from the previous sampling date. As with the previous sampling date, the amount of information that is gained or added by these divisions or further divisions is low.

Many of the species that help to characterize Groups 2-7 of this sampling date are found in the same groups of the previous sampling date. This indicates that there are not many community characteristic changes between these two sampling dates. Because there

is a slightly larger eigenvalue associated with the divisions at Level I, the treatment differences found at Level III (along the left side of the dendrogram) display slightly more information than the differences between treatments differences from the previous sampling date. Again, these differences are associated with very low eigenvalues and care should be taken when making definitive conclusions about the treatments.

DECORANA Output

Four ordination scatterplots were created, displaying randomly selected quadrats from both seeded sites for each sampling date. The eigenvalues of each axis have been identified for each of the following scatterplots.

Randomly sampled quadrats recorded for April 1994 are displayed in Figure 25. Axis I (X-axis) seems to correspond slightly with the presence and absence of cultivation

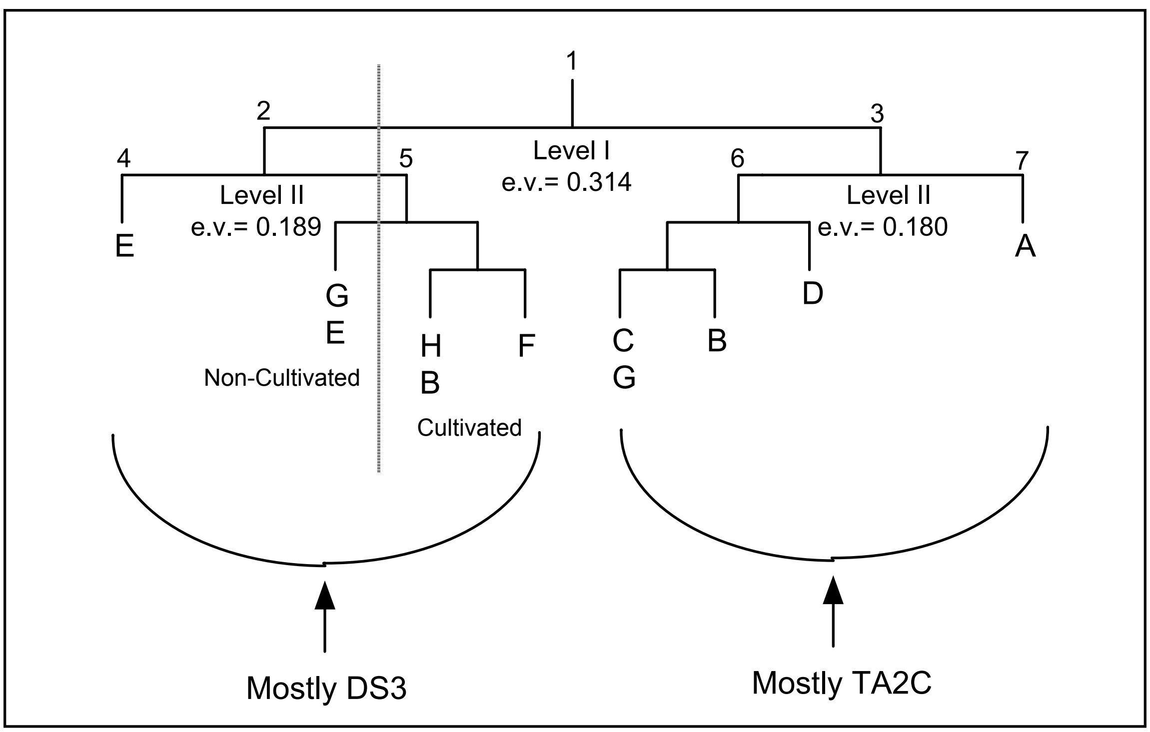

Figure 24. Clustering dendrogram of treatment plots for June 1995. A = Site TA2C, Non-cultivated, Seedmix #002; B = Site TA2C, Cultivated, Seedmix #002, C = Site TA2C, Non-cultivated, Seedmix #001; D = Site TA2C, Cultivated, Seedmix #001; E = Site DS3, Non-cultivated, Seedmix #001; F = Site DS3,

Cultivated, Seedmix #001, G = Site DS3, Non-cultivated, Seedmix #002; H = Site DS3, Cultivated, Seedmix #002.

prior to seeding measures (eigenvalue = 0.313). The majority of sampled quadrats are located in the center of the scatterplot while only a few of the plots are positioned outside of the centered group along the horizontal axis. This indicates the lack of differentiation between cultivation treatments for most of the sampled quadrats. Axis II (Y-axis) has a low eigenvalue of 0.144 and does not display a wide scatter about it, which indicates very little about any gradient characteristics.

Randomly sampled quadrats recorded for June 1994 are displayed in Figure 26. The cultivation treatments seem to correspond to the diagonal (lower left to upper right) of Axes I and II (eigenvalues - 0.308 and 0.172, respectively). This is the first of the three sampling dates to show a clear trend between the sampling treatments, but as the previous ANOVA and TWINSPAN results indicate, the difference in treatments are not significantly different. In this scatterplot, the spatial representation of the plots found within the non-cultivated treatments is greater than the cultivated plots, representing a greater diversity of quadrat characteristics. This diversity may include a greater variety in cover percentages and species richness per sampled quadrat.

Randomly sampled quadrats recorded for June 1995 are displayed in Figure 27. Differences between cultivated/non-cultivated treatments is evident. Two groupings of communities are shown, each representing the cultivated and non-cultivated

treatments of the two study sites (Axis I eigenvalue = 0.444; Axis II eigenvalue = 0.329). The difference between cultivated and non-cultivated treatments are shown to overlap spatially within the scatterplot, and the eigenvalues associated with each axis are low; less
than 0.50. This result indicates that there is not much difference in species composition between the cultivation treatments. For this sampling date however, previous ANOVA results indicate a nearly significant difference between cultivation treatments for mean percent cover.

A slightly stronger differentiation exists between cultivation treatments (slightly higher eigenvalues associated with the axes of this scatterplot) for this sampling date, which supports the conclusion of the previous ANOVA results that show a nearly significant difference between treatments. Definitive conclusions about the cultivation treatments should be made with caution however, due to the overall low eigenvalues.

Sampled quadrats from September 1995 (two neighboring communities and one stable, shrub-steppe community) are displayed in Figure 28. Spatial differences are shown between the three sampled sites. The quadrats associated with the stable, shrub-steppe site

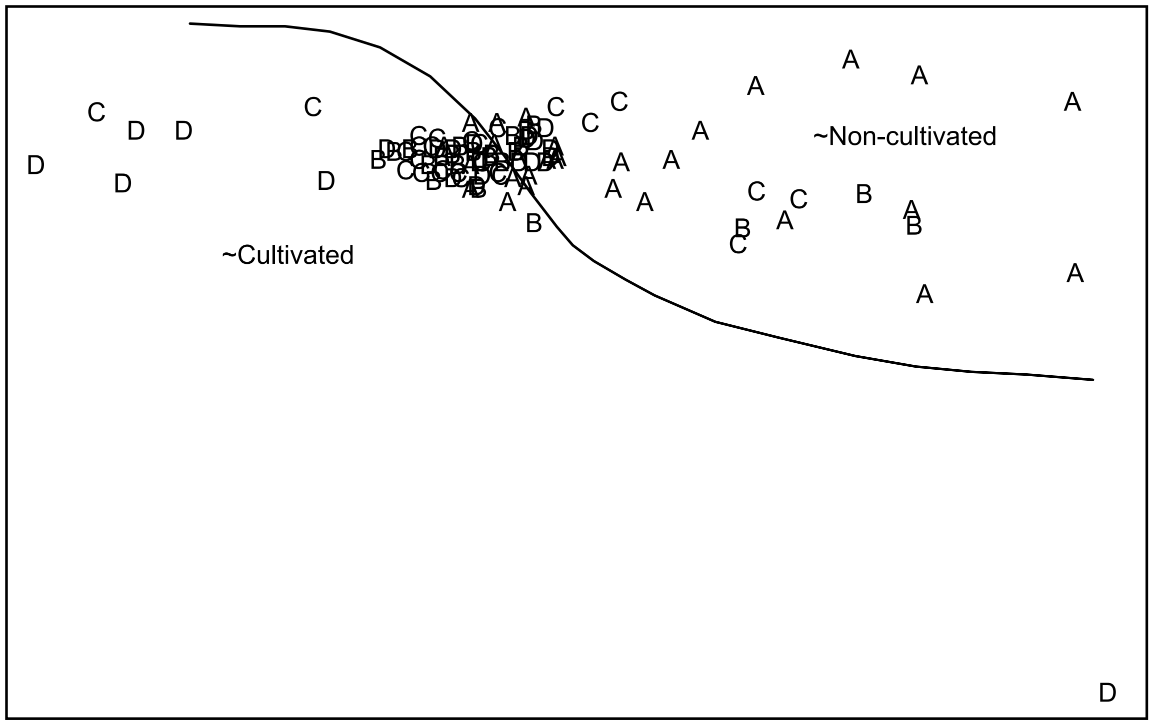

Figure 25. Two-dimensional scatterplot of treatment plots for April 1994. A = Site TA2C, Non-cultivated; B = Site TA2C, Cultivated; C = Site DS3, Non-cultivated; D = Site DS3, Cultivated.

are clearly grouped to the low end of Axis I (Axis I eigenvalue = 0.489, Axis II eigenvalue = 0.304). Quadrats associated with the two neighboring sites seem to overlap in the bottom-center of the scatterplot indicating some level of similarity between the sites. The

reference site is shown to be more similar to the neighboring site of DS3 than the neighboring site to TA2C.

Discussion

Changes over a period of 15 months in a reseeded shrub-steppe site in eastern Washington occurred, however without statistical comparisons or ecological

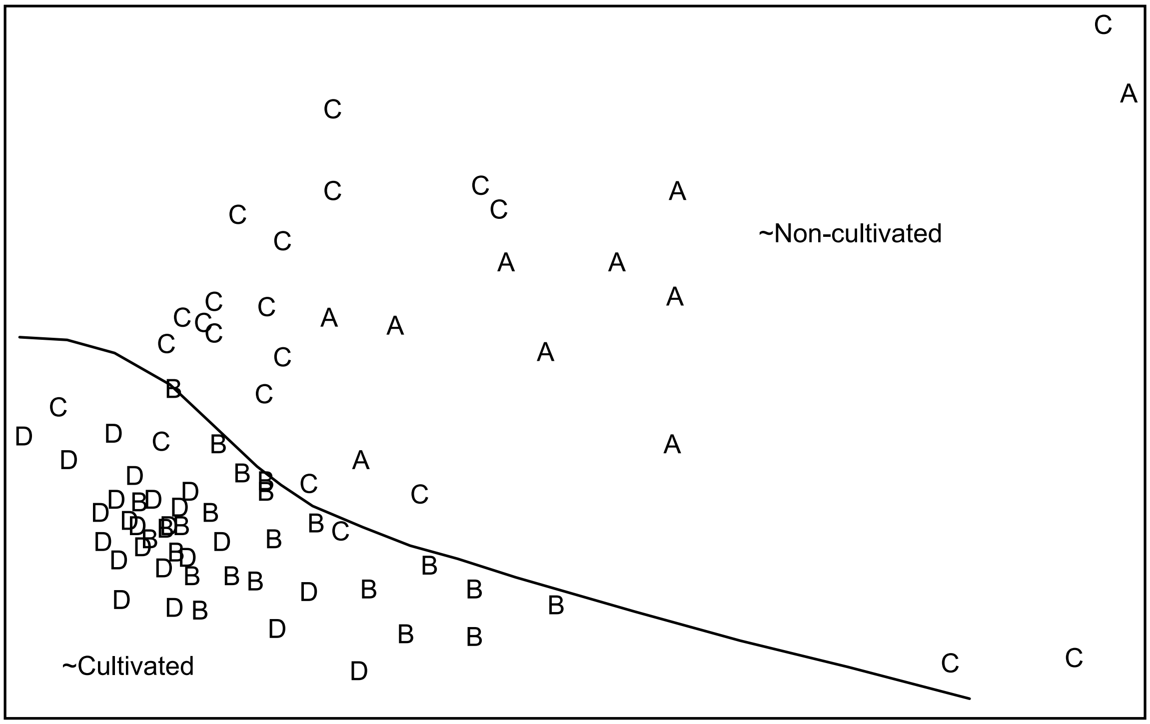

Figure 26. Two-dimensional scatterplot of treatment plots for June 1994. A = Site TA2C, Non-cultivated; B = Site TA2C, Cultivated; C = Site DS3, Non-cultivated; D = Site DS3, Cultivated.

ordination/classification techniques, the changes may have gone unnoticed. The two reseeded sites were invaded by a few early successional, weedy forb species during the early spring of the first growing season. By the middle of the second growing season, the species richness had decreased from 24 to 14 species, largely due to the loss of both native and non-native weedy species. The sites were still visually similar to their appearance the previous year. From a distance, the sites looked to be shrubless and almost lawn-like. A few invasive forb species have dominated the visual landscape to create a very short (approximately four inches tall) but evenly dispersed field of vegetation. The most noticeable difference between the two growing seasons was the increase in overall mean percent cover.

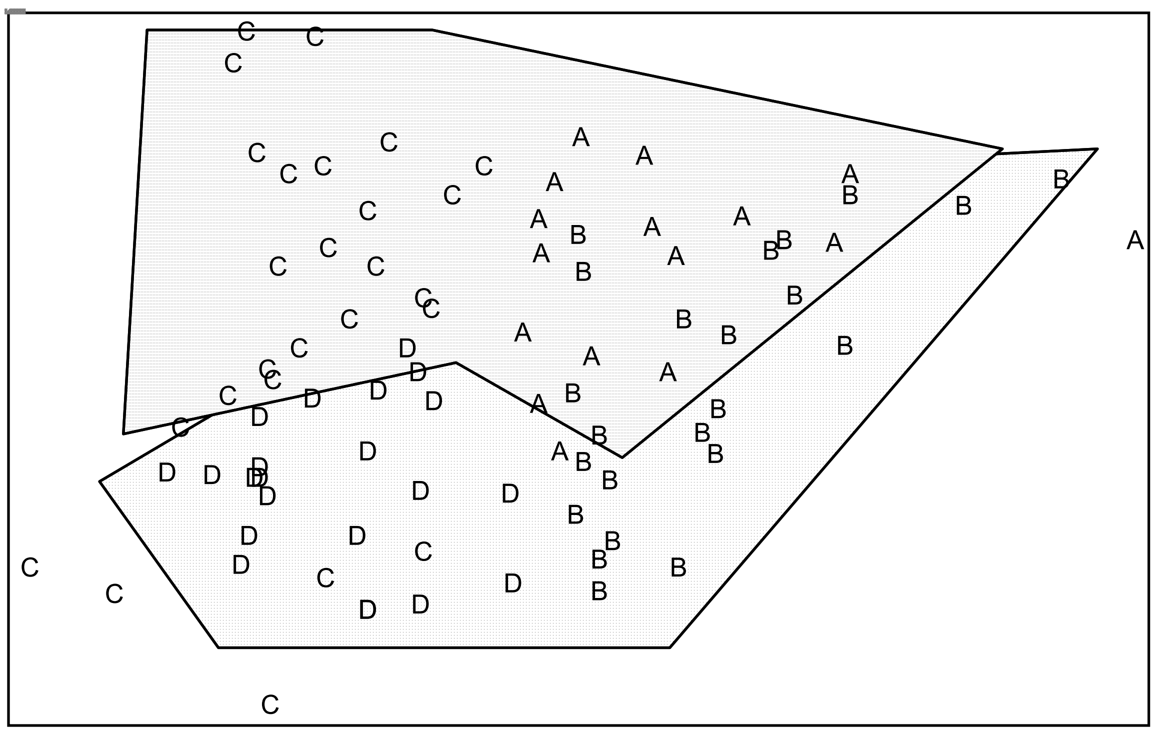

Figure 27. Two-dimensional scatterplot of treatment plots for June 1995. A = Site TA2C, Non-cultivated; B = Site TA2C, Cultivated; C = Site DS3, Non-cultivated; D = Site DS3, Cultivated.

Neither of the two seed mixes succeeded in germinating. Seeds failing to germinate is very common in extremely arid conditions. The year following the seeding treatments was extremely droughty. The droughty condition is speculated to be a major cause of the failed seed germination. Seeds of *Artemisia tridentata* , as well as other aridland shrub species, do not typically germinate or survive beyond their first year of existence. As an example, Walton found only 1.2 percent of field-planted sagebrush seeds emerged the first growing season after being planted, while only 11 percent of those seedlings survived longer than the first growing season (Walton et al. 1984). The seeds of many grass species, however, remain viable for as long as seven to nine years. Therefore, depending

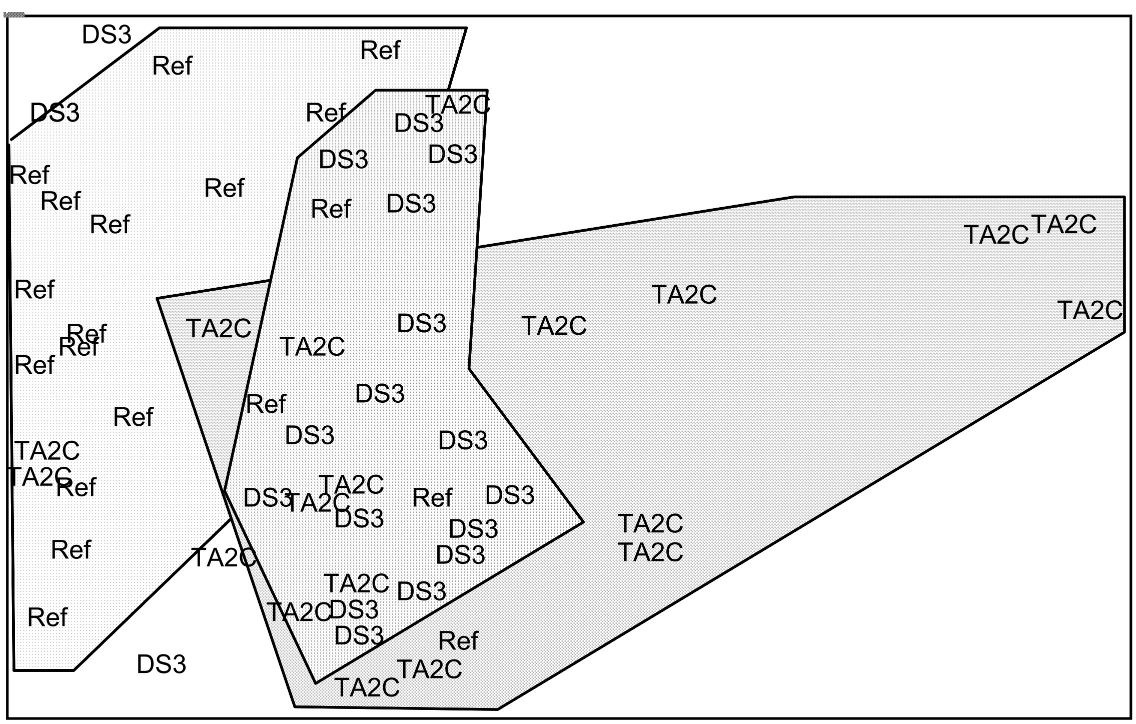

Figure 28. Two-dimensional scatterplot of neighboring and reference sites for September 1995. Ref. = stable, reference shrub-steppe community; DS3 = neighboring site to DS3; TA2C = neighboring site to TA2C.

on the importance placed upon establishing shrub species, further seeding efforts should be considered until a year of high precipitation can stimulate the germination of the seeds and produce a more desirous community of species. If a community composition of mostly grass species is desired, further seeding may not be required due to the longer viability of grass seeds compared to shrub seeds.

A slight difference in effect was identified between the cultivated and non-cultivation treatments. Overall, there was not a significant difference between cultivation treatments, however, during the second growing season, the difference between their mean percent cover neared significant ($p = 0.051$). When looking at native species only, not cultivating enhanced their establishment. When looking at annual species only, not cultivating appeared to enhance establishment.

Ultimately, the overall mean percent cover for these study sites is approximately 16%. The distribution of the established plant material is very uniform, which may lead to the successful reduction of soil erosion caused by wind. The established community types at these sites are comprised of species that may lend themselves to natural succession, allowing later successional plants to successfully invade in the future. This community response, which may allow for succession to occur, is quite different and potentially much more beneficial to wildlife than the community type that results from the spreading of *Agropyron cristatum* seeds; the current seed species of choice to be reseeded in disturbed areas of the Yakima Training Center. A community not dominated by one grass species is more likely to allow the reintroduction of less opportunistic, native species over time than would a community dominated by a single, highly dominant, grass species such as *A. cristatum* .

The ordination and classification analyses demonstrated that during the 15 months following the treatments, the differences between the cultivated and non-cultivated areas became only slightly more distinct. This indicates that some form of natural succession may be occurring. Definitive conclusions should not be drawn without caution regarding the cultivation treatments, as indicated by the ordination and classification techniques and ANOVA results.

For future considerations, surface mulches may be considered to help maintain more moisture in the upper horizons of the soil while possibly stifling potential opportunistic invaders from establishing quite so readily. Reseeding measures may also be attempted on north-facing slopes in order to reduce the amount of direct sunlight, which dries out the surface soils more rapidly. In either case, reseeding measures in arid regions should be expected to be unsuccessful more often that successful and care should be taken to reduce the amount of disturbance to begin with. If more older-aged sagebrush individuals can be spared from total annihilation during the disturbance activities, there may be a chance to speed the successional development of a particular site.

CONCLUSIONS

Attempts were made to restore the community composition of a disturbed shrub-steppe habitat following extreme surface disturbance. In this case, the disturbance was due to military activities such as bivouac camp sites and military vehicles. Two seedmixes were seeded in concert with either cultivation or non-cultivation treatments prior to the drill seeding of those seedmixes in order to reestablish native plant species on the freshly denuded study sites. This study aimed at explaining four elements of the rangeland restoration activities. Objectives were to:

1. Compare the establishment success of the two seedmixes,
2. Compare the establishment success of native species between the cultivated and non-cultivated treatments,
3. Identify whether succession is proceeding,
4. Compare species composition at the last sampling date to each site's neighboring community and reference community.

Neither seedmix successfully germinated at either site, but this result is not an uncommon one in arid regions such as eastern Washington. Establishment of seeded species is often poor as a result of the naturally occurring arid conditions unless unusually high amounts of precipitation are recorded for the year following the seeding treatments, usually twice the average annual precipitation totals (Ratzlaff and Anderson 1995, Young et al. 1994, Jackson et al. 1992, Briedé and McKell 1992, Heady 1975). Following surface soil disturbances, early spring sprouting perennials normally tend to establish as the pre-existing seedbank within the seeded soil is brought to the surface. In fact, the cultivated treatment sites displayed a greater establishment of perennials than the non-cultivated treatment sites, most likely because seeds were brought to the soil surface by the cultivation treatment.

Significant differences were found between the cultivated and non-cultivated treatments in terms of mean percent cover of native species only and annual species only. A nearly significant difference was found between the two cultivation treatments for the overall mean percent cover. The cultivated sites produced a slightly higer mean percent cover of vegetation than the non-cultivated sites. Within the non-cultivated sites, there was a greater mean percent cover of native species as well as annual species.

The overall mean cover value for the second growing season was only 16%. It is likely that successional change towards a shrub-steppe habitat can occur due to the lack of any single dominating species with a high percent cover value (Reichenberger and Pyke 1990, Allen and Knight 1984, Fowler 1986). If the sites had become dominated by any one species of grass, the chances of having that site develop into a shrub-steppe community would be greatly diminished (McLendon and Redente 1990). This is locally evident by the areas of the YTC that have been planted with *Agropyron cristatum* (crested wheatgrass). All of those sites have been dominated by that one species which has not allowed re-invasion by other native or non-native species. Monocultures have developed of *A. cristatum* since its seeds have been planted on disturbed sites.

Ultimately, the sites are being established by opportunistic invaders and previously buried perennial seeds, and may be beginning to develop their own initially unique communities. Because the re-establishment of *Artemisia tridentata* is a very slow process, the first two to three years after a major disturbance may result in a rangeland dominated by *Bromus tectorum* . In the middle of the second growing season, *B. tectorum* has become the dominant species (mean percent cover of 28.5%). New *Chrysothamnus nauseosus* individuals and remnant *A. tridentata* individuals seem to be the only shrub components of these sites, which is typical of the shrub-steppe habitat (Franklin and Dyrness 1969). *Salsola kali* and *Sisymbrium altissimum* may also dominate the disturbed rangeland for the first two to three years while *B. tectorum* increases in percent cover.

In summary, the most effective method of maintaining a healthy shrub-steppe habitat that can be utilized by native wildlife is to monitor the types of human-induced damages and to reduce as much as possible the loss of sagebrush individuals at any one site. In this case, even with severe damage to the community in respect to other native species, the site may not be subject to great levels of soil erosion and community re-establishment may occur at an excelerated rate as compared to a site which has been denuded of its vegetation completely.

If a site becomes entirely denuded of vegetation due to disturbance, drill seeding the site with a seed mix consisting of native species is encouraged following the disturbance. A successful seeding may not occur until a year of high precipitation occurs. Not cultivating the site is recommended if a native seed mix is going to be applied. Because the mean percent cover of the sites that were not cultivated was very low, considerations should be given towards the subject of soil erosion due to wind.

A stand of sagebrush is like an old-growth forest; it takes years to establish, is home to many native wildlife species, and appears to be constantly under attack by human action either as farming, ranching, or military activities. Care and effort must be afforded this type of habitat.

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APPENDIX A

Table A.1. List of Species and Codes

CODE	SCIENTIFIC NAME	COMMON NAME	LIFE	NATIVE/ NON	TYPE
acmi	*Achillea millefolium*	Western Yarrow	perennial	native	weed
agcr	*Agropyron cristatum*	Crested Wheatgrass	perennial	non	bunchgrass
agosaris	*Agosaris glauca*	False Dandelion	perennial	native	weed
agsp	*Agropyron spicatum*	Bluebunch Wheatgrass	perennial	native	bunchgrass
amsinkia	*Amsinkia species*	Fiddle-Neck	annual	non	weed
artrip	*Artemisia tripartita*	Threetip Sagebrush	perennial	native	shrub
artrwy	*Artemisia tridentata* subsp. *wyomingensis*	Big Sagebrush	perennial	native	shrub
ascu	*Astragalus cusickii*	Cusick's Milk-Vetch	perennial	native	weed
assu	*Astragalus succumbens*	Crouching Milk-Vetch	perennial	native	weed
astersp	*Aster species*	Sunflower Species	perennial	native	weed
brte	*Bromus tectorum*	Cheatgrass	annual	non	weed
cedi	*Centaurea diffusa*	Diffuse Knapweed	annual	non	weed
chna	*Chrysothamnus nauseosus*	Gray Rabbit-Brush	perennial	native	shrub
chte	*Chorispora tennella*	Blue Mustard	annual	non	weed
chvi	*Chrysothamnus viscidiflorus*	Green Rabbit-Brush	perennial	native	shrub
crepis	*Crepis species*	Hawksbeard	annual	native	weed
cryptant	*Cryptantha species*	White Forget-Me-Not	perennial	native	weed
depi	*Descurainia pinnata*	Tansymustard	annual	non	weed
houm	*Holosteum umbellatum*	Jagged Chickweed	annual	non	weed
kosc	*Kochia scoparia*	Burning-Brush	annual	non	weed
lepe	*Lepidium perfoliatum*	Peppergrass	annual	non	weed
lupine	*Lupinus species*	Lupine	perennial	native	weed
mesp	*Mertensia species*	Bluebell	perennial	native	weed
orhy	*Oryzopsis hymenoides*	Indian Ricegrass	perennial	native	grass
phlox	*Phlox longifolia*	Long-Leaf Phlox	perennial	native	weed
poasa	*Poa sandbergii*	Sandberg Bluegrass	perennial	native	bunchgrass
polygonum	*Polygonum species*	Knotweed	annual	native	weed
rate	*Ranunculus testiculatus*	Buttercup	annual	non	weed
saib	*Salsola kali*	Russian-Thistle	annual	non	weed
sial	*Sisymbrium altissimum*	Tumble Mustard	annual	non	weed
sihy	*Sitanion hystrix*	Bottlebrush Squirreltail	perennial	native	bunchgrass
stco	*Stipa comata*	Needle-And-Thread	perennial	native	bunchgrass
stth	*Stipa thurberiana*	Thurber's Needlegrass	perennial	native	bunchgrass
trdu	*Trifolium dubium*	Suckling Clover	annual	non	weed
bg	Bare ground	Bare Ground	n/a	n/a	n/a
l	Litter	Litter	n/a	n/a	n/a
r	Rock	Rock	n/a	n/a	n/a

APPENDIX B

Soil Descriptions for TA2C and DS3 sites.

TA2C - described April 1994

Horizons			(Typic Camborthid) (SCS 1993)
Ap	(0-5 cm)	-	Lower horizon boundary is clear and smooth. Dry color is light brownish gray (10YR6/2), moist color is dark grayish brown (10YR4/2). Texture is sandy loam with 2% clay. Structure is fine massive and consistence is loose when dry and moist, and not sticky or plastic when wet. pH is 6.8. Many fine roots are present.
A	(5-15 cm)	-	Lower horizon boundary is clear and smooth. Dry color is grayish brown (10YR5/2), moist color is dark grayish brown (10YR4/2). Texture is sandy loam with 3% clay. Structure is fine massive and consistence is slightly hard when dry, very friable when moist, and slightly sticky/slightly plastic when wet. pH is 6.8. Very few carbonates are present.
AB	(15-23 cm)	-	Lower horizon boundary is clear and wavy. Dry color is brown (10YR4/3), moist color is dark grayish brown (10YR4/2). Texture is sandy loam with 2% clay. Structure is massive and consistence is soft when dry, loose when moist, and not sticky or plastic when wet. pH is 6.8.
B	(23-43 cm)	-	Soil is white with many cobbles.

DS3 - described April 1994

Horizons			(Lithic Camborthid) (SCS 1993)
Ap	(0-8 cm)	-	Lower horizon boundary is gradual and smooth. Dry color is light olive brown (2.5Y5/3), moist color is olive brown (2.5Y4/3). Texture is sandy loam with 2% clay. Structure is massive and consistence is soft when dry, loose when moist, and not sticky or plastic when wet. pH is 7.0. Few fine roots are present.
A	(8-23 cm)	-	Lower horizon boundary is gradual and smooth. Dry color is brown (10YR5/3), moist color is dark grayish brown (10YR5/2). Texture is silt loam with 3% clay. Structure is massive and consistence is slightly hard when dry, loose when moist, and not sticky or plastic when wet. pH is 6.5. Few carbonates are present.
AB	(23-36 cm)	-	Lower horizon boundary is gradual and wavy. Dry color is light olive brown (2.5Y5/3), moist color is dark grayish brown (2.5Y4/2). Texture is silt loam with 4% clay. Structure is massive and consistence is slightly hard when dry, loose when moist, and slightly sticky/slightly plastic when wet. pH is 6.3. Few carbonates are present.
B	(36-46 cm)	-	Soil is white with $CaCO_4$ present.

APPENDIX C

Site Comparisons (REFERENCE ONLY).

Comparisons were made between the cultivation and non-cultivated sites for each of the two seeded sites independently. Statistical analyses will not be applied to these comparisons due to the lack of replication within each treatment level at each site (only two replications of each treatment per site). The data presented in these comparisons are raw data and, therefore, definitive conclusions should not be drawn. These comparisons show mean percent cover for the two treatment levels at each of the two seeded sites for a variety of selected data. Figure C.1 shows the treatment level comparisons for native, non-native, perennial, annual, grass, and shrub species independently. No further discussion will involve these comparisons. They are for reference only.

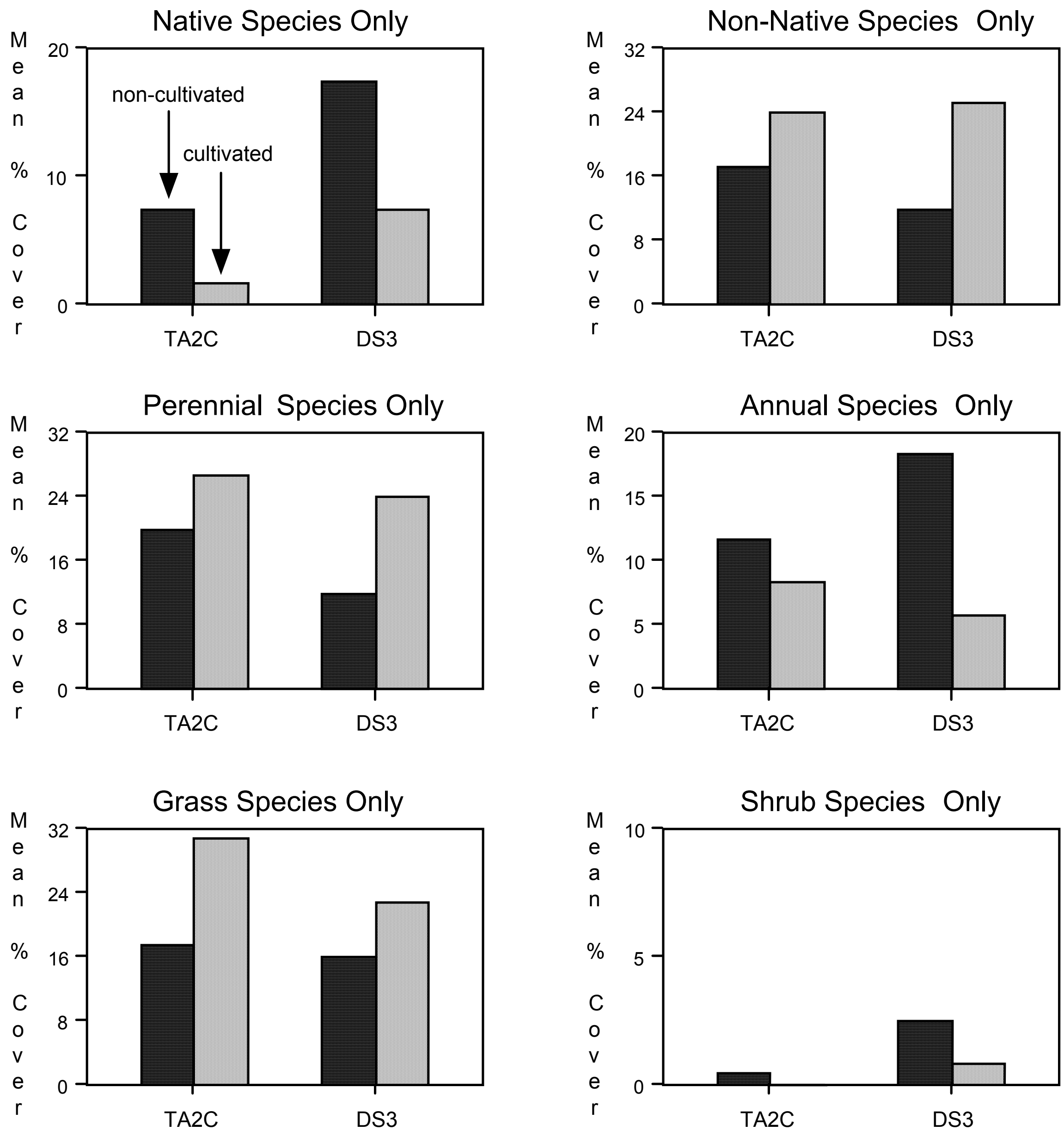

Figure C.1. Site comparisons of cultivation treatments for 1995 (FOR REFERENCE ONLY).