ESTABLISHMENT AND AESTHETIC VALUE OF NATIVE GRASS, LEGUME, AND FORB SPECIES FOR GRASSLAND RESTORATION IN THE NORTHERN INTERMOUNTAIN WEST

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

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in

Plant Science

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ABSTRACT

Establishment and Aesthetic Value of Native Grass, Legume, and Forb Species for Grassland Restoration in the Northern Intermountain West

by

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Interest in the restoration of landscapes native to the Intermountain West is growing as the value of these arid ecosystems is increasingly recognized. Many landscapes within the Intermountain region have been impacted by grazing, development, recreation, and other human-caused disturbances. The complex relationships within the native plant communities of these arid landscapes need to be well-understood biologically, while considering their aesthetic contribution, if restoration efforts are to succeed. Although the use of ecologically appropriate native species is increasing in popularity, there is discontinuity between aesthetics and meaningful ecological contributions. A series of studies was designed to aid in the restoration of a site located at the Utah Botanical Center in Kaysville, Utah. The restoration site is situated along the I-15 corridor which interfaces urban development. The high visibility and educational
purpose of the site requires that aesthetic as well as ecological concerns are addressed in the restoration of the native plant community. Specifically, the establishment of Intermountain grassland species was assessed using a variety of methods to test establishment rates as well as the potential value to the system of biologically fixed nitrogen provided by native legumes early within the establishment period.

(129 pages)
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CHAPTER 1

RESTORATION APPLICATION

The use of species native to the Intermountain West has been gaining recognition and popularity in both the public and private sectors of landscape design. Their value for water use efficiency, visual appeal, ecological services, and adaptability is increasing as the population grows in the arid West. The variety of available native species is increasing as growers, distributors, and consumers respond favorably to more place-appropriate landscape planting and design.

There is considerable plant species diversity found within desert environments because individual species have evolved to fill very specific niches within the harsh environment. The result has been a phenomenal display and variety of colors, forms and textures that are visually intriguing whether seen within the natural or constructed landscape. Because of the visual characteristics of these species, they promote a sense of place, facilitate an appreciation of the natural arid landscape we live in, and link the populace to the beauty of the surrounding Intermountain landscape.

Species Selection

A series of species native to the Intermountain grasslands were selected for this study and used for their restorative and visual characteristics; they were also chosen because they are established binding species for this region. These species were used in experiments conducted at the Utah Botanical Center in Kaysville Utah as well as in control environment (greenhouse) studies. Species that were chosen represent a variety of
functional groups, are appropriate ecologically and aesthetically, and provide year-round interest to the general populous.

The grass family, poaceae, contains more species that are distributed worldwide than any other family of plants and is considered to be the third largest family of flowering plants in the world (Brown, 1989). Although the flowers on grasses for the most part are small and inconspicuous, grasses bring a unique visual value of subtle tones and texture throughout the growing season and textural quality during fall and winter. Species selected for restoration efforts and greenhouse experimentation were also studied for their ability to become established under differing field and research conditions.

Cool Season Grasses

Bottlebrush squirreltail [Elymus elymoides (Raf.) Swezey] ELEL5

Bottlebrush squirreltail (Plates 1 and 2) is a short-lived, cool season perennial and is widely distributed. Its range stretches from British Columbia to Saskatchewan and south throughout the Western and Central United States and into Mexico (Monsen et al., 2004). This species is commonly found as an understory component in sagebrush steppe communities (Jones, 1998) and grows in dry gravelly soils that may be alkaline (Jensen et al., 1990).

Perhaps the most important contribution this species provides for restoration or horticultural use is its ability to compete with nonindigenous grass species. Bottlebrush squirreltail has long been considered one of the more competitive native grasses on cheatgrass-dominated rangelands (Monsen et al., 2004) due to its ability to germinate
rapidly across a wide temperature range and to its ability to establish on disturbed sites (Young and Evans, 1977).

Bottlebrush squirreltail is best used in naturalized areas and as one of several components due to its weaker structural characteristics. Squirreltail is small, with a height from 50 to 75 cm (Mee et al., 2003), limited leafy material and course solid stems (Monsen et al., 2004). The seedheads are proportionally large (12 cm in diameter) when compared to the short seedstalks, and become showier as they dry. As the seedheads dry, the long awns flair acutely from stalks, creating a subtle, fine texture after the grass has matured. Squirreltail greens early in spring and grows in dense stands (Monsen et al., 2004), with seeds maturing from June to September depending on site conditions (Link, 1993). These dense stands create soft textures that provide interest with motion and light and provide binding qualities within a landscape. This species is found ranging in elevation from 1070 to 3500 m (3400 to 11,000 feet) (Welsh et al., 2003).

**Basin wildrye** [*Leymus cinereus*(Scribn. & Merr.) A. Love] LEC14

Basin wildrye (Plates 3 and 4) is a coarse, robust, and densely tufted perennial bunchgrass, and one plant can form a clump up to 1 m across (Monsen et al., 2004). It is the largest cool-season bunchgrass native to the western United States (Abbot, 1991; Anderson et al., 1995; Cash et al., 1998) growing from 0.6 to 2.4 m (2 to 8 feet) (Mee et al., 2003). This species occurs throughout the western United States and Canada and reportedly as far east as Minnesota (Arnow, 1987; Asay and Jensen, 1996). In the Intermountain West it occurs in a wide range of community types from salt desert...
shrublands to ponderosa pine communities (Arnow, 1987). This species may occur scattered among other species or it may form pure stands or stringers along riparian areas, dry washes, roadsides, and on floodplains or in other areas that receive runoff water, subirrigation, or that have high water tables (Jankovsky-Jones et al., 1999; Wasser, 1982). It occurs at elevations from 4800 to 10,000 feet (1520 to 3200 m) (Welsh et al., 2003).

The use of basin wildrye is limited within the nursery trade, but it has great potential to be more widely used. Because of the unique size and habit of this species, it provides variety of height and depth as well as a moderately coarse texture within the landscape. Basin wildrye has a unique tall, wide columnar form. When established it exhibits a gradation of color during the growing season with a bright green foliage and yellow stalks and seedheads. The seedheads are spike-like and upright, accentuating the columnar habit. This species is well suited for use in both natural areas and designed landscapes and can be used as an accent or screen within a composition.

**Idaho fescue (Festuca idahoensis Elmer) FEID**

Idaho fescue (Plates 5 and 6) is one of the most common bunchgrasses found in the Intermountain West. It is a densely tufted, non-rhizomatous, long-lived perennial (Monsen et al., 2004) that ranges from southwestern Canada to northern California and east from central Montana to northern New Mexico (Tisdale, 1959). It is found at elevations ranging from 250 to 3800 m (800 to 12,000 feet), and in areas with annual precipitation ranging from 40 to 75 cm (Daubenmire, 1966).
Idaho fescue is not commonly found within the horticultural trade; however, a number of other fescue species are available and have become popular ornamentals commonly found in local nurseries. Idaho fescue is similar in form to that of its popular relative, blue fescue, being a compact, tufted bunchgrass. The dominant visual difference is that Idaho fescue is deep olive green in color. Its leaves are smooth and remain green through the growing season with adequate water, and seedheads reach 30 to 90 cm tall. The culms and seedheads extend far above the tufted herbage and form delicate spires. Idaho fescue can be used in a variety of landscape applications including specimens in pots or in groupings within the landscape. The tufted, bunchgrass habit creates a soft, fine texture individually and a course texture when viewed as grouping as the bunch-like habit punctuates each plant.

Bluebunch wheatgrass [Pseudoroegneria spicata (Pursh) A. Löve] PSSP6

Bluebunch wheatgrass (Plates 7 and 8) is a perennial, cool-season bunchgrass native to the Intermountain West. It occurs from Alaska to Saskatchewan and south to California, Arizona, New Mexico and Texas (Arnow, 1987). On the Palouse Prairie it occurs in pure stands, but is mostly co-dominant with Idaho fescue (Festuca idahoensis), and Sandberg bluegrass (Poa secunda) (Miller et al., 1986). Within the Intermountain West it commonly grows in association with big sagebrush (Artemisia tridentata), and antelope bitterbrush (Purshia tridentata) (Wright and Bailey, 1982). Bluebunch wheatgrass is found growing in soils that vary in texture, depth, and parent material, but it
is not tolerant of alkaline soils (Monsen et al., 2004). It is found at elevations from 1370 to 2900 m (4300 to 9100 feet) (Welsh et al., 2003).

Bluebunch wheatgrass is recognized for its unique blue-green color and bunching form. It has a distinct, divergent awn on select varieties that is emphasized when the seedhead dries; the awns create a light, airy texture. The seedheads are slender and spikelike. This species exhibits considerable variation (Plummer et al., 1968), depending on the available moisture and soils of a particular site, (Monsen et al., 2004). This species typically grows between 30 and 90 cm tall. Bluebunch wheatgrass is well suited for use in groupings, massing or in naturalized areas. The leaf blades are narrow and finely textured. Aesthetic qualities of this species are best highlighted in groups or mass plantings. This species is not typically found within the nursery trade, but is widely used in restoration projects due to its value for fauna and the high success of emergence and establishment in a variety of conditions.

Warm Season Grasses

**Alkali sacaton [Sporobolus airoides (Torr.) Torr.] SPAI**

Alkali sacaton (Plates 9 and 10) is a long-lived, native perennial bunchgrass that forms dense clumps that often grow in large, uniform masses. This species occurs throughout the western United States, the Great Plains, and northern Mexico. It is most abundant in salt desert shrub, desert shrub, blackbrush, sagebrush-grass, and pinyon-juniper vegetation communities (Monsen et al., 2004). It occupies lower, slightly moist alkaline flats and can be found scattered along drainages in desert and semidesert areas
(Monsen et al., 2004). Alkali sacaton tolerates soils with up to 3 percent total salts (Blaisdell and Holmgren, 1984); it grows poorly in sandy soils, fair on silty soils, and well on clayey soils (Vallentine, 1971). This species ranges in elevation from 800 to 2350 m (2500 to 7400 feet) (Welsh et al., 2003).

Alkali sacaton is an ornamental species which has great potential for a wide range of applications within the landscape; however, it is not readily available in local Intermountain nurseries. The strong clumping habit of the species and pale green to lavender-colored panicle seed heads can be an outstanding addition to any garden or natural area. Seedheads are open, pyramidal panicles and flowers in June into the fall. This species works well in massed plantings, borders or as components within planting combinations. Alkali sacaton can grow up to 180 cm (Mee et al., 2003), but its height is typically between 60 and 150 cm, depending upon environmental conditions. The foliage is finely textured and will remain green throughout the growing season with adequate irrigation.

Sand dropseed [Sporobolus cryptandrus (Torr.) A. Gray] SPCR

Sand dropseed (Plates 11 and 12) is a tufted, drought-tolerant bunchgrass that is native to the Intermountain West (Monsen et al., 2004). It is distributed from Ontario to Alberta in Canada and is found in Washington state, southern California, and northern Mexico. In the eastern U.S., it can be found in the Midwest and south to North Carolina, (Hitchcock, 1971). This species is a perennial in southern regions and often appears as an annual in northern climates (Welsh et al., 2003). Sand dropseed is commonly found in
sandy soils and is a major component of sagebrush-bunchgrass ecosystems, particularly in Idaho and Utah as well as short-grass prairie communities (Monsen et al., 2004). This species is a prolific seed producer and spreads well from natural and artificial seedings, making it a desirable species for restoration projects (USDA Forest Service, 1937; Weaver and Albertson, 1956).

Sand dropseed is a mid-sized grass, ranging in height from 60 to 150 cm, with a bunch-like form. Its habitat ranges in elevation from 850 to 2870 m (2700 to 9000 feet) (Welsh et al., 2003). Its habit is similar to alkali sacaton with airy seedheads and finely textured foliage. This species is ideal for naturalized areas as it competes well with invasive grasses, and can be used within a landscape composition. It is not typically available within the nursery industry, perhaps due to its variable seed dormancy during propagation, but could potentially provide additional variety within a landscape design if made available.

Non-leguminous Forb Species

**Rocky Mountain penstemon (Penstemon strictus Benth.) PEST2**

Rocky Mountain penstemon (Plates 13 and 14) is an herbaceous perennial that is found in pinyon-pine, oak-service berry, sagebrush, aspen, Douglas fir, and spruce-fir communities throughout the Intermountain West and Rocky Mountains in Wyoming, Colorado, New Mexico, Arizona, and Utah (Welsh et al., 2003). This species prefers rocky and sandy loam soils that range from weakly acidic to alkaline, and is best adapted
to areas with 38 to 50 cm of annual precipitation (Monsen et al., 2004). Elevation ranges from 2065 to 3275 m (6500 to 10,200 feet) (Welsh et al., 2003).

Rocky Mountain pestemon is a semi-evergreen species that has an abundance of dark, glossy green leaves with blue to violet flowers borne on stalks 30 to 75 cm tall (Monsen et al., 2004). This species establishes fairly readily and can be used effectively in either a naturalized landscape or a more structured landscape composition. Its bloom period begins in June and can last through August with proper climatic conditions and irrigation. Rocky Mountain penstemon can be a vibrant color component in restored landscapes and natural areas, as well as constructed landscapes. The compact habit of the stalks and blooms can also add interest to more formalized planting plans. This, as well as other penstemon species, are available within the nursery trade and are popular options for landscape designers who are interested in water conservation but do not want to sacrifice aesthetic interest and vivid colors.

**Munro’s globemallow** [*Sphaeralcea munroana* (Douglas) Spach] SPMU2

Munro’s globemallow (Plates 15 and 16) occurs in valleys and foothills of mixed desert shrub vegetation communities but is more commonly found in sagebrush and mountain brush communities. It is found in Montana, Idaho, Washington, Wyoming, Nevada, California, and Utah at elevations ranging from 1370 to 2440 m (4300 to 7700 feet) (Welsh et al., 2003). It does well in coarse, low-fertility soils and prefers full exposure to the sun.
Munro’s globemallow is a hardy, drought-tolerant species that will flower and produce an abundance of color under even the most severe conditions. It has a slightly prostrate habit with several branches coming from a semi-woody base. The foliage exhibits a medium texture that is yellow-green to gray, covered with fine hairs. The blooms are a bright orange and provide dramatic contrast within its natural habitat of sagebrush and grassland vegetation communities. Munro’s globemallow varies in size from 15 to 75 cm tall. The bloom period begins in June and can last until August with proper climatic and irrigation conditions. This species is ideal for use in restored landscapes or naturalized areas because of its high drought tolerance, or it can be used within a constructed landscape to add color in early to mid-summer. It also is well-suited for park strips and other areas where irrigation is limited.

Legumes

Legume species are important additions to the natural landscape and have many unexploited qualities to offer within the constructed landscape setting. Legumes species are able to fix atmospheric nitrogen that can be transferred to, and aid in, the growth of grasses and non-leguminous forbs, and thus can help in the restoration of disturbed landscapes. Additionally they offer aesthetic qualities with vibrant blooms and rich foliage.

Utah sweetvetch (*Hedysarum boreale* Nutt.) HEBO

Utah sweetvetch (Plates 17 and 18) is a well-known Intermountain native frequently used in seeding mixtures for restoration and revegetation projects. Its
popularity may be due in part to its seed availability as well as its aesthetic appeal. This species is a perennial legume that occurs in most western states including Utah, Nevada, Arizona, New Mexico, and Texas. It grows in mixed desert shrub, pinyon-juniper, mountain brush, ponderosa pine, and aspen communities at elevations ranging from 1150 to 2700 m (3700 to 8700 feet) (Welsh et al., 2003). Utah sweetvetch can establish in various soil types, and because of its ability to fix atmospheric nitrogen, it is able to tolerate poor or degraded soils.

Utah sweetvetch is not commonly found within the nursery trade despite its pleasant appearance. It flowers in late July and early August and has showy pink blooms and finely textured pinnate leaf structure. Utah sweetvetch ranges between 15 and 68 cm in height (Mee et al., 2003). This species has horticultural potential for both its aesthetic appeal as well as its potential contributions of fixed nitrogen to the landscape. The branching and sprawling form give the species an informal appearance and would make it ideal to use as a raised border that could spill over the edges of landscape elements. Utah sweetvetch could be used effectively within constructed landscapes or natural areas to add variety of color and texture. This species is relatively drought-hardy and will have a second and third bloom within a growing season if trimmed and properly irrigated.

Silvery lupine (*Lupinus argenteus* Pursh) LUAR3

Silvery lupine (Plates 19 and 20) is a perennial legume native to the Intermountain West and is found in aspen, meadow, mixed conifer, riparian, and spruce-fir communities ranging in elevation from 2500 to 3300 m (7800 to 10,500 feet). Its distribution and range includes Idaho, Montana, South Dakota, Nevada, Colorado, Utah,
and northern Mexico (Welsh et al., 2003). Because of its ability to fix atmospheric nitrogen, silvery lupine is able to establish in soils that have been disturbed or depleted. This species does best with full sun exposure, but it will tolerate some shade.

Silvery lupine ranges from 15 to 90 cm in height and has several branches stemming from a semi-woody base. Its form is vase-like with softly rounded sides, and its prominent palmate leaves provide a coarse texture. Silvery lupine blooms from late June to early August, with conically arranged blooms that range across blue, blue-purple, and white (Welsh et al., 2003). This species is not available within the nursery industry although other lupine species, such as bigleaf lupine, are popular within the trade. Silvery lupine can provide unique form within a garden or naturalized landscape. In addition, with its ability to fix atmospheric nitrogen, it can help to reduce the amount of fertilizer needed to optimize plant productivity.

References


Plate 1. *Elymus elymoides*, Bottlebrush squirreltail.
Plate 2. *Elymus elymoides*, Bottlebrush squirreltail.
Plate 5. *Festuca idahoensis*, Idaho fescue.
Plate 15. *Sphaeralcea munroana*, Munro’s globemallow.
Plate 17. *Hedysarum boreale*, Utah sweetvetch.
Plate 18. *Hedysarum boreale*, Utah sweetvetch.
CHAPTER 2

GRASSLAND RESTORATION

Much of the Intermountain West falls within the broad classification of a grassland, although today these grassland communities are often dominated by communities of sagebrush, sagebrush grasslands, and shrub steppes (Brown, 1989). The large majority of this vast expanse of land falls into what is known as the Great Basin, which includes over half the state of Utah, nearly all of Nevada, the southern-most part of Idaho and eastern portions of California and Oregon. It is thought that previous to the introduction of domestic grazing animals, sagebrush was not as abundant in these areas as it is today. With the onset of cattle grazing in the mid-1800s, plant species diversity was reduced by preferential herbivory, allowing species like sagebrush to proliferate beyond its normal habitats as well as causing the occurrence of forbs and grasses to become significantly reduced. The exact nature of the former vegetation in the Intermountain region is largely unknown; however, because it historically sustained large numbers of large ruminant grazing animals it is considered to be a grassland (Brown, 1989). Due to grazing pressures, agricultural production, and land use patterns by humans, the semi-arid grasslands of the Intermountain region have been significantly altered. Much of the land that was suitable for native grassland plant communities has been converted to agricultural use, industrial use, left disturbed and abandoned, or developed for housing. Where the canopy of grassland communities is opened by death or the disturbance of affiliate species (native grasses and forbs), this has permitted a host of nonindigenous species to become established (Weaver, 1954).
Natural landscapes within the Intermountain West have been degraded to a point where only remnants of vegetation communities remain in much of the region. As such, these systems may be viewed as wastelands with limited value, resulting in mismanagement and misuse. The continued over-utilization of Intermountain grassland ecosystems is perpetuated with poorly managed grazing allotments and, in recent times, the development of the oil and gas industry on thousands of acres of private and public land. While an ecological aesthetic is present at varied levels in degraded landscapes, the lack of knowledge and appreciation of the ecosystem perpetuates exploitation and causes difficulty in gaining public support to restore the landscape. However, understanding and shared knowledge of these unique systems may improve future land management practices and further the incorporation of ecological design into the cultural mainstream.

Historical use of land and introduction of nonindigenous species, which displace native vegetation, makes re-establishment of native grassland communities in the Intermountain West a challenging process. The value of native grasslands includes their function as carbon sinks, the maintenance of air and water quality, and the support of pollinating insects (Kemp and Michalk, 2005). Native birds and small mammals also depend on native vegetation for survival.

There are six broad-based and encompassing types of grasslands that are recognized to occur in North America: 1) eastern grasslands, 2) tallgrass prairie, 3) mixed tall- and short-grass prairie, 4) shortgrass prairie, 5) Intermountain grasslands, and 6) California grasslands (Brown, 1989). The need for restoration efforts becomes more urgent when one considers the rate and scale of loss of natural grasslands and
biodiversity, locally, nationally and globally. It is important, therefore to appreciate the effect that loss of grasslands and grassland biodiversity has on our wider environment (Minns et al., 2001). Consideration of cultural values can provide a partial explanation of the rate at which grassland communities have been and are continuing to be developed or natural resources depleted. Human response to native vegetation is shaped by numerous forces; some learned and some innate (Williams and Cary, 2001). Orians and Heerwagen (1992) proposed that evolutionary forces have resulted in inherited tendencies to prefer environments that appear safe and productive, and which provide for basic human needs such as food, water, and shelter. In a landscape perception survey, Williams and Cary (2001) found that 4 out of 5 respondents who viewed photos of natural grasslands suggested that the area should be developed by heavier grazing, cropping or application of fertilizer, while only 1 out of 5 respondents indicated the grassland should be protected for its ecological value. From the study he concluded that aesthetic preference is linked to functional aesthetics, meaning that a place is more pleasing if it can serve a utilitarian purpose. While restoration provides redemption for degraded landscapes, preserved intact systems often contain more biodiversity than restored sites. The protection of these systems may be heavily dependent upon public opinion; therefore, public outreach and education can significantly contribute to the protection of ecosystems and biodiversity.

Currently, there is a need for educational experiences that connect communities to native ecosystems associated with a region. The lack of such connection of communities to surrounding natural environments can affect decisions about land use that directly impact the overall quality of life for surrounding communities. Restoration of grassland
systems can provide a medium to educate communities located in urban and suburban regions, increasing awareness, understanding and appreciation of the ecosystem in which they are located. Experience limited to houses, roads, factories, and traffic inhibits the urban individual’s appreciation of the subtleties of composition and function of natural ecosystems (Ruff and Tregay, 1982). A deliberately obvious example of the critical elements of the Intermountain grassland ecosystems will foster aesthetic appreciation for these elements. The ultimate goal of this study was to support the establishment of a functioning grassland that visually emphasizes the critical aesthetics of an Intermountain grassland as an aid to appreciation for both practitioners and the public.

Overview of Grassland Types in North America

Climate largely determines natural ecosystem boundaries at all scales (Bailey, 1996). According to Troll (1966) and Bailey (2005), the most important climatic factor is the “climatic regime” which is defined as the daily and seasonal fluxes of energy and moisture. Eastern grasslands receive ample water ranging between 635 mm and 1400 mm annually. Precipitation in the tallgrass prairie ranges from approximately 635 to 990 mm. Mixed grass prairies receive between 335 and 584 mm, while short grass prairies to the west receive as little as 255 mm per year. The climate in the Intermountain West is arid; precipitation averages between 255 and 380 mm annually (Brown, 1989). Annual precipitation within the California grasslands varies greatly between the Coast Range and the Central Valley habitats, ranging from 737 mm within the coastal region and 152 mm within the Central Valley. Precipitation occurs in the fall, winter, and spring months,
creating a weather pattern that helps to form a Mediterranean climate (Brown, 1989). As these factors change, the patterns of the dominant life-form of plants and animals change, as do the kinds of soils (Bailey, 2005).

The Intermountain grasslands, interrupted by shrublands, woodlands and deserts, occur from southern Canada to central Mexico and between the Cascades and Sierra Nevada ranges to the west and Rocky Mountains to the east. These grasslands have developed in response to moisture gradients that result from local topography and altitude (Brown, 1989). These grassland communities include the Basin and Range grassland, the California prairie, desert grasslands, and the Palouse prairie (Coupland, 1992).

Characteristics of Intermountain West Grasslands

With the exception of a few areas, most of Utah can be classified as Intermountain grasslands. The term Wasatch oasis is given to the belt of irrigated land developed by Mormon pioneers in the nineteenth century that stretches from Logan (Utah) in the north, where the water of the Bear River is diverted for irrigation, to Provo in the south, which the Mormon pioneers developed in the nineteenth century (Beaumont, 1989). Much of the area’s native plant communities were converted into agricultural fields and/or used as rangeland for grazing cattle and sheep, which significantly altered the composition of native plant communities. Grazing, logging, mining and recreational activities have also introduced and spread many nonindigenous plant species in Intermountain West grasslands. Because of these historic land uses and more recent urban development, the majority of lower-elevation plant communities have become
severely limited in biodiversity and functionality. Since European settlement, semidesert shrub vegetation has invaded wide areas of the western United States that were formerly steppe grasslands, due to overgrazing and trampling by livestock (Bailey, 1995). This lack of ecological context makes the selection of plant species capable of becoming established and sustained in restoration projects a challenge.

**Basin and Range**

The ability of a specific site to produce vegetation is determined by the factors that influence soil formation as well as the history of land use (Klemmedson and Teidemann, 1995). Soil types found within the Intermountain West are complex, and soil conditions change rapidly over just a few miles. Consequently, the vegetative communities form complex mosaics and islands in the Intermountain area (Fenneman, 1981). Depending on parent material, soils within this region are often alkaline; few are neutral or more rarely acidic (Shelford, 1963). Aridisols are saline and/or alkaline soils low in organic matter, and dominate all basin and lowland areas, along with narrow bands of Entisols, which are relatively young soils not yet significantly influenced by environmental or plant interactions. Entisols are found in stream floodplains and rocky landscapes. Salt flats and playas without soils are extensive in the lower parts of basins (Bailey, 1995).

West and Young (2000) separate major grassland vegetation types into five distinct groups that are found within the Intermountain grasslands: 1) sagebrush steppe, 2) Great Basin sagebrush, 3) saltbush-greasewood, 4) blackbrush-dominated, 5) and
piney-juniper woodlands. The sagebrush steppe communities occur predominantly in the northern portion of the Intermountain region. Native perennial grasses associated with this community include Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), western wheatgrass (*Pascopyrum smithii*), and thickspike wheatgrass (*Elymus lanceolatus*) (Young and Evans, 1977).

Within the second vegetation type, Great Basin Sagebrush, *Artemisia* species dominate. Within this community shrubs are generally less densely spaced than in the sagebrush steppe, in which *Artemisia* spp. make up more than 70 percent of the relative plant cover. This community contains a relatively low number of species. Those found within this association include bottlebrush squirreltail, (*Elymus elymoides*) and rabbitbrush spp. (*Chrysothamnus*) (West and Young, 2000). The saltbush-greasewood association dominates a considerable portion of the Intermountain lowlands having alkaline soils. This community is dominated by various greasewood species (*Sarcobatus* spp.). Blackbrush (*Coleogyne ramosissima*)-dominated communities are located in the lower but nonalkaline portions of the Intermountain valleys. These communities contain a simple palette of flora, and are generally limited to grass species. Grass species found consist of big galleta (*Pleuraphis rigida*), James’ galleta (*Pleuraphis jamesii*), Indian ricegrass (*Atnatherum hymenoides*), and needlegrass (*Stipa* spp.) (West and Young, 2000).

Pinyon-juniper woodlands are found at elevations slightly higher than the previously mentioned vegetation community types. While the dominant vegetation consists of woody *Pinus* and *Juniperus* spp., the understory varies so greatly over the
vegetation type that it is more reasonable to say it is similar to adjacent grasslands and shrub steppes (West and Young, 2000).

Variation in competitive ability may determine the distribution and abundance of species along environmental gradients (Barton, 1993; Keddy, 1990; Tilman, 1998; Walter, 1985). It has been shown that greater plant diversity can lead to greater productivity because of “niche complementarity” among particular combinations of species (Tilman et al., 2001). Evidence shows that increased productivity can be achieved by combining species of different stature, growth form, phenology, or rooting structure (Trenbath, 1974). Tilman et al. (2001) stated that diverse species composition, particularly added legume species, has been found to have significant positive effects on above ground or total biomass; Piper (2007) argues that inter-specific interactions among plant species contending for resources can be competitive, neutral, or facilitative. As such, understanding species characteristics and requirements is important when composing seeding mixtures or the selection of plugs for restoration design. Also, it should be noted that environment and competition have much larger influences on the performance of juvenile plants in field conditions, making the control of nonindigenous species a priority of restoration, along with site history and selection of appropriate species for the desired mature vegetation community (Peltzer, 2001).

Intermountain Grasslands: Ecosystem Restoration and Aesthetic Consideration

The Intermountain West contains complex ecological mosaics of plant and animal communities that are determined by unique interactions of abiotic factors such as
temperature, precipitation, topography, and soils, as well as interactions with associated biotic factors (Trimble, 1989). It is in these and other unique details that the visual qualities of the area begin to emerge. It is important that open spaces, or natural areas, are not dominated by a visual aesthetic that overwhelms other senses---taste, smell, touch, and hearing---that are so much a part of the natural world (Ruff and Tregay, 1982). These systems should be valued for the biodiversity they contain and the potential that restoration can have on ecological and aesthetic values of the site.

Relative affluence and technological advances have enabled humans to inhabit areas that until recently were limited mainly by lack of water. The value of using native plant materials within landscape design is becoming more appreciated as water conservation becomes increasingly important due to external consumption limitations. Regions that are limited by water have unique challenges in restoration such as a negative perception of the aesthetic value of semi-arid landscapes. These landscapes will never meet the non-native tradition of a lush, well-watered landscape so should be appreciated for their unique function and diversity. To embrace landscape restoration and design imitating natural systems found within the Intermountain West, ecosystems that are looked to for inspiration should be remnant systems that contain a diversity of plants and emulate intact ecological function. The challenge of cultural perception and establishment of indigenous vegetation communities is calling upon restorationists and designers to work collaboratively to explore ecologically and economically sustainable solutions.
Species Selection: Choosing Ecologically and Aesthetically Appropriate Species

Reference ecosystems selected from the native landscapes found throughout the valleys of the Intermountain West should be used to develop a template for restoration and integration of indigenous plant species into residential, commercial, county, state, and federal landscapes.

Not all indigenous species found within the Intermountain West meet the aesthetic requirements for use in every landscape application; thus, species selection is dependent upon the restoration and design intent of a landscape, location, and standards mandated by land owners and users. Intact and functional reference ecosystems used as templates for design and restoration efforts offer a diversity of species appropriate for the various design applications that meet the needs of consumers.

Functional groups that vary in vegetation structure and diversity is a significant component found within healthy ecosystems (Ruiz-Jaen and Aide, 2005), and landscape designers should include this range of functional groups within landscapes designed for the human scale. Careful selection of native plant species used to represent complimentary community types can underpin aesthetic value by being fully functional. A functioning system produces vegetation that is vigorous, in turn producing more blooms and foliage, thus generating a landscape that is better able to self-perpetuate. Sustainability through species selection results in less maintenance and fewer weed, pathogen or insect problems while meeting high aesthetic standards.

Grasslands have been said to be an infinite experience because one can see vast, uninterrupted distances in a grassland landscape, and the dominant grass species provide
homogeneity and a binding quality in an otherwise chaotic planting scheme.

Grasslands support more species than those found within the poaceae or grass family. They include a great diversity of forb species as well as scattered trees and shrubs.

Great seasonal variation can be found within grassland systems and the species diversity found within these systems provides a rich palette of color, form, texture and lines. Many plant species found in grasslands are well-adapted for horticultural and restorative uses throughout North America. Particular species have been identified as having a more pleasing aesthetic, are more easily propagated in controlled environments, more readily established on disturbed sites, and fill ecological niches within a system.

Species selection is dependent upon the overall context of a site as well as cultural perceptions. Perceived aesthetic value can determine the success of created or restored ecosystems. For example, species that are less formal and sometimes referred to as “weedy” may not be appropriate for use in highly designed areas of a landscape such as areas adjacent to commercial or residential structures. These species would, however, be highly appropriate for use in naturalized areas. Species selection should be appropriate to design and site context.

Linking Ecosystem and Aesthetic Value Through Design Fundamentals

Urbanization significantly influences the functioning of ecosystems and the services they provide to humans and other life (Alberti, 2005). Urban development fragments, isolates, and degrades natural habitats; simplifies and homogenizes species composition; disrupts hydrological systems; and modifies energy flows and nutrient cycling (Alberti et al., 2003). Vitousek (1994) identified land-cover changes by humans
as a primary effect of humans on natural systems. As such, choices made by planners, engineers, and designers could have significant impacts on local, regional, and even global ecosystems. An ecological approach to urban land-use planning is not only desirable but essential to maintain the long-term sustainability of ecosystem benefits, services, and resources (Zipperer et al., 2000).

One significant shift in the theoretical direction of landscape architecture over the past fifty years has been the development of concepts of “ecological” and “sustainable” design (Swaffield, 2002). Many educators and professionals in the design and planning fields have made a “turn to ecology,” where “turn” implies a shift in emphasis and priorities (Hill et al., 2002). McHarg (1969), a pioneer in the field of landscape ecology, stated that “Man is that uniquely conscious creature who can perceive and express. He must become the steward of the biosphere. To do this he must design with nature.” Design, as defined by landscape architect J.T. Lyle (1985), “is giving form to physical phenomena,” with which humans as a species feel more comfortable and process more easily. This human process of organization can influence, and in many cases hinder, the success of restorative efforts and ecological functionality.

In shaping ecosystems, three organizational concepts are fundamentally important: scale, design process, and underlying order. As stated by Lyle (1985), every ecosystem is a part—or subdivision—of a larger system, no matter how small or disconnected a system may appear. The design process will vary according to the scale of concern and the situation at hand, thus determining the pattern of thought that is followed
when dealing with the frame of reference. Lastly, the concept of order includes identifying which processes are essential for the long-term success of the design.

Although there remains a certain ambiguity over the content and relationship that ecology and creativity have with one another, an increasing number of designers are interested in restoration design, and a growing number of successful restoration projects are found within urbanized areas (Corner, 1997). These include large restoration efforts comprised of hundreds of acres, to backyard prairie recreations implemented by private citizens.

Ecosystem Scale: Restoration Opportunities in Landscapes Large and Small

Ecological gardens come in many shapes, sizes, and scales. These begin at the level of small, home landscape patches forming mosaics of small backyards that cumulatively change the fabric of urban neighborhoods, and they extend to gardens the size of large watersheds in which people harvest timber, grow crops, mine minerals, recreate and contemplate, and build houses and cities (Johnson and Hill, 2002). By retrofitting urban landscapes with ecologically appropriate plant species, communities have an opportunity to create healthier, more sustainable environments through individual action. By replacing large expanses of lawn, and including adapted plant species that provide habitat and food for insects and wildlife, smaller component landscapes can begin to merge into larger, valuable ecosystems.

Martin and Warner (1997) state that urban areas have been largely neglected by ecologists, even though they are indeed ecosystems. The ever-expanding presence of
humans composes an increasingly significant portion of the environment. Smaller landscapes have the potential to contribute to improving ecological systems rather than require the input of resources. When these landscapes are designed with ecological considerations included, such as proper plant selections, wildlife habitat components, reduced requirements for supplemental water, and minimal use of insecticides, herbicides and fertilizer, they have the potential to contribute positively to the greater ecosystem. As suggested by Loram et al. (2007), private domestic gardens are known to constitute a considerable proportion of “green space” in urban areas and are therefore of potential significance for maintaining biodiversity and providing ecosystem services. Urbanism affects ecological systems by altering habitat with the loss and fragmentation of natural vegetation. Gardens can be a major component of urban “green space,” thus, a complex and heterogeneous mosaic of habitats composed of native species is possible, even in the midst of urban development.

Both aesthetic and biological richness can be achieved by using species that are native to an area where both restoration and beauty within the landscape is the desired result. The basic design principles used in any type of artistic composition can be successfully applied when designing with Intermountain natives. Scale and density of natural plant communities differ from those found in constructed landscapes. Within constructed landscapes, designers have the liberty of arranging plant materials more densely to have a greater aesthetic impact than what generally occurs in the natural landscape because of water or nutrient limitations.
Distinct relationships exist between ecological utility and the basic design principles. These principles include, but are not limited to, line, color, form, texture, variety, repetition, balance, emphasis, and scale. The basic principles of plant design and management are the same regardless of the size of the plot or plant species chosen.

An essential difference between contemporary, post-modern landscapes and ecologically designed landscapes is the sensory and biological richness, which is customized to a place and provides value to life other than human life (wildlife, insects, and aquatic life), which in turn improves human quality of life. As humans continue to modify, create, and participate within the broader ecosystem, one can realize that contributions to environmental health can be made through both large and small design choices.

Natural Lines

Lines found within the natural environment are gently sweeping curves that follow water sources, topographic change, soil types, and disturbance patterns. Lines can result from the intimate interactions of insects and animals within a landscape. Abrupt changes within vegetation communities rarely form distinct lines; gentle transitional gradients are more commonly found. Lines found within natural landscapes are subtle and understated. The spacing and distribution of plants is often determined by the water resources available.

Creating natural or organic lines within a constructed, typically smaller landscape is facilitated by the availability of irrigation water. The density of plants of varying color,
texture, and form can be increased to make the landscape less chaotic and more manageable by choosing carefully from the available palette of native plant species.

Color: Embracing the Palette of the Region

Many species have developed special adaptations to attract the passing insect for pollination. One of these adaptations involves the use of vividly colored blooms as well as staggered bloom periods among species. This is not only advantageous for propagation, but it is also ideal for the visual qualities of the landscape. With correct species selection, this adaptation can provide year-round variety and interest within a revegetation project, residential and commercial landscapes, or naturalized areas. Along with considering species color, appropriate soils must be patterned after the site where the species originates in order to create areas conducive to habitat requirements, e.g., fine or sandy texture, pH, salinity, organic matter content, aspect, and slope. It is important to duplicate the location from which the plant is being introduced sufficiently to allow for natural pollinators to re-colonize and facilitate reproduction (N.N. Youssef, pers. comm.). This creates circumstances that enable species to proliferate and create more dynamic vegetation communities.

Greater biological diversity provides a large palette of species and colors to incorporate into a landscape composition. The colors found within the Intermountain West are unique, and include deep blue-grey, pink, washes of orange, cream, tan, and soft gray-green hues. These landscapes have perfectly paired complimentary colors of
Finding Form in Nature

Competition for soil, light, and moisture has forced the evolution of species into differing forms to gain an advantage for capturing resources, or in some instances, making do with mineral resources. Many species native to the Intermountain West are compact and efficient, indicative of the requirements of the landscape.

The form of many Intermountain natives is informal in nature. Because of this informality, care must be taken to ensure that smaller scale landscapes do not result in designs that look haphazard or are perceived as “weedy.” Jensen (1939) speaks of grouping individuals of a species together…“some plants to be at their best need association in a small colony or group”...For Intermountain species, this need for association generates form and fills a functional niche for increasing water available for themselves and associated species. Intermountain species may be widely scattered in the natural landscape and are more visually effective when used in groupings or masses in designed environments for added impact through perceived structure.

Functional Texture

A variety of species found in arid grasslands or shrublands, such as grass and sage, have a fine texture compared to landscapes where water is more abundant to reduce
transpiration by reducing leaf surface area. Contrast is found along streams and wetlands where vegetation commonly has more coarsely textured foliage.

Hydrozones, or plantings with similar water requirements, allow designers to emphasize differences in textures between vegetation communities contained in small-scale planting plans. When using more finely textured species in constructed landscapes, it is important that contrasting species are incorporated to give structure and context to the species. This will emphasize the textural qualities of both species types and provide depth to the composition.

Biodiversity Through Variety

Desert environments have been noted for their abundance of biodiversity when compared to most other environments. Biodiversity denotes a healthy system as well as aesthetic opulence. Both the vastness of the Intermountain West’s landscape and binding plant communities allow for a great variety of species while maintaining aesthetic appeal.

When implementing variety within a landscape, scale is an important consideration. A common mistake in small-scale native landscape design is the use of an array of species, setting aside the other fundamental design principle of repetition of form, texture, color and consideration of scale. This creates a landscape that resembles a collection found in an herbarium rather than a deliberately designed landscape.
Repetition: Binding Properties

Repetition within a design creates homogeneity. Repetition prevents a composition from appearing disconnected and chaotic. Differing species of grasses and shrubs with similar form, scale and texture serve to create unity within the landscape; closer inspection reveals great variety. Grouping plants of similar form and texture, and repeating them throughout the design creates unity within the landscape.

Emphasis: Finding Focus

Emphasis is often created by elements including broad swaths of wildflower blooms, groupings or masses of vegetation, landscape features such as rock outcroppings, buttes, hills, water features, and other contrasting elements of natural landscapes. Emphasis can be achieved by directing the eye to a certain portion of the landscape with the use of lines, form, variety, and color. Emphasis within a native Intermountain West landscape is frequently accomplished with landform. The unique and exposed geology of the Great Basin and contained grasslands serves as both backdrop and point of emphasis. This landscape is a land of contrasts; with the smallest trickle of water comes vibrant green hues. These extremes of exposure and limited resources bring emphasis through landscape structure and vegetation patterns.

Place (Intermountain West)

The Intermountain West has experienced a rapid influx of growth and development in the recent past, in part because of the tremendous natural beauty of the
native landscape that the region has to offer. Despite the fact that much of the population was drawn to the region by its natural, wide open landscapes, the area has been and continues to be developed using techniques and planting materials that are native to high-rainfall temperate climates. The essence of the high desert environment is in many cases being lost in the effort to replicate an “English garden” standard. This is not only detrimental to the unique aesthetics of the region but it is also a great threat to the fragile native grassland ecosystem. Just as the ecosystems of the region are unique, so are the aesthetic qualities. Through the identification and proper presentation of aesthetic characteristics of the region, designers and planners can develop a more appropriate cultural aesthetic for the Intermountain West.

References


CHAPTER 3

ESTABLISHMENT AND INTERACTIONS OF INTERMOUNTAIN WEST NATIVE PLANT SPECIES¹

Abstract

Although the use of ecologically appropriate native species is increasing in popularity, there is discontinuity between aesthetics and meaningful ecological contributions. A series of studies was designed to aid in the restoration of a site located at the Utah Botanical Center in Kaysville, Utah which interfaces urban development. A controlled-environment establishment study demonstrated that weed competition was likely to be a significant impediment to the establishment of selected native species, and that there was no immediate benefit from biologically fixed nitrogen. A longer-term growth study showed that once established, warm-season grasses could be a significant contributor to native grassland productivity. Finally, a field study at the Utah Botanical Center was used to demonstrate the benefit of fall seeding for establishment, and the potential contributions to grasslands of native legumes and non-leguminous forbs.

Restoration of native vegetation and the regeneration of functioning ecosystems is a major conservation focus in many parts of the world, where poor management practices have resulted in serious land-degradation problems (Perrow and Davy, 2002). The addition of native forbs to grassland re-vegetation projects contributes to the

¹ Coauthored by B. M. Atkiin and J. W. MacAdam
establishment of a more complex community, enhancing the health and resilience of the stand, and the insect, bird and small mammal communities dependent upon them. Legumes add biologically fixed nitrogen to the system, and can increase nitrogen availability to grasses and non-leguminous forbs, enhancing habitat for wildlife, reducing the ability of exotic species to enter a community, and improving the aesthetics of a low maintenance landscape project (Walker and Shaw, 2005). The contribution of biologically fixed nitrogen to restored natural areas as well as constructed landscapes has the potential to supply critically needed nitrogen through a non-mechanical, non-chemical mechanism. Appropriate nitrogen management is central to restoration success (Baer et al., 2003). While elevated soil nitrogen levels or nitrogen fertilization will increase the rate of establishment of cover and thereby limit erosion (Johnson, 2000, MNDOT 2003), chemical nitrogen application is indiscriminate and can therefore lead to an explosion of weed species in recently replanted areas, hindering native plant establishment (Wilson and Gerry, 1995). One way to provide proper amounts of nitrogen to restoration sites is to include legume species in the planting plan (Graham, 2005). Legumes that are properly managed will supply nitrogen to the system through symbiosis with soil-living bacteria from the genus Rhizobia---in effect providing slowly released nitrogen that will be transferred to the soil through leaf litter, root turnover, or by transfer through herbivore utilization. It is therefore less likely to encourage the growth of weedy species once the native plant community has become established (Graham, 2005). Because many disturbed or degraded sites lack appropriate rhizobia in soil (Thrall et al.,
sown legumes require inoculation with the appropriate species of rhizobia to maximize establishment and growth (Thrall et al., 2005).

Legumes have important effects on many ecosystem processes due to their nitrogen-fixing ability. Minns et al. (2001) found that nitrogen pools in above-ground vegetation generally increased with species diversity and functional group richness. The effect of legumes occurs most directly via two mechanisms: one is by the reduced competition from nitrogen fixing legumes for soil nitrogen, and the second is the addition of fixed nitrogen to the soil through rapid decomposition of legume leaf litter (Minns et al., 2001). Non-leguminous species can benefit from this legume nitrogen input to the soil (Khanna, 1997). Biological nitrogen fixation by legumes can be a viable alternative to fertilizer nitrogen for increasing community productivity, health and sustainability (Gebhart et al., 1993) in natural landscapes as well as in agricultural settings (Minns et al., 2001).

The degree of disturbance is the most important environmental variable determining the short- and long-term persistence of plant populations introduced for restoration (Lesica and Allendorf, 1999). Residual soil nutrients from previous land use can have significant effects on the establishment of selected restoration species. Specific site conditions are important aspects to consider in the planning of restoration or revegetation projects. The addition of legumes can be a critical contribution in sites denuded of top soil or sites that require additional nitrogen to promote native plant sustainability, compete with invasive, non-native species, and reduce the need for supplemental fertilization. In nitrogen-deficient environments, the formation of effective
nitrogen-fixing symbiotic associations between rhizobia and legumes assists seedling establishment, promotes rapid early seedling growth and increases plant survival (Thrall et al., 2005).

Peltzer (2001) suggests that environment and competition are long-term influences, while the performance of juvenile plants in the field is strongly influenced by the level of soil disturbance. Invasive nonindigenous species may be more adapted to altered soil nutrient content. Species such as cheat grass (*Bromus tectorum*), a winter annual that grows at a time of plentiful water and nitrogen, depletes the soil of both and severely limits the growth of native plant species. Regardless of the disturbance, provisions must be made to control existing weeds or prevent their entry onto prepared seedbeds (Hull and Holmgren, 1964). In many instances of attempted restoration efforts, nonindigenous species assume the dominant role and prevent the establishment of more desirable species (Monsen et al., 2004). Competition between nonindigenous species and seeded native species has proven to be one of the greatest challenges for restoration projects.

Restoring vegetation communities by seeding of shrubs and broadleaf herbs has been hindered because of erratic germination characteristics of native species as well as the lack of planting equipment capable of operating in varied terrain (Monsen et al., 2004), required to seed plant species at appropriate depths for germination and emergence. Fall plantings have had higher success rates within the Great Basin and Intermountain West (Monsen et al., 2004) because of reduced weed competition and higher seasonal precipitation. Cold stratification combined with scarification has resulted
in much faster and more uniform germination of some legume species (Kaye and Kuykendall, 2000). Fall plantings, which allow for an over-winter chilling period combined with freeze-thaw cycles to naturally scarify seed, should produce higher rates of legume emergence and establishment.

Because individual plant species have different requirements for optimal germination rates, knowing these prerequisites can aid in the establishment of restoration projects or horticultural cultivation. Many species require a ripening period of up to 9 months to optimize germination and establishment. Seasonal timing of seeding is a critical consideration for species native to the Intermountain West. Hard seedcoats that inhibit water uptake are typical of many legumes (Baskin and Baskin, 1998), making pre-planting scarification important for increased germination for many legume species.

The differences observed in germination success of seeds from different lupine populations of the same species suggest that seed dormancy and viability can vary from one seed source to another (Kaye and Kuykendall, 2000). Because species, and populations within a single species, can vary greatly, initial germination studies can provide valuable information because they allow for adjustment of seeding rates if necessary. The series of studies reported in this chapter should add to our understanding of secondary successional processes occurring when combinations of species are planted together (Walker et al., 1995).

In this study, the establishment and early growth of selected native grass, legume, and non-legume forb species were analyzed to predict the successful establishment of these species under field conditions. When experiments are conducted in the field, there
are many variables that cannot be controlled, but which can affect the success of the experiment. On the other hand, experiments conducted in controlled environments (greenhouse) eliminate variable environmental conditions that occur in the field. Results from controlled environment experiments allow for further dissection of questions relating to the establishment of grassland species native to the Intermountain West.

The use of species indigenous to an area where restoration is attempted or a constructed landscape is being used to demonstrate aesthetic values presents a range of challenges. Landscape restoration using species native to the Intermountain West is a goal of the Utah Botanical Center (UBC) located in Kaysville Utah. The reported studies were designed to address issues of site disturbance and past management specific to the UBC. These findings, however, will also contribute to a broader base of knowledge that will be useful for restoring grassland landscapes in the western United States.

To begin, I assessed the practicality of using selected species native to the Intermountain West by evaluating their early establishment. Germination and establishment become key factors in the feasibility of use of species native to the Intermountain West. In native grasslands, legumes and non-leguminous forbs are important elements, but only legumes contribute biologically fixed nitrogen to the benefit of the entire system. Therefore, experiments designed to determine the relative value of the addition of legume or non-legume forb components to seeding mixtures on the establishment and relative aboveground herbage biomass production of native grasses were included.
The experiment was based on my hypothesis, based on evidence in the literature from other environments, that the addition of a legume component to a native grass mixture would improve the overall establishment and production of the aboveground biomass, a prerequisite of longer-term sustainability. Six native grass species, two non-leguminous forbs, and two legume species were used in controlled-environment and field studies. These species were selected for their landscape, restoration, and establishment potential.

My thesis project explored both the agronomic and aesthetic traits of native grassland species in an attempt to create a landscape that is sustainable, inherently interesting and appealing, and which illustrates design elements useful for native, water-efficient landscapes.

Materials and Methods

**Greenhouse Establishment of Native Grasses as Affected by Nitrogen or Legumes**

The objective of this experiment was to compare the inclusion of a native legume with a modest application of nitrogen fertilizer on the establishment of native grasses. This was a greenhouse study in which light, temperature, and application of water were the same for all species. Competition from weedy plant species was also controlled in this initial study. The study was carried out at the Utah State University Research Greenhouses in Logan, Utah. The emergence and establishment of selected native grass species with the addition of either N or a legume were evaluated, and the above-ground
biomass of grass species grown with N or with the addition of a legume species were compared to the control grass mixture with no nitrogen source.

Native soil was obtained from the UBC. This soil is part of the Parleys series that is a well-drained, medium-textured, silty loam. Topsoil was taken from 0-25 cm, mainly from the A horizon. Native vegetation that was historically supported on this site was gambel oak, sagebrush, and native bunchgrasses (USDA SCS, 1968). Analysis of a composite soil sample found 1.72 % carbon content, 0.16 % nitrogen, and 2.9 % Walkley-Black organic matter. Historically, the site was used as pastureland for dairy cattle, and just prior to the UBC’s establishment, the area was used for two years as a sod farm. The analysis of UBC Soil #1 is included in Appendix A.

A wooden frame was constructed on a greenhouse bench with subdivisions measuring 58 x 43 x 15 cm deep, and filled to a 14-cm depth with UBC soil. Soil was compacted to reduce settling with irrigation. The bottom of the frame was open and placed on perforated plastic sheeting to allow for drainage. The greenhouse unit cycled between a minimum night temperature of 15 °C (59 °F) and maximum day temperature of 32 °C (89°F). Supplemental lighting was used from 6 AM to 9 PM to provide a 15-hour (mid-summer) daylength during the study.

Species used in this experiment were alkali sacaton (*Sporobolus airoides*), sand dropseed (*Sporobolus cryptandrus*), bottlebrush squirreltail (*Elymus elymoides*), basin wildrye (*Leymus cinereus*), Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Pseudorergneria spicata*), silvery lupine (*Lupinus argenteus*), and Utah sweetvetch (*Hedysarum boreale*). Species were seeded at recommended depths, with alkali sacaton
and sand dropseed seeded at 6 mm, and all remaining species at 12 mm. The seeding rate was 320 pure live seed (PLS) m\(^{-2}\), based on germination and hard seed data on seed tags. Legume species were inoculated prior to planting with appropriate rhizobia (Nitragen, EMD Crop Bioscience, Milwaukee, WI 53209). Plots were hand-seeded, with species randomly assigned within a grid pattern.

Plots were seeded on 27 September 2006. The four treatments were assigned to frame subdivisions in a completely randomized block design, with four replicates. The four treatments were Grass, Grass + N, Grass + Vetch, and Grass + Lupine. The Grass treatment consisted of a mixture evenly divided among the six grass species with no legume component or nitrogen amendments added, and served as the control. The Grass + N treatment was comprised of the same six grasses, with a single nitrogen application of 11 kg per ha (10 lbs. per acre) in liquid form 6 weeks after planting. The Grass + Vetch treatment contained the six grasses with the addition of Utah sweetvetch, and the Grass + Lupine treatment contained the six grasses with the addition of silvery lupine. For the Grass + Vetch and Grass + Lupine treatments, 320 seeds m\(^{-2}\) were comprised of 35 percent legume and 65 percent grass species. Plots were covered with hydro mulch (Nature’s Own, Twin Falls, Idaho) at the time of planting and irrigated every 1 to 2 days. Any non-seeded species that emerged were removed, to prevent the dominance of weed species. See Figure 3.1, which shows an un-weeded plot to illustrate the proliferation of non-seeded species.

Number and identity of emerged plants were assessed once a week using a fixed quadrat measuring 30 x 15 cm to determine the timing of emergence, and these data were
analyzed for effect of days after planting (DAP). For the last count, taken 53 DAP, effects of treatment and species on plant numbers were analyzed. Herbage DM was harvested on 19 December 2006 and separated by species. Plants were dried for 2 days at 60 °C. Specimens were weighed as they were removed from the oven to prevent moisture accumulation. Plant number and shoot DM were analyzed to determine the main effect of treatment and species, and the effect of species within each treatment on these variables was also determined.

The study was designed as a randomized complete block with days after planting, nitrogen source (none, fertilizer N, Vetch, Lupine) and species as fixed factors. An analysis of variance (ANOVA) was performed using the Proc Mixed procedure of SAS (SAS, 2010).

**Germination of Native Grass, Forb, and Legume Species**

The germination response of species in the four perennial plant functional groups was assessed to determine how well actual germination compared to the germination percentage stated on seed tags. Among the six native grass species used in this study, two were warm-season grasses (alkali sacaton and sand dropseed), and four were cool-season grasses (bluebunch wheatgrass, Idaho fescue, basin wildrye, and bottlebrush squirreltail). Non-legume forbs selected for the study were Rocky Mountain penstemon (*Penstemon strictus*) and Munro’s globemallow (*Sphaeralcea munroana*); legumes studied were silvery lupine and Utah sweetvetch. Seed of alkali sacaton, sand dropseed, Rocky Mountain penstemon, Munro’s globemallow, silvery lupine, and Utah sweetvetch were purchased from Granite Seed Company in 2006 and seed of bluebunch wheatgrass, Idaho
fescue, basin wildrye and bottlebrush squirreltail were donated to the project by the Utah Agriculture Experiment Station.

Seed were placed on 9-cm-dia. filter paper in 10-cm-dia Petri dishes, moistened with distilled water (Kaye and Kuykendall, 2000) and kept at room temperature, which fluctuated between 15 °C and 25 °C (60 °F and 80 °F). One hundred seed of each species were placed in each Petri dish and kept moist with distilled water to promote imbibition. Legume species were nicked individually with a razor blade to ensure consistent scarification of each individual. Germination was counted every other day for 2 weeks until all seed had germinated or began to severely mold or decompose. Germination was defined as emergence of the radicle (Kaye and Kuykendall, 2000). Data are reported but this study was not replicated, so no statistical analysis was conducted.

**Legume Effect on Herbage Biomass (Column Study)**

This study was designed to determine if nitrogen-fixing legume species influence the above-ground herbage accumulation of companion grass and forb species. A single plant of one of the two legume species, silvery lupine or Utah sweetvetch, was planted in the center of a 20-cm-diameter, 60-cm-deep column with single plants of two warm-season grasses, alkali sacaton and sand dropseed, and single plants of two cool-season grasses, bottlebrush squirreltail and bluebunch wheatgrass, to evaluate the influence of the legume on the biomass of the mixture. The control consisted of single plants of each of the four grass species with a central bluebunch wheatgrass plant in place of the legume component.
Plants were grown in PVC columns in well-drained Kidman sandy loam soil. The Kidman soil was used rather than the UBC soil in this study because it performs well in column studies and is weed-free. Columns were lined with plastic sleeves to prevent water from channeling to the outside of the columns, causing inconsistent wetting of the soil profile. Soil was tamped into columns during filling to create consistent bulk density and reduce settling. Sand dropseed and alkali sacaton were seeded at a 6 mm depth and bottlebrush squirreltail, bluebunch wheatgrass, silvery lupine, and Utah sweetvetch at a 12 mm depth.

The study was planted on 9 November 2006. Columns were irrigated once daily during establishment to ensure adequate conditions for germination and emergence of species. Seedlings were reduced to the five target plants after germination. Once species were established, columns were irrigated every 2 to 3 days. The greenhouse unit used in this study cycled between a minimum night temperature of 15 °C (59 °F) and maximum day temperature of 32 °C (89°F). Supplemental lighting was used from 6 AM to 9 PM to provide a 15-hour (mid-summer) day length during the study.

The experiment was arranged in a randomized complete block design with four replicates. The three treatments were Grass, the control, which consisted of the four grasses plus a central bluebunch wheatgrass plant; Grass + Vetch, the four grasses plus Utah sweetvetch; and Grass + Lupine, the grasses plus silvery lupine. Silvery lupine had a high mortality rate due to powdery mildew, so data were collected only on the Grass and Grass plus Vetch treatments. Because of poor germination of Utah sweetvetch seed,
pre-germinated plugs of this species were used in the experiment. Utah sweetvetch plugs were added to the Grass + Vetch treatment on 23 January 2007, 10 weeks after planting.

Plants were harvested twice during the course of this experiment. The first harvest was on 4 March 2007 (16 weeks after planting) and the second on 28 April 2007 (24 weeks after planting). In March, only the grass species were harvested to a height of approximately 5.1 cm, leaving the legume intact. Grasses were separated by species, dried, and weighed directly from the oven to determine aboveground biomass. At the second harvest, all aboveground biomass was clipped and separated by species, including the legume species. Samples were dried and weighed to determine aboveground biomass for each species.

The study was designed as a randomized complete block and an analysis of variance (ANOVA) was performed using the Proc Mixed procedure of SAS (SAS, 2010). The biomass of each species as well as the sum of biomass for each treatment were calculated and analyzed for two successive harvests. The main effect of treatment and species, and the effect of species within treatment were determined.

**Establishment of Native Grass, Legume and Forb Species in the Field**

This study assessed establishment of a native grassland community with the inclusion of either two Intermountain native legume species, Utah sweetvetch and silvery lupine, or two native non-leguminous forbs, Rocky Mountain penstemon and Munro’s globemallow. The goal of this experiment was to further our understanding of secondary
successional processes occurring when combinations of species are planted together (Walker et al., 1995) and to assess the possible benefits legumes or other forbs may have during the establishment period in Intermountain grassland restoration.

An experimental plot was established at the Utah Botanical Center, Township 3 North Range 1 West, Kaysville, Utah, in the fall of 2006, measuring 8 x 16 m, with treatments applied to sub-plots measuring 1.5 x 3 m. Soils found on this site are part of the Kidman series consisting of moderately well drained fine sandy loams. A composite soil sample was used for a complete nutrient analysis. The soil contained 1.16 % carbon, 0.09 % nitrogen, and 2.9 % Walkley-Black organic matter content. The nutrient analysis is included in Appendix A as UBC Soil #2.

The control consisted of a mixture of six native grasses comprised of two C₄ grasses: sand dropseed and alkali sacaton, and four C₃ grasses: bottlebrush squirreltail, Idaho fescue, basin wildrye, and bluebunch wheatgrass. The seeding rate was 80 PLS per 0.3 m² divided equally among the six grasses. The other four treatments consisted of the six grasses plus either the two legumes or the two non-legume forbs at the same total seeding rate. The Grass + 25% Forb treatment contained 25 percent of the above two forbs and 75 percent grasses on a PLS basis. The Grass + 50% Forb treatment contained 50% non-leguminous forbs and 50% grasses. The Grass + 25% Legume and Grass + 50% Legume treatments contained 25 and 50% legumes on a PLS basis. The percent of seed of forb or legume was evenly divided between the two species of forb or legume, and the percent grass was evenly divided among the six grasses. Legumes were scarified with fine sandpaper and inoculated with the appropriate rhizobium species prior to planting.
The treatment containing the non-leguminous forbs was designed to contrast with the treatments containing nitrogen-fixing legumes and to address the question of whether forbs can displace weeds in grass stands. Plots were seeded 27 October 2006 and were broadcast seeded, hand raked and compacted with a cultipacker. Hydro mulch (Nature’s Own, Twin Falls, Idaho) was applied by hand to aid in soil moisture retention. Plots were sprinkler irrigated once a week during April and May of the following spring to assure seedling survival and establishment.

Establishment success was measured by monitoring plant germination and persistence of species once established. A 59 x 59 cm quadrat was systematically placed in the center of each plot and individual species were counted on two separate occasions to document survival of species, weed competition, and overall establishment success of different seed mixtures. Weeds were not removed. Data were collected on 5 May 2007, and all vegetative growth from each plot was clipped with hand shears to a height of 8 to 13 cm at this time to reduce competition with non-seeded species. Plots were not watered during the month of June after seeded species had become adequately established, to curb the growth of non-seeded invasive species and expose plots to the more natural climatic conditions encountered in the Intermountain West. Data were collected again on 30 June 2007. Seeded species as well as non-seeded or invasive species were counted on both dates.

*Statistical Analysis:* The study was designed as a randomized complete block design and an analysis of variance (ANOVA) was performed using the Proc Mixed procedure of SAS (SAS, 2010). Data collected from field plots were analyzed to
determine the effect of treatment on the number of plants of each individual species as well as the sum of plants in each treatment. The main effect of treatments and species, as well as the effects of species within treatment were determined along with number of non-seeded species within each treatment.

Results and Discussion

Greenhouse Establishment of Native Grasses as Affected by Nitrogen or Legumes

Number of Plants

For this study, establishment was defined as the mean of the number of individuals of seeded species counted weekly between 14 and 53 days after planting (DAP). The effect of days after planting on mean plant number averaged across species and treatments is shown in Fig. 3.2. Absolute plant numbers continued to increase through 46 DAP, but there was no interaction of DAP and treatment effects (p=0.9323; Appendix B, Table B1d; Table 3.1) or DAP and species effects (p=0.7279; Appendix B, Table B1c; Table 3.2), so all plant counts taken between 14 and 53 DAP were used to determine the effects of treatment and species on establishment.

Plant numbers were greatest for the Grass Only and Grass + N treatments and least for the Grass + Lupine and Grass + Vetch treatments (Fig. 3.3). The effect of plant species on establishment (Fig. 3.4) varied by plant species and functional group. The two warm-season grasses, alkali sacaton and sand dropseed, had lower establishment than all cool-season grasses. Of the four cool-season grasses, bluebunch wheatgrass had higher
plant numbers than basin wildrye while bottlebrush squirreltail was intermediate. Idaho
fescue had lower plant numbers than basin wildrye. The two legume species, silvery
lupine and Utah sweetvetch, were intermediate in plant number to Idaho fescue and the
two warm-season grasses. The low plant counts of the two legume species (35% of PLS)
contributed to the lower plant counts of the two treatments that contained legumes (Fig.
3.3).

In the two treatments that included legumes, both bluebunch wheatgrass and
bottlebrush squirreltail plant numbers were reduced sufficiently to account for the added
legume plant numbers (Table 3.3). Basin wildrye numbers were negatively affected by
slivery lupine but not by Utah sweetvetch, suggesting that lupine is more competitive
than Utah sweetvetch, and that basin wildrye is less competitive than bluebunch
wheatgrass and bottlebrush squirreltail. Bottlebrush squirreltail appears to have benefited
the most from the nitrogen fertilization treatment. Idaho fescue had the lowest plant
numbers of the cool-season grasses except in the Grass + Lupine treatment, and was
statistically similar to alkali sacaton and sand dropseed in all treatments.

**Shoot Dry Matter of Plants**

Plants in the greenhouse establishment study were destructively harvested 12
weeks after planting, and final shoot dry matter was determined (Table 3.4). These data
support the results for plant counts: shoot matter of the Grass Only and Grass + N
treatments was greater than for the Grass + Lupine treatment, and the Grass + Vetch
treatment was intermediate (Fig. 3.5). Basin wildrye had higher shoot biomass than all
species except bluebunch wheatgrass (Fig. 3.6). Basin wildrye is described as a “large,
coarse, robust, perennial bunchgrass” that “may reach 3 feet in diameter and 3 to 6 feet tall (10 feet under excellent soil and climate conditions)” (Ogle, 2006). Within treatments (Table 3.4), basin wildrye had the highest shoot dry matter in the Grass + Vetch treatment, and along with bluebunch wheatgrass and bottlebrush squirreltail, was statistically higher than all other species in the Grass Only and Grass + N treatments. There were no statistical differences among species in shoot dry matter in the Grass + Lupine treatment, again suggesting that lupine successfully competed with the more dominant grasses and promoted a more diverse and balanced mixture of species.

These data for plant numbers and shoot dry matter do not, however, provide support for the underlying hypothesis of this study, which was that nitrogen contributions from the legume functional group will result in more aboveground biomass production. However, the initial contribution of the nitrogen-fixing rhizobia-legume association is to the legume. It is only with breakdown of nodules in the soil and leaf litter on the soil surface that this nitrogen is transferred to associated species. A longer-term study (Hood, 2004) suggests that significant nitrogen would eventually be contributed from legumes to other species because nitrogen inputs from legumes are available primarily through microbial release of organic matter or transfer via the waste of grazing ruminants. While there may be no direct nitrogen benefit of legumes to grasses during establishment, legumes add valuable biodiversity to grasslands. In this study, weeds were removed, and results for the Grass Only and Grass + N treatments were not significantly different, suggesting that a low rate of nitrogen does not directly alter the establishment of these native grass species or their interaction.
Germination of Native Grass, Forb, and Legume Species

In the establishment study conducted in the greenhouse, the mean emergence of grasses compared with the number of seeds planted was approximately 30 percent for all treatments. Legume emergence was lower, with silvery lupine at 13% and Utah sweetvetch at 10%. Because apparent germination compared with seed tag pure live seed data were so low, an unreplicated 2-week-long in vitro germination test was run to compare actual with expected germination.

After 2 weeks, germination of grasses varied widely among species (Fig. 3.7), with basin wildrye germination at 94% and sand dropseed at only 2% germination. Bluebunch wheatgrass had germination of 91%, bottlebrush squirreltail 73%, Idaho fescue 72%, and alkali sacaton 42%. Warm season grasses had lower germination than cool-season grasses, potentially because the seed coats of sand dropseed and alkali sacaton are hard; these species often require a ripening period and pre-chilling or over wintering (Monsen et al., 2004). In this germination study, seeds were neither scarified nor stratified. The germination of Rocky Mountain penstemon was 75% after 2 weeks, while Munro’s globemallow had germination of only 14%. Legume species exhibited low germination, with silvery lupine at 47% and Utah sweetvetch at 45%, but these levels were achieved in just a few days (Fig. 3.7). These legumes also had a tendency to mold after only a few days when kept in an environment that was constantly moist and with minimal air circulation.

Although the germination of some species was less than optimal, restoration literature specific to the western United States indicates that this should not prevent the
use of species with low germination rates. Optimal germination and establishment of these species often requires a very specific set of environmental conditions. Munro’s globemallow has a hard seed coat that may inhibit germination and require mechanical or acid scarification to increase germination rates (Monsen et al., 2004). Furthermore, globemallow seed may have better emergence rates if dusted with appropriate insecticide to prevent destruction by weevils when seeded into a landscape (Pendery and Rumbaugh, 1986). The freezing and thawing of fall-planted seeds can substitute in nature for scarification and stratification, so identifying the optimal season for planting plays an important role in establishment success. However, for warm season grasses, no scarification or stratification is usually applied to these seed before germination, and they do not fare as well when planted in fall as in late spring in the northern Intermountain West.

**Legume Effect on Herbage Biomass (Column Study)**

In this study, one plant of each of four grass species was grown to maturity in columns filled 60 cm deep with sandy loam soil. In the center of the column there was either a second bluebunch wheatgrass plant or a Utah sweetvetch plant. At harvest, only the four perimeter grass plants were dried and weighed to compare the effect of the grass or legume center plant. Harvest 1 occurred after 4 months of growth, and Harvest 2 occurred after 6 weeks of regrowth. There were no significant differences between the Grass Only and the Grass + Vetch treatment at either harvest (Tables 3.5 and 3.6), and no significant differences among grasses within treatments. As in the establishment study, the warm season grasses were numerically lower in shoot dry matter at the first harvest.
and comprised only 18% of the total shoot dry matter (Table 3.5). However, by the second harvest, the dry weight of alkali sacaton had surpassed the other species, and the two warm-season grasses comprised almost 50% of the total shoot dry matter (Table 3.6). It is apparent that these grasses are capable of contributing significant dry matter, but are difficult to establish, even in the greenhouse in part due to poor germination.

**Establishment of Native Grass, Legume and Forb Species in the Field**

While the results of establishment studies depend on specific soil and environmental conditions, they can be of value on a local or regional scale. Results from such experiments can be used to screen species before they are used in restoration projects or cultivated for sale. For a large-scale, mechanically seeded restoration to succeed, at least some species must germinate and establish more quickly than the seed bank of weedy species. For long-term aesthetic and wildlife benefit, it is important to understand which slower-germinating species will survive.

Field plots were established in the fall of 2006, and counts of species in these plots were made on 5 May 2007 and 30 June 2007. These plots were not weeded, but they were clipped after the first plant count. A statistical comparison of treatments for numbers of plants indicated that treatments were significantly different at Harvest 1 but not at Harvest 2 (Figs. 3.8 and 3.9). The Grass + 50% Forb treatment had the highest number of established plants at Harvest 1, but by Harvest 2, plant numbers in the Grass + 50% Forb treatment had decreased while the Grass Only and the two grass-dominated
treatments (Grass + 25% Forb and Grass + 25% Legume) treatment plant counts had increased.

There were no significant differences among treatments for non-seeded (weed) species (Fig. 3.10 and 3.11), but the absolute number of weeds decreased by one-third from Harvest 1 to Harvest 2, while the overall count of seeded species remained constant. Weed numbers were comprised mostly of annual broadleaf species. While there were no significant differences in weed counts among treatments, legumes or non-leguminous forbs are more likely to provide competition for broadleaf weed species. However, the greatest decrease in weed counts (50%) was in the Grass Alone treatment, and the smallest (12%) decrease was in the Grass + 50% Forb treatment.

Among the species used in the field study, Rocky Mountain penstemon plant numbers were higher than all other component species at Harvest 1 (Fig. 3.12), causing the Grass + 50% Forb treatment at Harvest 1 to be higher than other treatments (Table 3.7; Fig. 3.8). Silvery lupine was also relatively high at Harvest 1, statistically higher than all remaining species (Table 3.7), contributing to the high plant numbers in the Grass + 50% Legume treatment at Harvest 1. By Harvest 2, forb (Rocky Mountain penstemon and Munro’s globemallow) and legume (silvery lupine and Utah sweetvetch) numbers had decreased and bluebunch wheatgrass and bottlebrush squirreltail plant numbers had increased and were equivalent to silvery lupine and Rocky Mountain penstemon plant numbers (Table 3.8; Fig. 3.13). Basin wildrye, Idaho fescue, Utah sweetvetch and Munro’s globemallow formed an intermediate group by Harvest 2. Sand dropseed, and alkali sacaton were absent in the field at both harvests.
A comparison of plant counts for the field establishment study, where weeds were not removed (Table 3.7 and 3.8), and the greenhouse establishment study, where plots were hand-weeded (Table 3.3), illustrates the impact of non-seeded species on the establishment of native grasses, legumes and forbs. While fall-seeding provides natural scarification and stratification, warm-season grasses did not survive. However, when germination was not the deciding factor, as in the column study, the two warm-season grasses performed well after establishment. Warm-season grasses have a lower tolerance than cool-season grasses for chilling injury (Monsen et al., 2004) so any germination that occurred did not proceed to establishment due to the growth inhibition of cold spring soils.

Among the cool season grasses used in these studies, bluebunch wheatgrass established quickly and remained productive. Bottlebrush squirreltail also germinated reliably and persisted in mixtures. Idaho fescue also established readily in the field but was less competitive, decreasing in number of plants by the second harvest. Basin wildrye seemed even less competitive than Idaho fescue. Since there were no significant differences among treatments in the field study at either harvest, legumes did not appear to contribute significant nitrogen during the early developmental stages of the grass species. The biomass of treatments in the greenhouse column study was also not increased with the addition of a legume (Tables 3.5 and 3.6). However, there is unquestionably aesthetic and ecological value in including perennial broadleaf species in grassland restoration. There will be a contribution of nitrogen to the system over the long term as the high-protein leaves of legumes are returned to the soil. Forbs are generally
tap-rooted and will draw water from deeper in the soil profile than cool-season grasses, perhaps even contributing to the availability of water for grasses by hydraulic lift during dry periods. Legumes also expand the feeding and nesting habitat for birds, and their flowers and fruits support a broader range of insects to increase the biodiversity of a native grassland. These data suggest in particular that Rocky Mountain penstemon and silvery lupine can compete with both weeds and the more vigorous grasses to add beauty and balance to grassland ecosystems in the northern Intermountain West.

References


Minnesota Department of Transportation (MNDOT). 2003 Seeding manual. Office of Environmental Services Erosion Control Unit, St. Paul, MN.


Table 3.1 Greenhouse Establishment Study: Mean counts per m$^2$ for treatments by days after planting.

<table>
<thead>
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<th>Treatment</th>
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<td>Grass + Lupine</td>
<td>19</td>
<td>26</td>
<td>21</td>
<td>25</td>
<td>33</td>
<td>33</td>
<td>26</td>
</tr>
<tr>
<td>Grass + Vetch</td>
<td>25</td>
<td>23</td>
<td>27</td>
<td>37</td>
<td>51</td>
<td>36</td>
<td>33</td>
</tr>
<tr>
<td>Mean of Day</td>
<td>29</td>
<td>30</td>
<td>37</td>
<td>38</td>
<td>47</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>Days after Planting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>14</td>
<td>23</td>
<td>30</td>
<td>37</td>
<td>46</td>
<td>53</td>
<td>Mean</td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>0.25</td>
<td>0.25</td>
<td>0.50</td>
<td>0.13</td>
<td>0.50</td>
<td>0.69</td>
<td>0.39</td>
</tr>
<tr>
<td>Basin wildrye</td>
<td>1.81</td>
<td>1.19</td>
<td>1.88</td>
<td>2.44</td>
<td>2.94</td>
<td>2.00</td>
<td>2.04</td>
</tr>
<tr>
<td>Bluebunch wheatgrass</td>
<td>2.63</td>
<td>2.38</td>
<td>3.75</td>
<td>3.38</td>
<td>3.56</td>
<td>4.69</td>
<td>3.40</td>
</tr>
<tr>
<td>Bottlebrush squirreltail</td>
<td>2.31</td>
<td>2.94</td>
<td>2.88</td>
<td>2.88</td>
<td>3.56</td>
<td>2.88</td>
<td>2.91</td>
</tr>
<tr>
<td>Idaho fescue</td>
<td>0.88</td>
<td>1.25</td>
<td>1.13</td>
<td>1.25</td>
<td>1.75</td>
<td>1.06</td>
<td>1.22</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>0.13</td>
<td>0.13</td>
<td>0.25</td>
<td>0.38</td>
<td>0.63</td>
<td>0.38</td>
<td>0.31</td>
</tr>
<tr>
<td>Utah sweetvetch</td>
<td>1.00</td>
<td>0.75</td>
<td>0.50</td>
<td>1.00</td>
<td>1.75</td>
<td>1.50</td>
<td>1.08</td>
</tr>
<tr>
<td>Mountain lupine</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>0.75</td>
<td>1.00</td>
<td>1.75</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Table 3.3 Greenhouse Establishment Study: Mean counts m$^{-2}$ by species and treatment.

<table>
<thead>
<tr>
<th>Species</th>
<th>Symbol</th>
<th>Grass</th>
<th>Grass + N</th>
<th>Grass + Lupine</th>
<th>Grass + Vetch</th>
<th>Mean of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluebunch WG</td>
<td>PSSP</td>
<td>92$^a$</td>
<td>87$^a$</td>
<td>60$^a$</td>
<td>63$^a$</td>
<td>75</td>
</tr>
<tr>
<td>Bottlebrush ST</td>
<td>ELEL</td>
<td>63$^a$</td>
<td>103$^a$</td>
<td>52$^{ab}$</td>
<td>44$^{abc}$</td>
<td>65</td>
</tr>
<tr>
<td>Basin wildrye</td>
<td>LECI</td>
<td>63$^a$</td>
<td>46$^b$</td>
<td>17$^{bc}$</td>
<td>56$^a$</td>
<td>45</td>
</tr>
<tr>
<td>Idaho fescue</td>
<td>FEID</td>
<td>18$^b$</td>
<td>31$^{bc}$</td>
<td>29$^{abc}$</td>
<td>31$^{abcd}$</td>
<td>27</td>
</tr>
<tr>
<td>Silvery lupine</td>
<td>LUAR</td>
<td></td>
<td></td>
<td>18$^{bc}$</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Utah sweetvetch</td>
<td>HEBO</td>
<td></td>
<td></td>
<td></td>
<td>24$^{bcd}$</td>
<td>24</td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>SPAI</td>
<td>11$^b$</td>
<td>9$^c$</td>
<td>3$^c$</td>
<td>11$^{cd}$</td>
<td>9</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>SPCR</td>
<td>14$^b$</td>
<td>4$^c$</td>
<td>5$^c$</td>
<td>6$^d$</td>
<td>7</td>
</tr>
<tr>
<td>Mean of Treatment</td>
<td></td>
<td>43</td>
<td>47</td>
<td>26</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>

Means within columns with unlike subscripts differ (p ≤ .05)
Table 3.4 Greenhouse Establishment Study: Shoot dry matter 12 weeks after planting in grams per m$^{-2}$.

<table>
<thead>
<tr>
<th>Species</th>
<th>Symbol</th>
<th>Grass</th>
<th>Grass + N</th>
<th>Grass + Lupine</th>
<th>Grass + Vetch</th>
<th>Mean of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluebunch WG</td>
<td>PSSP</td>
<td>106.7$^{a}$</td>
<td>98.2$^{a}$</td>
<td>66.2$^{a}$</td>
<td>82.2$^{b}$</td>
<td>88.3</td>
</tr>
<tr>
<td>Bottlebrush ST</td>
<td>ELEL</td>
<td>77.4$^{a}$</td>
<td>89.8$^{a}$</td>
<td>58.9$^{a}$</td>
<td>45.7$^{c}$</td>
<td>68.0</td>
</tr>
<tr>
<td>Basin wildrye</td>
<td>LECI</td>
<td>103.1$^{a}$</td>
<td>108.7$^{a}$</td>
<td>67.4$^{a}$</td>
<td>127.5$^{a}$</td>
<td>101.7</td>
</tr>
<tr>
<td>Idaho Fescue</td>
<td>FEID</td>
<td>0.8$^{b}$</td>
<td>2.8$^{b}$</td>
<td>12.4$^{a}$</td>
<td>1.6$^{d}$</td>
<td>4.4</td>
</tr>
<tr>
<td>Silvery lupine</td>
<td>LUAR</td>
<td>13.2$^{a}$</td>
<td></td>
<td></td>
<td></td>
<td>13.2</td>
</tr>
<tr>
<td>Utah sweetvetch</td>
<td>HEBO</td>
<td></td>
<td></td>
<td></td>
<td>16.8$^{d}$</td>
<td>16.8</td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>SPAI</td>
<td>23.7$^{b}$</td>
<td>2.4$^{b}$</td>
<td>18$^{a}$</td>
<td>12.4$^{d}$</td>
<td>14.1</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>SPCR</td>
<td>4.8$^{b}$</td>
<td>2.8$^{b}$</td>
<td>1.2$^{a}$</td>
<td>0.8$^{d}$</td>
<td>2.4</td>
</tr>
<tr>
<td>Mean of Treatment</td>
<td></td>
<td>52.7</td>
<td>50.8</td>
<td>33.9</td>
<td>41.0</td>
<td></td>
</tr>
</tbody>
</table>

Means within columns with unlike subscripts differ (p ≤ 0.05)
Table 3.5 Column Study Harvest 1: Legume effect on shoot dry matter per m² four months after planting.

<table>
<thead>
<tr>
<th>Species</th>
<th>Symbol</th>
<th>Grass + Vetch</th>
<th>Grass</th>
<th>Species Means</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluebunch WG</td>
<td>PSSP</td>
<td>900</td>
<td>783</td>
<td>842</td>
<td>33</td>
</tr>
<tr>
<td>Bottlebrush ST</td>
<td>ELEL</td>
<td>967</td>
<td>1050</td>
<td>1009</td>
<td>40</td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>SPAI</td>
<td>417</td>
<td>383</td>
<td>400</td>
<td>16</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>SPCR</td>
<td>283</td>
<td>317</td>
<td>300</td>
<td>12</td>
</tr>
<tr>
<td>Tmt Means</td>
<td></td>
<td>642</td>
<td>633</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.6 Column Study Harvest 2: Legume effect on shoot dry matter per $m^{-2}$ after 6 weeks of regrowth.

<table>
<thead>
<tr>
<th>Species</th>
<th>Symbol</th>
<th>Grass + Vetch</th>
<th>Grass</th>
<th>Species Mean</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluebunch WG</td>
<td>PSSP</td>
<td>783</td>
<td>1184</td>
<td>984</td>
<td>27</td>
</tr>
<tr>
<td>Bottlebrush ST</td>
<td>ELEL</td>
<td>1267</td>
<td>583</td>
<td>925</td>
<td>25</td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>SPAI</td>
<td>750</td>
<td>1400</td>
<td>1075</td>
<td>30</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>SPCR</td>
<td>667</td>
<td>633</td>
<td>650</td>
<td>18</td>
</tr>
<tr>
<td>Treatment Mean</td>
<td></td>
<td>867</td>
<td>950</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.7 Field Establishment Study, Harvest 1: Plant counts m⁻².

<table>
<thead>
<tr>
<th>Species</th>
<th>Symbol</th>
<th>Mean Plant Counts by Treatment and Species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grass + 25% Forb</td>
</tr>
<tr>
<td>Bluebunch WG</td>
<td>PSSP</td>
<td>8.6&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bottlebrush ST</td>
<td>ELEL</td>
<td>2.15&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Idaho fescue</td>
<td>FEID</td>
<td>10.8&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Basin wildrye</td>
<td>LECI</td>
<td>0.72&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Munro’s globemallow</td>
<td>SPMU</td>
<td>2.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Rocky Mtn. penstemon</td>
<td>PEST</td>
<td>19.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Utah sweetvetch</td>
<td>HEBO</td>
<td></td>
</tr>
<tr>
<td>Silvery Lupine</td>
<td>LUAR</td>
<td></td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>SPAI</td>
<td>0.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>SPCR</td>
<td>0.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Means by Treatment</td>
<td></td>
<td>5.6</td>
</tr>
</tbody>
</table>

Means within columns with unlike subscripts differ (p ≤ .05)
Table 3.8 Field Establishment Study, Harvest 2: Plant counts m$^{-2}$

<table>
<thead>
<tr>
<th>Species</th>
<th>Symbol</th>
<th>Grass + 25%</th>
<th>Grass + 50%</th>
<th>Grass + 25%</th>
<th>Grass + 50%</th>
<th>Grass Alone</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottlebrush ST</td>
<td>ELEL</td>
<td>10.0$^{ab}$</td>
<td>12.9$^{ab}$</td>
<td>10.0$^{ab}$</td>
<td>10.0$^{ab}$</td>
<td>20.8$^a$</td>
<td>12.8</td>
</tr>
<tr>
<td>Idaho fescue</td>
<td>FEID</td>
<td>7.2$^{ab}$</td>
<td>2.9$^c$</td>
<td>9.7$^{ab}$</td>
<td>4.3$^{bc}$</td>
<td>5.0$^b$</td>
<td>5.8</td>
</tr>
<tr>
<td>Basin wildrye</td>
<td>LECI</td>
<td>1.4$^{ab}$</td>
<td>1.4$^c$</td>
<td>0.0$^b$</td>
<td>0.7$^c$</td>
<td>2.2$^b$</td>
<td>1.1</td>
</tr>
<tr>
<td>Bluebunch WG</td>
<td>PSSP</td>
<td>16.5$^a$</td>
<td>18.7$^a$</td>
<td>15.1$^a$</td>
<td>14.4$^{bc}$</td>
<td>25.8$^a$</td>
<td>18.1</td>
</tr>
<tr>
<td>Rocky Mtn. penstemon</td>
<td>PEST</td>
<td>14.4$^{ab}$</td>
<td>17.2$^a$</td>
<td></td>
<td></td>
<td></td>
<td>15.8</td>
</tr>
<tr>
<td>Munro’s globemallow</td>
<td>SPMU</td>
<td>0.7$^{ab}$</td>
<td>7.2$^{bc}$</td>
<td></td>
<td></td>
<td></td>
<td>3.9</td>
</tr>
<tr>
<td>Utah sweetvetch</td>
<td>HEBO</td>
<td></td>
<td></td>
<td>5.0$^{ab}$</td>
<td>11.5$^{ab}$</td>
<td></td>
<td>8.3</td>
</tr>
<tr>
<td>Silvery Lupine</td>
<td>LUAR</td>
<td></td>
<td></td>
<td>13.6$^a$</td>
<td>18.7$^a$</td>
<td></td>
<td>16.1</td>
</tr>
<tr>
<td>Alkali sacaton</td>
<td>SPAI</td>
<td>0.0$^b$</td>
<td>0.0$^c$</td>
<td>0.0$^b$</td>
<td>0.0$^c$</td>
<td>0.0$^b$</td>
<td>0.0</td>
</tr>
<tr>
<td>Sand dropseed</td>
<td>SPCR</td>
<td>0.0$^b$</td>
<td>0.0$^c$</td>
<td>0.0$^b$</td>
<td>0.0$^c$</td>
<td>0.0$^b$</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.3</td>
<td>7.5</td>
<td>6.7</td>
<td>7.4</td>
<td>9.0</td>
<td></td>
</tr>
</tbody>
</table>

Means within columns with unlike subscripts differ (p ≤ .05)
Figure 3.1 Greenhouse establishment study illustrating dominance of non-seeded species in un-weeded vacant box in comparison to weeded treatments.
Figure 3.2 Greenhouse Establishment Study, effect of days after planting on plant numbers.
Figure 3.3 Greenhouse Establishment Study, effect of treatment on plant numbers.
Figure 3.4 Greenhouse Establishment Study, effect of species on plant numbers.
Figure 3.5 Greenhouse Establishment Study, effect of treatment on shoot dry matter.
Figure 3.6 Greenhouse Establishment Study, effect of species on shoot dry matter.
Figure 3.7 Germination Study, numbers of germinated seeds by species.
Figure 3.8 Field Establishment Study, Harvest 1, treatment effects on plant number.
Figure 3.9 Field Study, Harvest 2, treatment effects on plant number.
Figure 3.10 Field Study, Weed Counts, Harvest 1.
Figure 3.11 Field Study, Weed Counts, Harvest 2.
Figure 3.12 Field Study, Harvest 1, species effects on plant number.
Figure 3.13 Field Study, Harvest 2, species effects on plant number.
CHAPTER 4
CONCLUSIONS

We conclude from this study that the potential contribution of legume species cannot be measured during early stages of grass development within seeded communities. The nature of even a system with a limited number of species is tremendously complex. The experiments included in this thesis have identified a small number of native species that are well-adapted for emergence at this site if there is good seedbed preparation, mulching to retain moisture for seedling development, sprinkler irrigation, and if they are seeded during the appropriate (fall) season.

Forb or legume species often exhibited the highest emergence rates in field plots, but did not have a statistically significant effect on weed number or biomass production. However, the long-term effects of these species on the suppression of exotic species could not be measured given the relatively short duration of this study.

A highly relevant element influencing restoration success is the site history. This study was designed to address two failed attempts at establishing research plots in two locations at the UBC on 22 May 2006 and 19 June 2006. Failure of the initial research plots was attributed to an inadequate irrigation system that was designed to irrigate crops, possibly making the application too coarse for the fragile native seedlings. High spring and summer temperatures are detrimental to the establishment of seedlings and provide no ripening period, stratification or scarification. Although observations were not reported in this thesis on the earlier attempts to establish research plots at the UBC, they are informative and worthy of mention, and will be briefly described here.
The first two plantings occurred in an area that had been grazed, utilized as a dairy, sod farm, and left uncultivated for a period of time, allowing invasive, nonindigenous species to proliferate. In contrast, the fall-planted field study reported here demonstrated that, given proper seedbed preparation, seeding depths, irrigation, and more careful management, some native species can readily become established.

The first plots were planted in early May and a heavy rain storm washed the seedlings out and formed a hard crust on the soil surface that likely prevented the emergence of remaining seeds or recovery of damaged seedlings. The second attempt proved difficult in large part because of the difficulty in getting plots properly irrigated with conventional farm irrigation equipment. Only a few plants of Munro’s globemallow and Utah sweetvetch appeared later in the fall. In observing the progression of events in attempting to establish plots, the importance of water, water quantity and water timing is inseparable from the success of restoration efforts of this type. Others have also observed the most critical issue to be considered in revegetating semiarid and arid sites is the availability of soil moisture for seedling establishment (Jordan, 1983). Arid conditions and naturally irregular moisture patterns simply may not be sufficient to support restoration seedling establishment (Monsen et al., 2004). The timing of planting is critical for germination and establishment. The irregularity of seeds contained in a diverse native seed mixture makes planting difficult when using conventional farm equipment that has been designed to plant uniformly sized and shaped seeds. Field planting was successful using a small broadcast seeder, paper-based mulch and compaction with a roller pulled by a small tractor following seeding.
The type, location, and extent of uses, past and present, of a site are important for evaluating present and potential carrying capacity of the site (Austin, 1984). The high level of disturbance that the UBC site has experienced has removed or depleted soil fertility and structure, and allowed an abundance of non-native species to build up a significant seed bank. The restoration of disturbed sites in arid regions is a complex challenge. The data presented here is not definitive, but will contribute to the understanding of restoration of Intermountain grassland systems.

Specific recommendations based on this study can be made to the Utah Botanical Center regarding species that are more likely to succeed given the conditions of the site. The native cool-season species bluebunch wheatgrass and bottlebrush squirreltail are the most promising grasses for future restoration work at the UBC. The two legumes and the two non-leguminous forbs all established and persisted well in the field, and added significant biological and aesthetic diversity to the site.

One of the most significant challenge to both establishment as well as appealing to general aesthetics is the control of invasive, weedy species. The presence, and often times dominance, of these species gives the site an unkempt look which diminished the aesthetic quality of the plot area. This can complicate justifications to surrounding communities of the value of sites such as the UBC, which are embedded within urban areas. Because aesthetic value, maintenance, and eventual restoration of self sustaining native plant communities is complimentary, it is important to approach the restoration task in a way that will communicate a beautiful and healthy landscape to the larger populous.
Because restoration of severely degraded sites can be difficult using conventional farming equipment and the associated large-scale approach, a successional or phased approach may be more appropriate. Recreating native plant communities in areas such as the UBC would benefit by identifying smaller areas given priority for planting. These areas could be seeded with broad monoculture swaths of individual species that would enable the use of selective herbicides. Using plug plantings and pre-emergent soil treatments to give desirable native plants an advantage over the existing weed seed bank could greatly enable establishment. In areas where the use of herbicides is not appropriate due to biodiversity of vegetation or proximity to water, hand pulling of noxious or perennial weeds by workers skilled in plant identification could also be an integral part of successional or phased restoration when used in relatively small spaces intended for educational purposes, such as the UBC.

As part of the planning process for restoration efforts, linking ecosystem function and aesthetic value can be advanced with the implementation of fundamental design principles: line, color, form, texture, variety, repetition, and focus. The species selected for experimental studies were chosen to fill functional groups, perceived ease of establishment, seed availability, regional occurrence, and previously published literature. Other considerations for species selection included form of plant, bloom color and duration, textural qualities, and a species’ ability to create a visually binding quality within a landscape. For example, bluebunch wheatgrass, Idaho fescue, bottlebrush squirreltail, and sand dropseed were selected for their ability to create a cohesive landscape aesthetic through similarity of texture, form, and color. Basin wildrye, a tall
and columnar species, was chosen for its form which can be used as a focal point or as a species that forms strong lines within the landscape with course textural qualities and variety in height. Alkali sacaton with its soft pyramidal form, moderate height, and fine textural qualities can be used in masses or linear form to lead the viewer’s eye. Flowering species which were selected, Munro’s globemallow, Rocky Mountain penstemon, silvery lupine, and Utah sweetvetch, were chosen while considering these species individually as well as how they pair with each respective co-species. For example, the vibrant orange of Munro’s globemallow pairs well to create both contrast and complement of color with the purple hues of the other blooming species. While the purple hues of these species contrast with the orange, they also create repetition to provide cohesion within the landscape.

The application of design fundamentals and the way species are arranged can have both practical (e.g. weed control, ease of establishment) and aesthetic (color massing, organizational properties such as form and line for cultural interpretation, textural, height, and color contrasts, and binding qualities to unify the landscape) purposes. By introducing fundamental design elements within the restoration or creation of native plant communities, perception of value of these landscapes will likely increase and become more obvious to visitors.

More research is needed to further knowledge for successful restoration efforts in the Intermountain West as well as design approaches that cue visitors to the beauty of the natural and native landscape. Often times an area is reseeded with a standard seed mixture and left with the assumption that seeded species will be able to establish in the conditions present, when in reality considerations for establishment must be much more
complex. Seeding the UBS with a seed mixture would produce a landscape that does not fully satisfy the general public’s preference for pleasing aesthetics, and which fails to exploit the opportunity to design a grassland in which the unique characteristics and most beautiful components are emphasized sufficiently to inspire replication in home landscapes.

The difficulty that Intermountain West grasslands present for restoration should remind us that long-standing, mature, and intact native plant communities should be preserved. While destruction of these systems can occur in a relatively short amount of time, the restoration of these areas requires a great deal of thought, effort, study, planning, and time for even moderate success.

References


APPENDICES
15 MAY 2007

BRIDGET ATKIN
JENNIFER MACADAM
263 W CENTER #3
LOGAN UT 84321

SOIL SAMPLES RECEIVED: 05/01/2007

<table>
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<tr>
<th>USU #</th>
<th>IDENT</th>
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Appendix B

Table B1. Greenhouse establishment of native grasses as affected by nitrogen or legumes.

**B1a. Counts data for species across treatments using means of dates.**

<table>
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<tbody>
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**B1b. Counts data for day of count across treatments using means of species.**

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B1c. Counts data for species across treatments using data for all dates.

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B1d. Counts data for treatments across species using data for all dates.

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B1e. Dry matter data for treatments across species.

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Table B2. Column study of established native grasses as affected by presence or absence of a legume.

B2a: Dry matter data for treatments across species for Harvest 1.

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B2b. Dry matter data for treatments across species for Harvest 2.

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Table B3. Field study of establishment of native grasses as affected by legumes or forbs.

B3a. Counts data for treatments across species for Harvest 1.

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B3b. Counts data for treatments across species for Harvest 2.

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B3c. Counts data of weeds for treatments across species at Harvest 1.

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