The colonization of Montana roadsides by native and exotic plants
by Gretchen Ann Meier

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University

Abstract:
Roadside communities throughout Montana were sampled to identify native species suitable for roadside vegetation management and to determine exotic species needing control. Information was gathered by sampling roadside communities within broad environmental zones, with the assumption that plants growing well on sites representative of a major environmental type will grow well on other sites within that zone. I found 211 plants in the 370 sites established along Interstate and primary highways. Of these species only 50, 28 native and 22 exotic species, were common (constancy greater than 10%) in at least one of Montana's five major environmental zones (Kuchler, 1964).

The results are presented in two ways. The first presentation lists species occupying typical and uncommon roadside environments. A list of species with highest occurrence in each environmental zone is presented first, followed by lists of species adapted to extremes of climate (temperature and precipitation). Additional lists highlight plants adapted to atypical environmental conditions including soil water balance (water holding capacity, clay, sand), soil fertility (organic carbon, pH) salinity (conductivity) and topographic features (plot position and aspect).

The second presentation focuses on species rather than environments. In Appendix A, 50 species profiles illustrate the response of a species to each of the eleven environmental variables listed above. Each profile compares the distribution of that species with the distribution of all study sites across eleven environmental conditions to identify species adapted to specific conditions.

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Gretchen Ann Meier

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Graduate Dean — Date: 2/11/97

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Date 11 feb 91

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ABSTRACT

Roadside communities throughout Montana were sampled to identify native species suitable for roadside vegetation management and to determine exotic species needing control. Information was gathered by sampling roadside communities within broad environmental zones, with the assumption that plants growing well on sites representative of a major environmental type will grow well on other sites within that zone. I found 211 plants in the 370 sites established along Interstate and primary highways. Of these species only 50, 28 native and 22 exotic species, were common (constancy greater than 10%) in at least one of Montana's five major environmental zones (Kuchler, 1964).

The results are presented in two ways. The first presentation lists species occupying typical and uncommon roadside environments. A list of species with highest occurrence in each environmental zone is presented first, followed by lists of species adapted to extremes of climate (temperature and precipitation). Additional lists highlight plants adapted to atypical environmental conditions including soil water balance (water holding capacity, clay, sand), soil fertility (organic carbon, pH) salinity (conductivity) and topographic features (plot position and aspect).

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INTRODUCTION

Montana Department of Transportation (MDT) manages over 6, 600 miles of road throughout the state. Adjacent roadsides are managed for driver safety, to provide effective maintenance, and for emergency parking. Roadside managers seek to stabilize soil, exclude weeds, minimize maintenance and provide an aesthetic view.

The MDT plants aggressive species intended to establish vegetation and to permanently protect the sites from erosion. The primary objective for this study was to identify native plants suitable for roadside reclamation. A secondary objective was to identify especially troublesome weeds. We approached these objectives by identifying native and exotic plants which have colonized roadsides in major environmental zones. To determine optimal conditions of these plants we related their performance to environmental zones and to important environmental conditions within each zone. Specifically we correlated plant performance with mean July temperature, mean annual precipitation, soil water-holding capacity, soil texture, soil fertility, plot position and aspect. The results of this work should be applicable to low elevation forest and grassland types throughout the Northern Rocky Mountains and Great Plains.

LITERATURE REVIEW

Composition of Roadside Communities

Historically, roadside communities have been studied on several continents. Clements (1897) first identified roadside vegetation as a unique community in Nebraska. He described the plant associations occurring in waste areas as a product of "tensions existing between invading weeds and the adjacent undisturbed vegetation." Since then roadside communities have been extensively studied in Europe, where road systems have been established for centuries (Heidl and Ulmann, 1991). These studies focused on defining specific plant associations growing in disturbed areas, environmental influences to roadside plant communities, propagule dispersal, and the threat of noxious weeds.

Roadside communities are influenced by climate (Wein et al., 1992; Ullmann, 1989; Ullmann and Hendl, 1991; Wilson et al., 1992) especially precipitation (Lausi and Nimbis, 1985), latitude (MacClellan and Stewart, 1986), adjacent vegetation (Lausi and Nimbis, 1985) and deicing salts (Scott and Davidson, 1985).

Roadways and motor vehicles aid the dispersal of roadside weeds (Ridley, 1930; Clifford, 1959). Nearly all seeds regardless of size are transported by vehicles (Schmidt, 1989). Thus, the absence of roadside species is not limited by dispersal (Wilson et al., 1992). Roads aid dispersal by acting as corridors and disturbance of the roadside area may favor the maintenance of weedy vegetation (Nip van der Voot et al., 1979; Tyson and Worley, 1992). Many exotic species have spread northward along highways and railroads, though alien species richness declines from roadways to adjacent undisturbed vegetation (Wester and Juvik, 1983; Weaver et al, 1989; Wein et al., 1992)).

Roadside Vegetation Management

Native species are useful in roadside reclamation. Some species may reduce the cost of vegetation maintenance, weed infestation and fire hazard, while encouraging desirable wildlife and discouraging pests (Brown et al., 1994). Native perennial grasses may decrease the cost of vegetation management by reducing the need for herbicides, and prevent weed invasion either by competition or by releasing allelopathic compounds (Brown et al., 1994). Conservationists may view roadside right-of-ways as a public area to be managed as a refuge for native species (Daar, 1994). Extensive work has been conducted to recommend native species suitable for specific areas (Weaver, 1989; Daar, 1994; Brown, Bugg and Anderson, 1994).

Roadside reclamation has been a MDT policy since the early 1960's (MDT, 1974). Three laws, the Highway Seeding Act, the County Noxious Weed control Act, and the Water Quality Act, mandate the establishment and maintenance of vegetation on highway right-of ways. (MOCC, 1978). Traditionally, reclamation science focused on establishing single species stands of exotic grasses. As native seed became commercially available, managers began to design multi-species 'communities' using a mixture of native species.

In 1994, President Clinton issued a Presidential Directive instructing Federal agencies to use regionally native plants for landscaping to minimize adverse effects on natural habitats (Clinton, 1994). This study addresses species particularly useful for the reclamation of Montana roadsides.

While the exotic grass species used for roadside reclamation establish quickly and provide adequate and attractive cover, they may have drawbacks. Because they are highly competitive, these species exclude native species from grassland sites (Wilson, 1989). *Agropyron cristatum*, *Bromus inermis* and *Poa pratensis* are useful species though their aggressive nature makes their use in roadside revegetation undesirable. Uniform stands of *Agropyron cristatum* have more exposed soil and are more susceptible to erosion than stands of native grasses (Wilson, 1989). *Bromus inermis* and *Poa pratensis* are capable of colonizing and spreading in fine texture soils along roadsides. *Bromus inermis* has invaded some grassland and shrubland ecotones in Canada (Wein et al., 1992) and *Poa pratensis* invades native vegetation in Montana (Weaver et al., 1989).

One objective for roadside reclamation is to prevent roadsides from becoming a source of noxious weeds for crop and rangeland. Noxious weeds are a serious threat to adjacent rangeland, cropland and recreation areas. In Montana, roadside exotics invade adjacent native vegetation, especially if this area is disturbed (Weaver et al., 1989). The noxious weed, *Centaurea maculosa*, is especially invasive (Tyser and Worley, 1992; Lindquist et al, 1996). The maintenance of a vigorous native vegetation may be an important strategy for minimizing the invasion of exotic species (Wein et al., 1992).

ENVIRONMENTAL SETTING

Study Area

This study applies to much of the Northern Plains and Northern Rocky Mountain Provinces. The area sampled extends from the Montana-Canada border in the north (49°N latitude) south to the Montana-Wyoming border (45°N latitude). The eastern boundary was set east of Stanley, North Dakota (102°E longitude) to adequately sample Montana's eastern-most grassland environmental type. I sampled west to the Montana-Idaho border (Figure 1).

Geology

The landscape east of the Rocky Mountains is dominated by flat sedimentary layers of Cretaceous sandstone and mudstone. These layers form the oil-rich Williston Basin in west-central North Dakota. The eastern plains of central Montana are flat and uniform. The northern half of this area is glaciated, adding to its low relief. The Yellowstone River and igneous island mountains provide rare relief from this flat landscape (Alt and Hyndman, 1986).

West of the Rocky Mountain front, the terrain is mountainous. Precambrian sedimentary rocks are folded and faulted creating mountains, hills and valleys of

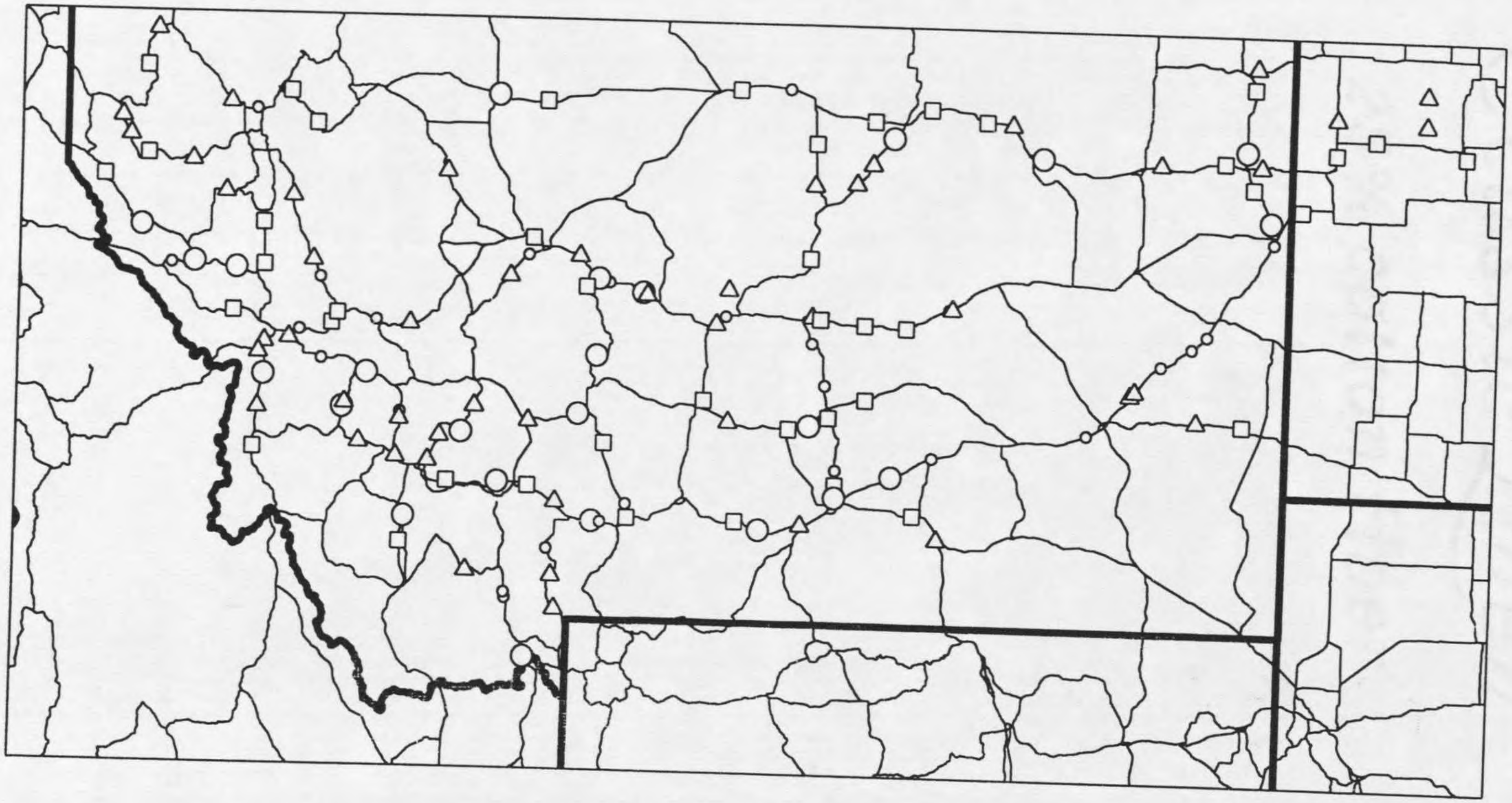

Figure 1. Location of Study Sites in Montana and North Dakota. Symbols represent plots locations. Small circles indicate locations with one plot, triangles=2 plots, squares=3 plots, and large circles=4 plots.

Northwestern Montana. The Rocky Mountain trench extends from Eureka to St. Ignatius and separates the Precambrian beds of northwestern Montana from the Cretaceous beds of the Rocky Mountains and eastern plains. The layered beds that form the northern Rocky Mountains contain sedimentary layers varying in age from Precambrian in the west to Paleozoic in the east and Mesozoic at the eastern margin of the Rocky Mountains. Western Montana was heavily glaciated. These glaciers carved broad valleys leaving piles of rubble behind. In contrast, the landscape of south-central Montana, is dominated by wide valleys and occasional igneous batholiths (Alt and Hyndman, 1986).

Soils

The soils along roadsides are those common to grasslands and forests of the region. In northwestern North Dakota, eastern Montana, and the grassland areas of south central Montana, the soils are primarily Mollisols (dark colored base rich grassland soils) and Vertisols (extremely clay rich grassland soils characterized by wide deep cracks opening under dry conditions). In contrast, soils occurring in wooded areas of northwestern and south-central Montana are light colored Inceptisols and Alfisols, slightly to moderately acidic with a brownish subsoil horizon of clay accumulation (Montagne et al., 1982).

Environmental Types

Regions within this area have different environmental types indicated by the vegetation that covers them (Kuchler, 1964; Daubenmire, 1968). The most widespread environmental types in the area are three grassland and two forest types (Figure 2). Each environmental type is occupied by a different group of plants, though some species overlap. Each environmental type is characterized by at least one dominant and distinctive species (Kuchler, 1964). The name of this distinctive species is used as a name for the environmental type. The study of these broad environmental types permitted adequate sampling of representative segments of roadside in each type. I eliminated two types, the *Artemisia - Agropyron* type and the eastern *Pinus ponderosa,* because roads pass through too few suitable sites.

The three grassland types are the *Andropogon scoparium* (ANSC) type, the *Bouteloua gracilis* (BOGR) type, and the *Agropyron spicatum* (AGSP) type. The ANSC environmental type is relatively moist and is covered by a moderately dense stand of medium stature grasses. This type occupies the northeastern and southeastern corners of Montana, and the western Dakotas south to the Nebraska border (Figure 2). Dominant plant species are *Andropogon scoparium, Agropyron smithii, Stipa viridula, Stipa comata* and *Bouteloua gracilis* (Kuchler, 1964).

The BOGR environmental type is semiarid, and occupied by a short and open grassland dominated by *Bouteloua gracilis, Agropyron smithii* and *Stipa comata.* This type occupies most of Montana extending eastward from the Rocky Mountains to the

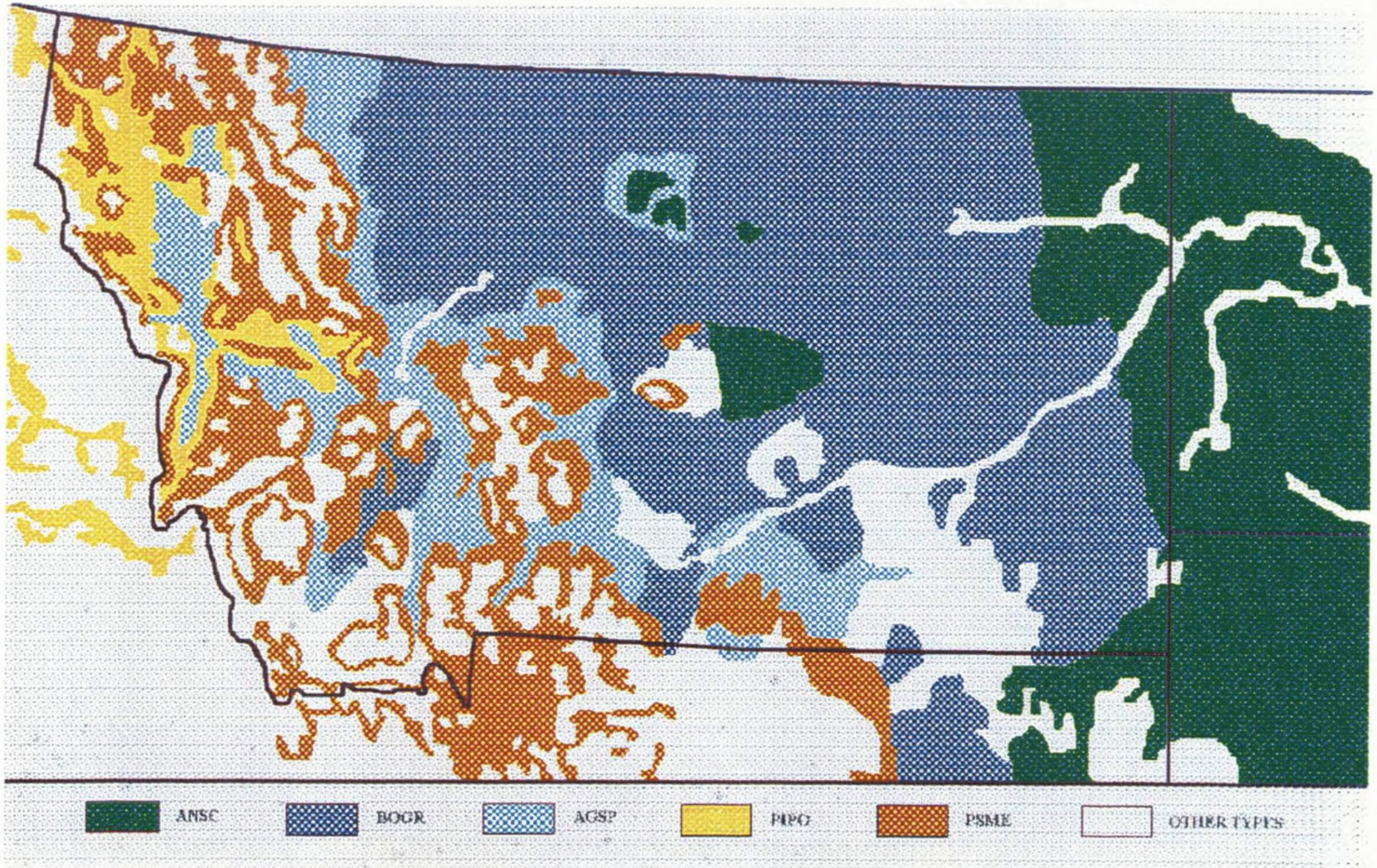

Figure 2. Environmental Types across the Northern Rocky Mountain Provinces.

western edge of the ANSC prairie and southward through Wyoming to Texas (Kuchler, 1964; Weaver 1996).

The AGSP environmental type is more moist and occupies gravel rich soils. It is occupied by an open stand of short bunch grasses, dominated by *Agropyron spicatum, Festuca idahoensis, Festuca scabrella,* and *Stipa comata* (Kuchler, 1964). This type occupies the foothills between the BOGR type of eastern Montana and the forest types of the Rocky Mountains (Figure 2).

The two forest environmental types studied were the low elevation western *Pinus ponderosa* (PIPO) and the higher elevation *Pseudotsuga menziesii* (PSME) types (Kuchler, 1964). The PIPO type is occupied by moderately dense stands of *Pinus ponderosa* with grassy or shrubby understories of *Agropyron spicatum, Festuca idahoensis, Festuca scabrella, Symphoricarpos albus* and/or *Physocarpus malvaceus* (Figure 2). Forests of *P. ponderosa* extend from central British Columbia south to Mexico (Daubenmire, 1978). *P. ponderosa* occurs in the drier portions of western and eastern Montana. The western *P. ponderosa* type extends from central Washington to the east slope of the Rocky Mountains and to south central Idaho (Kuchler, 1964). The eastern *P. ponderosa* forest occurs in southeastern Montana though infrequently adjacent roads. I was unable to sample enough locations of the eastern type therefore data for this type was not analyzed.

The PSME type is a relatively moist forest environmental type and is occupied by stands of *Psuedotsuga menziesii* of medium height and density (Kuchler, 1964). This forest type covers extensive portions of western North America (Figure 2). Variations of the PSME type are common throughout the Rocky Mountains and in the wetter portions of north-western Montana.

Road Construction and Road Morphology

Roadsides are engineered to facilitate drainage, to retain topsoil, and to provide an area for maintenance and emergency use. Gravel and selected local parent material are mixed, layered and compacted to create a raised roadbed. The platform is topped with an impermeable layer and covered with gravel. The last layer, called the base course, is designed to promote water drainage from underneath the roadbed (Figure 3). The road is laid on top of the base course. The inslope is the side of the raised roadbed extending from the pavement edge down into the ditch bottom. Exposed base course extends from the edge of the pavement partially down the inslope, depending on its thickness (Figure 3). Until recently, only the inslope from the edge of base course to the ditch bottom was covered with topsoil. The backslope or roadcut extends from the edge of the ditch to the furthest edge of the right-of-way and consists of exposed substrate and covered with a thin layer of topsoil if the slope is less than 33% (MDT, 1995; Figure 3).

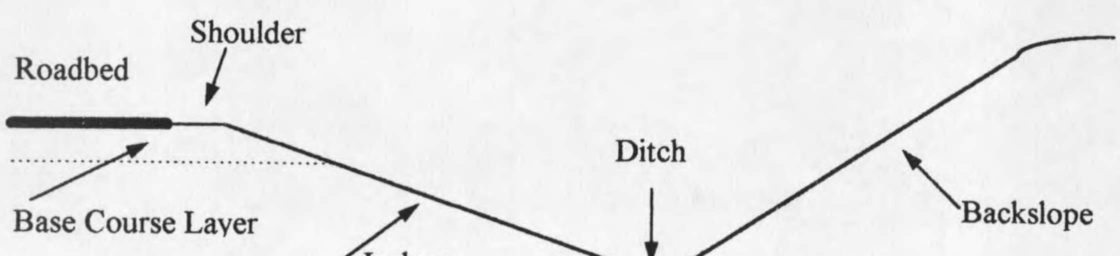

Figure 3. Diagram of a Typical Roadside Section.

MDT used construction and vegetation techniques to stabilize the soil on recently constructed sites. Techniques used to minimize soil erosion include 1) minimizing of slope angles, 2) slope roughening and terracing, 3) temporarily seeding with cover crops, and 4) sediment traps or barriers or other appropriate measures (MDT, 1995).

MDT uses mixtures of seed applied to roadside surfaces to establish vegetation. Seeds are planted in three zones adjacent the roadbed. All areas with slopes less than 3:1 and the exposed base coarse are drill seeded with fertilizer. Areas with slopes greater than 3:1 are broadcast seeded with mulch (either straw or recycled paper fiber) and a tackifier in a water propellant. The tackifier binds the mulch and protects the applied seed mixture from wind and rain erosion (MDT, 1995).

Environmental Characteristics of Study Area

The principle variables that determine differences in vegetation between environmental zones are precipitation and temperature regimes. Both variables are influenced by elevation. Large scale trends of these variables are shown in Table 1. Mean annual precipitation and mean July temperature were chosen as indices of water availability and growing season temperature.

Table 1. Comparison of environmental variables across five environmental types.

variable	Environmental Types[1] ANSC	BOGR	AGSP	PIPO	PSME
Elevation (m)[A]	2200	3000	4000	5000	5000
Mean July Temperature (°C)[B]	22	21	20	20	17
Mean Annual Precipitation (cm)[B]	53	35	38	55	58
Sand (%)[C]	*	33±3	36±4	36±14	36±5
Clay (%)[C]	*	28±2	27±3	28±8	12±2
Organic Carbon (%)[C]	*	1.5±0.1	2.8±0.7	2.9±0.5	1.2±0.2
pH[C]	*	7.4±0.2	6.5±0.1	6.4±0.3	5.6±0.3

[A] typical elevation as seen in Montana Atlas, 1994, [B](Weaver, 1980), [C](Weaver, 1978),
[1] Environmental types are ANSC = *Andropogon scoparium*, BOGR = *Bouteloua gracilis*, AGSP = *Agropyron spicatum*, PIPO = *Pinus ponderosa*; PSME = *Pseudotsuga mensizeii*, see text for more detailed descriptions. * information not available.

Within an environmental type, microsites are differentiated by soil characteristics including texture, fertility, salinity, and topography. The fine earth fraction of the soil contains three particle sizes, sand, silt and clay. Soils rich in the largest particle size, sand, allow water to infiltrate and drain the soil profile. Soils rich in the finest particle size, clay, retain water. Plant distributions are also affected by fertility, indexed by pH, organic matter, and salinity, indexed by electrical conductivity (Ellis and Mellor, 1995).

METHODS

Introduction

The objectives of the study were to determine which plant species have successfully established on roadsides and which environmental factors are correlated with their establishment. Successful establishment in the past should indicate future success, whether due to climatic zone or by local soil condition. Thus, native species aggressively colonizing roadside areas are considered good candidates for roadside plantings. Similarly aggressive exotic plants invading roadsides are potential threats to the stability of roadside and adjacent vegetation throughout the region. Observations were made in five environmental types (Kuchler, 1964), determined primarily by temperature and precipitation. Observations made within types show the effects of soil texture, soil organic matter, pH, salinity, aspect and plot position.

Sites Selection Criteria

I selected site locations approximately 24 km apart along Montana interstates and primary highways (Figure 1). To be eligible, sites within a location had to be uniform, relatively undisturbed, and representative of the local vegetation. Preferred locations had groups of four sites, an inslope and backslope plot on opposite sides of the road.

Especially in hilly regions of northwestern Montana ideal locations were difficult to find. Thus plots are often disjunct from one another, with inslope plots not paired with backslope plots. Sites were recorded according to highway name, milepost, plot position (backslope or inslope), and aspect (N, S, E, W).

Five environmental types (ANSC, BOGR, AGSP, PIPO and PSME) (Kuchler, 1964) were outlined on a current Montana highway map. Sites lying within an environmental type were grouped and analyzed together to determine the effect of environmental type on species distributions. Sites occupying other types (e.g. eastern *P. ponderosa*), lying on ecotones, or occupying unidentified environmental types were not analyzed.

To determine the effect of aspect on plant establishment in each environmental type four aspects (north, south, east and west) were sampled in approximately equal numbers. Sites analyzed had bearings north-south or east-west and within 10 degrees of that aspect.

Plot position within the roadside cross section was analyzed to determine the effects of slope and site preparation on roadside vegetation. Positions are defined in terms of four zones seen as one moves away from the roadbed. The first zone is an untopsoiled gravel strip, the exposed base course, approximately 1-3 m wide adjacent to the roadbed. (Figure 3). The second zone is the topsoiled inslope, extending from the exposed gravel to the top edge of the ditch. The third zone is the ditch, which is relatively wet and occupied by different vegetation. Ditches were not sampled and are not a significant component of the vegetation cover of roadside areas. The last zone is the backslope (or road cut) and it extends from the far edge of the ditch to the top of the slope.

Plots were established in the center of the slope, to maximize the homogeneity of the vegetation by avoiding edges. The upper edge of the inslope plot was located below the exposed base course and the lower edge was located above the edge of the ditch. The top edge of the backslope was often irregular, and occupied by different vegetation. The backslope site was located in the center portion of the slope, above the ditch and below the top edge of the slope to maximize homogeneity of the vegetation.

Vegetation Measurements

I sampled 1-4 plots at each location. Each plot was 10 meters long parallel to the roadbed and as wide as the area permitted. I measured the sites with a meter tape and marked the corners with survey flags. Inslope plots were 1-2 meters wide and backslope plots ranged from 5 to 50 meters wide. Inslope and backslope plots are different sizes. The larger backslope plot is expected to have more species than the inslope plot.

In each sample plot, I listed all species covering more than 1 % of the site and estimated their cover. I used two methods, ocular and point intercept, to measure total cover and the cover of individual species (%). I chose both methods as efficient sampling techniques suitable for extensive sampling. Ocular estimates were made, as a primary measure, on all sites by viewing the vegetation covering the sites, ignoring the underlying surface characteristics and estimating total cover and species by species cover (%).

A point intercept method (Evans and Love, 1957) was used to calibrate the ocular cover estimates. On plot edges perpendicular to the roadbed, I placed two survey flags dividing the plot edge into thirds. I paced two lines parallel to the roadbed, each from one survey flag to its opposite flag. I obscured my feet with a clipboard to prevent me from selecting sampling points. At each step the species intercepted by a point on my boot tip was recorded. The number of intercepts for each plant species divided by the total number of steps (~100) established the percent cover for the individual species. The sum gave the total cover for the site.

Ocular estimates were adjusted to accommodate point intercept measurements. The discrepancy between the two measurement techniques decreased with experience. Early in the season, point counts were made daily and often at each site. With experience the need for pacing was reduced. At mid-season point estimates were done only at the beginning of the week and on any site where an ocular estimate seemed difficult. Late in the season point counts were made only at the beginning of the week.

Unknown plants were present at many sites. Individuals of these species were collected, pressed, and identified later in the MSU Herbarium. Data for these species were incorporated after the identifications were completed. I found two hundred and eleven species on the roadsides (Appendix B) and selected 50 species for analysis (Appendix C). Of the species chosen, 46 species occurred in at least 10% of the sites in one environmental type, 3 were borderline species (9% occurrence) of interest, and one, *Bouteloua gracilis*, is an important component of dry grasslands.

Environmental Correlates of Vegetation

Climate Data

Mean annual precipitation and mean July temperature were chosen as indices of growing season temperature and water availability. Climate for each location was read from MAPS ATLAS (Caprio et al., 1990) using latitude and longitude reference points. MAPS ATLAS gives an array of other soil, climate and vegetation data for three square mile polygons throughout Montana. Climate data for North Dakota were interpolated from climate maps (NOAA, 1974).

Physical Environment

Five landscape characteristics were recorded on each plot. Adjacent land use (range, crop, forest or residential) was observed. Plot position (inslope, backslope) was recorded. Aspect (north-, south-, east- and west-facing) was measured with a compass. Percent slope(0-1%, 2-5%, 5-10%, 10-25%, 25% and above) was an ocular estimate.

Erosion was indicated by the amount of hummocking, number of rills, the number of gullies, and the presence of slumps. Hummocks are the result of soil erosion between grass clumps, creating pedestals. The amount of hummocking was measured in three categories, none, slight and extreme. Rills are eroded trenches less than 30 cm across. The number of rills in each site was counted and placed in one of three categories, 0, 1-5, 6 or more. Gullies are large rills, 30 to 50 cm across. The number of gullies in each site was counted and placed in three categories, 0, 1-5, 6 or more. A slump or backcut is large movement of soil and rock down the backslope, undercutting the top of the slope. The presence or absence of a slump or backcut was noted at each site.

Roadside vegetation may be influenced by factors not analyzed due to time and financial limitations. These include three landscape variables, adjacent land use, slope and evidence of erosion and disturbance factors, herbicide and pesticide spraying, changes in seed mixtures and pollution.

Soil surface characteristics recorded at each site are exposed parent rock (%), surface rock (%), bare ground (%), basal vegetation cover (%) and ground litter (%). Each characteristic was measured with an ocular estimate, ignoring the over-lying vegetation. Surface rock was any loose rock greater than 1 cm in diameter. Bare ground was gravel and soil with particles less than 1 cm in diameter. Basal vegetation cover was the area of ground covered by the basal rosettes of the plant alone. Litter is any remaining dead organic material on the soil surface. This information may be analyzed at another time.

Soil Measurements and Laboratory Analysis

At each site I collected a soil sample to determine soil texture, pH, organic carbon and conductivity for correlation with plant performance. I used a spade to remove at least the top six inches of soil at three to five locations in the plot. Equal portions from each shovelful were mixed in a labeled ziplock bag. Soil collection was often difficult because sites were compact, rocky, and with little soil development. In some cases, samples were small and had a little fine earth.

The soil samples were prepared for analysis by drying at 40 degrees centigrade, grinding, and sieving to remove course fragments (>2mm). Both fine and coarse portions of the sample were weighed and labeled separately. Percent soil and percent coarse fragments were calculated from these weights.

The MSU soil testing lab analyzed the samples for texture, organic carbon, pH and electrical conductivity on the fine earth portion of the soil samples. Soil texture is determined by the sand, silt and clay contents of the fine earth fraction. Clay content (particles less than 0.002mm) strongly influence water-holding capacity, and index a soils capacity to store winter moisture for summer use. Sand (particles >0.05mm and <2. mm) is an index of a soil's permeability and its capacity to absorb summer rain. The MSU soil testing lab analyzed soil texture (% sand, silt and clay) with a modified hydrometer method. The soil was dispersed in a mixture of calgon and water to separate soil aggregates and blended to create a slurry. The differential settling by particle size allows estimation of the proportion of particles in each size class (Bouyoucos, 1962; Tan, 1996).

Soil organic matter is material derived from living or decomposing plant or animal tissues. It contributes to soil water-holding capacity and because it is a source of plant nutrients and binds cations, it is also an index of soil fertility. The MSU soil testing lab determined organic carbon (%) with a wet dichromic acid digestion (Walkley, 1947) followed by a measure of absorbence at 600mμ (Sims and Haby, 1971). Organic carbon is estimated from a standard curve relating absorbence at 600mμ to organic carbon content(%).

Most plants grow best in slightly acid soils because nutrients are most available at this pH (Tan, 1996). The MSU soil testing lab measured the pH of each soil sample on a slurry of one part soil to two parts water. The electrode was calibrated in a 7.0 buffer solution before use (McLean, 1982).

Salinity is due to the accumulation of salts in the soil and is indexed by electrical conductivity (Ellis and Mellor, 1995). The MSU soil testing lab measured conductivity on a slurry of one part soil and two parts water. The conductivity was determined using a temperature compensating conductivity meter (Rhoades, 1982).

Statistics

Correlation's between plant distribution and environmental factors were evaluated with three statistical techniques. The data set includes 370 sites, 50 plant species and 11 variables. A multitude of univariate tests were used to determine the effect of each variable on the distribution of each species. A Kruskal-Wallis non-parametric ANOVA (Box et al., 1978) was used to relate plant performance to categorical variables (environmental type and mean annual precipitation). A randomization test (Manley, 1991) was most appropriate for relating plant performance to the continuous variables (July temperature, water-holding capacity, clay, sand, organic carbon, pH, and salinity).

Interaction plots were used to evaluate the effects of plot position and aspect. All results were interpreted at the 0.05 alpha level.

A Kruskal-Wallis non-parametric analysis of variance (ANOVA) was used to determine the relationships between the plant distributions and the categorical variables, environmental type and mean annual precipitation. This test established which plant species varied among factor levels. Kruskal-Wallis p-values are presented in Appendix C. This test ranks all measurements within a category and the ANOVA was performed on the rankings not the actual data, making this test robust for non-normal data (Box et al., 1978). Because a Kruskal-Wallis test does not identify distinct factor levels, a pairwise comparison of all possible combinations of data were performed on the data to determine which levels had significant effects (Box et al., 1978). A multiple comparisons test performs a pairwise comparison on every paired combination of data and provides a p-value for each comparison. The resulting table of p-values (Appendix E) allows one to establish which categories are significantly different and which are not.

Kruskal-Wallis rankings are reported in all environmental type and precipitation graphs in Appendix A. The rank of the cover indicate the relative performance of the species across categories. These rankings are helpful for interpreting the differences determined by the multiple comparisons tests.

A Randomization test (Manley, 1991) was used to evaluate the relationships between the continuous variables (mean July temperature, water-holding capacity, clay, sand, organic carbon, pH and conductivity), and each plant species. This test compared conditions on which each plant was growing with the conditions of all roadside sites.

The randomization test has three stages. First, from the original 370 sites, I drew, with replacement, a random sample equal to the number of sites on which the plant species occurred and calculated the mean This process was repeated 1000 times. This stage created a distribution of 1000 randomly generated means of the variable considered. Second, I calculated the variable mean for a plant species. Then I calculated the critical values of a 95% confidence interval for the distribution of 1000 means. Third, I compared the mean of the variable where the plant species grew with the critical values to determine whether the species mean fell within the confidence interval. If the plant mean fell outside the 95% confidence interval we determined the plant's distribution to be significantly affected by the factor rather than by random variation. Appendix F gives means for all species across all randomized variables. The graphs in Appendix A compare species distributions on each factor with the overall distribution of that factor.

Plot position and aspect are highly correlated. For this reason I cannot distinguish the effect of plot position from that of aspect. These variables are discussed qualitatively using interaction plots.

My sampling procedure was designed to cover a large, variable area quickly and consequently two characteristics require comment. First, the sampling design lacks any formal randomness, thereby restricting the use of many statistical tests. Classical statistical tests, such as the Kruskal-Wallis ANOVA, are inappropriate due to the lack of an underlying probability model provided by random sampling. Second, I did a large number of comparisons to establish differences between groups. No correction factor such as a Bonferonni correction factor, was used to treat resulting probabilities more conservatively to account for random significant results. Therefore where p-values, or other significant results appear they highlight differences but do not indicate actual probabilities.

RESULTS AND DISCUSSION

Two hundred and eleven species were found on Montana roadsides (Appendix B). These species either were planted or colonized from other sources. Colonizers can be desirable native species, noxious exotic weeds or perhaps desirable exotic species. We seek to identify strong native colonizers for use in future plantings. Correlation's between species establishment and the environments in which they establish can be used to refine recommendations for planting by indicating where that species is most likely to succeed.

Species Selected for Analysis

I selected 50 species for analysis (Appendix C). Of these, 46 species occurred in at least 10% of the sites in one environmental type, three species occurred in 9% of the sites. *Bouteloua gracilis* is infrequent but included because it is an important component of dry grasslands. Twenty nine of the species, 13 grass and 16 forb, are native. The native species may be useful for roadside reclamation. Twenty one of the species chosen,9 grass and 13 forb species, are exotic. Exotic grass species can be useful in reclamation especially if the threat to adjacent vegetation is limited. Exotic forb species are weedy and some, such as *Centaurea maculosa,* considered noxious. Highly invasive weedy exotic species are, of course, not recommended for roadside reclamation.

Richness of Roadside Communities

We evaluated richness in roadside communities by comparing the number of constant species in an environmental type with the number of constant species in native vegetation occupying the same environmental type. Table 2 contains comparisons between roadside communities (bold) and similar native communities (indented). Roadside stands had an average of 7 constant species (constancy > 25%) whereas similar native stands had an average of 22 constant species (Table 2). Compared to native communities, roadside communities in grassland environments have fewer grass species, far fewer composite species and more legumes (Table 2). Roadside communities in forest environments lack the tree and shrub species that predominate in native forest communities. More grass species and fewer forb species occur in the understories of roadsides communities than in native forest communities growing in the same environments. Overall, roadside communities have fewer species in every category than do native communities (Table 2). Thus, roadside communities are depauperate in terms of constant species (Table 2).

Table 2. Number of Constant (constancy >25%) Species in Roadside and Native Communities across Montana.

Type	Tree	Shb[A]	Grs[B]	Forb				Ttls[F]
				Cmp[C]	Cruc[D]	Lgm[E]	Othr	
ANSC[1]	**0**	**1**	**4**	**1**	**0**	**2**	**0**	**8**
BOGR[1]	**0**	**2**	**4**	**1**	**0**	**2**	**0**	**9**
STCO[2]	0	5	8	2	0	1	3	19
STCO/AGSM[2]	0	4	12	6	0	2	6	30
AGSP[1]	**0**	**0**	**7**	**1**	**0**	**1**	**0**	**9**
AGSP/BOGR[2]	0	7	6	6	0	1	6	26
AGSP/BOGR/LIPU[2]	0	3	10	11	0	1	7	32
AGSP/AGSM[2]	0	4	9	11	0	1	7	32
AGSP/AGSM/STVI[2]	0	7	12	19	0	4	15	57
AGSP/POSA[2]	0	4	5	9	0	3	9	30
AGSP/POSA/STCO[2]	0	6	7	11	1	2	18	45
PIPO[1]	**0**	**0**	**5**	**1**	**0**	**1**	**1**	**8**
PIPO/AGSP[3]	3	3	2	1	0	0	0	9
PIPO/FEID[3]	3	3	2	1	0	0	0	9
PIPO/SYAL[3]	3	4	3	1	0	0	1	12
PSME[1]	**0**	**0**	**7**	**1**	**0**	**1**	**0**	**9**
PSME/AGSP[3]	4	4	2	1	0	0	1	12
PSME/FEID[3]	2	1	2	2	0	0	0	7
PSME/SYAL/AGSP[3]	2	5	5	2	0	0	0	14
PSME/SYAL/SYAL[3]	3	9	3	2	1	0	4	22
PSME/PHMA/PHMA[3]	2	6	2	1	1	0	3	15
PSME/CARU/CARU[3]	2	6	2	1	1	0	3	15
PSME/CAGE[3]	4	4	3	2	1	0	3	17
PSME/SPBE[3]	4	7	5	2	0	0	4	22

[1] Environmental types used in this document, [2] from Mueggler & Stewart (1980), [3] from Pfister et al. (1977), [A] Shb=Shrub species, [B] Grs = Grass species, [C] Cmp = Composite species, [D] Crus = Crucifers, [E] Leg = Legumes, [F] Tls = Totals.

Roadside communities in Montana have very few species with high cover. In roadside communities, 3% of all species found have cover greater than 50 %, 19% of all species have cover of 10-50%, the remaining 77% of species have cover of less than 10%. Almost identical observations were made on roadsides in Europe (Schmidt, 1989). In both cases roadside communities are characterized by very low numbers of high presence species and high numbers of low presence species.

Response of Individual Species to Environmental Conditions

Plants likely to be successful in an environment are those which establish in that environment. Most species displayed some specialization for climate, soil or topographic factors. Exceptions are *Gaura coccinea* and *Symphoricarpos albus*. Appendix A summarizes the response of 50 species to eleven environmental variables. Appendices D and E contain p-values establishing the difference between groups and Appendix F contains means of randomized variables.

Environmental Type

Twenty-six species have significantly ($p<0.05$) higher cover (%) in at least one environmental type (Table 3 and Appendices D and E). Individual reports for each species are summarized in Appendix A. Twenty-four species, 14 native and 10 exotic had similar ($p>0.05$) cover in all environmental types (Appendices A and D).

Species with high ($p<0.05$) cover in one or several types and their origin (native or exotic) are listed in Table 3. Species designated with an A have highest cover in that type. Native species abundant in the ANSC type are *Dalea purpurea,* and *Stipa viridula* (Table 3). Exotic species abundant in the ANSC type are *Avena sativa, Lactuca serriola, Bromus inermis* and *Poa pratensis* (Table 3). Five native species, *Agropyron smithii,* *Artemisia frigida, Hordeum jubatum, Koeleria nitida* and *Stipa viridula,* and five exotic species, *Agropyron cristatum, Agrostis stolonifera, Bromus tectorum, Poa pratensis,* and *Thlaspi arvense* have high cover in the BOGR type. Five native species, *Achillea millefolium, Agropyron dasystachyum, Artemisia frigida, Festuca scabrella,* and *Stipa comata,* and five exotic species *Bromus tectorum, Dactylis glomerata, Kochia scoparia, Melilotus offincinalis,* and *Poa pratensis,* have high cover in the AGSP type. Three native species *Agropyron dasystachyum, Festuca idahoensis* and *Festuca ovina* and four exotic species, *Bromus tectorum, Dactylis glomerata, Poa compressa,* and *Phalaris arundinacea* have highest cover in the PIPO type. In the PSME type, two native species, *Agropyron dasystachyum* and *Stipa viridula,* and five exotic species, *Dactylis glomerata, Melilotus offincinalis, Phalaris arundinacea, Poa pratensis,* and *Thlaspi arvense,* are most abundant.

Many of the species mentioned above have highest cover in only one type while others perform best in several types. Species with high cover in more than one type are presumed to have broader tolerances and should allow more latitude to land managers.

Table 3. Plant Species with Significant ($p<0.05$) Differences of Cover (%) between Environmental Types. Types sharing a letter do not significantly differ. Appendix A presents underlying data for each species and Appendix D and E establish differences between groups.

		Environmental type				
	Origin	ANSC	BOGR	AGSP	PIPO	PSME
Avsa[A]	E	A	B	B	B	B
Lase	E	A	B	B	B	B
Dapu	N	A	B	B	B	B
Brin	E	A	BC	BC	C	AB
Stvi	N	A	A	B	B	A
Popr	E	A	A	A	B	A
Thar	E	AB	A	B	AB	A
Arfr	N	B	A	A	AB	AB
Agcr	E	B	A	B	C	C
Agsm	N	B	A	B	B	B
Agst	E	B	A	B	B	B
Hoju	N	B	A	B	AB	B
Koni	N	B	A	B	B	AB
Brte	E	B	A	A	A	AB
Meof	E	B	AB	A	AB	A
Stco	N	BC	AB	A	C	BC
Kosc	E	B	B	A	B	B
Fesc	N	B	B	A	B	B
Acmi	N	C	B	A	BC	AB
Dagl	E	B	B	A	A	A
Agda	N	C	B	A	A	A
Poco	E	C	C	B	A	BC
Feov	N	D	CD	BC	A	B
Feid	N	C	C	BC	A	AB
Phar	E	B	B	B	A	AB
Phpr	E	B	B	B	AB	A

[A] Refer to Appendix B for species acronym.

Temperature

Another component of environment is growing season temperature. We indexed growing season temperature with mean July temperature. Average July temperature was 18.8°C and significantly affected the distribution of 19 species. Native species thriving on sites with mean July temperature above 18.8°C are *Agropyron smithii, Artemisia frigida, Bouteloua gracilis, Heterotheca villosa, Lupinus argenteus* and *Hordeum jubatum* (Table 4). Exotic grass and forbs growing on warm sites are *Agropyron cristatum, Avena sativa,* and *Medicago sativa* (Table 4). Many of these species are abundant in the BOGR type. Native species thriving on sites with mean July temperature significantly ($p<0.05$) less than 18.8°C are *Agropyron dasystachyum*, and *Festuca idahoensis* (Table 4). Exotic species growing on cool sites are *Dactylis glomerata, Medicago polymorpha, Phalaris arundinaceae, Phleum pratense, Poa pratensis, Trifolium hybridum,* and *Verbascum thapsus*. Many of these species are abundant in either the PIPO, PSME or both types. Thirty-one species, 19 native and 12 exotic, had similar ($p>0.05$) cover in cool and warm sites.

Table 4. Species Thriving on Sites with Mean July Temperature Significantly Different from the Mean for all Sites (18.8°C). Appendix A presents underlying data for each species

	Origin [A]	Habit [B]	Mean J temp
Species with means greater than 18.8°C			
Bouteloua gracilis	N	G	20.0
Artemisia frigida	N	F	19.8
Avena sativa	E	G	19.8
Medicago sativa	E	F	19.8
Heterotheca villosa	N	F	19.6
Agropyron cristatum	E	G	19.6
Hordeum jubatum	N	G	19.4
Agropyron smithii	N	G	19.2
Species with means less than 18.8°C			
Trifolium hybridum	E	F	14.4
Medicago polymorpha	E	F	16.1
Pinus ponderosa	N	T	16.5
Centaurea maculosa	E	F	16.9
Lupinus argenteus	N	F	17.1
Verbascum thapsus	E	F	17.1
Festuca idahoensis	N	G	17.3
Phalaris arundinaceae	E	G	17.3
Poa compressa	E	G	17.5
Agropyron dasystachyum	N	G	17.7
Dactylis glomerata	E	G	17.7
Phleum pratense	E	G	17.7

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F) or tree (T)

Precipitation

Another component of environmental condition is precipitation. I used mean annual precipitation and significantly affected the distribution of nineteen species (Table 5). Appendix A shows the distribution of each species against the precipitation in all sites. Appendices D and E give p-values establishing differences between groups. Thirty-one species do not have cover significantly (p>0.05) higher in any category (Appendices A and D)

Table 5. Distribution of Species across Precipitation Categories. Species performance does not significantly (p<0.05) differ among regimes sharing a letter. * Indicates category with highest mean cover. Appendix A presents underlying data for every species. Appendices D and E give p-values establishing differences between precipitation levels.

	Precipitation categories (cm)								
name	20-25	25-30	30-35	35-40	40-45	45-50	50-75	75-100	100-150
Mepo [A]	*A	B	B	B	B	B	B	B	B
Bogr	*A	B	C	BC	C	BC	C	BC	BC
Spco	*A	B	BC	C	BC	BC	C	BC	BC
Syal	*A	C	C	C	C	AB	C	B	B
Agcr	*A	AB	CD	BC	E	E	E	E	BDE
Meof	*A	CE	CD	BDE	CE	AD	BDE	AC	AB
Cema	*A	BC	CD	CD	CD	CD	D	AC	AB
Veth	*A	C	C	BC	BC	BC	C	BC	AB
Koni	AD	AB	BCD	BD	CD	AD	CD	AD	*A
Stco	AB	AC	BD	BC	DF	CDE	EF	CDE	*A
Agsm	BC	A	A	BCD	C	AB	BC	AC	*AD
Brin	E	BDE	A	CB	ABC	AC	BDE	D	*ABC
Dagl	BD	D	D	D	*A	AB	BC	ACD	BD
Agda	ADE	BE	BE	E	A	AC	BCD	*AB	DE
Phpr	BCE	DE	DE	BCE	AC	AE	A	*ABD	BE
Feov	AD	D	D	BD	BCD	A	AC	*AB	AD
Feid	CD	CD	D	CD	CD	B	C	*A	CD
Phar	BC	C	BC	C	C	BC	B	*A	BC
Trhy	BC	C	C	C	C	BC	B	BC	*A

[A] Refer to Appendix B for species names and acronyms.

Plants adapted to relatively dry or moist conditions are listed in Table 5. Native species adapted to dry (8-10cm) roadsides are *Bouteloua gracilis, Symphoricarpos alba,* and *Sphaeralcea coccinea.* Exotic species with cover (%) higher on dry sites are *Verbascum thapsus, Agropyron cristatum* and *Medicago polymorpha.* One exotic species, *Dactylis glomerata* is adapted to sites with moderate precipitation of 40-50cm. Native species abundant on moist (75-100 cm) sites are *Festuca ovina* and *Festuca idahoensis.* Three exotic species, *Phalaris arundinaceae. Bromus inermis, Phleum pratense* and *Trifolium hybridum* are adapted to moist sites. The remaining species in Table 5 are abundant in particular categories but show no clear pattern of distribution among species.

Soil Water-Holding Capacity and Clay Content

The availability of water for growth is affected by soil water-holding capacity as well as climate because the impact of a drought period is buffered by water stored in the soil. Soil water-holding capacity is largely determined by, and may be calculated from, its clay and organic matter content.

Twelve species occupied sites with either a higher or lower than average soil water-holding capacity. Average water-holding capacity for all sites is 8.4%. One native plant, *Artemisia frigida,* is adapted to sites with high water-holding capacity (Table 6). Exotic species adapted to these sites are *Agropyron cristatum, Medicago sativa* and *Thlaspi arvense* (Table 6).

Similarly, *Agropyron smithii, Artemisia cana, Artemisia frigida,* and *Opuntia polycantha* are native species found on sites with significantly higher than average soil clay content (Table 7). Exotic species found on high clay sites are *Agropyron cristatum* and *Medicago sativa* (Table 7). Thirty-eight species occurred on sites with both low and high water holding capacity (Appendices A and D). Thirty-four species occurred on sites with both low and high clay content (Appendices A and D).

Table 6. Species Occupying Sites with Mean Soil Water-Holding Capacity (WHC) Significantly Different from the Mean for all Sites (8.4%). Appendix A presents underlying data for every species.

Name	Origin [A]	Habit [B]	Mean WHC
Species with mean greater than 8.4			
Thlaspi arvense	E	F	11.5
Medicago sativa	F	E	9.7
Artemisia frigida	F	N	9.6
Agropyron cristatum	G	E	9.3
Species with means less than 8.4			
Centaurea maculosa	F	E	5.1
Verbascum thapsus	F	E	5.2
Phalaris arundinaceae	G	E	5.5
Dactlyis glomerata	G	E	5.6
Festuca idahoensis	G	N	5.6
Poa compressa	G	N	5.7
Medicago polymorpha	F	E	5.9
Agropyron dasystachyum	G	N	6.5
Festuca ovina	G	N	6.7
Phleum pratense	G	E	6.9
Bromus tectorum	G	E	7.5

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F) or tree (T)

Native species growing on sites with lower than average water-holding capacity are *Agropyron dasystacum, Festuca ovina,* and *Festuca idahoensis* (Table 6). Exotic species growing on sites with low water-holding capacity are *Bromus tectorum, Centaurea maculosa, Dactylis glomerata, Medicago polymorpha, Phlaris arundinaceae, Poa compressa, Phleum pratense,* and *Verbascum thapsus* (Table 6).

Native plants growing on sites with lower than average clay content are *Agropyron dasystachyum, Festuca idahoensis, Festuca ovina,* and *Pinus ponderosa* (Table 7). Exotic species growing on sites with lower than average clay content are *Dactylis glomerata, Phalaris arundinaceae, Centaurea maculosa, Medicago polymorpha* and *Poa compressa* (Table 7).

Plants occupying sites with especially high water content are expected to occupy sites with high clay content because clay content is an important determinant of water-holding capacity. Similarly plants occupying sites with lower water-holding capacity are expected to occupy sites with low clay content. However the lists presented above are not parallel. Species that occupy sites with high clay but not high water-holding capacity, *Agropyron smithii, Artemisia cana, Medicago sativa* and *Opuntia polycantha,* may tolerate drought conditions due to low summer precipitation with high run off.

Table 7. Species with Mean Soil Clay Content Significantly Different than the Mean for all Sites (23.8%). Appendix A presents underlying data for every species.

Name	Origin [A]	Habit [B]	Mean
Species with means greater than 23.8			
Opuntia polycantha	N	F	30.1
Artemisia cana	N	F	28.4
Medicago sativa	E	F	27.5
Artemisia frigida	N	F	27.2
Agropyron smithii	N	G	26.5
Agropyron cristatum	E	G	26.2
Agropyron dasystachyum	N	G	18.2
Species with means less than 23.8			
Pinus ponderosa	N	T	12.7
Centaurea maculosa	E	F	13.2
Festuca idahoensis	N	G	15.2
Phalaris arundinacea	E	G	15.4
Poa compressa	E	G	15.8
Medicago polymorpha	E	F	16.1
Dactylis glomerata	E	G	16.3
Agropyron dasystachtum	N	G	18.2
Festuca ovina	N	G	19.7

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F) or tree (T)

Sites with low clay but average water-holding capacity may support species that require high infiltration of summer rains such as, *Pinus ponderosa*. Similarly sites with significantly low water-holding capacity and average clay content may support species requiring rocky sites with high run off such as *Bromus tectorum*, and *Verbascum thapsus*

Soil Permeability

Sand and coarse fragments allow summer rain to penetrate the soil surface, reducing the effects of drought. I used soil sand content as an index to permeability.

Average sand content for all sites is 45.6%. Native plants associated with sand contents higher than 45.6% are *Agropyron dasystachyum, Festuca idahoensis,* and *Festuca ovina* (Table 8). Exotic species associated with high sand contents are *Dactylis glomerata, Phalaris arundinacea, Phleum pratense, Poa compressa, Centaurea maculosa, Medicago polymorpha,* and *Verbascum thapsus* (Table 8). Native species growing on sites with average sand content lower than 45.6% are *Agropyron smithii, Artemisia cana, Artemisia frigida, Artemisia tridentata, Dalea purpurea, Gutierriezia sarothrae* and *Opuntia polycnatha* (Table 8). Exotic species growing where soils contain lower than 45.6 % sand are *Agropyron cristatum* and *Medicago sativa* (Table 8). Thirty-two species occurred on sites with both low and high sand content (Appendices A and D)

Table 8. Species Growing on Sites with Mean Soil Sand Content Significantly ($p<0.05$) Different from the Mean for all Sites (45.6%). Appendix A presents underlying data for every species.

Name	Origin[A]	Habit[B]	Mean
Species with mean greater than 45.6			
Phalaris arundinacea	E	G	59.2
Centaurea maculosa	E	F	58.7
Poa compressa	N	G	58.3
Festuca idahoensis	N	G	57.8
Dactylis glomerata	E	G	56.5
Agropyron dasystachyum	E	G	54.1
Medicago polymorpha	E	F	53.8
Verbascum thapsus	E	F	53.5
Festuca ovina	N	G	53.2
Phleum pratense	E	G	51.3
Species with means less than 45.6			
Dalea purpurea	N	F	29.8
Opuntia polycantha	N	F	34.4
Gutierriezia sarothrae	N	F	35.6
Artemisia tridentata	N	F	36.7
Artemisia cana	N	F	39.6
Artemisia frigida	N	F	40.0
Medicago sativa	E	F	40.5
Agropyron cristatum	E	G	42.0
Agropyron smithii	N	G	42.4

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F) or tree (T)

Fertility

Organic carbon indexes fertility because organic matter contains nitrogen, sulfur and phosphorus available on decomposition. In addition organic carbon has a high cation exchange capacity and therefore retains cations against leaching. Mean organic carbon was 2.7% for all sites. No roadside plants were significantly more abundant on sites with high organic carbon. Native plants found on sites with soil organic carbon averaging less than 2.7% were *Festuca ovina, Gutierriezia sarothrae,* and *Opuntia polycantha* (Table 9). One exotic species *Melilotus officinalis* was found on sites with low organic carbon. (Table 9). The remaining 46 species are successful on sites with average organic carbon (Appendices A and D).

Table 9. Species Occupying Sites with Mean Soil Organic Carbon (OC) Content Significantly Lower than the Mean for all Sites (2.7%). Appendix A presents underlying data for every species.

Name	Origin [A]	Habit [B]	Mean OC
Festuca ovina	N	G	2.09
Gutierriezia sarothrae	N	F	1.96
Melilotus officinalis	E	F	2.39
Opuntia polycantha	N	F	1.77

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F)

Soil pH, by indicating the chemical binding of nutrients, is another indicator of soil fertility. In the pH 6-9 range Fe, Bo, Mn, Cu and Zn become increasingly unavailable while N and P become increasingly unavailable above pH 8 (Daubenmire, 1974). Mean pH for all sites is 7.5. Two native species, *Artemisia frigida* and *Dalea purpurea,* occurred on sites with pH significantly greater than 7.5 (Table 10). One native species, *Lupinus argenteus* and three exotic species, *Alyssum alyssoides, Trifolium hybridum* and *Centaurea maculosa* occurred on sites with pH significantly less than 7.5 (Table 10).

Table 10. Species Occurring on Sites with Mean Soil pH Significantly Different than the Mean for all Sites (7.5). Appendix A presents underlying data for every species.

Name	Origin [A]	Habit [B]	Mean pH
Species with mean pH greater than 7.5			
Dalea purpurea	N	F	8.2
Artemisia frigida	N	F	7.7
Species with mean pH less than 7.5			
Trifolium hybridum	E	F	6.8
Lupinus argenteus	N	F	6.9
Centaurea maculosa	E	F	7.1
Alyssum alysoides	E	F	7.2

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F)

Salinity

High salinity may reduce plant performance either on dry plains or along winter salted roads. Electrical conductivity is an index of salinity (Ellis and Mellor, 1995) Mean conductivity for all sites was 0.27 mmhos/cm. Native plants tolerant of high salinity were *Agropyron smithii, Artemisia cana, Heterotheca villosa, Koeleria nitida, Opuntia polycantha* and *Poa sandbergii* (Table 11). Exotic plants growing on saline sites were *Agropyron cristatum Agrostis stolonifera,* and *Medicago sativa.* Native plants significantly more abundant on sites with lower than average salinity were *Agropyron dasystachyum, Festuca idahoensis, Festuca ovina* and *Pinus ponderosa* (Table 11). Exotic species unable to tolerate saline areas were *Centaurea maculosa, Medicago polymorpha, Phleum pratense, Poa compressa, Trifolium hybridum* and *Verbascum thapsus* (Table 11).

Table 11. Species with Mean Soil Conductivity (EC) Significantly Different than the Mean for all Sites (0.27mmhos/cm). Appendix A presents underlying data for every species.

Name	Origin	Habit	Mean EC
Species with mean EC greater than 0.27			
Opuntia polycantha	N	F	0.45
Artemisia cana	N	F	0.40
Hordeum jubatum	N	G	0.39
Poa sandbergii	N	G	0.37
Koeleria nitida	N	G	0.36
Agrostis stolonifera	E	G	0.36
Heterotheca villosa	N	F	0.35
Medicago sativa	E	F	0.34
Artemisia frigida	N	F	0.33
Agropyron smithii	N	G	0.33
Agropyron cristatum	E	G	0.32
Species with mean EC less than 0.27			
Medicago polymorpha	N	F	0.13
Festuca idahoensis	N	G	0.13
Trifolium hybridum	E	F	0.14
Pinus ponderosa	N	T	0.15
Poa compressa	N	G	0.15
Centaurea maculosa	E	F	0.15
Verbascum thapsus	E	F	0.17
Festuca ovina	N	G	0.19
Agropyron dasystachyum	N	G	0.21
Phleum pratense	E	G	0.22

[A] Origin = exotic(E) or native (N). [B] Habit = grass (G), forb (F) or tree (T)

Plot Position and Aspect

Plot position (backslope and inslope) and aspect (N, S, E, W) were expected to influence plant distribution along roadsides. Mean plant cover for inslopes (adjacent roadbed) and backslope (adjacent native vegetation) was compared in interaction plots presented for individual species in Appendix F. *Artemisia frigida, Gaura coccinea,* *Heterotheca villosa* and *Stipa comata,* all native species, were more abundant on backslopes than inslopes. The exotic species, *Bromus inermis, Dactylis glomerata,* and *Phalaris arundinacea* and one native species, *Poa sandbergii,* were more common on inslopes than backslopes.

Effects of aspect were analyzed by comparing mean cover of opposing aspects in interaction plots. *Achillea millefolium* had highest cover south-facing slopes. Astonishingly no other species demonstrated higher cover on any other aspect.

CONCLUSIONS

The following conclusions can be drawn from this study.

1. Roadsides support depauperate communities, containing approximately half the number of species found in native communities occupying similar environments. Roadside communities are characterized by having few high presence species and many low presence species.

2. Twenty-eight native species are common (constancy greater than 10%) along Montana roadsides (Table 19). These species colonizing roadsides are good candidates for revegetation.

3. Twenty-two exotic species are common (constancy greater than 10%) along Montana roadsides. They include species intentionally introduced and invading species. While some exotic species are useful for management they may have undesirable impacts on the stability of roadside vegetation. Exotic species should be used with care to minimize impacts on adjacent farm or range land. Especially invasive noxious weeds can never be recommended for revegetation. This survey will help managers identify environments where undesirable exotic species are likely to be problematic.

4. I list species with higher occurrence in atypical levels of eleven environmental factors (pages 23-40, Appendix A) including, climate (temperature, precipitation), soil water conditions (water-holding capacity, clay, sand), soil fertility (organic carbon and pH), and salinity. These species are good candidates for planting in extreme conditions. Species growing poorly in these areas are especially bad candidates.

5. The response of each individual species to eleven environmental conditions is presented in Appendix A.

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APPENDICES

APPENDIX A. RESPONSE OF INDIVIDUAL SPECIES TO ELEVEN ENVIRONMENTAL CONDITIONS

Introduction to Appendix A

The environmental data presented help managers identify species likely to establish under typical and a typical conditions. Environmental conditions likely to control the distribution of roadside plants are environmental type, July temperature, mean annual precipitation, soil water-holding capacity, clay, sand, organic carbon, pH, conductivity, slope and aspect.

Environmental data is displayed in graphical form. Histograms for the categorical variables environmental type and precipitation, indicate species performance across categories. Refer to page 21 for an explanation of statistical methods used to establish differences between categories. Mean rank is the average Kruskal-Wallis ranking for that category and is used to illustrate differences between groups. Frequency diagrams for temperature, water-holding capacity, clay, sand, organic carbon. pH and conductivity display the presence of the species at each level and the distribution of that variable across all roadside sites. If the distribution of that species occurrences is significantly different from the distribution of all roadside occurrences then the means are displayed in the upper right corner of the graph. Graphs for slope and aspect show the interacting effects of slope and aspect on mean cover. Acquisition, analysis, and application of this data is discussed in the methods and results sections of the text.

1. Origin, Duration and Habit: Species are characterized by Latin name, family and origin, duration, habit and vegetative reproduction. Exotic plants that sometimes are questionable in plantings are identified under origin. Perennial plants, most useful in planting are identified under duration. Grass, forb and shrub life forms and vegetative reproduction are identified under habit.

2. Environmental type: Refer to text (Pgs 8-11, 29-30) for an explanation of methods and results.

3. Temperature: Mean July temperature (°C) is presented as an index for comparing growing season temperatures among environmental types.

4. Precipitation: Mean annual precipitation (cm) is used to compare precipitation among environmental types.

5. Water-holding capacity: WHC is calculated using the Decker equation, refer to page 19 for a description of methods. Fifteen bar WHC is the weight of water stored in a dry soil, expressed as a percent of the soils dry weight. 1/3 bar WHC (twice 15 bar) is a measure of the soils total water storage capacity. 1/3 bar WHC - 15 bar WHC indexes the amount of water a moist soil can deliver to plants.

6. Clay: Contribution to total soil (%). High clay is positively correlated with water storage capacity and negatively correlated with water infiltration.

7. Sand: Contribution to total soil (%). High sand is positively correlated with infiltration and negatively correlated with water storage.

8. Organic carbon: Contribution to total soil (%). Organic matter percent in approximately 1.82 X %OC. Organic matter contributes to total soil WHC. Refer to Methods (p19) for an explanation of methods. It adds to soil fertility both through nutrient released from decomposition and through a high cation exchange capacity.

9. pH: A measure of acidity and an indicator of fertility. All nutrients are most available at pH 7 and most become less available when pH deviates significantly.

10. Conductivity: Electrical conductivity of a 2:1 suspension of soil in water. Indexes salinity.

11. Position: On the inslope (between shoulder and ditch) or on the backslope (on the roadcut above the ditch.

12. Aspect: Compass direction of the slope within 5 degree of north, south, east or west.

***Achillea millefolium* (Acmi)** **yarrow** **Asteraceae**

Origin, Duration and Habit [1]: Native Perennial Forb, not vegetatively reproducing.

Environmental Type [2]: Acmi cover (%) is highest in the AGSP and PSME types, lower in PIPO and BOGR types and lowest in the ANSC type (Fig. 4).

Temperature: Temperature does not differ between Acmi sites and average sites (Fig. 5A).

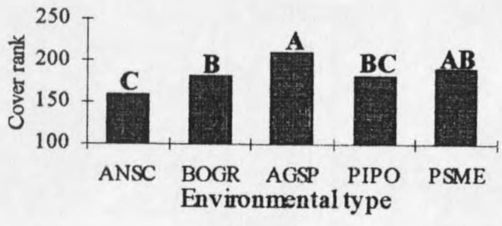
Precipitation: Acmi cover (%) does not differ among categories (Fig. 4).
Water-holding capacity: WHC does not differ between Acmi and average sites (Fig. 5B).
Clay: Clay does not differ between Acmi sites and average sites (Fig. 5C).
Sand: Sand does not differ between Acmi sites and average sites (Fig. 5D).

Organic carbon: OC does not differ between Acmi sites and average sites (Fig. 5E).
pH: pH does not differ between Acmi sites and average sites (Fig. 5F).

Conductivity: Conductivity does not differ between Acmi sites and average sites (Fig. 5G).

Position and Aspect: Acmi does not occur on east, west, or north-facing inslopes or backslopes. Mean percent cover is slightly higher on south-facing inslopes than south-facing backslopes (Fig. 5H).

[1] Refer to introduction (p52) for a description of each category. [2] Significant category.



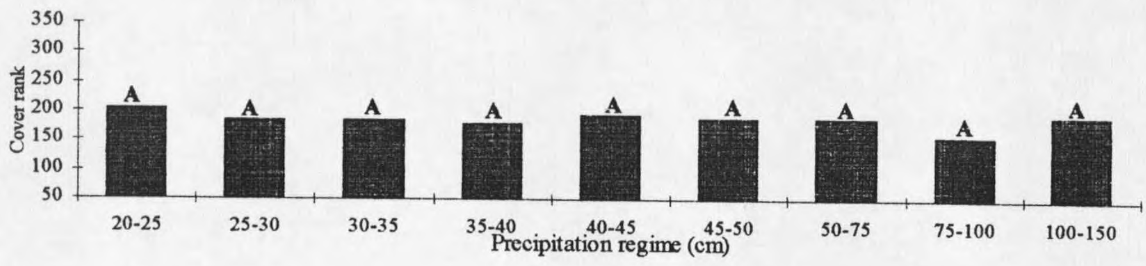


Figure 4. Effect of Environmental Type and Precipitation on Cover (%) of *Achillea millefolium*. Categories sharing a letter do not significantly ($p>0.05$) differ.

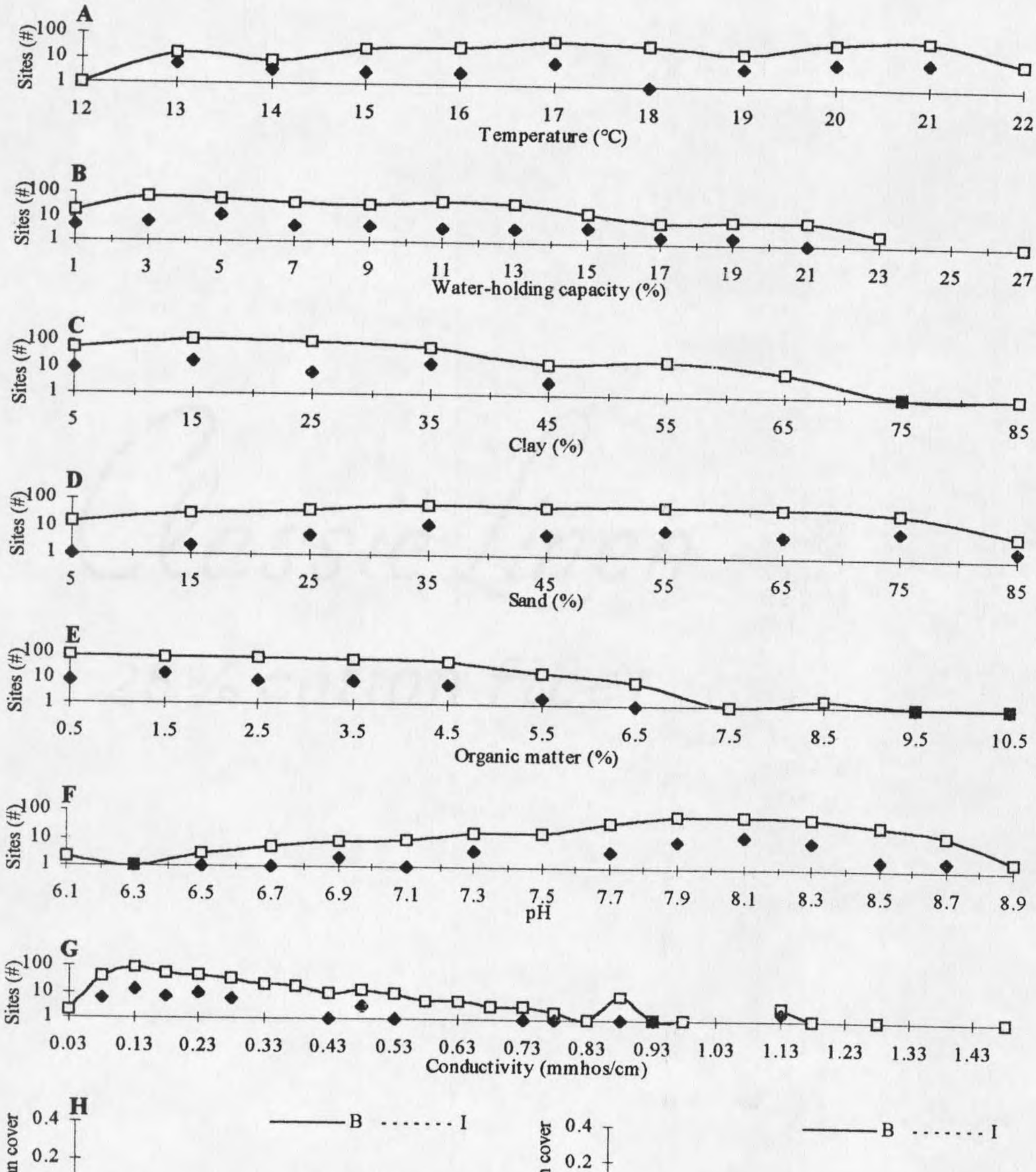


Figure 5. The Distribution of *Achillea millefolium* Sites (solid diamonds) and all Roadside Sites (open squares) across Nine Site Characteristics. Where the mean of sites occupied by *Achillea millefolium* is significantly ($p<0.05$) different from the mean of all sites, both are shown in the upper right of the graph.

***Agropyron cristatum* (Agcr)** **crested wheatgrass** **Poaceae**

Origin, Duration and Habit [1]: Exotic Perennial grass, not vegetatively reproducing.

Environmental Type[2]: Agcr cover (%) is highest in the BOGR type, lower in the ANSC and AGSP types, and lowest in PIPO and PSME types (Fig. 6).

Temperature [2]: Temperature is higher than in average sites (Fig. 7A).

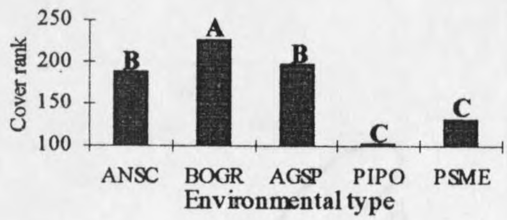
Precipitation [2]: Agcr cover (%) tends to be higher on drier sites than in moist sites. Cover (%) is highest in 20-25cm. and 25-30cm (Fig. 6).
Water-holding capacity [2]: WHC in Agcr sites is higher than in average sites (Fig. 7B).
Clay [2]: Clay in Agcr sites is higher than in average roadside sites (Fig. 7C).
Sand [2]: Sand in Agcr sites is lower than in average roadside sites (Fig. 7D).

Organic carbon: OC does not differ between Agcr sites and average sites (Fig. 7E).
pH: pH does not differ between Agcr sites and average sites (Fig. 7F).

Conductivity [2]: Conductivity in Agcr sites is higher than average sites (Fig. 7G).

Position and Aspect: An interaction between aspect and plot position occurs for north and south-facing inslopes and backslopes. Percent cover for east-facing backslopes is higher than east-facing inslopes (Fig. 7H).

[1] Refer to introduction (p52) for a description of each category. [2] Significant category.



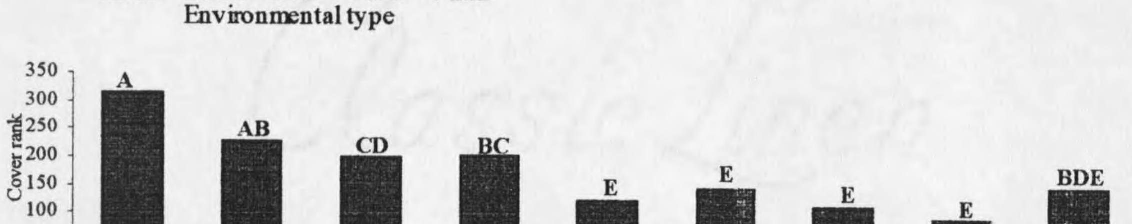


Figure 6. Effect of Environmental Type and Precipitation on Cover (%) of *Agropyron cristatum*. Categories sharing a letter do not significantly (p>0.05) differ.

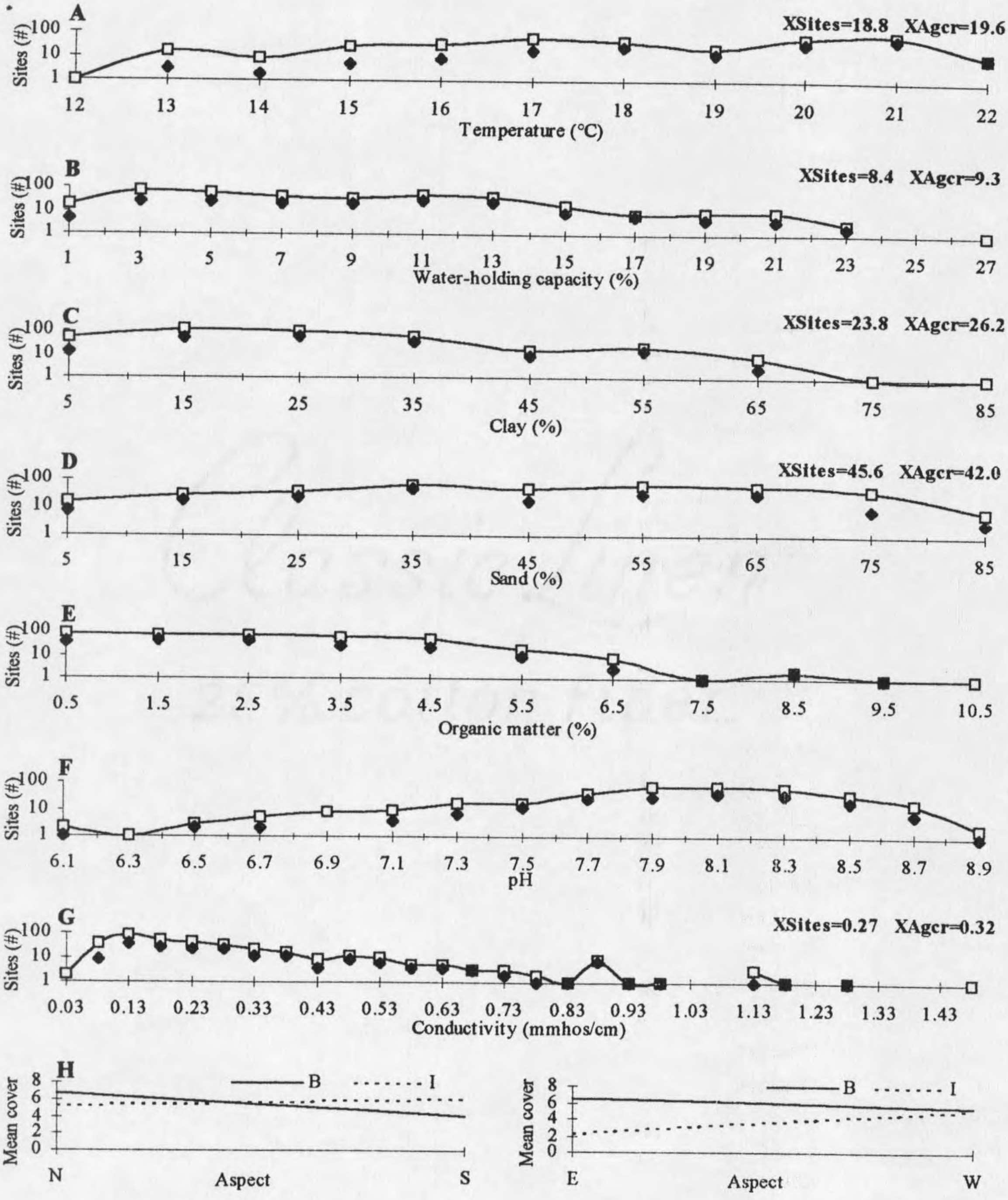


Figure 7. The Distribution of *Agropyron cristatum* Sites (solid diamonds) and all Roadside Sites (open squares) across Nine Site Characteristics. Where the mean of sites occupied by *Agropyron cristatum* is significantly ($p<0.05$) different from the mean of all sites, both are shown in the upper right of the graph.

***Agropyron dasystachyum* (Agda) thickspike wheatgrass Poaceae**

Origin, Duration and Habit [1]: Native Perennial Grass, vegetatively reproducing.

Environmental Type[2]: Agda cover (%) is highest in the PIPO, PSME and AGSP types and lowest in the BOGR and ANSC types (Fig. 8).

Temperature [2]: Temperature in Agda sites is higher than in average roadside sites (Fig. 9A).

Precipitation [2]: Agda cover is higher in moist (45-100 cm) sites than in dry sites (Fig. 8).
Water-holding capacity [2]: WHC of Agda sites is lower than average roadside sites (Fig. 9B).
Clay [2]: Clay in Agda sites is lower than average roadside sites (Fig. 9C).
Sand [2]: Sand in Agda sites is higher than average roadside sites (Fig. 9D).

Organic carbon: OC does not differ between Agda sites and average sites (Fig. 9E).
pH: pH does not differ between Agda sites and average sites (Fig. 9F).

Conductivity: Conductivity does not differ between Agda sites and average sites (Fig. 9G).

Position and Aspect: Mean Agda cover (%) is equal on north and west-facing inslopes and backslopes. Cover is higher on south and east-facing inslopes than backslopes (Fig. 9H).

[1] Refer to introduction (p52) for a description of each category. [2] Significant category.

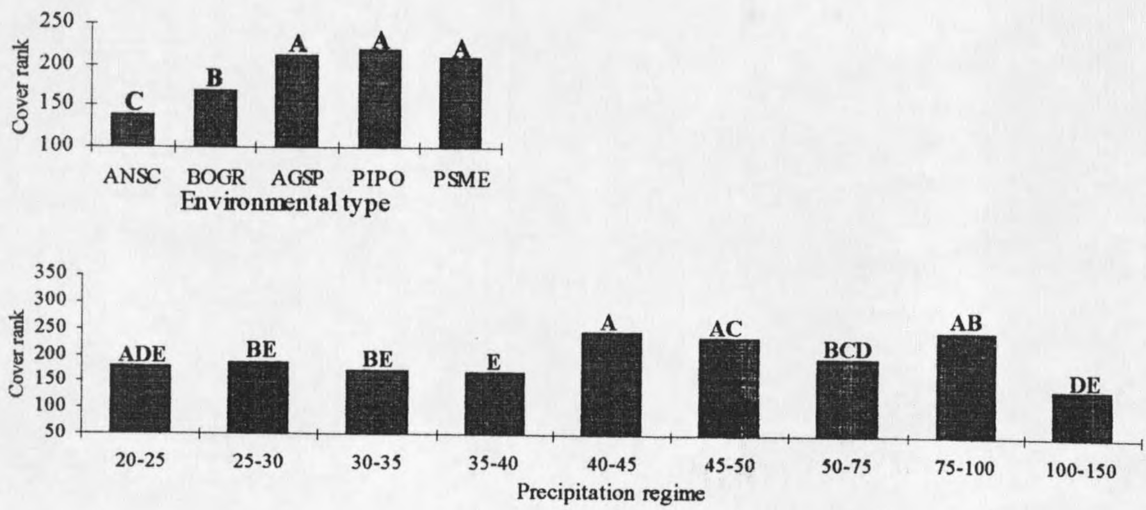


Figure 8. Effect of Environmental Type and precipitation on percent cover of *Agropyron dasystachyum*. Categories sharing a letter do not significantly ($p>0.05$) differ.

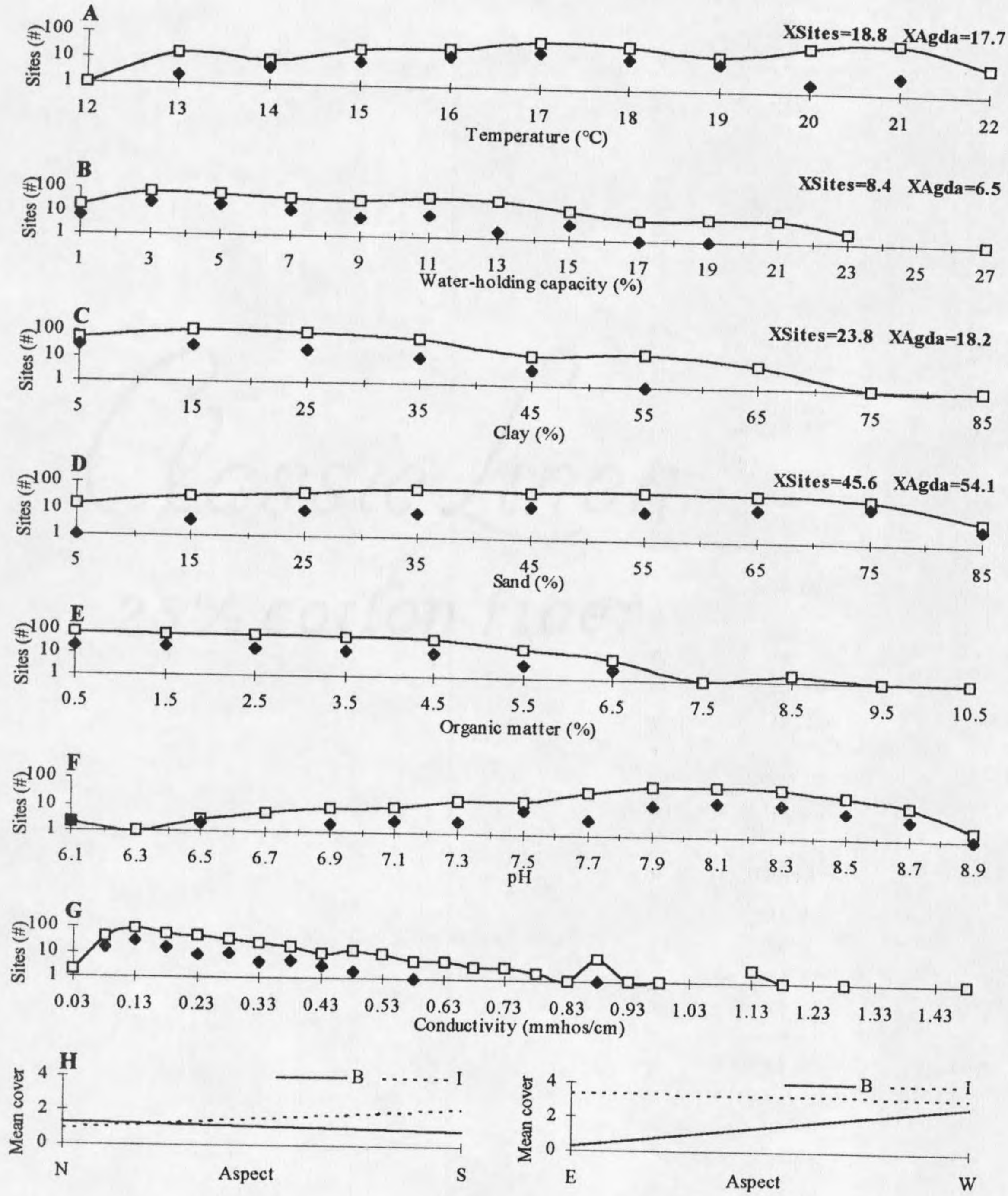


Figure 9. The Distribution of *Agropyron dasystachyum* Sites (solid diamonds) and all Roadside Sites (open squares) across Nine Site Characteristics. Where the mean of sites occupied by *Agropyron dasystachyum* is significantly ($p<0.05$) different from the mean of all sites, both are shown in the upper right of the graph.

***Agropyron smithii* (Agsm)** **western wheatgrass** **Poaceae**

Origin, Duration and Habit [1]: Native Perennial grass, vegetatively reproducing.

Environmental Type[2]: Agsm cover (%) is highest in the BOGR type than any other type (Fig. 10).

Temperature [2]: Temperature in Agsm sites is higher than average roadside sites (Fig. 11A).

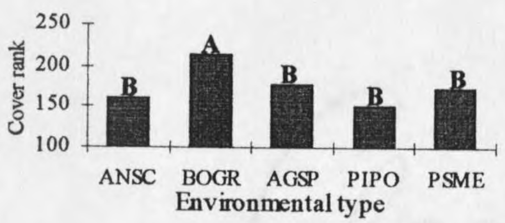
Precipitation [2]: Agsm cover (%) is highest on moist sites (100-150 cm) (Fig. 10).
Water-holding capacity [2]: WHC does not differ between Agsm and average sites (Fig. 11B).
Clay [2]: Clay in Agsm sites is higher than in average roadside sites (Fig. 11C).
Sand [2]: Sand in Agsm sites is lower than in average roadside sites (Fig. 11D).

Organic carbon: OC does not differ between Agsm sites and average sites (Fig. 11E).
pH: pH does not differ between Agsm sites and average sites (Fig. 11F).

Conductivity: Conductivity in Agsm sites is higher than in average sites (Fig. 11G).

Position and Aspect: There is an interaction between plot position and aspect in north and south-facing inslopes and backslopes. Mean cover (%) is higher on east and west-facing backslopes than north and south-facing inslopes and backslopes (Fig. 11H).

[1] Refer to introduction (p52) for a description of each category. [2] Significant category.



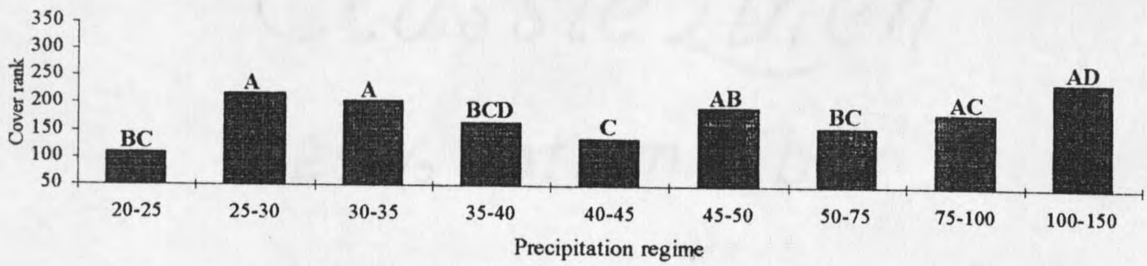


Figure 10. Effect of Environmental Type and Precipitation on Cover (%) of *Agropyron smithii*. Categories sharing a letter do not significantly differ.

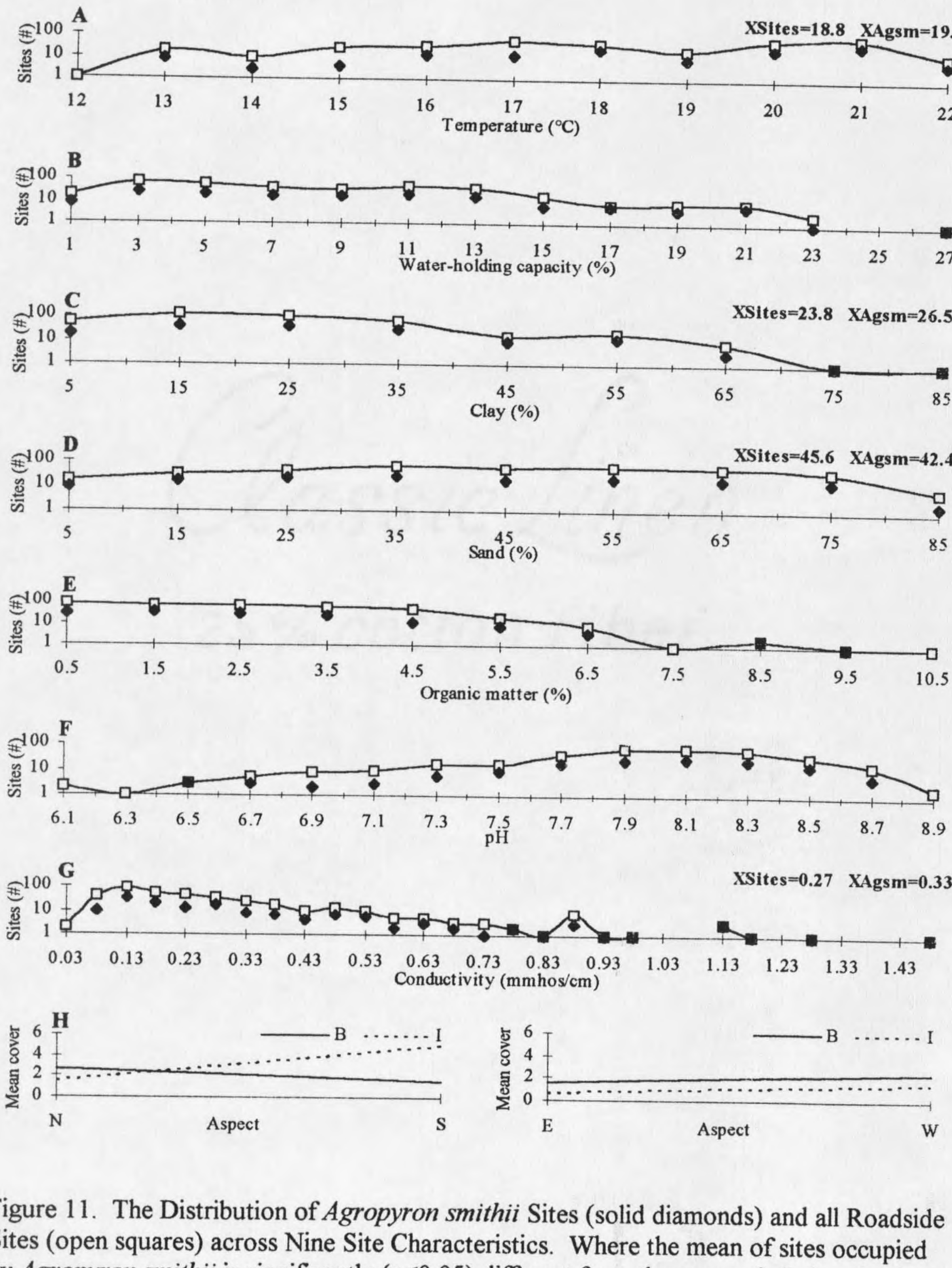


Figure 11. The Distribution of *Agropyron smithii* Sites (solid diamonds) and all Roadside Sites (open squares) across Nine Site Characteristics. Where the mean of sites occupied by *Agropyron smithii* is significantly ($p<0.05$) different from the mean of all sites, both are shown in the upper right of the graph.

***Agropyron spicatum* (Agsp)** **bluebunch wheatgrass** **Poaceae**

Origin, Duration and Habit [1]: Native Perennial Grass, not vegetative reproducing.

Environmental type: Agsm cover (%) does not differ among types (Fig. 12).

Temperature regime: Temperature in Agsp sites does not differ from average sites (Fig. 13A).

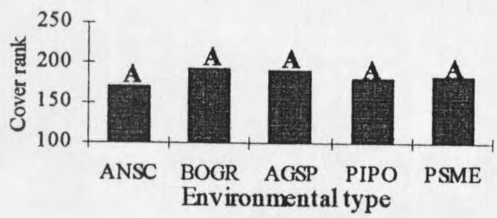
Precipitation: Agsp cover (%) does not differ among categories (Fig. 12).
Water-holding capacity: WHC does not differ between Agsp sites and average sites (Fig. 13B).
Clay: Clay does not differ between Agsp sites and average sites (Fig. 13C).
Sand: Sand does not differ between Agsp sites and average sites (Fig. 13D).

Organic carbon: OC does not differ between Agsp sites and average sites (Fig. 13E).
pH: pH does not differ between Agsp sites and average sites (Fig. 13F).

Conductivity: Conductivity does not differ between Agsp and average sites (Fig. 13G).

Position and Aspect: Mean cover (%) is higher on north and south-facing backslopes than inslopes. Mean cover is approximately equal on east and west-facing inslopes and backslopes (Fig. 13H).

[1] Refer to introduction (p52) for a description of each category.



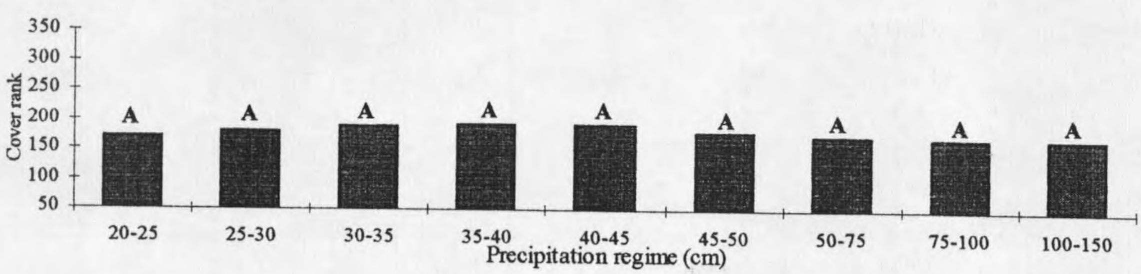


Figure. 12. Effect of Environmental Type and Precipitation on Cover (%) of *Agropyron spicatum*. Categories sharing a letter do not significantly differ.

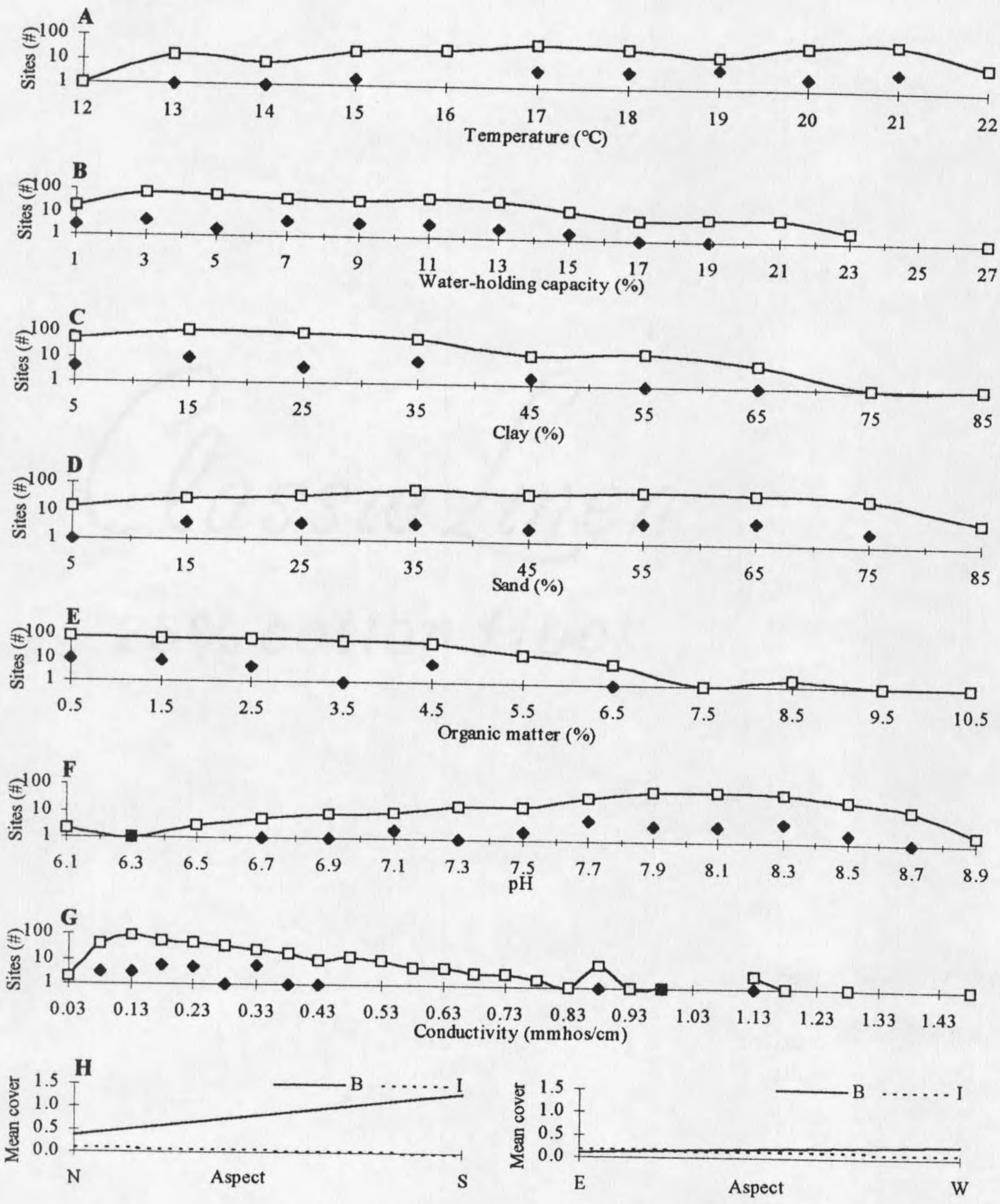


Figure 13. The Distribution of *Agropyron spicatum* Sites (solid diamonds) and all Roadside Sites (open squares) across Nine Site Characteristics. Where the mean of sites occupied by *Agropyron spicatum* is significantly ($p<0.05$) different from the mean of all sites, both are shown in the upper right of the graph.

***Agrostis stolonifera* (Agst)** **redtop bent grass** **Poaceae**

Origin, Duration and Habit [1]: Exotic Perennial grass, vegetatively reproducing.

Environmental Type[2]: Agst cover (%) is higher in the BOGR type than in any other type (Fig. 14).

Temperature: Temperature does not differ between Agst sites and average sites (Fig. 15A)

Precipitation: Agst cover (%) does not differ between moist and dry sites (Fig. 14).
Clay: Clay does not differ between Agst sites and average sites (Fig. 15C).
Sand: Sand does not differ between Agst sites and average sites (Fig. 15B).
Water-holding capacity: WHC does not differ between Agst sites and average sites (Fig. 15D).

Organic carbon: OC does not differ between Agst sites and average sites (Fig. 15E).
pH: pH does not differ between Agst sites and average sites (Fig. 15F).

Conductivity [2]: Conductivity is higher on Agst sites than average sites (Fig. 15G).

Position and Aspect: Does not occur on south-facing backslopes or east facing inslopes. Mean cover (%) is highest on south-facing inslopes and west-facing backslopes (Fig. 15H).

[1] Refer to introduction (p52) for a description of each category. [2] Significant category.

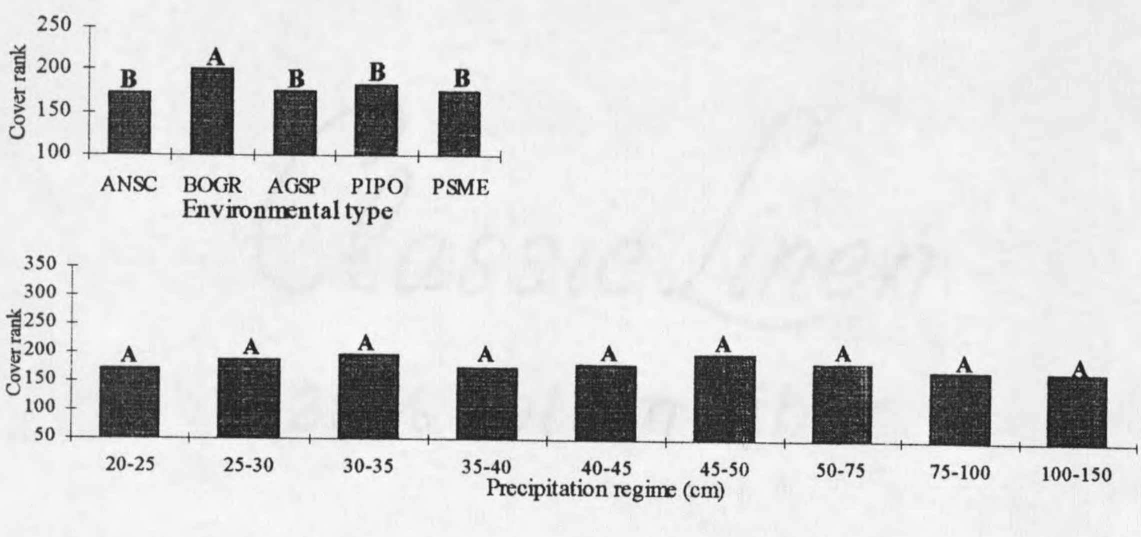


Figure 14. Effect of Environmental Type and Precipitation on Cover (%) of *Agrostis stolonifera*. Categories sharing a letter do not significantly differ.

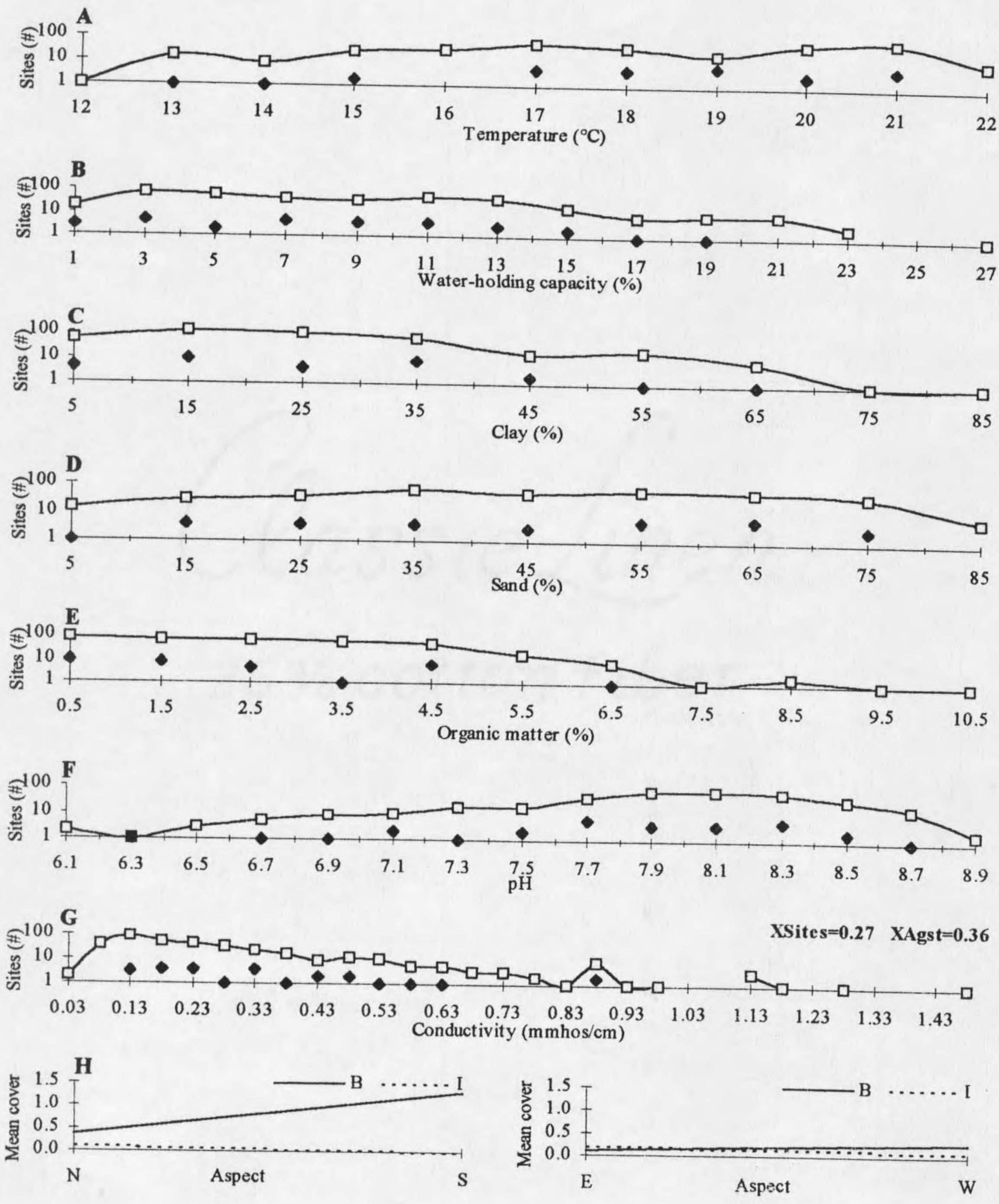


Figure 15. The Distribution of *Agrostis stolonifera* Sites (solid diamonds) and all Roadside Sites (open squares) across Nine Site Characteristics. Where the mean of sites occupied by *Agrostis stolonifera* is significantly ($p<0.05$) different from the mean of all sites, both are shown in the upper right of the graph.