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THE EVALUATION OF TWO  
TYPES OF MULTIVARIATE ANALYSES  
APPLIED TO GRASSLAND VEGETATION DATA  
FROM A RECLAIMED COAL MINE AREA  
IN SOUTHEAST KANSAS, USA.

A Thesis Submitted to the Graduate School

in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

Karen Frances Yates

Pittsburg State University

Pittsburg, Kansas

December 1996



In the actual living of life there is no logic,  
for life is superior to logic.

D. T. Suzuki  
"Practical Methods of Zen Instruction"

THE EVALUATION OF TWO  
TYPES OF MULTIVARIATE ANALYSES  
APPLIED TO GRASSLAND VEGETATION DATA  
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An Abstract of the Thesis by  
Karen F. Yates

This study presents an analysis of the use of classification and ordination techniques for the detection of sub-communities at a reclaimed coal refuse dump and strip mined area in southeast Kansas. Cover values for 58 grass, forb, and woody species were estimated in 103 systematically positioned plots across the reclamation grassland using the modified Daubenmeyer cover scale. The data were submitted to an array of default and variant classification and ordination analysis programs in order to assess their ability to detect sub-communities. The classifications obtained from the analyses were mapped and analyzed for differences in species composition, diversity, and spatial contiguity. Of the two classifications produced by TWINSpan, the variant analysis was better able to detect a sub-community characterized by high cover levels of *Panicum virgatum*, which appears to be exerting a negative impact on local diversity and evenness compared with areas where the grass is present at lower cover levels. Both TWINSpan analyses detected sub-communities characterized by a consociation of *Bouteloua curtipendula*, *Andropogon gerardii*, and *Solidago canadensis*, with higher species diversity and evenness than sub-communities of a *B. curtipendula* and *A. gerardii* association; the variant TWINSpan analysis was better able to detect the spatial parameters of this sub-community. The default Canonical Correspondence Analysis, a constrained ordination technique, indicated

the effect of two environmental variables, frequency of standing water and level of mine refuse at the soil surface, account for only a fraction of variation in species composition within the reclamation area. Within the environmentally-focused ordination diagram produced by the default analysis, there occurred a separation in species composition between plots influenced by high levels of one or the other of the two variables. However, as the ordination diagram yielded no clearly-defined clusters of plots representing discrete, natural sub-communities, the classification derived from the partitioning of ordination space is somewhat arbitrary. Higher eigenvalues were obtained in a variant ordination in which species planted during the reclamation were made passive. This may indicate that the systematic sowing of a homogeneous seed mix nine years earlier still confounds a more typical ecological separation of grassland species. However, this variant ordination, and two others, did not prove useful in creating more interpretable ordination diagrams.

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# CHAPTER I

## INTRODUCTION

Multivariate analysis is a branch of statistics that deals with the simultaneous variation and treatment of two or more variables (Sokal and Rohlf 1981, Gauch 1982). Although Sokal and Rohlf (1981) describe several examples of multivariate analysis techniques, general references to multivariate analysis in current ecological literature often refer to the two techniques of classification and ordination.

Gauch (1982) narrowed the definition, specifying that these two multivariate techniques are able to treat the data set as a whole, and that their major purpose is a characterization of the entire data. These data analysis tools digest, clarify, and provide graphical displays of large amounts of information in the search for increased understanding of communities (Green 1980, Pielou 1984).

Community data sets are of necessity multivariate (Pielou 1984). They are collected from biological systems not easily or inexpensively experimented upon (Green 1980), and, indeed, the raw data matrices generated in surveys are interesting in their own right (Pielou 1984). Significance testing, the hallmark of inferential statistical analysis and hypothesis-driven experiments, loses its power when the variables are numerous species abundances (Green 1980), each species displaying a unique (and probably unknown) distribution in relation to complexes of environmental factors. Greig-Smith (1983) observed that significance tests are rarely applicable to survey data.

Although experimental approaches toward an increased understanding of communities will continue to be conducted, an observational approach, one possibly not driven by hypothesis testing, can be an efficient and informative methodology in the "successive refinement" of understanding communities (Green 1980, Gauch 1982, Ludwig and Reynolds 1988, Palmer 1995).

"The human mind is confused by heterogeneity. . . ." (Hill *et al.* 1975).

Multivariate analysis tools such as classification and ordination serve as a link between the biological complexity of communities and the limitations of human perception (Gauch 1982). What these tools reveal, according to Pielou (1984), are the structure of the data at hand.

In recent years, a wide array of multivariate data analysis software has become available to ecological researchers (Palmer 1995). The choice of an ordination or classification technique diverges significantly from the use of inferential statistical analysis techniques, such as ANOVA and linear regression. Instead of an analysis being dictated by the relationship between experimental variables, it sometimes appears that the application of a particular multivariate analysis technique is governed by subjective criteria, ranging from a researcher's infatuation with the mathematical elegance of a technique (Austin 1985), to the more mundane consideration of the availability and ease of use of an inexpensive software package (Palmer 1995).

This arbitrariness over the choice of an analysis technique increases the likelihood that an analysis will produce misleading results, as do the inherent complexity of the techniques themselves. Researchers have assumed two stances toward this dilemma.



Pielou (1984) entreated ecologists to master the basic Principle Components Analysis ordination technique using a small data set and a hand calculator before proceeding to field experiments with dozens of species and sampling units. On the other hand, Gauch (1982) and more recently, Palmer (1995) presented casual, informal introductions to ordination techniques with practical "tricks of the trade" for students and practitioners not schooled in matrix algebra and eigenanalysis.

The easy apprehension of complex ecological relationships afforded by an ordination diagram or a classification dendrogram belies the voluminous calculations from which they were born. It is inevitable that in the coming years a pragmatic balance must develop between the necessity for robust, yet easily executed multivariate data analyses.

This study proposes to explore the application of classification and ordination techniques to a vegetation data set collected at a reclaimed coal mining facility in southeast Kansas. The analysis programs used in this study, TWINSpan (Hill 1979) and CANOCO (ter Braak 1990), are two multivariate data analysis software programs frequently used by academic researchers and land managers of public and private conservation agencies. Given the ease of use of these two analysis packages, the goal of this study will be to compare the results of analyses produced by "default" parameters -- found by the program's authors to be robust in their application -- with results produced through variations on the default analyses. The relative efficacy of the different analyses will be evaluated on their ability to produce a classification that illuminates important ecological processes that may be occurring at the study site.

## CHAPTER II

### LITERATURE REVIEW

#### Perspectives on Ordination and Classification

Ecologists' use of multivariate analysis methods such as classification and ordination has lagged behind the development of univariate techniques such as the F-test and t-test (Jongman *et al.* 1995). However, an upsurge in the analysis of community data with multivariate techniques unfolded when computers able to handle the voluminous calculations became more available to ecological researchers and land managers (Gauch 1982, Digby and Kempton 1987, Jongman *et al.* 1995). As a consequence, over the last four decades the literature of multivariate analysis of community data has been in a state of flux. It has been typical to find criticisms of algorithms being answered by mathematical or geometrical counter arguments in their defense, and the subsequent creation of improved algorithms (Barbour *et al.* 1980). Further, more than one technique's mathematical elegance or ease of use has resulted in a popularity later found unwarranted for every application (Palmer 1993, Norris 1995).

Reviews and criticisms of classification and ordination methods found in scientific literature frequently have analyzed the methods from a theoretical or mathematical perspective (Barbour *et al.* 1980). One re-occurring concern has been the problem of fitting unknown and complex species response patterns to linear or unimodal distribution

models assumed in the mathematical techniques (Gauch and Whittaker 1972, Greig-Smith 1983, Pielou 1984). Also, an on-going debate continues over the applicability of a myriad of data transformations, standardizations, and similarity measures that variously affect ordination and classification results (Gauch and Whittaker 1972, van der Maarel 1979, Gauch 1982, Pielou 1984, Digby and Kempton 1987, Palmer 1993, Norris 1995).

Further, some ecologists have expressed concern that use of these exploratory analysis technologies may have negative consequences for basic and applied ecological investigations. Austin (1985) asserted some ecologists' preoccupation with ordination techniques had come at the expense of their use of traditional ecological methodologies and reliance on hypothesis-driven experiment design. Indeed, Digby and Kempton (1987) observed the increased use of classification and ordination by ecologists was accompanied by a shift away from development and refinement of species distribution models and theory toward more descriptive, exploratory approaches.

Barbour *et al.* (1980) criticized ordination studies in which a truncated form of the original data is presented in an ordination diagram, preventing a reader from reaching an independent conclusion about the data. The likelihood of a misuse or misunderstanding of classification and ordination results owing to the inherent complexity of the methods (Pielou 1984, Norris 1995) is a concern of some writers. Norris (1995) also observed a reticence in some researchers to become familiar with the literature of multivariate analysis techniques, limiting exchanges between the various scientific disciplines and between academic research scientists and government land managers.

In spite of criticisms, admonitions, and cautions, the increased use of classification

and ordination techniques is driven by academic researchers' and land managers' demands for cost-effective, objective data analysis tools that facilitate insight into relations between environmental quality factors or management practices and species' abundances (Gauch 1982, Digby and Kempton 1987, Jongman *et al.* 1995, Norris 1995).

In the early years of their development, classification and ordination were viewed as conflicting and competing methodologies, each used by practitioners of two schools advancing differing theories explaining community organization (Gauch 1982, Goldsmith *et al.* 1986, Ludwig and Reynolds 1988). One group of ecologists approached communities as an organism, and viewed species assemblages as discrete, organismic entities, their parameters detectable through classification techniques. The other group saw species distributions as being individualistic and continuous across a number of resource gradients. This second perspective promoted ordination techniques, which ordered sampling units along a continuum, as a better method for representing community variation. This dichotomy of perspective on the use of one or the other of these techniques is not present in contemporary literature, however. Indeed, classification and ordination techniques are currently viewed as complementary approaches for investigation of community variation (Green 1980, Gauch 1982, Greig-Smith 1983, Digby and Kempton 1987).

It is important to note that the application of any classification technique to a data set will result in the creation of a number of groups, regardless of whether discrete groups of species assemblages actually occur in nature (Pielou 1984, Jongman *et al.* 1995). A similar arbitrariness occurs in ordination analysis when it is not clear whether gaps

between clusters of samples in the ordination diagram reflect real discontinuities in a community or unforeseen gaps in data collection (Woods and Cogbill 1994).

The imposition of a classification where distinct species assemblages may not actually exist in nature is an acknowledged limitation of all computerized classification techniques, requiring the ecologist to carefully evaluate the classes and the ecological separation between them, as well as the original sampling design, to determine to what extent the groups really exist. However, for some applications, such as land management or vegetation mapping, an imposed classification, however arbitrary, is useful for detecting sub-populations that reflect some diagnostic value or management concern (Gauch 1982, Greig-Smith 1993). This limitation in mind, the application of classification or ordination to a data set (considered by some to be an art) cannot stand alone as an ecological methodology, but rather must be used as a tool that is combined with the experience and understanding of the ecologist.

### **Use of Classification and Ordination**

Classification and ordination techniques mathematically distill or summarize large data sets so that their most salient features become more clear. This removal of extraneous information in a community data matrix is based on two assumptions (Gauch 1982, Pielou 1984, Jongman *et al.* 1995). First, it must be assumed that species abundances within a community co-vary systematically or in a coordinated way, in response to environmental factors. This coordinated species response is exhibited as a

redundancy within the data matrix and is reflective of those factors. Second, the processes of sampling and other random events generate chance occurrences of species in a sample, or uncoordinated species responses, often described as noise. In a large data matrix, this noise can obscure more interesting components of community structure. Classification and ordination techniques act on the data matrix by mathematically condensing the redundancy and suppressing the noise. Although there are many types of classification and ordination, they all share the goals of uncovering structure in the data and providing relatively objective summarization of the data (Gauch 1982).

## **Classification**

One of the more intuitive multivariate analysis techniques, the process of classification has been observed to be an ubiquitous mental activity (Sokal 1974). Classification techniques decompose the  $s$  species by  $n$  samples data matrix into  $g$  sets of samples, where  $g < n$ . The samples within the  $g$  groups are more similar to one another than are the samples in different groups (Green 1980). Information about a community is subsequently extracted from the classification by noting the concurrence of species within groups. Also, it is possible to intuitively or statistically detect relations between the delineated groups and environmental variables (Gauch 1982, Greig-Smith 1983, Pielou 1984, Jongman *et al.* 1995).

In addition, most classification techniques extract information about a data matrix beyond the detection of sub-groups. For example, a hierarchical classification arranges samples within a hierarchy, which displays degrees of relationship among the samples

(Pielou 1984). The visual representation of a hierarchical classification is a dendrogram, sampling units arranged as successively branching limbs of a tree. The term "cluster" is used as a synonym for a sample or groups of samples in a hierarchical classification.

Two other informative data exploration aids are returned by the classification program TWINSpan, which is an hierarchical classification technique. The first is an ordered data matrix or two-way table, which simultaneously displays the classification of both the species and the samples. The second aid is a binary code assigned to each group of samples based on its dichotomization history. A dichotomous key using differential species delineated during the classification can be constructed from this binary code and subsequently used to classify samples not included in the original analysis (Goldsmith *et al.* 1986, Jongman *et al.* 1995).

## Ordination

Ordination technologies are not as intuitive as those of classification. Ordination was born out of ecologists' observations that species abundances often display linear or unimodal distributions along environmental gradients such as altitude or soil moisture (Gauch 1982). Orloci (1974) described ordination as an information transfer system that must effectively summarize the data while minimizing distortion and a loss of information. In an ordination, the many unvisualizable dimensions produced by a  $s$  species by  $n$  samples data matrix are reduced to a matrix of  $p < s$  by  $n$ ,  $p$  being the number of reduced dimensions, or axes in a coordinate frame (Green 1980, Pielou 1984, Ludwig and Reynolds 1988).

Probably the most recognized result of ordination analysis is the ordination diagram -- a visually interpretable spatial arrangement of samples (or species) in a coordinate frame such that their relative positions reflect ecological distances (Gauch 1982, Pielou 1984, Goldsmith *et al.* 1986). The axes in the ordination diagram, typically two or three, represent continua of variation in data composition that are usually interpreted in terms of environmental gradients (Gauch 1982, Pielou 1984, ter Braak and Prentice 1988).

The ordination diagram gives the ecologist the benefit of a visual assessment of community data, facilitating a more intuitive comprehension (Gauch 1982). The value in ordinating data is not limited to this visual aspect, however. The algorithm that determines the ordination diagram coordinates for the samples also produces a quantitative gauge of the importance of an axis -- the eigenvalue.

In practical terms, an axis' eigenvalue can be thought of as expressing the amount of variation in the original data matrix that is explained or accounted for by that axis (Gauch 1982, Kremen 1992). The higher the eigenvalue for an axis, the more variation explained. The eigenvalue also is a measure of the relative importance of an ecological gradient (Palmer 1995).

Some ordination programs, such as CANOCO, also calculate a set of ordination diagnostic statistics that report the influence of individual species, samples and environmental variables on the ordination results (ter Braak 1987, Palmer 1995).

There are many variations on the basic ordination diagram of samples (or species) positioned in a two or three dimensioned coordinate frame. For example, a display of



both species and samples within the same coordinate frame is possible with the weighted averages ordination technique. The weighted averages family of ordinations (Correspondence Analysis, Detrended Correspondence Analysis, and Canonical Correspondence Analysis) is used for data sets in which species responses to environmental gradients do not conform to a linear model (Gauch 1982, ter Braak and Prentice 1988). This technique produces both samples and species scores, which plotted together within an ordination diagram produce a joint plot, also used as an interpretive aid. This joint display of species and samples has the effect of visually summarizing dominant patterns in community composition as expressed by both the species and the samples (ter Braak 1986). In addition, within the joint plot, a sample is positioned at the center of gravity of the species found within it (ter Braak and Prentice 1988). Thus, inspection of the ordination diagram allows the prediction of the likely species composition within a given sample or cluster of samples (ter Braak 1986, ter Braak and Prentice 1988).

Further, weighted average techniques order species and samples along an axis so that there is a maximum possible correlation between species scores and sample scores. The eigenvalue reported for each axis is equal to the correlation coefficient between the two sets of scores (Gauch 1982, Pielou 1984, Palmer 1993, Jongman *et al.* 1995).

As with any technology, some of the limitations of early ordination programs have been remedied over time, opening up avenues of data testing initially deemed impossible. The constrained (or canonical) ordination is a recent modification of earlier techniques, which unites in one algorithm a repetitive sequence of weighted averages ordination and multivariate regressions (ter Braak 1986, ter Braak and Prentice 1988, Palmer 1993).

Like other ordination techniques, a constrained ordination reduces the dimensionality within the data, but it differs in that it constrains the axes to be linear combinations of measured environmental variables (ter Braak and Prentice 1988). The result is an ordination diagram with species and samples positioned within an ordination space that has been forced to reflect the effects of environmental variables of interest. As with earlier versions of ordination techniques, the eigenvalues report the amount of variation within the data accounted for or explained by the forced or constrained axes.

Further, because environmental variables are included in its calculation, a constrained weighted averages ordination is able to position environmental variables (depicted as arrows representing low to high levels of a variable) within the species/sample joint plot, creating a triplot. The species points and the environmental variable arrows jointly reflect species' distributions along gradients of the respective environmental variables (ter Braak 1986). Thus, a triplot provides an even more effective (although approximate) visualization of community patterns because it displays the relations between species, sites, and environmental variables. It is also possible to construct a joint plot of species and environmental variables, or samples and environmental variables.

The development of constrained ordination has been greeted with enthusiasm by some ecologists, for the technique remedies some of the criticisms of earlier ordination methods. In particular, it is now possible to apply statistical tests to constrained ordination eigenvalues, testing the hypothesis that species abundances are governed by the measured environmental variables (ter Braak and Prentice 1988). The test used in the CANOCO software package is the Monte Carlo permutation (ter Braak 1987). The

Monte Carlo is a type of randomization test that treats the original data matrix as if it were a population, randomly re-sampling from it numerous times to test how frequently a result is arrived at through chance (Palmer 1995).

The other major benefit of constrained ordination for ecological data analysis is that the addition of environmental variables has the effect of producing more robust ordinations. For example, using highly skewed simulated data, Palmer (1993) demonstrated that Canonical Correspondence Analysis was able to extract ordination results faithful to the original data structure, in spite of a violation of the assumption of unimodal distributions for species.

### **Classification and Ordination in Grassland Research**

Classification and ordination analysis techniques have been applied to a range of grassland ecological inquiries. Following his seminal use of simple linear (one dimensional) ordination on stands of Wisconsin forests (Curtis and McIntosh 1951, cited in Ludwig and Reynolds 1988), John Curtis and the Wisconsin Plant Ecology Laboratory (PEL) produced a series of ordination studies on central North American prairies. Curtis and his colleagues concluded that soil moisture was the primary gradient influencing variation in these prairie communities. Curtis also developed the often-cited classification scheme of Wisconsin prairies based on moisture-related groups of species (Kindscher and Wells 1995).

Recent reanalysis of the original Wisconsin PEL data (Umbanhower 1992), using

the more sophisticated ordination technique Detrended Correspondence Analysis (Hill 1979), indicated that a substantial portion of variation in Curtis' prairie communities was left unexplained by a simple soil moisture gradient. Umbanhower's ordination study suggested instead that a complex of soil nutrients and latitudinal variation were additional significant correlates of compositional variation within North American prairies.

Owing to the wide ecological amplitude of several dominant native grasses and forbs species on an Iowa prairie, Brotherson's (1983) ordination of 37 upland prairie sites was unable to distinguish discrete subcommunities within the prairie. Nonetheless, observation of outlying species in ordination space was deemed informative for identifying species exhibiting peculiar distribution patterns. Brotherson found these outlying species useful as indicator species. Using an hierarchical agglomerative (clustering) classification technique, McNaughton (1983) identified seventeen community types in his extensive study of species composition, diversity, and spatial heterogeneity and pattern of the Serengeti grasslands in Tanzania and Kenya.

The objective classification of grassland species into groups has not been limited to multivariate analysis of species abundances in sample stands. Using ecological and morphological traits of 158 prairie species, Kindscher and Wells (1995) detected eight statistically different groups or guilds of prairie species using ordination, classification and discriminant function analyses.

Blewett's comprehensive ordination study and Cottam's classification and mapping of data from two prairie restoration projects (Blewett 1981 and Cottam and Wilson 1966, cited by Cottam 1987) elucidated community dynamics on artificial prairies. Although not

originally conceived as scientific experiments, beginning in 1951 sampling quadrats were laid out on a grid across two restored prairies every five years (another of John Curtis' ecological investigations). These data permitted the mapping of community types (based on indicator species derived from Curtis' ordination of Wisconsin prairies) over a 25-year period for the two restored prairies (Cottam 1987). In Blewett's study, changes in individual species abundances over the 25-year period were illustrated through a time series ordination that tracked species' behavior along moisture and disturbance gradients. Both studies underscored the dynamic nature of vegetation composition over time in restored prairies in response to short-term variation in climate as well as increased the understanding of the autecology of "increaser" and "decreaser" prairie species.

Several researchers have used ordination and classification analysis to investigate the effect of different management regimes on North American prairies and other grasslands. Ongoing, long-term collection of data at the Konza Prairie in northeast Kansas permitted the ordination of data from several management units and the identification of time since burning as a principal gradient of variation in prairie vegetation (Gibson and Hulbert 1987). However, Gibson's (1988) later ordination of data from four watersheds at the Konza Prairie induced him to qualify earlier findings regarding compositional variation at the Konza. In his 1988 study, four management units separated in ordination space on a gradient of low to high heterogeneity presumably related to unknown historical management.

Bosch and Kellner (1991) ordinated plots that were deliberately chosen to reflect a degradation gradient caused by cattle grazing in a semi-arid grassland in southern Africa.

The position of individual species within the ordination diagram was used to classify species into decreaser and increaser categories. A prairie management study conducted by the Missouri Department of Conservation (Norman and Nigh 1993) used ordination and classification analyses to identify species that exhibited tolerance or intolerance to cattle grazing and other management regimes. This study also illustrated in ordination space divergences in species composition among the different management units after five years.

Most of these grassland studies used ordination and classification in concert with other more traditional methodologies, such as multiple regression analyses, indices of interspecific association, and computation of diversity indices.

## **CHAPTER III**

### **MATERIALS AND METHODS**

#### **Project Location**

The study site is an 80-acre (32.38 ha) reclaimed strip mine and coal processing facility located in southern Crawford county, Kansas, 3.5 miles (5.63 km) southwest of Pittsburg, Kansas (NE 1/4 of S17, T31S, R24E) (Figure 1). The site is located within the Osage Plains section of the Central Lowlands geographical province of North America, where bituminous coal veins have fueled underground and strip mining activities since the last quarter of the 19th century (Powell 1970, Marcher and Kenney 1984).

Southeast Kansas has a humid continental climate with a normal annual precipitation of 36 to 40 inches (91.4 to 101.6 cm) (Marcher and Kenny 1984). The elevation of the study site is ca. 930 feet (283.5 m) above sea level (U.S.G.S. 1964). Historically the area was part of the ecotone between the deciduous hardwood forests of eastern North America and tallgrass prairie (Anderson 1982). Contemporary land uses in the region include coal strip mines, cropland, rangeland or pasture, woodland, and small urban and industrial centers (Powell 1970, Marcher and Kenny 1984).

In 1984, approximately 17 acres (7 ha) of coal refuse from the abandoned processing plant were graded and capped with strip mine overburden or spoil and crushed limestone. The piles of refuse were shaped into a series of five terraces that

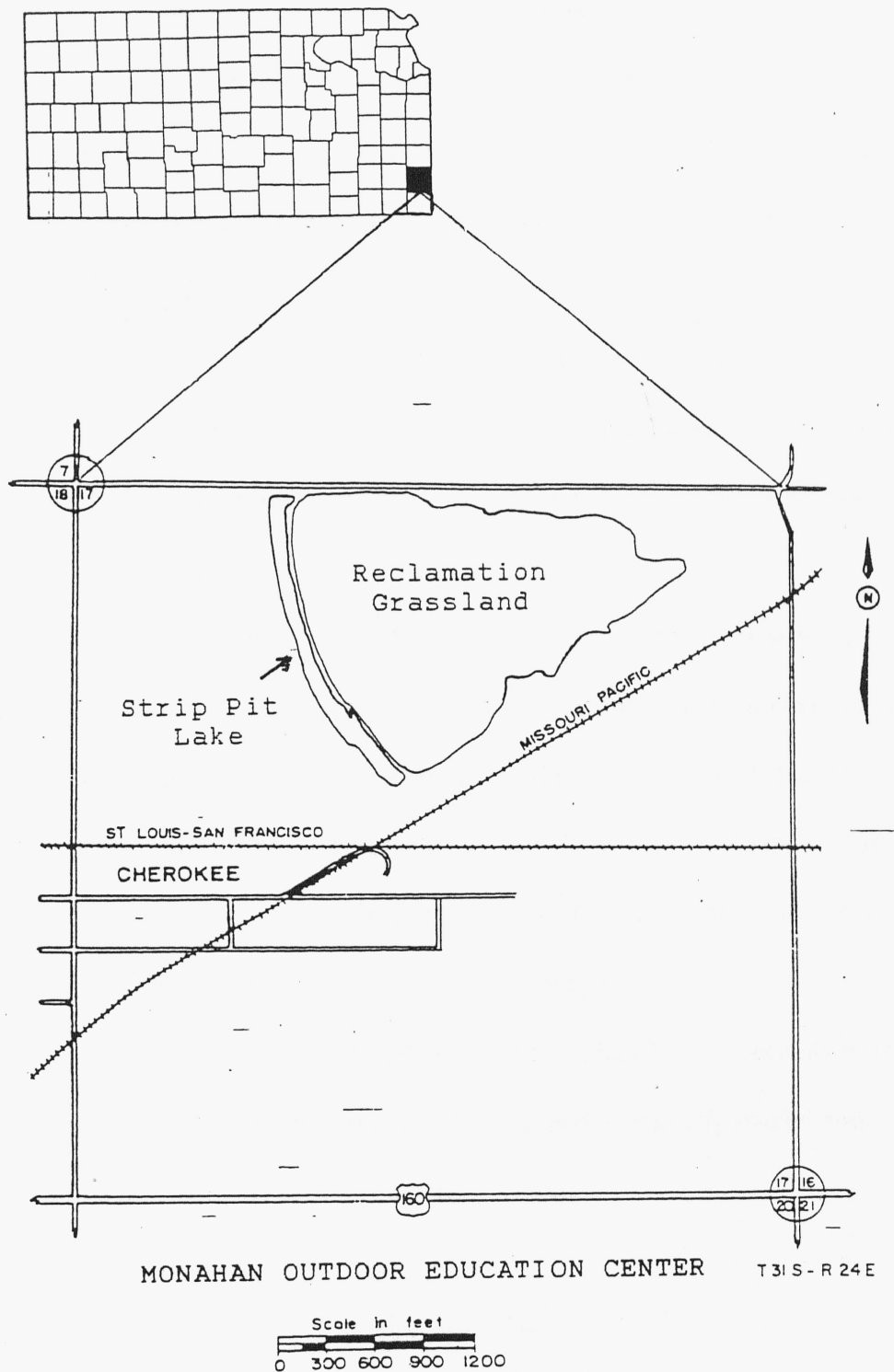


Figure 1. Location of study site. Adapted from William J. Reals abandoned mine land project -- site plan: U. S. Department of Agriculture Soil Conservation Service. 1981.



generally slope from south to north and west to east. The five terraces were designed to shunt surface water away from coal waste material under the spoil cap into a system of drain pipes leading off the site. Also, a system of strip pits west and south of the mound were filled with refuse, and capped with spoils, as was a 30 acre (12 ha) coal slurry pond at the east edge of the refuse pile.

Following the fall sowing of an oat cover crop, the entire site was drill seeded in the spring of 1985 with a mixture of seven native warm and cool season grass cultivars and three native forbs (Appendix 1). A variety of tree and shrub saplings were planted at the reclamation site as well (USDA 1981).

Powell (1970) presented a comprehensive physical, cultural, and historical geography of the region where the study site is located. Imhoff (1994) summarized the history of coal mining for the region and at this particular site, and provided details of the reclamation process at the Monahan grassland. Vickers (1989) compared the performance of the individual native grass cultivars for providing ground cover of the study area two and three years after the conclusion of reclamation activities.

In 1988, the reclamation site and other adjacent unmined and unreclaimed land was dedicated as the Monahan Outdoor Education Center, and is presently owned and managed by Pittsburg State University, Pittsburg, Kansas.

### **Data Collection**

In the late summer of 1994, a grid of 103 contiguous 50 x 50 meter plots was laid

out across the somewhat triangular-shaped reclamation site (Figure 2). A baseline was sited across the mound perpendicular to the gravel road north of the reclamation area, two points along the baseline being permanently staked. Grid center points were subsequently located using survey equipment. Center points for the 103 plots were staked and labeled. Each plot was assigned an alpha-numeric code corresponding to coordinates of rows running north to south (A - K) and rows running west to east (6W - 1W, Baseline, 1E - 5E). The center points served as the starting point for the random placement of five 2 m<sup>2</sup> sampling quadrats within each plot. The five sampling units, henceforth referred to as quadrats, were located by coupling pairs of values from two lists: the first was a list of 360 random compass headings; and the second was a randomized list of the number of meters from the plot center-point, ranging from 0 meters to 24 meters. The two lists were generated using a random number function in a spreadsheet (Trius Inc. 1992).

This sampling scheme is a systematic-random design, that is, the randomly-sited quadrats are located within plots that were determined systematically (evenly spaced) across the reclamation area. Systematic-random sampling has been shown to improve sampling precision and allows the results of classification or ordination analyses to be plotted and examined for spatial pattern (Green 1979, Greig-Smith 1983).

During field assessment before sampling, it was determined that stepping-off meters was an adequate substitute for tape measurement in locating quadrat position. The upper right-hand corner of the quadrat frame was placed at this point. Sampling was restricted to the reclamation grassland -- to diminish an edge effect in the data, plots

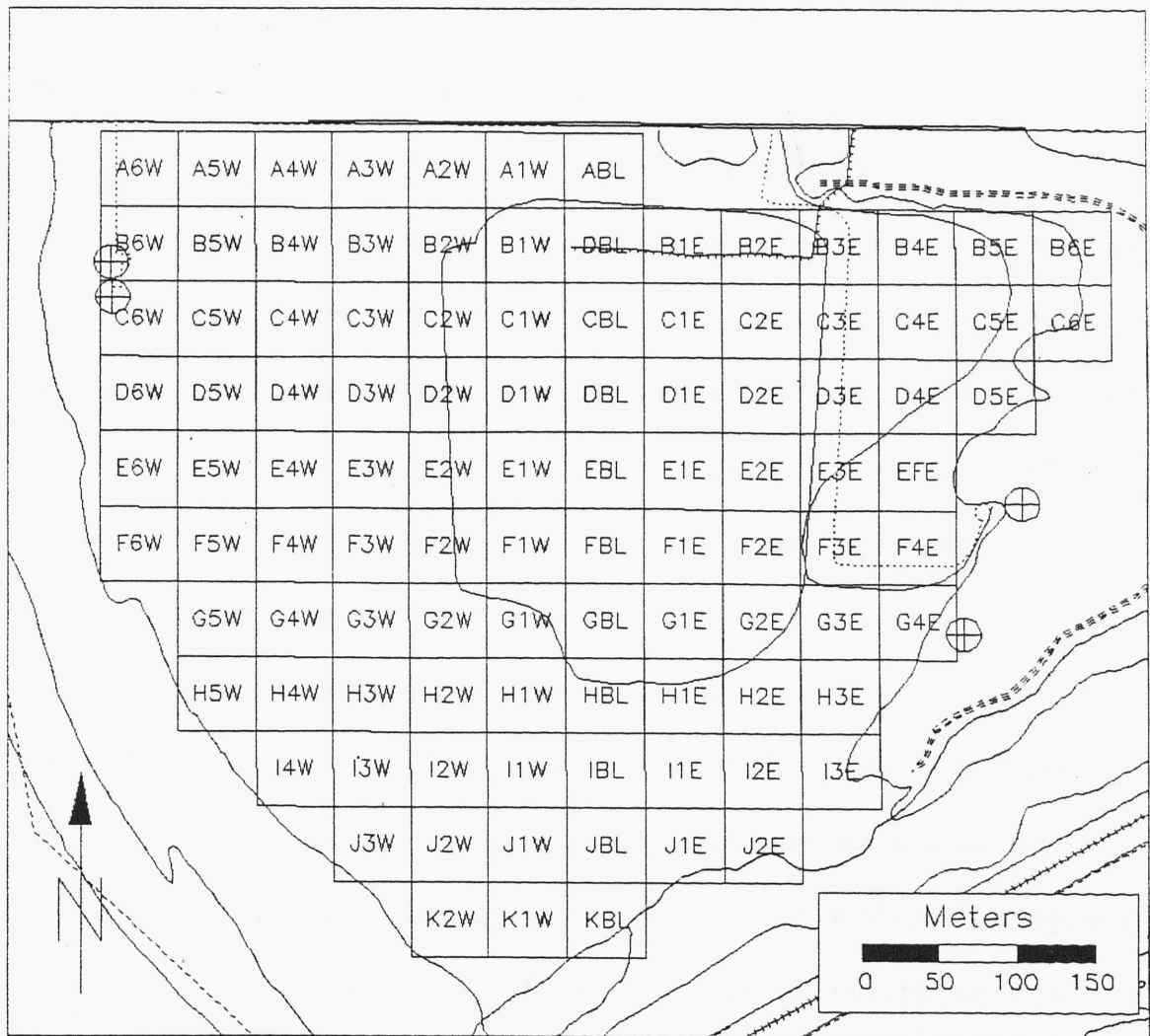


Figure 2. Location of sampling plots by alpha-numeric code.

within five meters of the woodland adjacent to the reclamation area were discarded.

The quadrat size was a 1 X 2 meter rectangle, conforming to Curtis and McIntosh's (1950, cited in Bonham 1989) guideline that the sampling unit be one to two times the size of the mean area per individual of the most common species. This was determined to be *Panicum virgatum*: clumps observed prior to sampling measured from 1/2 meter square to well over one square meter.

Within each of the quadrats, cover for all vascular plant species was visually estimated and assigned to one of the seven ordinal classes of the modified Daubenmeyer cover scale (Bailey and Poulton 1968) (Table 1). Cover was defined as canopy cover, or the percentage of the ground within the quadrat occupied by the perpendicular projection of the aerial parts of a particular species (Greig-Smith 1983). The quadrat frame was constructed of 1/2" PVC pipe, and marked at quarter and eighth intervals to promote consistent cover estimates.

Voucher specimens of all grasses, forbs, and woody plants were collected and identified and are deposited in the Theodore Sperry Herbarium at Pittsburg State University. Two taxa within the Cyperaceae family, lacking flowering or fruiting structures during the sampling period, were identified to genus level based on vegetative characteristics. Two species of *Dichanthelium* were combined into one taxa at the genus level due to misidentification in the field. Two species of *Melilotis* were also combined into one taxa in a similar manner. Nomenclature follows Flora of the Great Plains (Great Plains Flora Association 1986).

Table 1. Daubenmeyer canopy cover class scale.

Cover Class	Range of Cover (percent)	Class Midpoints (percent)
1	0-1	0.5
2	1-5	3.0
3	5-25	15.0
4	25-50	37.5
5	50-75	62.5
6	75-95	85.0
7	95-100	97.5

Source: Bonham, C. D. 1989. Measurements for Terrestrial Vegetation. John Wiley and Sons, New York.

Two environmental parameters were assessed within each quadrat at the time of sampling. Prior to sampling, an effort was made to identify environmental factors that might influence species composition within the reclamation site. Two factors were chosen: (1) regularity of standing water, and; (2) amount of mine refuse present at the ground surface.

The role of soil moisture as one of the key factors determining grassland community composition has been investigated through both direct (regression) and indirect gradient analyses (ordination) (McNaughton 1983, Gibson and Hulbert 1987, Umbanhower 1992). It was anticipated a similar effect might be observed within the reclamation area. The assignment of a particular level for Variable 1, regularity of standing water, for a given quadrat was based on a visual assessment of a complex of factors: the estimation of slope and aspect within the quadrat in relation to the surrounding area, the actual presence of water in relation to recency of precipitation, and physical evidence of regularly standing water, such as rotting vegetation, the presence of peat-like organic matter at the soil surface, or the presence of terrestrial algae.

Variable #2, the amount of mine refuse present at the soil surface, was chosen when preliminary examination of the reclamation grassland revealed patches of ground depauperate of vegetation coinciding with visible remnants of mining debris. The assignment of the amount of mine refuse at the soil surface variable was made by visually assessing the ground surface within the quadrat for the presence of shales, pyritic materials, coal fines or chunks, iron hydroxide crusts, or crystallized mineral salts.

An ordinal scale was constructed of three classes for each of the two variables

(Table 2). In order to avoid a circular argument in subsequent data analyses, in which vegetation would be a component of both the dependent and independent variables, the assessment of environmental variables was not linked to the presence or absence of any plant species that might be indicative of one or the other environmental conditions.

Sampling took place from September 28 to November 12, 1994, the time of year when the dominant plant species, the warm season grasses, had reached their maximum growth and were identifiable by flower or fruit.

### **Data Analysis**

One purpose of data analysis was to identify compositionally similar groupings of plots, which when mapped, would provide a baseline of spatial data for the Monahan grassland 9 years after the reclamation project was concluded. It was anticipated that a mapped classification would likely elucidate ecological processes occurring within the reclaimed grassland that could influence management decisions, monitoring, and interpretive purposes. Two multivariate analysis approaches were chosen toward this end: TWINSpan, a hierarchical, divisive, polythetic classification method that uses a data matrix of species within samples to derive classifications of species and sites; and Canonical Correspondence Analysis (CCA), which positions species, sites, and environmental variables in relation to axes that can be interpreted as explaining some level of variation within the data.

Table 2. Environmental variable scales.

Variable	Rank	Level of Variable within the Quadrat
1. Regularity of Standing Water		
	1	0-33% of the time
	2	34-66% of the time
	3	67-100% of the time
2. Level of Mine Refuse at Soil Surface		
	1	0-33% cover
	2	34-66% cover
	3	67-100% cover



The original matrix of cover class ranks for the 58 species in the 515 quadrats was reduced to a matrix of 58 species in 103 plots by converting the cover class rank for each species to the class midpoint (Table 1), and then averaging the percent cover per species for the five quadrats within each of the 103 plots to arrive at percent mean cover per species per plot. All further calculations were made on this 58 species by 103 plots percent cover matrix (Appendix 2).

The matrix of two environmental variables within the 515 quadrats was likewise reduced to a matrix of two variables within 103 plots by calculating the mean of the ordinal class values for the five quadrats for each plot. The two environmental variables were subsequently logarithmically transformed in line with Palmer's (1993) suggestion for transformations of resource gradients used in Canonical Correspondence Analysis.

### **Step One: General Descriptive Data Analyses**

Four diversity indices were calculated for the 103 plots in order to summarize species abundance relations. Hill's index for species richness,

$$N0 = S$$

where  $S$  is the total number of species, was chosen for its quality of being clearly interpretable (Ludwig and Reynolds 1988). Hill's two indices for species diversity,

$$N1 = e^{H'}$$

where  $H'$  is Shannon's index, and

$$N2 = 1/\lambda$$

where  $\lambda$  is Simpson's index, were chosen because they express Shannon's and

Simpson's well known indices in units that are numbers of species, N1 in units of "abundant" species and N2 in units of "very abundant" species (Ludwig and Reynolds 1988).

Alatalo's modification of Hill's evenness ratio,

$$E = (N2 - 1) / (N1 - 1)$$

was chosen for its ease in interpretation: the ratio approaches zero as a single species becomes increasingly dominant (Ludwig and Reynolds 1988). Computations for the two diversity indices and the evenness ratio were made using the SPDIVERS program on the diskette that accompanied Statistical Ecology: A Primer on Methods and Computing (Ludwig and Reynolds 1988).

A table of mean canopy cover, percent frequency, relative canopy cover and relative frequency for each species was constructed to generally characterize the overall structure of the entire data set.

In order to determine whether species' responses to environmental or spatial factors might elucidate patterns in the data, three artificial classifications (not derived from multivariate analysis) of plots were created. The first artificial classification was derived by separating plots into four groups based on the regularity of standing water, and the second artificial classification was similarly derived by creating three groups based on the level of mine refuse at the soil surface. A third classification was created based on plot location in the reclamation grassland: edge plots, interior plots, and mound plots. Differences in mean cover per species between the groups in the three artificial classifications were tested with one-way ANOVA and the least significant difference

(LSD) technique of multiple comparison of means using the GLM procedure with SAS (SAS Institute 1988) (Appendices 3, 4, and 5).

It is important to caution that such an *a posteriori* creation of any classification system violates the requirement of random allotment of treatments (the groups) to the sampling units, and cannot be considered a valid inferential statistical analysis (Jongman *et al.* 1995). The above analyses were made to help identify important ecological differences in species abundances linked to environmental or spatial factors, not to establish causal relationships.

## **Step Two: Classification by TWINSpan**

Using a data matrix of species occurrences in samples, TWINSpan (Hill 1979) creates a classification of both the species and samples. The algorithm iteratively ordines, dichotomizes, and re-ordinates progressively smaller groups of samples via Correspondence Analysis (CA) ordinations. The dichotomizations of groups are successively refined through the identification of differential species, that is, species that appear to have an ecological preference for one side or the other of the ordination axis. TWINSpan identifies differential species that are real species, but also uses pseudo-species, the latter being artificial species created by a partitioning of the abundances of real species into the presence/absence of one or more pseudo-species (Hill 1975, Jongman *et al.* 1995). The effect of the creation of pseudo-species helps insure that species presences that may be a result of random "noise" do not unduly affect the classification (Pielou 1984).

TWINSPAN orders the species and samples into an arranged matrix exhibiting the relations between the species and samples. This is an important tool in the subsequent interpretation of the classification (Hill 1979). TWINSPAN does not produce species and sample scores that reflect their positions along ordination axes.

The 58 species by 103 plots matrix was submitted to TWINSPAN's standard analysis in which all parameters were set to default (Table 3). Hill (1979) reported that TWINSPAN's default pseudospecies cut levels had proved effective with percentage data, and cautioned that the creation of many cut levels at higher abundance values may overweight the effect of dominance. The pseudo-species cut levels for the standard analysis, dubbed DEFAULT, are 0, 2, 5, 10 and 20 percent.

A second variant TWINSPAN analysis added two higher pseudo-species class levels to the default settings (Table 3). A check of a number of selected prairie grassland studies revealed that mean cover and frequency values for *Panicum virgatum*, *Bouteloua curtipendula*, and *Solidago canadensis* were distinctly higher in the Monahan Grassland than in historic native tallgrass prairies (Abrams and Hulbert 1987, Norman and Nigh 1993, Kindscher and Wells 1995) (Table 4). It was expected that additional higher pseudo-species classes could more closely reflect the true range of cover values at the Monahan grassland and the ecological impact of three species with cover values over 40%: *Panicum virgatum* (from 3.7 to 76%), *Bouteloua curtipendula* (from 0.1 to 52.5%) and *Solidago canadensis* (from 0.1 to 44.5%). For the variant analysis, dubbed TWN7LVLS, the seven pseudo-species cut levels were at 0, 2, 5, 10, 20, 40, and 60 percent.

Table 3. A Summary of the parameters for the default and variant TWINSpan.

TWINSpan Option	Pseudospecies Cut Levels (% cover)	Ordinal Ranking	Effect on Classification
DEFAULT	0 to < 2	1	Hill reports this scale reflects typical values of abundance, and cautions that many relatively high cut levels may over-weight the effect of dominance.
	2 to < 5	2	
	5 to < 10	3	
	10 to < 20	4	
	> 20	5	
VARIANT	0 to < 2	1	The creation of additional higher cut levels was an attempt to reflect actual abundance values, and allow the detection of the competitive effects of dominant species at very high cover and frequency values.
	2 to < 5	2	
	5 to < 10	3	
	10 to < 20	4	
	20 to < 40	5	
	40 to < 60	6	
	> 60	7	

Source: Hill, M. O. 1979. TWINSpan -- A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Department of Ecology and Systematics, Cornell University, Ithaca, N. Y.

Table 4. Comparison of percent cover values for six selected species from three studies of North American tallgrass prairies.

Species	Kindscher and Wells 1995 <sub>1</sub>	Norman and Nigh 1993 <sub>2</sub>	Abrams and Hulbert 1987 <sub>3</sub>
<i>Andropogon gerardii</i>	20.76	16.70	83.50
<i>Andropogon scoparius</i>	20.34	6.50	43.30
<i>Bouteloua curtipendula</i>	0.00	0.00	0.00
<i>Panicum virgatum</i>	0.82	1.10	12.50
<i>Solidago canadensis</i>	0.23	0.00	0.00
<i>Sorghastrum nutans</i>	2.48	5.60	21.50

1. Percent cover values based on 50 m<sup>2</sup> plots on each of three upland prairie sites in northeastern Kansas, June, 1989. Source: Kindscher, K. and P. V. Wells. 1995. Prairie plant guilds: A multivariate analysis of prairie species based on ecological and morphological traits. *Vegetatio* 117: 29-50.

2. Percent cover values based on 90 - 50 x 100 cm quadrats on a triennially hayed upland prairie in southwest Missouri in the fall of 1989. Source: Norman, F. and T. A. Nigh. 1993. Changes in the composition of a Missouri tallgrass prairie in relation to eight management treatments. Natural History Division, Missouri Department of Conservation. Jefferson City, Missouri.

3. Percent cover values based on 20 - 10 m<sub>2</sub> plots on lowland soils at the Konza Prairie Research Natural Area in northeast Kansas, 1984. Source: Abrams, M. D. and L. C. Hulbert. 1987. Effects of topographic position and fire on species composition in tallgrass prairie in northeast Kansas. *The American Midland Naturalist* 117: 442-445.

The results of the two TWINSpan analyses were compared using the eigenvalue reported in the initial ordinations, examination of the arranged matrices, and plotting the resulting groups on maps of the study site. In addition, differences between the means of the four diversity indices among the groups delineated by the two TWINSpan analyses were tested with one-way ANOVA using the least significant difference (LSD) technique of multiple comparison of means using the GLM procedure with SAS (SAS Institute 1988).

### **Step Three: Ordination by CCA**

The 58 species in 103 plots matrix was analyzed with the CANOCO program, version 3.10 (ter Braak 1990). Before an array of default and variant ordinations could be tried, it was necessary to determine whether the data were suited to a linear or unimodal analysis (ter Braak 1987). Ter Braak (1987) and Gauch (1982) suggest a trial analysis with Detrended Correspondence Analysis (Hill 1979) with detrending-by-segments to determine the relative length of the primary gradients expressed in the species composition. If the gradient is short (less than 1.5 Standard Deviation Units) the data is essentially linear in response and a linear ordination method (such as Principle Components Analysis or Redundancy Analysis) should be used rather than a unimodal method (weighted averages) (ter Braak 1987, ter Braak and Prentice 1988). The length of gradient for the first two axes reported in the initial DCA analysis was 2.348 and 2.175 standard deviation units, so Canonical Correspondence Analysis, (CCA) a unimodal method, was used in all subsequent ordinations of the data.

The literature on multivariate analysis is replete with a wide variety of often contradictory recommendations and admonitions over the editing, transformation, and weighting of data submitted to analysis (van der Maarel 1979, Gauch 1982, Pielou 1984, Palmer 1993, Palmer 1995, Jongman *et al.* 1995). Many of these techniques have been found to emphasize or de-emphasize a certain element or character of the data, or purportedly produce more readily interpretable results (van der Maarel 1979, Gauch 1982).

A suite of three of these methods was chosen for application to the percent cover vegetation matrix in order to compare the results with those obtained through the default parameters of the program (Table 5). In one variant ordination, planted and seeded species were made passive in order to determine whether colonizing species' abundances would reveal ecological patterns obscured by the planted species. When species are made passive in an ordination, their abundances do not contribute to axes extraction (ter Braak 1987). In the second variant ordination, infrequent species were down-weighted by a factor relative to the commonest species. Down-weighting of rare species is a popular data transformation option purported to reduce noise that could make interpretation more difficult (Gauch 1982). Finally, the third variant ordination compressed the original percent cover data into a scale of one to eight, markedly reducing the magnitude between low and high values, thereby reducing the effect of dominant species on ordination results (van der Maarel 1979, Gauch 1982, Palmer 1995).

Following data analysis, the default ordination diagram was examined for the presence of clusters or patterns of plots in ordination space. The ordination diagram was



Table 5. Summary of default and variant ordination options chosen for analysis of Monahan grassland data.

CCA Option	Effect on Ordination
<u>CCA-DEFAULT</u>	
No transformation of percent cover values. All species weighted the same; all influence axes extraction.	"Baseline" ordination Palmer (1995) reports raw data values work well in a constrained ordination.
<u>CCA-PASSIVE</u>	
Planted and seeded species are made passive and have no influence on axes extraction (ter Braak 1987).	Kindscher (pers. com. 1995) suggested an ecological group, in this case the colonizers, may hold patterns obscured by the planted and seeded species.
<u>CCA-DOWN</u>	
Rare species are down-weighted by a factor relative to the commonest species (ter Braak 1987).	A common ordination that is purported to reduce the effect of "noise" generated by minor species. (Gauch 1982)
<u>CCA-OCTAVE</u>	
Data are compressed into a scale with a smaller magnitude of difference between low and high values.	Similar to logarithmic or square root transformation: Van der Maarel (1979), Gauch (1982), and Palmer (1995) report these dampen the effect of dominant species on ordination results.

Sources:

Gauch, H. G., Jr. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press, Cambridge. 298 p.

Kindscher, K. 1995. Personal Communication, October 1995. University of Kansas, Lawrence, KS.

Palmer, M. S. 1995. (EMAIL: carex@osuunix.ucc.okstate.edu) Ordination Gopher. [gopher://bubba.ucc.okstate.edu:70/11/academic\_services/botany/ordinate].

ter Braak, C. J. F. 1987. CANOCO - a FORTRAN program for community ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis, and redundancy analysis, version 2.1. ITI-TNO, Wageningen, The Netherlands. (Microcomputer Power, Ithaca, New York.)

van der Maarel, E. 1979. Transformation of cover-abundance values in phytosociology and its effects on community similarity. Vegetatio 39: 97-114.

subsequently partitioned into a classification system consisting of three groups of plots. The classification derived from the default CCA analysis was mapped so that the groups' spatial relationships could be assessed. As with the TWINSpan-generated classification, differences between the means of the four diversity indices among the groups created by the default CCA analysis were tested with one-way ANOVA using the least significant difference (LSD) technique of multiple comparison of means using the GLM procedure with SAS (SAS Institute 1988).

The default and three variant ordinations were compared using the ordination summary statistics supplied by CANOCO. Ordination diagrams of the default and variant analyses were produced with CANODRAW LITE (Smilauer 1992) visually inspected and compared.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### General Descriptive Analysis

58 species were encountered within the 103 plots, with species richness in the plots ranging from a low of 5 to a high of 18 species (Appendix 6). N1 diversity (abundant species) per plot ranged from 1.26 to 8.69; N2 diversity (very abundant species) per plot ranged from 1.08 to 6.86. Evenness values per plot ranged from 0.33 to 0.91.

Mean percent cover, relative cover, frequency, and relative frequency were calculated for the 58 species (Appendix 7). Average cover values ranged from a high of 30% for *Panicum virgatum* to a low of less than 1% for several species, each of which occurred at 0.1% cover in one plot only. Relative cover values ranged from 40% for *P. virgatum* to less than 1% for several species. Percentage frequency values ranged from 100% for *P. virgatum* to less than 1% for several species; whereas relative frequency values ranged from 9% for *P. virgatum* to less than 1% for several species. Overall, *P. virgatum*, or Switch Grass, was the dominant species at the reclamation site.

The 35 species that were encountered in at least 5% of the plots were ranked by percent frequency and relative frequency (Table 6). The general character of the grassland at the Monahan Outdoor Education Center has not changed markedly since

Table 6. Percent frequency and relative frequency of taxa present in at least 5% of 103 plots.

SPECIES	PERCENT FREQUENCY	RELATIVE FREQUENCY
<i>Panicum virgatum</i>	100	9.3
<i>Solidago canadensis</i>	97	9.0
<i>Andropogon gerardii</i>	95	8.9
<i>Bouteloua curtipendula</i>	90	8.4
<i>Erigeron strigosus</i>	83	7.7
<i>Andropogon scoparius</i>	76	7.1
<i>Sorghastrum nutans</i>	74	6.9
<i>Agropyron smithii</i>	69	6.4
<i>Helianthus maximiliani</i>	32	3.0
<i>Aster pilosus</i>	27	2.5
<i>Poa pratensis</i>	26	2.4
<i>Acalypha virginica</i>	21	2.0
<i>Sporobolus aspera</i>	21	2.0
<i>Sphenopholis obtusa</i>	21	2.0
<i>Dalea purpurea</i>	18	1.7
<i>Geum vernum</i>	18	1.7
<i>Gaura biennis</i>	14	1.3
<i>Carex</i> sp. #1	14	1.3
<i>Dicanthelium</i> sps.	12	1.1
<i>Melilotus</i> sps.	12	1.1
<i>Desmanthus illinoensis</i>	11	1.0
<i>Festuca pratensis</i>	10	0.9
<i>Pycnanthemum tenuifolium</i>	9	0.8
<i>Panicum capillare</i>	9	0.8
<i>Oxalis dillenii</i>	9	0.8
<i>Buchloe dactyloides</i>	8	0.7
<i>Ratibida pinnata</i>	8	0.7
<i>Cornus drummondi</i>	8	0.7
<i>Physalis longifolia</i>	8	0.7
<i>Eupatorium rugosum</i>	8	0.7
<i>Euthamia gymnospermoides</i>	7	0.6
<i>Tripsacum dactyloides</i>	6	0.5
<i>Achillea millefolium</i>	5	0.5
<i>Populus deltoides</i>	5	0.5
<i>Conyza canadensis</i>	5	0.5

Vickers' (1989) analysis of the site two and three years following reclamation activities: the area then and in the present study was dominated by the planted grass species and several weedy or colonizing grass, forb, and woody species. However, species richness increased from Vickers' 28 species to 58 in 1993; frequencies of the planted grass and forb species also increased. Mean percent cover, relative cover, frequency, relative frequency, and range of cover values were compiled for the grass, forb, and woody species that were planted as part of the reclamation work (Table 7).

The initial check on gradient length or level of species turnover on DCA's first two unconstrained axes reported 2.348 and 2.175 Standard Deviation Units on a scale of four units in which a score of 4.00 would equal a complete turnover in species composition from one end of the axis to the other (ter Braak and Prentice 1988). These relatively low SDU's indicate that many species are present along the entire lengths of the first two DCA axes, and this is numerical evidence the study area is largely a homogeneous community. The Monahan grassland does not appear to contain "natural" sub-communities with discrete boundaries clearly discernable through ordination or classification. Therefore, an evaluation of the different analysis techniques used in this study is limited to gauging the efficacy of the resulting classification groups (i.e. "artificial" sub-communities) for identifying important ecological processes at the study site, and not for detecting real, historic sub-communities with distinct ecological boundaries. The primary use of such a classification and would be as a assessment tool in the management, monitoring, and interpretation of the ecology of the Monahan grassland. Utility is gauged in regard to these uses only.

Table 7. Mean percent cover, frequency, and range of percent cover values for species seeded and planted during reclamation project.

SPECIES SEEDED AND PLANTED WITH RECLAMATION	MEAN PERCENT COVER	FREQUENCY	RANGE OF % COVER VALUES
GRASS SPECIES			
<i>Agropyron smithii</i>	0.58	68.9	0.1 - 7.6
<i>Andropogon gerardii</i>	11.13	95.1	0.6 - 33.5
<i>Andropogon scoparius</i>	2.24	75.7	0.1 - 17.3
<i>Bouteloua curtipendula</i>	15.35	90.2	0.1 - 52.5
<i>Buchloe dactyloides</i>	0.15	7.7	0.1 - 7.5
<i>Panicum virgatum</i>	30.06	100.0	3.7 - 76.0
<i>Sorghastrum nutans</i>	2.23	73.7	0.1 - 19.2
FORB SPECIES			
<i>Dalea purpurea</i>	0.04	18.4	0.1 - 0.6
<i>Helianthus maximiliani</i>	0.22	32.0	0.1 - 3.7
<i>Ratibida pinnata</i>	0.07	7.8	0.1 - 3.6
WOODY SPECIES			
<i>Elaeagnus angustifolia</i>	0.03	1.0	3.0
<i>Rhus aromatica</i>	0.06	1.9	3.0

## Data Analysis by TWINSpan

The differences between the two TWINSpan analyses were created through the pseudo-species cut-level function (Table 3). The default analysis generated 138 combined species and pseudo-species from the original matrix of 58 species, whereas the variant analysis generated 142 combined species and pseudo-species. The four additional pseudo-species were created via species whose abundances occurred between 20 and 40 percent, between 40 and 60 percent, and between 60 and 100% cover: two additional *Panicum virgatum* pseudo-species, one additional *Bouteloua curtipendula* pseudo-species, and one additional *Solidago canadensis* pseudo-species. This change resulted in a slightly higher primary eigenvalue of 0.152 for the variant analysis compared with 0.135 for the default analysis. Thus, the addition of the four pseudo-species in the variant analysis resulted in slight increase in the correlation coefficient between the species scores and the sample scores for the first axis.

Inspection of the arranged two-way tables produced by the analyses (Appendices 8 and 9) revealed that the addition of four pseudo-species to the variant TWINSpan analysis did not substantially change the arrangement of plots, which seemed to generally reflect a slight moisture gradient. This was determined by observing trends in the cover values of four species: *Andropogon gerardii*, *B. curtipendula*, *P. virgatum*, and *Sorghastrum nutans*. Exploratory ANOVA analysis of the artificial classification of groups based on levels of regularity of standing water indicated that differences in cover values for these species may be associated with the regularity of standing water (Appendix

3). However, the relatively low eigenvalues for both TWINSpan analyses indicate that whatever the environmental gradient represented by the first axis, it may not be the primary environmental force influencing species composition.

In the following section, groups defined by the two TWINSpan analyses are designated by a code that is the binary record of the group's position in the classification hierarchy. The binary codes for the plots are listed at the bottoms of the two-way matrices of the two analyses (Appendices 8 and 9). Within a given analysis, it is possible to examine the codes of two groups to determine how closely related they are within the hierarchy. For example, the codes for group 110 and group 111 indicate that these groups are closely related at the first and second hierarchical level, but diverge at the third level. The codes for a group 100 and a group 000 diverge at the first hierarchical level, and are not closely related compositionally. An asterisk in the code indicates that TWINSpan discontinued dichotomization due to small group size. Typically, codes cannot be compared between the default and variant analyses. Within the text of this study, the binary codes for groups created by the default analysis are prefaced with the alphanumeric CLSD, while the binary codes for groups created by the variant analysis are prefaced with CLS7. A differential species is one that was detected by TWINSpan to have an ecological preference for one group over another.

### **TWINSpan Default Analysis**

The TWINSpan default analysis unites into the fifth pseudo-species class cover values from 20 to 100 percent, so it is not surprising four of its seven classification groups



are characterized by *Panicum virgatum* at 20% cover or more. Due to the ubiquitous nature of *P. virgatum* at the reclamation area, most of the plots (and therefore the TWINSpan generated groups) contain at least 10% cover of this species. The differences among the four groups in this complex are found in other species that coexist with *P. virgatum* (Appendix 8), their spatial location within the reclamation area (Figure 3), and in the suite of diversity measures calculated for each group (Table 8).

The first of these *P. virgatum* dominant groups, CLSD-100, (Figure 3) incorporates three spatially-linked arrangements of plots that generally coincide with the lowland drainage systems east and west of the mound. These plots are characterized by the dominance of *P. virgatum* and the presence of *Poa pratensis*, as well as low N1 species diversity compared with other groups in the *P. virgatum* dominant complex (Table 8). Three individual *P. virgatum*/*P. pratensis* plots occur on the mound, one at the low point of the eastern-most drainage terrace, and two others on the north-facing slope of the mound. Together, the linked and individual *P. virgatum*/*P. pratensis* plots make up 26% of the Monahan grassland.

The second *P. virgatum* group, CLSD-11\*, is composed of three plots and is generally characterized by the differential species *Sorghastrum nutans* at 5% cover. This group has the highest species richness of the *P. virgatum* dominant complex (Table 8). Several species not found in other groups occur in this group: *Andropogon virginicus*, *Aristida dichotoma*, *Croton capitatus*, three weedy colonizing species, and *Scirpus pendulus*, and *Spiranthes cernua*, two common tallgrass prairie species (Great Plains Flora Association 1986). These plots are linked spatially, occurring at the eastern edge

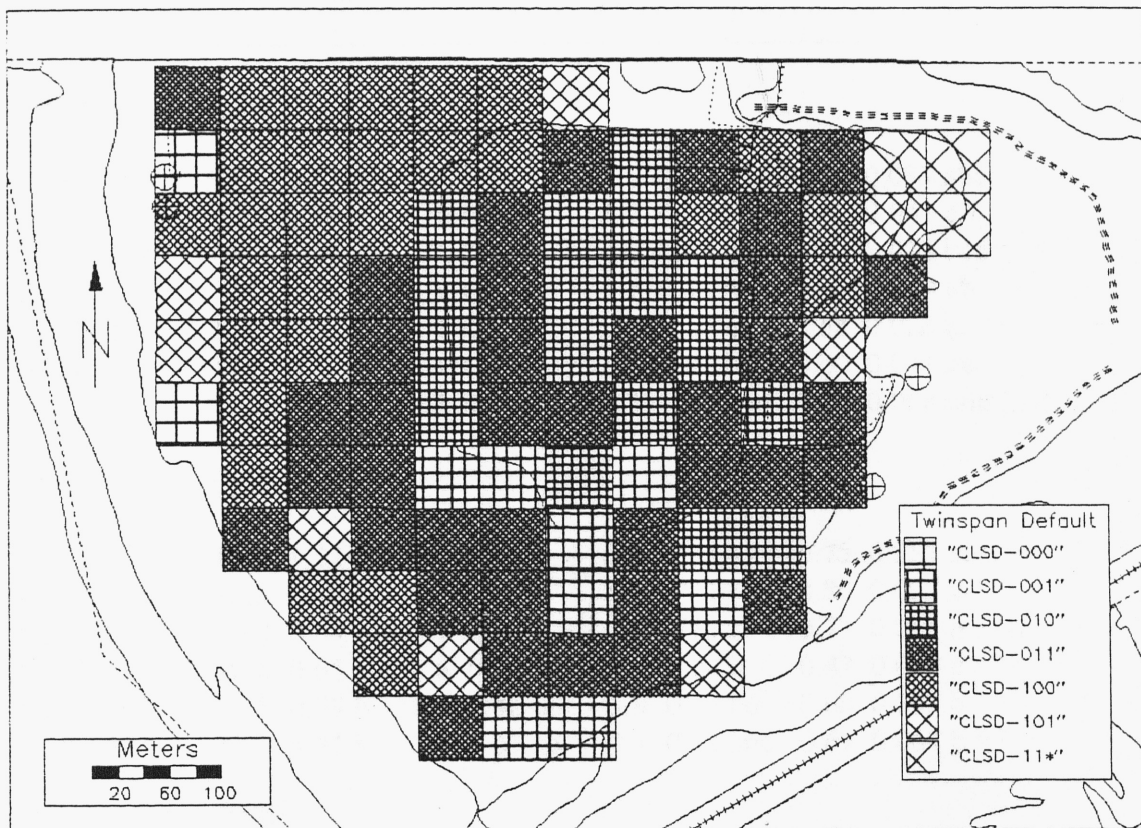


Figure 3. Groups created by default TWINSpan analysis.

Table 8. Exploratory ANOVA of differences between means of the groups created by TWINSPAN-DEFAULT, TWINSPAN-VARIANT and CCA-DEFAULT. Means with different letters are significantly different at  $p < 0.05$ . The non-random assignment of plots to groups (treatments) violates assumptions required for hypothesis testing; results should be interpreted with caution.

	RICHNESS		N1		N2		EVENNESS	
	MEAN	s.d.	MEAN	s.d.	MEAN	s.d.	MEAN	s.d.
<u>TWINSPAN DEFAULT</u>								
CLSD-000	14.5	1.56 ab	7.2	0.96 a	5.8	0.84 a	0.76	0.083 abc
CLSD-001	11.9	0.78 b	6.0	0.48 ab	5.3	0.42 a	0.85	0.041 a
CLSD-010	8.8	0.54 c	3.7	0.33 d	3.0	0.29 bc	0.72	0.028 bcd
CLSD-011	9.2	0.36 c	4.3	0.22 cd	3.6	0.19 b	0.78	0.019 ab
CLSD-100	12.2	0.42 b	3.9	0.26 d	2.9	0.23 c	0.58	0.023 e
CLSD-101	12.5	0.78 b	4.8	0.48 bc	3.5	0.42 bc	0.62	0.041 ce
CLSD-11*	17.0	1.27 a	5.7	0.78 abc	4.1	0.69 abc	0.61	0.068 cde
<u>TWINSPAN VARIANT</u>								
CLS7-00*	15.3	1.22 ab	7.0	0.58 a	5.6	0.53 a	0.75	0.055 ab
CLS7-010	10.3	0.49 c	5.3	0.23 b	4.4	0.21 b	0.80	0.022 a
CLS7-011	9.9	0.34 c	4.1	0.16 c	3.3	0.15 c	0.73	0.015 b
CLS7-100	10.6	0.65 c	2.6	0.31 d	1.9	0.28 d	0.47	0.029 c
CLS7-101	13.5	0.99 b	5.0	0.48 bc	3.8	0.43 bc	0.66	0.045 b
CLS7-11*	17.0	1.41 a	5.7	0.67 ab	4.1	0.61 abc	0.61	0.063 b
<u>CCA ORDINATION</u>								
IBMR	13.6	0.66 a	5.3	0.34 a	4.2	0.30 a	0.72	0.030 a
IBSW	10.4	0.58 b	3.1	0.30 b	2.3	0.26 b	0.53	0.026 b
LIBV	10.1	0.33 b	4.6	0.17 a	3.7	0.15 a	0.76	0.015 a

of the reclamation area in a low area where top soil has eroded to reveal coal fines (Figure 3) (Yates pers. obsv. 1994).

The third group in the default *P. virgatum* dominant complex, CLSD-101, also reflects a spatial component: all eight plots in this group are found within 100 meters of an edge of the reclamation area (Figure 3). In addition to dominant cover by *P. virgatum*, this group is characterized by two differential species: *Solidago canadensis* at 5% cover and the presence of *Populus deltoides*, both colonizing species. CLSD-101 has moderate species richness, diversity, and evenness (Table 8). Several infrequent species (those found in less than 5% of the 103 plots) occur in the plots that make up this group -- *Rhus copallina* and *Rubus flagellaris*, two woody shrubs, and *Lespedeza violacea*, a *Gaillardia* cultivar, and a *Carex* species. However, these species are not unique to this group, and were not used by TWINSpan as differential species.

In the fourth group of the *P. virgatum* complex, CLSD-011, the dominant Switch Grass coexists with *Bouteloua curtipendula* and *Andropogon gerardii* at cover values of 10% or more. This group of 38 plots is also characterized by low cover values of the differential species *S. canadensis*. This group has lower species richness and higher evenness compared with the three other *P. virgatum* dominant groups (Table 8).

The remaining three groups delineated by the TWINSpan default analysis are characterized by *B. curtipendula* and *A. gerardii* at cover values of 10% or more, but contain *P. virgatum* at lower cover values than in the previous four groups. Differences among the remaining three groups lie in the other species coexisting with *B. curtipendula* and *A. gerardii*, their spatial arrangement within the reclamation area, and differences in

diversity indices.

The first group in this *B. curtispindula/A. gerardii* dominant complex, CLSD-010, is related in some respects to the fourth group of the *P. virgatum* dominant complex. The two groups are spatially integrated upon the mound area (Figure 3). However, the 17 plots of CLSD-010 do not occur in the lowland of the reclamation area, as do some of the plots in CLSD-011. Cover of *P. virgatum* is generally less than 20% for the plots in this group. Indices of richness, diversity, and evenness for the two groups were comparable (Table 8). The presence of *S. canadensis* at very low cover values (0 to 2 percent) is a characteristic unique to this *B. curtispindula/A. gerardii* group, although it was not used by TWINSpan as a differential species.

The species composition of the second and third *B. curtispindula/A. gerardii* dominant groups, CLSD-001 and CLSD-000, are very similar to one another (Appendix 8). The two groups are not different in indices of species richness, diversity, and evenness (Table 8). The key distinction between the two groups is the presence of the differential weedy species *Cirsium altissimum* in CLSD-000. In addition, the two groups diverge spatially. The eight plots of CLSD-001 are restricted to the southern edge and south of the mound; whereas the two CLSD-000 plots are restricted to the western edge of the reclamation area (Figure 3). Plots within CLSD-001 contain four woody species, two of which were planted at the base of the mound during reclamation (*Elaeagnus angustifolia* and *Rhus aromatica*), and are unique to the group. The two plots that make up CLSD-000 include three non-differential woody species unique to that group. These woody colonizers are likely indicative of this latter group's proximity to an unreclaimed woodland

area west of the study site: *Toxicodendron radicans*, *Ulmus pumila*, and *Juniperus virginiana*.

### **TWINSPAN Variant Analysis**

The TWINSPAN variant analysis produced six classification groups compared with the seven groups created in the default analysis. The groups dichotomize into two complexes: three groups generally characterized by at least 5% cover of *Bouteloua curtipendula* and various levels of *Andropogon gerardii*, and three groups characterized by a minimum of 20% cover of *Panicum virgatum*. The same criteria for the default analysis were used to analyze differences between groups: species composition (Appendix 9), spatial location (Figure 4), and the suite of diversity indices calculated for each group (Table 8).

The majority of plots making up the first group within the *P. virgatum* dominant complex, CLS7-100, contain at least 60% cover values of *P. virgatum*. The 14 plots of this group lie within the lowland drainage system and at the low-point of the eastern-most terrace on the mound (Figure 4). This group is characterized by the lowest levels of species richness, diversity, and evenness in the *P. virgatum* complex (Table 8). Moreover, this group has the lowest N1 and N2 and evenness indices of the six groups created by the TWINSPAN variant analysis.

The second group of plots in the *P. virgatum* complex, CLS7-101, also lies in the lowland drainage areas west of the mound (Figure 4). *P. virgatum* cover levels within the six plots of this group range from 10 to 40 percent, coexisting with 10% cover of *A.*

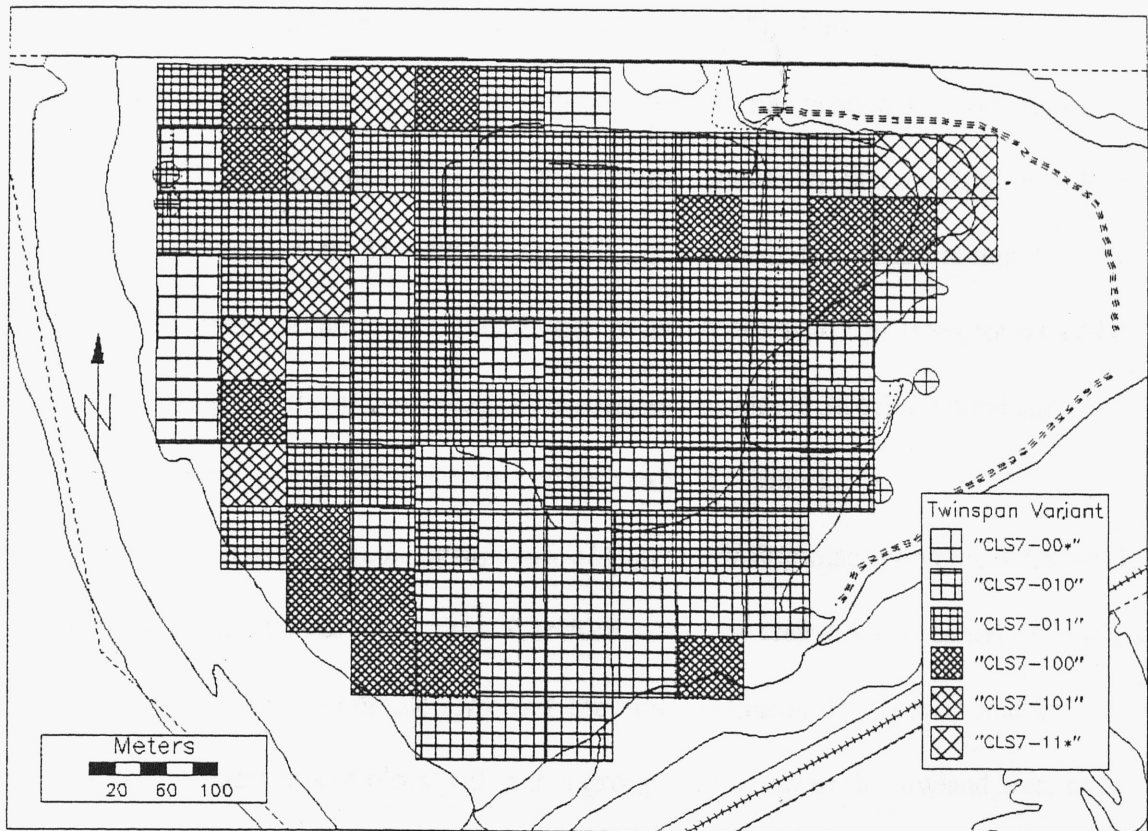


Figure 4. Classification of Monahan grassland produced by variant TWINSpan.

*gerardii*, and the presence of *B. curtipendula*, *Erigeron strigosus*, *P. pratensis*, and *Oxalis dillenii*, the latter three colonizing species. Species richness is at a moderate level within the *P. virgatum* dominant complex (Table 8).

The third group of plots within the *P. virgatum* dominant complex, CLS7-11\*, is unusual in that it is the only group that shared complete homogeneity of plot membership with a group generated by the default analysis (CLSD-11\*). This group of three plots lies at the eastern edge of the reclamation area where top soil has eroded and coal fines are exposed (Figure 4). As with CLSD-11\*, this group is generally characterized by at least 10% cover of *P. virgatum*. The differential species *Sorghastrum nutans* is found at 5% cover. These plots contain several species not found in other groups (see group CLSD-11\*). This group has the highest species richness within the *P. virgatum* dominant complex generated by the TWINSpan variant analysis (Table 8).

The first group of the *B. curtipendula*/*A. gerardii* dominant complex, CLS7-011, is the largest group delineated by the TWINSpan variant analysis, comprised of 51 plots. Plots in this group almost completely cover the mound (Figure 4). Several smaller contiguous arrangements of plots within this group also occur in the lowland area, east and west of the mound. The group has the lowest N1 and N2 diversity indices within the *B. curtipendula*/*A. gerardii* dominant complex (Table 8). The plots within this group generally exhibit low cover and in some cases an absence of *Andropogon scoparius*, *Solidago canadensis* and *S. nutans*.

The second group of plots in the *B. curtipendula*/*A. gerardii* complex, CLS7-010, diverge from the first group in this complex in their higher cover values for the differential



species *A. scoparius*, *S. canadensis* and *S. mutans*. There are 25 plots in this group. Species diversity and evenness are higher in this group compared with the first group (Table 8). Nearly all of the plots within this group lie at the southern edge and south of the mound (Figure 4).

The third group of the *B. curtipendula*/*A. gerardii* dominant complex, CLS7-00\*, is a group of four plots lying at edges of the reclamation area, three on the west edge, and one on the north (Figure 4). TWINSpan used low levels of four colonizing species as differential species for this group: *Geum vernum*, *Aster pilosus*, *S. canadensis*, and *Rhus copallina*. Of the three *B. curtipendula*/*A. gerardii* groups, species richness and diversity are highest for this group (Table 8).

### **Comparison of the Two TWINSpan Analyses**

Implicit in a comparison of the two TWINSpan-generated classifications is the question whether the default parameters create a classification adequate for revealing important patterns of community organization that would be useful for management, monitoring, and interpretive purposes. Given the inherent complexity of the technique, the default parameters should be robust for most applications.

The TWINSpan default analysis generated classification groups distinct in species composition and diversity indices. Within the plots of the *Panicum virgatum*-dominant complex (CLSD-11\*, CLSD-101, CLSD-100, and CLSD-011), there appears to exist a gradient in species richness ranging from a low of 9.2 to a high of 17.0 (Table 8).

Exploratory ANOVA analysis found that these four groups of plots separate into three

groups exhibiting significant differences between their means along this gradient. Further, the default analysis distinguished the *P. virgatum* complex group CLSD-100 as unique in frequencies of *Bucheloe dactyloides*, *Poa pratensis*, *Festuca pratensis*, *Gaura biensis*, and *Aster pilosus*. The *P. virgatum* complex group CLSD-11\* is unique for the presences of several species not occurring in other groups.

In addition, the default groups exhibit spatial contiguity when mapped. The plots of CLSD-100 generally lie in the lowland drainage areas, whereas the plots of CLSD-010 are restricted to the mound area. Plots within the groups CLSD-000 and CLSD-11\* separate from similar contiguous plots undoubtedly due to the presence of unique microclimates at the west and east edges of the reclamation area: CLSD-000 with woodland edge species, and CLSD-11\* with a unique assemblage of species that either tolerate or take advantage of continuing disturbance at the eroding eastern edge.

If a management goal were an increase in species diversity and richness, areas low in these values as delineated by the default analysis could be targeted for more frequent mowing, light disking, or other practices that would lessen the competitive effect of the two dominant grasses, *Panicum virgatum* and *Bouteloua curtipendula*. Areas delineated as having high levels of *P. virgatum* offer interpretive/educational value, as they can demonstrate the negative impact of competitive relations between different species, as well as the soil-generating capacity of this aggressive grass species. Further, edge areas delineated by TWINSPAN default may serve as useful interpretive areas or field laboratories exhibiting woody species colonization in the case of the west edge, and early successional stages in the case of the east edge plots that lie over coal fines and are often

water-laden. Finally, the default analysis establishes a baseline of spatial data for long-term monitoring of ecological processes at the Monahan Grassland. Thus, the default TWINSpan classification provides sufficient information for management, interpretive, and monitoring purposes.

However, the variant analysis created groups that are generally more homogeneous, and thus offer more detail regarding ecological processes occurring within sub-communities at the Monahan grassland. In particular, the variant analysis better represents the distribution and the impact of high cover values of *Panicum virgatum*, and to a lesser degree of *Bouteloua curtipendula* and *Andropogon gerardii* on community diversity and evenness.

The variant analysis detected a group of plots within the lowland, group CLS7-100, which clearly reflect the influence of greater than 60% cover values of *P. virgatum* on species diversity and evenness. Although species richness in CLS7-100 was not significantly different from two of the other five groups created by the variant analysis, N1 and N2 diversity and evenness within CLS7-100 are significantly lower than in the other five groups (Table 8). The default analysis also created a lowland group with high cover values of *P. virgatum*, however, the broadness of the highest pseudo-species class (20% to 100% cover) precluded the detection of groups of plots with very high cover levels of *P. virgatum*. These areas with greater than 60% cover values of *P. virgatum* coincide with slowly draining or depressional wetland areas within the lowland created during or following reclamation activities. The abundant moisture and accumulated organic matter in these areas undoubtedly fostered the robust growth of the grass, ultimately resulting in a

negative impact on diversity and evenness.

The variant analysis also detected what may be a similar negative impact on diversity due to high cover values of *B. curtipendula* and *A. gerardii*. Within the three groups of the *B. curtipendula*/*A. gerardii* complex (CLS7-00\*, CLS7-010, and CLS7-011), there is a gradient in N1 and N2 species diversity, ranging from lows of 4.1 and 3.3 to highs of 7.0 and 5.6 respectively (Table 8). Plots on the mound, group CLS7-011, exhibit the lowest diversity values, which exploratory ANOVA found to be significant. In addition, this same group CLS7-011 presents a higher degree of spatial contiguity than do the two groups that comprise the mound area in the default analysis. In the variant analysis, most of the mound area and slopes coming off the mound are covered by one classification group, distinct in composition compared to lowland drainage areas (Figure 4). The default analysis, on the other hand, created a patchwork of two different groups upon the mound (Figure 3), owing to the default analysis' failure to detect differences in plots with *P. virgatum* at cover values greater than 20% but less than 40%. The higher degree of precision in detection of the competitive effects of *P. virgatum* and the combined effects of *B. curtipendula* and *A. gerardii* is due to the variant analysis' ability to more accurately reflect actual abundance differences and hence ecological impacts within sub-communities of the grassland.

In addition, the variant analysis was better able to delineate the range of a consociation of *B. curtipendula*, *Andropogon gerardii* and *Solidago canadensis* at the south edge and south of the mound (CLS7-010) (Figure 4). This consociation, which appears to support a sub-community of higher species diversity and evenness than on the

mound (Table 8), also was detected by the default analysis (CLSD-001). However, the spatial extent of its coverage was obscured by the inability of the default analysis to distinguish between different degrees of cover by the dominant *P. virgatum*. Monitoring of this area could determine whether the large colonies of *S. canadensis* are a remnant of colonization by the weedy species during early stages of the reclamation or an indicator of continuing disturbance in this area, and possibly a threat to the integrity of the spoil cap over the refuse mound.

Thus, the variant TWINSpan classification analysis is more informative of ecological processes at the community level, and provides more detail for management, monitoring, and interpretive purposes. It is possible that the unique history of the Monahan grassland, that is, the systematic planting of a homogeneous seed mixture across the study area, the vigor of cultivar plants (specifically *Panicum virgatum*, *Bouteloua curtipendula*, and *Andropogon gerardii*), and young age of the reclamation project makes this community an exception to Hill's (1979) general rule of the adequacy of five pseudo-species being able to reflect typical values of abundance.

## **Data Analysis by CCA**

### **CCA Analysis With Default Parameters**

CCA-DEFAULT constrains the first  $n$  axes to be linear functions of the  $n$  measured environmental variables (Lavorel and Lebreton 1992). The eigenvalue scores for the first and second axes of the CCA-DEFAULT analysis (Table 9) indicate a

Table 9. Ordination diagnostic statistics. (a) Summary of axes eigenvalues and correlations between sample scores derived from species data and from environmental data; and (b) Summary of correlations between sample scores derived from species scores and environmental data.

(a) SUMMARY OF THE ORDINATION

	CCA- DEFAULT	CCA- PASSIVE	CCA- DOWN	CCA- OCTAVE
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EIGENVALUE SCORES:

AXIS 1	0.141	0.171	0.124	0.074
AXIS 2	0.045	0.099	0.021	0.043
AXIS 3	0.361	0.672	0.169	0.237
AXIS 4	0.251	0.639	0.142	0.223

SPECIES-ENVIRONMENT CORRELATIONS:

AXIS 1	0.753	0.646	0.704	0.654
AXIS 2	0.516	0.497	0.431	0.635
AXIS 3	0.000	0.000	0.000	0.000
AXIS 4	0.000	0.000	0.000	0.000

(b) WEIGHTED CORRELATION MATRIX

	CCA- DEFAULT	CCA- PASSIVE	CCA- DOWN	CCA- OCTAVE
SPEC AX1/STANDWAT	0.7445	0.6309	0.7006	0.5670
SPEC AX1/REFUSE	0.2214	0.2444	0.1647	0.4252
SPEC AX2/STANDWAT	-0.0756	-0.1084	-0.0417	-0.3170
SPEC AX2/REFUSE	0.4930	0.4597	0.4194	0.4824

relatively small amount of variation in the Monahan grassland was explained by the two environmental variables (eigenvalues 0.141 and 0.045 respectively). The species-environment correlations and the weighted correlation matrix produced by CCA indicate that Axis 1 corresponds to the level of standing water, and Axis 2 to the presence of mine refuse (Table 9). Axes 3 and 4 are unconstrained and represent two unidentified, unmeasured gradients.

The CCA-DEFAULT ordination diagram for Axis 1 and 2 arranges the plots into a constellation of points that resembles a broad right angle (Figure 5). Species composition in plots located close to the origin of the angle reflects no or low impact by the two environmental variables. The two diverging sides of the right angle are made up of two distinct plot assemblages. The vertical side of this broad angle includes plots whose species composition is explained by levels of mine refuse, and the horizontal side consists of plots whose species composition is explained by levels of the regularity of standing water. A triplot of species, plots, and environmental variables confirms this interpretation of this constellation (Appendix 10).

The classification derived from the ordination diagram was achieved by positioning somewhat arbitrary lines dividing the two sides of the right angle, creating three groups: (1) a large group of plots ( $N = 33$ ) with no or low impact by the two variables (Group LIBV); (2) a group of plots ( $N = 21$ ) experiencing impact by standing water (Group IBSW); and (3) a group of plots ( $N = 16$ ) experiencing impact by mine refuse (Group IBMR) (Figure 5).

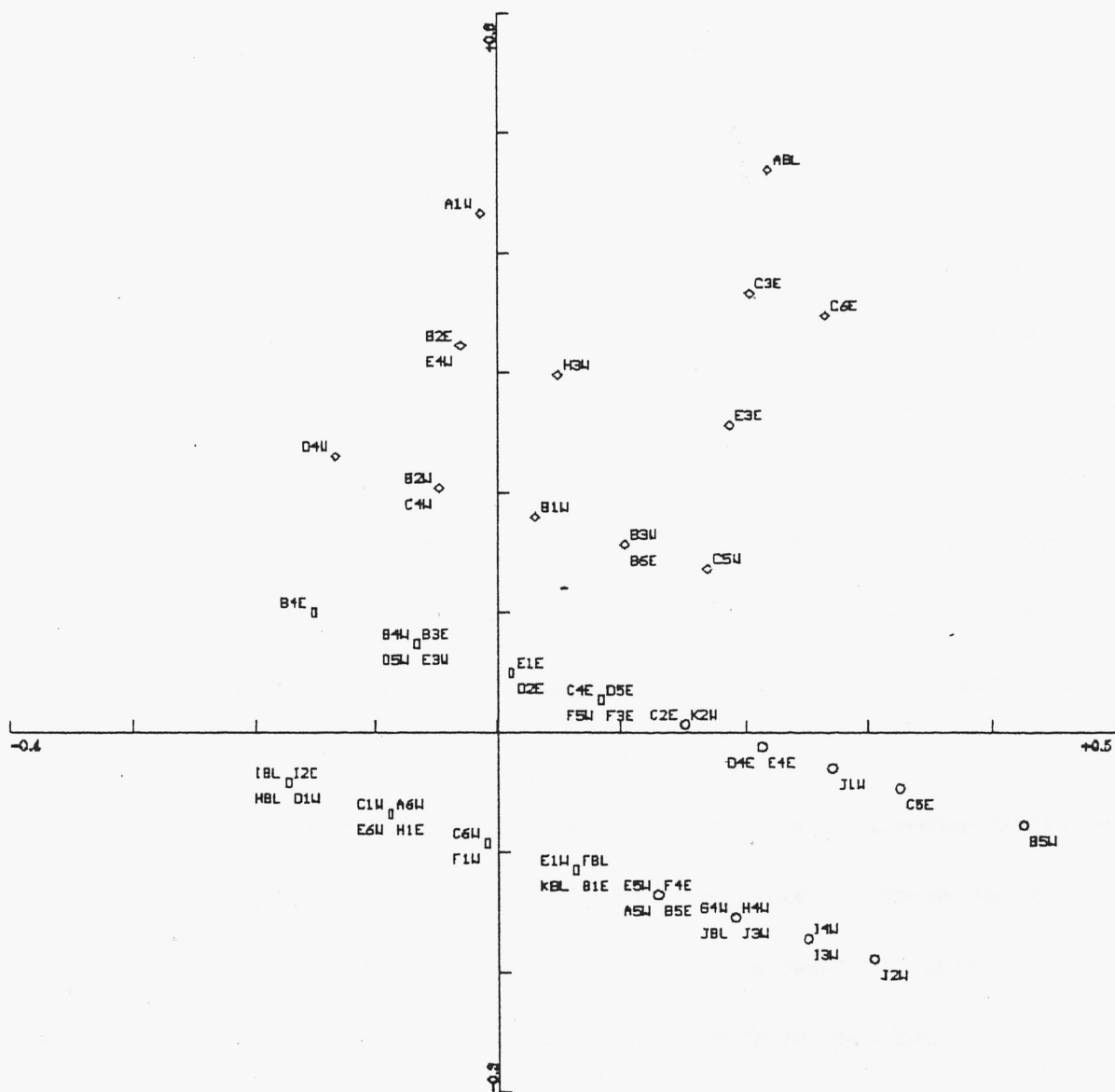


Figure 5. Ordination diagram of CCA-DEFAULT showing plots.



Exploratory ANOVA analyses were used to detect differences in species composition (Appendix 11) and in the suite of diversity indices among the three groups (Table 8). Also, observations of species points in relation to plot points in a bi-plot ordination space were used to further characterize typical species composition for the groups (Appendix 12). Further, the three groups were mapped so that spatial relationships among the plots could be observed and characterized (Figure 6).

Plots within Group LIBV are ubiquitous in distribution, occurring on the mound and within the lowland area (Figure 6). Exploratory ANOVA analysis found *Bouteloua curtipendula* and *Andropogon gerardii* at their highest levels of abundance in this group, although the latter also occurs at a high cover values in Group IBMR (Appendix 11). The ordination diagram indicates *Andropogon scoparius* and *Agropyron smithii* are two other characteristic species for this group (Appendix 12). Also, two forb species widespread across the Monahan grassland, *Helianthus maximilianii* and *Aster pilosus*, reach their highest levels of abundance in this group (Appendix 11). Mean species richness for plots in this group is low, whereas evenness is high (Table 8).

The plots within Group IBSW generally lie within the drainage system created by the reclamation, although two individual Group IBSW plots occur on the mound (Figure 6). Exploratory ANOVA analysis indicated three species reached their highest abundances in this group: *Panicum virgatum*, *Tripsacum dactyloides*, and a *Carex* species (Appendix 11). Inspection of the species/plot biplot diagram revealed no other species with a marked preference for plots in this group. Species richness was low for this group, but not different from the plots of Group LIBV; however, the diversity indices

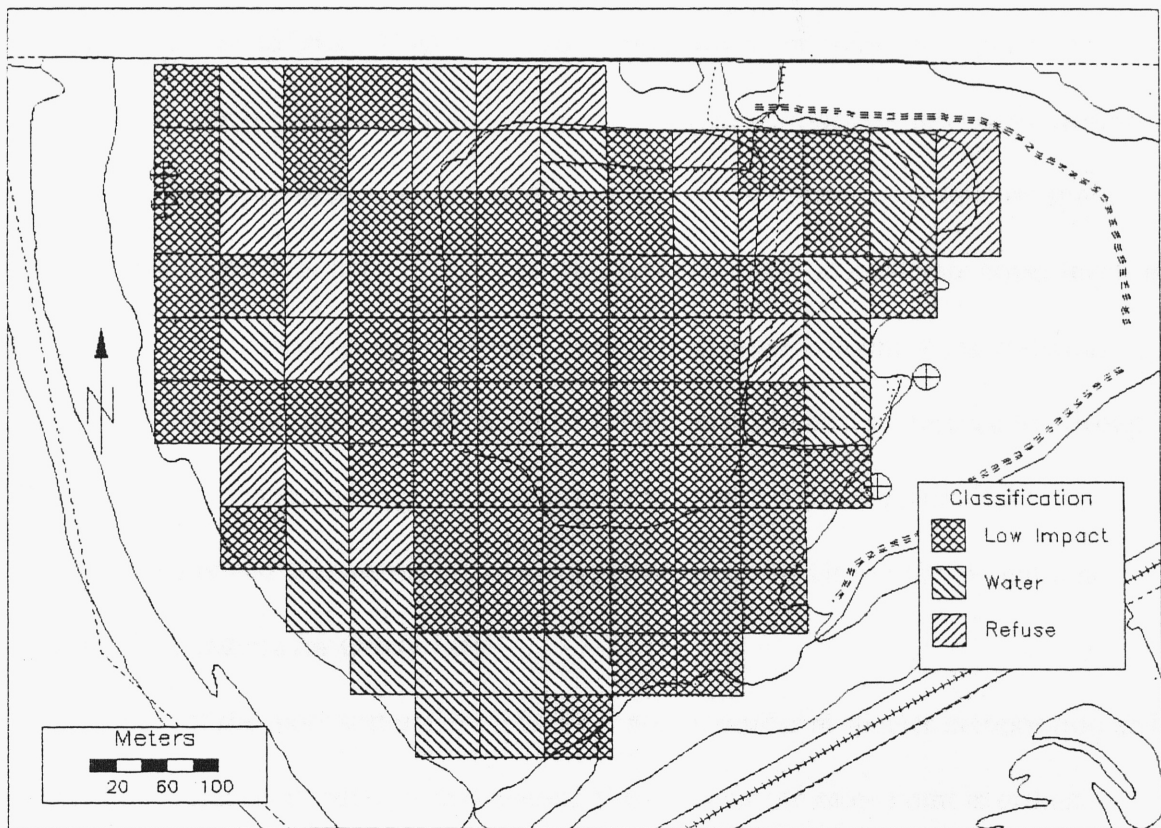


Figure 6. Classification of Monahan grassland produced by partitioning of CCA-DEFAULT ordination space.

N1 and N2 were lowest in Group IBSW, as was the evenness index (Table 8).

The plots within Group IBMR occur in three of areas of the grassland: on slopes coming off the mound, in the lowland within drainage areas, and at the eastern edge of the study site where erosion has uncovered a portion of the coal slurry settling pond (Figure 6). Exploratory ANOVA analysis found *Bucheloe dactyloides* and *Aristida dichotoma*, the latter a colonizing species, occurring at their highest abundance levels in this group (Appendix 11). In addition, ANOVA indicated that two other colonizing species besides *A. dichotoma*, are present at their highest levels: *Conyza canadensis* and *Oxalis dillinii*. Inspection of the species/plot biplot and plots of individual species in ordination space suggests that *A. gerardii* and *P. virgatum*, *Poa pratensis* exist at moderate cover levels in most of the plots (Appendix 12). Further, *Euthamia gymnospermoides* and *Ratibida pinnata* are two minor species that appear to exhibit an ecological preference for Group IBMR. Species richness among the three groups is highest for this group (Table 8). Species diversity and evenness is higher in this group than for Group IBSW, but it is comparable to indices for Group LIBV.

Many of the plots within Group LIBV were so similar in species composition and levels of environmental variables that several plots occupy the same point in ordination space (Figure 5). This is also true for several plots within Group IBSW. In contrast, plots making up Group IBMR are more scattered across ordination space with little overlap. This indicates that species composition within Group IBMR plots is more variable than within the other two groups. This pattern of dispersion of plots in ordination space also indicates that there is more variability in the level of standing water within Group IBMR

plots than there is for the level of mine refuse within the Group IBSW plots.

### **CCA Analysis With Variant Parameters**

Visual inspection of species and plots ordination diagrams generated by CCA-DOWN, CCA-PASSIVE, and CCA-OCTAVE (Appendices 13, 14, and 15) detected only slight differences compared to CCA-DEFAULT (Appendix 12) in the configuration of species and plot points in ordination space for the first two constrained axes. As the ordination diagrams for the four analyses were not substantially different, it was deemed superfluous to use any but the CCA-DEFAULT for the creation of a classification system.

In addition, the numerical outputs for CCA-DOWN, CCA-PASSIVE, and CCA-OCTAVE were on the same order of magnitude as those of the CCA-DEFAULT (Table 9) for the first two axes. These results are in line with Palmer's (1993) observation that constrained ordinations tend to converge on a robust extraction of ecological information, regardless of transformations applied to species data.

Differences in species-environment correlation coefficients and the weighted correlation matrix among the four ordination analyses suggest that the two environmental variables may be influencing community composition by creating variation within two different ecological groups of species occurring at the grassland (Table 9). However, these suggestions are tenuous at best, a further reflection of the low explanatory value of the two environmental variables.

Variation in cover among dominant species such as *P. virgatum*, *B. curtipendula*, and *A. gerardii* seems to be influenced by the level of standing water. The species-

environment correlation coefficients are lower for the CCA-OCTAVE and the CCA-PLANT PASSIVE variant analyses for Axis 1 (0.654 and 0.646) than the species-environment correlation coefficients for CCA-DEFAULT and CCA-DOWNWEIGHT (0.753 and 0.704) (Table 9). The species-environment correlation measures the strength of the relation between species and environment for a particular axis (ter Braak 1990). The CCA-OCTAVE and the CCA-PLANT PASSIVE variant analyses both produce the effect of a de-emphasis of the information content held in the abundances of the dominant species (for example, in CCA-PASSIVE, *Panicum virgatum*, *Bouteloua curtipendula*, and *Andropogon gerardii*, and in CCA-OCTAVE, *Solidago canadensis*). The correlation between the species data and the Axis 1 scores (the axis constrained to reflect the effect of regularity of standing water) is lower in these two analyses, suggesting that variation in the abundances of these dominant species may be influenced by the standing water. A similar systematic reduction in correlation scores among the four analyses is also observed in the correlation coefficients between Axis 1 species scores and the standing water scores in the weighted correlation matrix: CCA-DEFAULT = 0.7445, CCA-DOWN = 0.7006; CCA-PASSIVE = 0.6309, CCA-OCTAVE = 0.5670 (Table 9).

On the other hand, variation within the grassland caused by the presence of mine refuse appears to be more erratic. When rare species are down-weighted in CCA-DOWNWEIGHT, the correlation between the species data and the Axis 2 scores (the axis constrained to reflect the effect of the presence of mine refuse), drops to 0.431 (Table 9). This relatively low correlation coefficient (compared with 0.516 for CCA-DEFAULT) may indicate that information regarding variation induced by the presence of mine spoils

resides in the abundances of these rare species. When less frequent species are more evenly represented in the ordination, as in the CCA-OCTAVE analysis, the correlation between species data and Axis 2 scores reaches a higher score of 0.635. However, a similarly high species-environment correlation score is not reported for the CCA-PLANT PASSIVE analysis (0.497), which would have the effect of emphasizing colonizing species, thus confounding a general conclusion that mine refuse is a good explanatory variable for variation within plots that contain rare, less frequent, or colonizing species. A similar trend is observed among the four analyses in the correlation coefficients between Axis 2 scores for species and the mine refuse scores in the weighted correlation matrix (Table 9).

Markedly higher eigenvalues were extracted by the CCA-PASSIVE for the third and fourth axes than in CCA-DEFAULT (Table 9). Visual inspection of ordination diagrams of the third and fourth axes plotted against the first axis for the CCA-DEFAULT and the CCA-PASSIVE revealed substantial differences between the constellation of points for the two analyses (Appendices 16, 17, 18, and 19). This could be an indication that the fairly even distribution of the planted species -- six of the seven grass species seeded at reclamation occur in at least 69% of the plots -- may be confounding ecological patterns that are instead better reflected in the abundances of the colonizing species. It is possible the bulk of this information seems to lie in Axis 3 of CCA-PASSIVE, as the ordering of plots in Axis 4, although reversed, has a high degree of similarity to Axis 4 of CCA-DEFAULT, and may be expressing the same environmental gradient.

The higher Axis 3 and 4 eigenvalues for both CCA-DEFAULT (0.361 and 0.251)

and CCA-PASSIVE (0.672 and 0.639) (Table 9) suggests the presence of additional environmental factors with substantially greater roles in shaping community structure than the two measured environmental variables. Unfortunately, in the absence of additional measured variables the identification of the unknown gradient(s) remains problematic. The differences in magnitude between the two analyses for these unconstrained eigenvalues also may indicate these unknown gradients are further obscured by "noise" created by seeded species abundances.

Eigenvalues are sometimes described as indicators of the importance of an axis. If the first two CCA-DEFAULT eigenvalues (0.141 and 0.045) (Table 9) are compared with the third and fourth axes eigenvalues (0.361 and 0.251), it is seen the two constrained axes (reflecting standing water and mind refuse) account for a small part of the total community variation. Other ordination studies have identified moisture availability as a primary gradient in grassland community structure (McNaughton 1983, Umbanhowar 1992). However, a fairly young reclamation area such as the Monahan grassland is possibly a more dynamic community than a natural, historic grassland, and continues to experience other gradients induced by the reclamation process itself, such as secondary successional processes, soil compaction, or low soil fertility.

Inspection of the CCA ordination offers insight into limitations of the systematic-random sampling design for creating a classification. Plots are arranged more or less continuously in the ordination diagram, and do not cluster into discrete groups. During sampling, plots were placed in a regular pattern across the reclamation grassland to promote more even sampling and to permit easy location of plot center points for spatial

display of resulting classifications. As a result, the data set is heavily weighted with information regarding typical plots, compared to the amount of information from plots with non-typical species composition. The paucity of information regarding extreme areas inhibits the ability of CCA to detect distributions of species that occur in these areas only (Wassen and Barendregt 1992). It is possible that disproportionately heavy sampling of extreme area -- that is, the creation of more plots, smaller in size -- would result in more distinct clusters of sites within the ordination diagram. This, in turn, may permit less arbitrary imposition of boundaries between groups within ordination space, as well as the detection of groups more distinct in composition and diversity.

### **Comparison of TWINSpan and CCA Analyses**

The CCA derived classification is not strictly comparable with the analyses generated by TWINSpan. The classifications created by TWINSpan were created through the detection of similarities among plots based on vegetation abundances only. The classification derived from CCA-DEFAULT was based on the imposition of arbitrary class boundaries on the two-dimensional array of plots points in an ordination diagram. This array of plot points reflects the relationship between two measured environmental variables and vegetation data.

The utility of a classification derived from a constrained ordination is in its ability to focus the classification on environmental variables of interest (Palmer 1995). The overall patchwork nature of the resulting map indicates pockets where environmental



variables occur at high levels, and which are sometimes disconnected from other similar plots (Figure 6). The two environmental variables measured in this study account for only a fraction of total variation in the community, which may result in a narrow application for the classification. Therefore, the use of this classification also may be limited because of the arbitrary placement of boundaries between groups in ordination space.

In spite of these limitations, the classification derived from the CCA ordination reinforces and supplements the TWINSpan analyses. A basic dichotomy found to different degrees in the TWINSpan analyses is also depicted in the ordination groups: vegetation composition within the lowland drainage area differs substantially from vegetation composition on and adjacent to the mound. The ordination extracts additional information about some of these lowland plots by positioning them in a biplot that relates high levels of *P. virgatum* to a high occurrence of regularly standing water (Appendix 12). Both TWINSpan analyses chose high or very high abundances of *P. virgatum* as a differential species characteristic of lowland plots.

Also, this environmentally focused classification helps "explain" high levels of species richness found in a pair of groups created by the two TWINSpan analyses. Both TWINSpan analyses distinguished three plots in the settling pond area as unique in species composition. Exploratory ANOVA analysis detected differences in species richness between these and other nearby plots. The CCA derived classification delimits this area as experiencing higher levels of both standing water and mine refuse, two factors that likely account for the difference in species richness. Other TWINSpan groups are not as faithfully "explained" by the CCA classification, a limitation echoing the low

importance values (eigenvalues) for the first two ordination axes. However, comparison of the three maps allows more focused hypothesis generation on the link between environmental variables and different levels of species diversity between TWINSpan groups.

## CHAPTER V

### CONCLUSION

The Monahan grassland is largely a homogeneous grassland community. Initial ordination analysis of the data set with Detrended Correspondence Analysis reported 2.348 and 2.175 Standard Deviation Units for the first two axes. A score of 4.0 SDU would represent a complete turnover in species composition from one end of an axis to the other, or a highly heterogeneous community. Further, 100% of the plots sampled contained *Panicum virgatum*, which dominates the grassland not only in terms of numerical frequency, but in its competitive effects in lowland drainage areas. Both TWINSpan analyses and the DEFAULT-CCA created groups with low levels of species diversity coupled with high cover levels of *P. virgatum*.

The variant TWINSpan analysis created classification groups more informative of ecological processes occurring within the reclamation grassland, specifically the competitive effect of *P. virgatum* within the lowland areas, and of *Bouteloua curtipendula* and *Andropogon gerardii* on the mound. This distinction, plus the identification of a high diversity area characterized by a consociation of *B. curtipendula*, *A. gerardii*, and *Solidago canadensis*, provides more detail for management, monitoring, and interpretive purposes. Owing in large part to the systematic planting of a homogeneous seed mix of native grass varieties selected for vigor and high yields, this grassland community is an exception to Hill's general rule of the adequacy of five pseudo-species being able to reflect

typical values of abundance.

The default Constrained Correspondence Analysis ordination diagram illustrated the range of compositional separation between plots that was accounted for by two environmental variables: regularity of standing water and mine refuse at the soil surface. Within this environmentally focused analysis, there occurred a distinct separation in species composition between plots influenced by high levels of one or the other of the two variables. However, no clearly-defined clusters of plots representing distinct, natural sub-communities emerged, and as a result, the classification derived from the ordination suffers from a degree of arbitrariness. It is possible that more intensive sampling of areas with unusual species composition or extremely high levels of one or the other of the environmental variables would have provided more detail regarding the distribution of less frequent species. This change in sampling design could result in more clearly defined clusters within the ordination diagram and less arbitrary divisions between the sub-communities. A large amount of variation with the Monahan grassland was not accounted for by two environmental variables: regularity of standing water and level of mine spoils at the soil surface. Higher eigenvalues were obtained in a constrained ordination in which the effects of the seeded and planted species were made passive. This may indicate that the systematic sowing of a homogeneous seed mix nine years earlier still confounds a more typical ecological separation of grassland species based on soil moisture. Other unidentified environmental factors may also be the cause of variation, among them soil fertility, soil nutrient availability, or soil compaction.

Transformations of the percent cover data to an octave scale or down-weighting of

minor species or making the planted species passive did not prove useful in creating a more easily interpretable classification of the plots. The resulting variant ordination diagrams were very similar to the diagram produced on the percent cover data, and with the exception of the variant in which planted species were made passive, the eigenvalues were not substantially altered.

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## APPENDICES

## Appendix 1. Native Grass Cultivars and Forbs Used in the Monahan Reclamation Project

Native Grass Cultivar	Number of Seeds per Square Foot (percent of mix)
"Barton" Western Wheatgrass <i>Agropyron smithii</i> Rydb.	30
"Kaw" Big Bluestem <i>Andropogon gerardii</i> Vitman	10
"Aldrous" Little Bluestem <i>Andropogon scoparius</i> Michx.	10
"El Reno" Sideoats Grama <i>Bouteloua curtipendula</i> (Michx.)	15
"Improved" Buffalo Grass <i>Buchloe dactyloides</i> (Nutt.) Engelm.	5
"Blackwell" and "Kanlow" Switchgrass <i>Panicum virgatum</i> L.	20
"Osage" Indiangrass <i>Sorghastrum nutans</i> (L.) Nash	10
Forb	Pounds per Acre
Purple Prairie Clover <i>Dalea purpurea</i>	0.50
Maximillian Sunflower <i>Helianthus Maximilianii</i> Schrad	0.25
Greyhead Prairie Coneflower <i>Ratibida pinnata</i> (Vent.) Barhn.	0.25

Source: U. S. Department of Agriculture Soil Conservation Service. 1981. William J. Reals Abandoned Mine Land Project Site Plan.

## Appendix 2. Percent cover data matrix.

CODE	B6E	C6E	B5E	C5E	D5E	B4E	C4E	D4E	E4E	F4E	G4E
Acal_vir	0	0	0.2	0	0.1	0	0.1	0.2	0.3	0.4	0.1
Achi_mil	0	0	0.6	0	0	0	0	0	0	0	0
Agro_smi	0	0	0	0.1	0	0.2	0	0	0.2	0	0.3
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	4.2	0.6	4.9	1.9	17.1	12.6	7.8	7.8	7.8	10.2	24
Andr_sco	0.6	0	0.7	0	4.2	0	0.6	0.6	3.8	0.9	0.8
Andr_vir	0.1	0	0	0	0	0	0	0	0	0	0
Aris_dic	3	13.5	0	0	0	0	0	0	0	0	0
Aste_pil	0.1	0	0	0	0	0	0	0	0	0	0
Bout_cur	3.6	0	0.6	0	11.1	23.1	0	0	0.7	1.2	28.5
Buch_dac	0	0	0	0	0	0	0	0	0	0	0
Care_un1	0	0	0	0	0	0	0	0.2	0	0	0
Care_un2	3	0	3.1	3	0	0	0	0	0	0	0
Cirs_alt	0.1	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0.1	0	0	0	0	0
Corn_dru	0.7	0.1	0.1	0	0	0	0	0	0	0.2	0
Cron_cap	0	0.1	0	0	0	0	0	0	0	0	0
Cype_spe	0	0.6	0	0	0	0	0	0	0	0	0
Dale_pur	0	0	0	0	0	0	0	0	0	0	0
Desm_ill	0	0.2	0.1	0	0	0	0	0	0	0	0.1
Dica_sps	0	0	0.7	0	0	0	0	0	0.2	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0	0.3	0.9	0.8	0.1	0.8	0.4	3.3	0.3	0.3	0
Eupa_rug	0	0	0	0	0	0	0.1	0	0	0	0
Euth_gym	0.1	4.8	0.6	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	0	0	0	0	0	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0.6	0.1	0	0	0	0	0	0	0	0
Geum_ver	0.6	0	0	0	0	0	0	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0.1
Heli_max	0	0.1	0	0.1	0.1	0	0.1	0.1	0.3	0	0
Junc_un1	0	0.7	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	0	0	0	0	0	0	0	0	0	0	0
Oxal_dil	0	0	0	0	0	0	0	0	0	0	0
Pani_cap	0	0	0	0	0	0	0	0	0	0	0
Pani_vir	37.6	15.5	45.1	52.5	33	37.5	62.5	71	35.6	57	21.6
Phys_lon	0	0	0	0	0	0	0.1	0	0	0	0
Poa_pra	1.2	3	0	0	0	0	0	0	0	0	0
Popu_del	0	0	0	0.1	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0.1	0	0	0	0	0	0	0
Rati_pin	0	0	0	0	0	0	0	0	0	0	0
Rhus-aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	3	0	0	0	0	0	0	0	0	0	0
Rubu fla	0	0	0	0	0	0	0	0	0	0	0
Scir-pen	0	0.6	0	0	0	0	0	0	0	0	0
Soli_can	4.2	11.1	0.1	3.8	9.3	0.6	0.1	0.7	6	6.2	0
Sorg_nut	13.5	19.2	6.1	3.8	6.7	4.8	0.7	0	3.1	0.1	1.2
Sphe_obt	0.6	0	0	0	0	0.6	0.1	0	0	0	0
Spir_cer	0	0.1	0	0	0	0	0	0	0	0	0
Spor_asp	0	7.5	0	0	0	0	0	0	0	0	0.1
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	3.1	0.1	0	0	0	0	3	0	0
Ulmu_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

CODE	B3E	C3E	D3E	E3E	F3E	G3E	H3E	I3E	B2E	C2E	D2E
Acal_vir	0	0.2	0	0.1	0	0	0	0	0	0.1	0
Achi_mil	0	0	0	0	0	0	0	0	0	0	0
Agro_smi	0.8	0.9	1	0.3	0.4	0.4	6.7	0.2	0.4	0.1	7.6
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	9.1	17.1	17.1	19.5	15	7.8	4.8	19.5	13.5	4.3	14.1
Andr_sco	0	0	0.8	0.7	4.3	1.9	13.5	3.1	3.6	0	1.2
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0.6	0	0	0.1	0	0	0	0	0	0	0
Bout_cur	33.5	13.1	28.6	6.6	14.1	28.5	45.6	28.5	18.6	0.1	30.5
Buch_dac	0	0	0	0	0	0	0	0	0	0	0
Care_un1	0	0	0	0	0	0	0	0	0	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0.3	0	0	0	0	0	0	0	0.8	0	0
Corn_dru	0	0	0	0	0.6	0	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0	0	0	0	0	0	0
Dale_pur	0	0	0	0.1	0	0	0	0	0	0	0.1
Desm_ill	0	0	0.1	0	0	0	0	0	0.1	0	0
Dica_sps	0	0	0	0	0	0	0	0	0	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	3
Erig_str	0.2	1.5	0.8	0.5	3.1	0.2	0.1	0.1	0.6	0.1	3.2
Eupa_rug	0	0.6	0	0	0	0	0	0	0	0	0
Euth_gym	0	0	0	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	0	0	0	0	0.2	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0	0.1	0	0	0	0	0	0
Geum_ver	0.1	0	0	0	0	0	0	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0.7	0.1	0.2	0	0.1	0	0	0	0	0	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	3
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	0	0	0	0	0	0	0	0.1	0	0	0
Oxal_dil	0	0.1	0	0.1	0	0	0	0	0	0	0
Pani_cap	0	0	0	0	0.1	0	0	0	0.1	0	3
Pani_vir	26.3	33.5	24	12.6	19.5	14.7	4.8	21.6	12.6	66.5	6.7
Phys_lon	0	0	0	0	0	0	0	0	0	0	0
Poa_pra	0.6	0	0	0	0	0	3	0	0	0	0
Popu_del	0	0	0	0	0	0	0	0	0	0	0
Pycn_ten	0.1	0	0	0	0	0	0	0	0	0	0
Rati_pin	0	0	0	0	0	0	0	0	0	0	0
Rhus_aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0	0	0	0	0	0	0
Rubu fla	0	0	0	0	0	0	0	0	0	0	0
Scir_pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	0.7	0.7	0.7	7.6	0.7	3	3.1	11.2	3.6	0.2	0.1
Sorg_nut	0	3.6	1.2	0	0	1.2	0	4.2	1.2	3	0.6
Sphe_obt	0.6	0	0	0.6	0	0	0	0.1	0	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	0	0.2	0	0	0	0	0	0	0	0.1	0
Teuc_can	0.1	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	3	0	0	0	3	0	0	0	0	0
Ulm_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

CODE	E2E	F2E	G2E	H2E	I2E	J2E	B1E	C1E	D1E	E1E	F1E
Acal_vir	0	0	0	0	0	0	0	0	0	0	0
Achi_mil	0	0	0	0	0	0	0	0	0	0	0
Agro_smi	3.1	0.9	1	0.3	0.3	0	3.1	0	1.8	0	0.1
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	10.2	19.5	28.5	28.5	17.1	6	0	16.5	10.2	12.6	5.4
Andr_sco	0.7	1.8	1.9	3.6	0.6	0	0	0.1	0	1.2	1.8
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0	0	0	0	0	3.6	0	0	0	0	0
Bout_cur	21.2	16.5	29	52.5	30.5	0.6	23	36.1	21	19.2	43
Buch_dac	0	0	0	0	0	0	0	0	0	0	0
Care_un1	0.6	0	0	0	0	0	0.1	0	0	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0	0	0	0	0	0
Corn_dru	0	0	0	0	0	7.5	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0	0	0	0	0	0	0
Dale_pur	0	0	0	0	0	0	0	0	0	0	0
Desm_ill	0	0	0	0	0	0	0	0	0	0	0
Dica_sps	0	0	0	0	0	0.1	0	0	0	0	0.1
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	1.5	1.9	1.8	0	0.1	0	0.1	0	0.7	0.1	0.1
Eupa_rug	0	0	0	0	0	0	0	0	0	0	0
Euth_gym	0	0	0	0	0.1	0.2	0	0	0	0	0
Fest_pra	0	0	0	0	0	0	0	0	0	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0	0	0.7	0	0	0	0	0
Geum_ver	0	0	0	0	0	3	0	0	0.6	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0	0	0	0	0	0.1	0.1	0	0.6	0.2	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	0	0	0.6	0	0	3	0.1	0	0	0	0
Oxal_dil	0	0	0	0	0	0	0	0	0	0	0
Pani_cap	0	0	0	0	0	0	3.1	0	0	0	0
Pani_vir	14.7	24	21.6	17.1	11.7	28.1	16.6	6.6	3.7	31	11.7
Phys_lon	0	0	0	0	0	0	0	0	0	0	0
Poa_pra	0	0.1	0.1	3	0	0	0	0	0	0	0
Popu_del	0	0	0	0	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	0	0	0	0	0	0	0
Rati_pin	0	0	0	0	0	0.6	0	0	0	0	0
Rhus_aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0.6	0	0	0	0	0	0
Rubu fla	0	0	0	0	0.6	0.6	0	0	0	0	0
Scir-pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	1.2	1.9	4.8	1.3	16.2	26.1	0.1	0.1	0	6.7	0.1
Sorg_nut	1.2	0	3.6	1.2	9.6	0.7	0.1	0	0	0	0
Sphe_obt	0	0.1	0	0	0.6	0	0	0	3	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	7.5	0	0	0	0	0	0	0	12.5	0.7	3
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	0
Ulmu_pum	0	0	0	0	0	0	0	0	0	0	0



# Appendix 2. Percent cover data matrix - continued.

CODE	G1E	H1E	I1E	J1E	ABL	BBL	CBL	DBL	EBL	FBL	GBL
Acal_vir	0.1	0.1	0	0	0	0.1	0	0	0	0	0
Achi_mil	0.1	0	0	0	1.2	0	0	0	0	0	0
Agro_smi	0.2	0.2	0	0.2	0.8	0.2	0.1	0	0.7	0	0
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	7.2	12.6	12.6	29	4.2	0	0	0	0.7	3.6	0
Andr_sco	1.8	0.7	0	3.6	0	3	0.6	1.9	2.4	1.8	0.6
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0.6	0	0	0	0	0	0	0	0	0	0
Bout_cur	21	19.1	24.5	14.1	1.2	18.5	34	15	19.5	19.5	23.6
Buch_dac	0	0	0	0	0	0	0	0	0	0	0
Care_un1	0	0	0	0	0	0	0	0	0	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0	0	0	0	0	0
Corn_dru	0	0	0	0	0	0	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0	0	0	0	0	0	0
Dale_pur	0.1	0	0	0	0	0	0	0.1	0	0	0
Desm_ill	0	0	0	0	0	0	0	0	0.1	0	0
Dica_sps	0	0	0	0	0	0	0	0	0	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0.8	3.8	0.1	0.1	0	0.9	0.7	1.4	0.5	0.1	0.1
Eupa_rug	0	0	0	0	0.6	0.6	0	0.1	0	0	0
Euth_gym	0	0	0.1	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	0	0	0	0	0	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0.1	0	0	0	0	0	0	0
Geum_ver	0	0	0	0	4.2	0	0	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0.3	0	0	1.3	0.6	0	0	0.1	0.6	0	3
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0.1	0	0	0	0	0	0
Meli_sps	0	0.7	0	0	0	0.1	0	0	0	0	1.2
Oxal_dil	0	0	0	0	0.1	0	0	0	0	0	0
Pani_cap	0	0	0	0	0	0	0	0	0	0	0
Pani_vir	19.2	7.2	17.3	17.1	18	23.7	19.5	12.6	15	26.1	14.1
Phys_lon	0	0	0	0.6	0	0.1	0	0	0	0	0
Poa_pra	0	0	0	0	0	0	0	0	0	0	0
Popu_del	0	0	0	0	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	0.1	0	0	0	0	0	0
Rati_pin	0.6	0	0	0.1	3.6	0	0	0	0	0	0
Rhus-aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	7.5	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0	0	0	0	0	0	0
Rubu fla	0	0	0	0	0	0	0	0	0	0	0
Scir-pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	10.7	1.3	6.1	17.1	17.7	0.7	0.8	0.9	0.8	0.1	1.9
Sorg_nut	0.1	0.8	3.2	0	0.1	0	0.1	0	0.1	0.1	0.1
Sphe_obt	0	0.1	0	0	0	0	0	0	0	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	0.7	0	0	0	0	0	0	0	0.1	0	0.6
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	0
Ulmu_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

	HBL	IBL	JBL	KBL	A1W	B1W	C1W	D1W	E1W	F1W	G1W
CODE											
Acal_vir	0	0	0	0	0	0	0	0	0	0	0
Achi_mil	0	0	0.6	0	0	0	0	0	0	0	0
Agro_smi	0.2	0	0.8	0.6	1.3	0.1	0	4.9	0.1	0	0.9
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	7.2	24	10.2	12.6	8.1	9.7	12.6	24	7.8	9.6	12.6
Andr_sco	0.6	8.2	3	6.6	0	1.2	1.3	1.2	3.7	0.7	1.8
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0	0	0	0	0	0	0	0.1	0	0	0
Bout_cur	29	33.5	6.6	11.1	7.5	4.9	12.6	19.5	9.1	6.7	29
Buch_dac	0	0	0	0	0	3	0	0	0	0	0
Care_un1	0	0	0	0	0	0	0	0.6	0	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0.2	0	0	0	0	0
Corn_dru	0	0	0	0	0	0	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0	0	0	0	0	0	0
Dale_pur	0	0.1	0	0.1	0	0.1	0	0	0	0	0.1
Desm_ill	0	0	0	0	0	0	0.6	0	0	0	0
Dica_sps	0	0	0	0.1	0	0	0	0	0	0	0
Elae_ang	3	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0.6	0.6	0	0	0.1	0.4	1	1.9	0.2	0.1	0.2
Eupa_rug	0	0	0	0	0	0	0	0	0	0	0
Euth_gym	0	0	0	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	0	0	0	0	0	0	0.6
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0	0	0.6	0	0	0	0	0
Geum_ver	0.1	0	0	0	0.1	0	0	0	0	0	0.1
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0.1	3	0	3.6	0	0	0	0	0	0	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	9	0	0	0	8.7	6	0	0	0	0	0
Oxal_dil	0	0	0	0	0	0	0	0	0	0	0
Pani_cap	0	0	0	0	0	0	0	0	0	0	0
Pani_vir	16.2	10.2	43.5	11.7	18.5	24	12.6	26.1	19.5	21.6	16.5
Phys_lon	0	0	0	0	0	0	0	0	0	0	0
Poa_pra	0	0	0	0	7.5	0	0	0	0	0	0.1
Popu_del	0	0	0	0	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	1.2	0	0	0	0	0	0
Rati_pin	0	0	0	0.6	0	0	0	0	0	0	0
Rhus-aro	3	0	0	0	0	0	0	0	0	0	3
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0	0	0	0	0	0	0
Rubu fla	0	0	0	0.6	0	0	0	0	0	0	0
Scir-pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	11.7	6	11.3	21.6	7.2	0.1	3.2	1.9	2	1.3	15.5
Sorg_nut	7.5	0.1	3	9.6	0.6	0	0.1	0	3	0.7	9
Sphe_obt	0	0	0.6	0	0	0	0	0	0	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	0.1	0	0.1	0	0	0	0	0.6	0.6	0	0
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	0
Ulm_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

CODE	H1W	I1W	J1W	K1W	A2W	B2W	C2W	D2W	E2W	F2W	G2W
Acal_vir	0	0	0	0	0	0.2	0	0	0	0	0
Achi_mil	0	0	0	0	0	0	0	0	0	0	0
Agro_smi	1.5	0.1	0.8	0.2	0.2	0	0.1	0.3	0	0	0.5
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	17.1	21	13.5	15	0.6	9.1	3	3.8	6.6	3.6	19.5
Andr_sco	0	8.1	6.6	4.8	0	0.7	1.3	1.8	3	3	17.3
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0	0	0	0	0.1	0	0	0	0	0	0
Bout_cur	29	36.1	4.3	9.6	0	18.6	2.5	24.5	31.1	29	29
Buch_dac	0	0	0	0	0	3	0	0	0	0	0
Care_un1	0	0	0	0	0.6	0	0	0	0	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0.1	0	0	0	0	0
Corn_dru	0	0	0	0	0	0	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0.6	0	0	0	0	0	0
Dale_pur	0	0	0	0.6	0	0	0.1	0	0	0.1	0.1
Desm_ill	0	0	0	0	0	0	0	0	0	0	0
Dica_sps	0	0	0	0	0	0	0	0	0	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0.1	0.1	0	0	0	0.8	0.9	0.1	0.2	0	0.3
Eupa_rug	0	0	0	0	0	0	0	0	0	0	0
Euth_gym	0	0	0	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	1.2	0	0	0	0	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0	0.6	0	0	0	0	0	0
Geum_ver	0	0	0	0	0	0.1	0	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0	0	0	0.7	0	0.6	0	0	0	0	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0.1	0	0	0
Lesp_vio	0	0	0	0	19.5	0	0	0	0	0	0
Meli_sps	0	0	0	0	3.7	0.6	0	0	0	0	0
Oxal_dil	0	0	0	0	0	0	0	0	0	0	0
Pani_cap	0	0	0	0	0	0	0	0	0	0	0
Pani_vir	36.1	12.6	47.5	4.9	66	21.5	30.6	11.7	14.7	15	21.6
Phys_lon	0	0	0	0	0	0.1	0	0	0	0	0
Poa_pra	0	0	0	0	1.2	0.1	0	0	0	0	0
Popu_del	0	0	0	20	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	0	0	0	0	0	0	0
Rati_pin	0	0	0	0	0	0	0	0	0	0	0
Rhus-aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0	3	0	0	0	0	0
Rubu_fla	0	0	0	0	0	0	0	0	0	0	0
Scir-pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	17.1	4.8	14.7	6.2	3.2	0.7	0.6	0.7	0.2	0.6	15.2
Sorg_nut	6	3.7	1.2	6.6	0	0.1	0.2	3	0.7	0.1	3.6
Sphe_obt	0	0	0	0	0.1	0	0	0	0	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	3	0.6	0.1	3	0	0	0	0	0	0	0
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	0
Ulmu_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

CODE	H2W	I2W	J2W	K2W	A3W	B3W	C3W	D3W	E3W	F3W	G3W
Acal_vir	0	0	0	0	0	0.7	0.1	0	0	0.1	0.1
Achi_mil	0	0	0	0	0	0	0	0	0	0	0
Agro_smi	0.2	0	0	0.2	0	0.1	0.8	2.5	0.6	0.3	0
Alli_spe	0	0	0	0	0	0	0.6	0	0	0	0
Andr_ger	19.5	33.5	6.6	7.3	2.4	10.2	6.7	10.2	12.6	24	17.1
Andr_sco	3.6	0	0.6	4.3	0	0.6	0	6	1.8	6	0
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0	0	0	0	0.1	0	0	0	0	0	0
Bout_cur	15.6	16.5	0	27.6	12.5	6.6	13.1	0.7	17.1	43	16.3
Buch_dac	0	0	0	0.6	0	0	0	0	0	0	0
Care_un1	0	0	0	0	0	3	0	0	0	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0	0	0	0	0	0
Corn_dru	0	0	0	0	0	0	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0	0	0	0	0	0	0
Dale_pur	0	0	0	0	0	0.1	0	0	0	0	0
Desm_ill	0	0	0	0	0	0	0	0	0	0	0
Dica_sps	0	0	0	0	0	0	0	0	0	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0	0.6	0	0.2	0	1	5.4	1.5	4.3	0.4	0
Eupa_rug	0	0	0	0	0	0	0	0	0	0	0
Euth_gym	0	0	0.6	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	3	0.6	17	0	0	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0	0	0.1	3	0	0	0	0
Geum_ver	0	0	0	0	1.2	0	0	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0	0	0	0	0	0	0	0	0	0	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	0	0	0	0	0	0	0	0	0	0	0
Oxal_dil	0	0	0	0	0.1	0	0	0	0	0	0
Pani_cap	0	0	0	0	0	0	0	0	0	0	0
Pani_vir	33.5	24.2	59.5	31.1	57	26.6	21.6	33	47.5	17.3	31.1
Phys_lon	0	0	0	0	0	0.1	0	0	0	0	0
Poa_pra	0	0	0	0	0.6	0.8	16.1	0	0	0	0
Popu_del	0	0	0.6	7.5	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	0	0	0	0	0	0	0
Rati_pin	0	0	0	0	0	0	0	0	0	0	0
Rhus-aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	3	0	0	0	0	0	0
Rubu fla	0	0	0	0	0	0	0	0	0	0	0
Scir-pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	4.3	15.6	9.6	7.3	1.3	4.2	5.4	1	3.7	3.7	4.3
Sorg_nut	1.8	3.6	3	1.8	0	0	0	12	4.2	0.6	0.6
Sphe_obt	0	0	0.1	0	0	0	0.6	0	0.1	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	0	0	0	0	0	0	0	0	0.6	0	0
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	0
Ulmu_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

CODE	H3W	I3W	J3W	A4W	B4W	C4W	D4W	E4W	F4W	G4W	H4W
Acal_vir	0	0	0	0	0.1	0.2	0.1	0	0	0	0
Achi_mil	0	0	0	0.6	0	0	0	0	0	0	0
Agro_smi	0.2	0.1	0.2	1.2	0.7	0.8	0.7	1.4	3	0	0
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	17.1	6.1	1.3	14.1	15	14.7	19.5	15	30.5	10.5	6.6
Andr_sco	6	0.6	0.6	1.8	1.2	0	0.6	3	0	0	3
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0	0	0.2	1	1	0.1	0.6	0	0	0	0.6
Bout_cur	21	0	0	3.6	0.6	8.7	16.8	4.8	12.6	0.1	0
Buch_dac	0	0	0	7.5	0	0.6	0	0.6	0	0	0
Care_un1	0	0	0	0	0	0	0	0	0	0.1	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0
Cony_can	0	0	0	0	0	0	0	0	0	0	0
Corn_dru	0	0.1	0	0	0	0	0	0	0	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0.6	0	0	0	0	0	0
Dale_pur	0	0	0	0.6	0	0	0	0	0	0	0
Desm_ill	0	0	0	0	0	0	0.3	0	0	0	0
Dica_sps	0.1	0	0	0	0	0	0.1	1.3	1.2	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0	0	0.8	1.5	2	2.5	5.4	4.8	3.7	0.1	0.1
Eupa_rug	0	0	0	0	0	0	0.6	0.6	0	0	0
Euth_gym	0	0	0	0	0	0	0	0	0	0	0
Fest_pra	0	0	0	0	0	0	0.6	0	0	0	0.6
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0	0	0	1.2	0	1.2	0	0	0	0
Geum_ver	0	0	0.3	0	0.7	0.6	0	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0.6	0	0	0.6	0	0.1	0	0.1	3.7	0	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	0	0	0	0	0	0	0	0	0	0	0
Oxal_dil	0	0	0	0	0.1	0	0.1	0	0	0	0
Pani_cap	0	0	0.1	0	0	0	0	0.1	0	0	0
Pani_vir	6.2	64	76	43	43.5	33	17.1	29	12.6	59.6	53
Phys_lon	0	0	0	0	0	0	0	0	0.1	0	0
Poa_pra	0	3.6	0	0	11.1	0.1	6	3	0	0	0
Popu_del	0	0	0	0	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	0	0	0.1	1.2	1.2	0	0.6
Rati_pin	0	0	0	0.6	0	0	0	0	0	0	0
Rhus_aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0	0	0	0	0	0	0
Rubu_fla	0	0	0	0	0	0	0	0	0	0	0
Scir_pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	11.7	3.7	1.4	0.6	1.8	8.7	30	40.1	21.5	3.6	12.3
Sorg_nut	0	0	0.6	2.4	4.9	0.6	0.6	3	0	0	0.6
Sphe_obt	0	0.7	7.5	0	0	0.6	0	3	0	0	3
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	0.6	0	0	0	0	0	0	0	0	0	0
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	7.5
Ulmu_pum	0	0	0	0	0	0	0	0	0	0	0

# Appendix 2. Percent cover data matrix - continued.

CODE	I4W	A5W	B5W	C5W	D5W	E5W	F5W	G5W	H5W	A6W	B6W
Acal_vir	0.1	0	0	0	0	0	0	0	0	0	0
Achi_mil	0	0	0	0	0	0	0	0	0	0	0
Agro_smi	0	0.1	0	0.1	0.1	0.1	0.7	0	0.6	0.1	0
Alli_spe	0	0	0	0	0	0	0	0	0	0	0
Andr_ger	6.2	2.4	0.6	10.2	12	12	6.7	10.2	10.2	15	15
Andr_sco	0	0	0	3.6	4.3	0	8.1	0.6	1.3	4.8	9.6
Andr_vir	0	0	0	0	0	0	0	0	0	0	0
Aris_dic	0	0	0	0	0	0	0	0	0	0	0
Aste_pil	0.6	0.2	0	0.2	0.8	0.7	1.3	0.9	2.4	1.9	2.5
Bout_cur	1.2	0.6	0	3.6	7.2	3	0.6	3	14.3	33.5	28.5
Buch_dac	0.1	0.6	0	0	0	0	0	0	0	0	0
Care_un1	0	0	0.6	0	0	0.6	0	0.6	0.6	0	0
Care_un2	0	0	0	0	0	0	0	0	0	0	0
Cirs_alt	0	0	0	0	0	0	0	0	0	0	0.6
Cony_can	0	0	0	0	0	0	0	0	0	0	0
Corn_dru	0	0	0	0	0	0	0	0	0.1	0	0
Cron_cap	0	0	0	0	0	0	0	0	0	0	0
Cype_spe	0	0	0	0	0	0	0	0	0	0	0
Dale_pur	0.6	0	0	0	0	0.1	0	0	0.6	0.1	0
Desm_ill	0	0	0	0	0	0	0	0.1	0.1	0.6	0
Dica_sps	0	0	0	0	0	0	0.6	0	0.6	0	0
Elae_ang	0	0	0	0	0	0	0	0	0	0	0
Eleo_spe	0	0	0	0	0	0	0	0	0	0	0
Erig_str	0.3	0.8	0.7	1.3	7.3	13.7	4.8	2	1.4	4.3	1.9
Eupa_rug	0	0	0	0	0	0	0	0	0	0	0
Euth_gym	0	0	0	0	0	0	0	0	0	0	0
Fest_pra	0.1	0.6	0	0	0	0	0	0	0	0	0
Gall_cul	0	0	0	0	0	0	0	0	0	0	0
Gaur_bie	0	0.1	0	0	0.7	0	0	0.1	0	0	0
Geum_ver	0	0	0	0	0	0.1	0.6	0	0	0	0
Heli_ann	0	0	0	0	0	0	0	0	0	0	0
Heli_max	0	0.6	0.1	0	0	0	0	0	0	0	0
Junc_un1	0	0	0	0	0	0	0	0	0	0	0
Juni_vir	0	0	0	0	0	0	0	0	0	0	0
Lesp_vio	0	0	0	0	0	0	0	0	0	0	0
Meli_sps	0	0	0	0	0	0	0	0	0	0	0
Oxal_dil	0	0	0	0.1	0.1	0	0	0	0	0	0
Pani_cap	0	0	0	0.6	1.2	0.7	0	0	0	0	0
Pani_vir	66.6	76	71.5	71	28.2	47.5	45.6	57.5	28.5	35.6	33.5
Phys_lon	0	0	0	0	0.1	0	0	0	0	0	0
Poa_pra	0.1	0.1	0.7	0	0	3	0.7	0.1	0	0.6	0
Popu_del	0	0	0	0	0	0	0	0	0	0	0
Pycn_ten	0	0	0	0	0	0	0	0	0	0	0
Rati_pin	0	0	0	0	0	0	0	0	0	0	0.6
Rhus-aro	0	0	0	0	0	0	0	0	0	0	0
Rhus_cop	0	0	0	0	0	0	0	0	0	0	0
Rhus_gla	0	0	0	0	0	0	0	0	0	0	0
Rubu fla	0	0	0	0	0	0	0	0	0	0	0.6
Scir-pen	0	0	0	0	0	0	0	0	0	0	0
Soli_can	8.1	0.8	0.2	0.1	4.3	2	8.8	23.6	15.2	0	3
Sorg_nut	3	0.6	0	0	0.6	3.1	0	0	1.8	6.6	6
Sphe_obt	0	0	0	0	0	0.6	1.2	0	0	0	0
Spir_cer	0	0	0	0	0	0	0	0	0	0	0
Spor_asp	0	0	0	0	0	0.1	0	0	0	0	0
Teuc_can	0	0	0	0	0	0	0	0	0	0	0
Toxi_rad	0	0	0	0	0	0	0	0	0	0	0
Trip_dac	0	0	0	0	0	0	0	0	0	0	0
Ulm_pum	0	0	0	0	0	0	0	0	0	0	0

## Appendix 2. Percent cover data matrix - continued.

CODE	C6W	D6W	E6W	F6W
Acal_vir	0	0	0	0
Achi_mil	0	0	0	0
Agro_smi	0	0	0.1	0.2
Alli_spe	0	0	0	0
Andr_ger	11.7	9	4.3	3.6
Andr_sco	6.1	3	0.1	5.4
Andr_vir	0	0	0	0
Aris_dic	0	0	0	0
Aste_pil	2.4	4.3	26.1	14.7
Bout_cur	1.2	7.2	8.7	28.5
Buch_dac	0	0	0	0
Care_un1	0.1	0.6	1.2	0
Care_un2	0	0	0	0
Cirs_alt	0	0	0	0.7
Cony_can	0	0	0	0
Corn_dru	0	0	0	0
Cron_cap	0	0	0	0
Cype_spe	0	0	0	0
Dale_pur	0.6	0	0	0
Desm_ill	0	0	0	0
Dica_sps	0	0	0	1.2
Elae_ang	0	0	0	0
Eleo_spe	0	0	0	0
Erig_str	1.8	0.6	1.2	1.3
Eupa_rug	0	0	0	6
Euth_gym	0	0	0	0
Fest_pra	0	0	0	0
Gall_cul	0	3	0	0
Gaur_bie	0	0	0	0
Geum_ver	0.6	0.1	3.6	1.8
Heli_ann	0	0	0	0
Heli_max	0	0	0.6	0
Junc_un1	0	0	0	0
Juni_vir	0	0	0	0.1
Lesp_vio	0	0	0	0
Meli_sps	0	0	0	0
Oxal_dil	0	0	0.1	0
Pani_cap	0	0	0	0
Pani_vir	52	36.1	23	13.5
Phys_lon	0	0.6	0	0
Poa_pra	0	0	0.6	0
Popu_del	0	0	12.5	0
Pycn_ten	0	0	0	0.6
Rati_pin	0	0	0	0.6
Rhus_aro	0	0	0	0
Rhus_cop	0	0	29.5	0
Rhus_gla	0	0	0	0
Rubu_fla	0	0	0	0
Scir_pen	0	0	0	0
Soli_can	4.2	44.5	9.6	9.7
Sorg_nut	0.6	1.2	3.6	9
Sphe_obt	0	0	0	0
Spir_cer	0	0	0	0
Spor_asp	0	0	0	0
Teuc_can	0	0	0	0
Toxi_rad	0	0	0	0.6
Trip_dac	0	0	0	0
Ulmu_pum	0	0	0	0.1

Appendix 3. Results of exploratory ANOVA of differences between mean cover values of species within plots grouped by level of the regularity of standing water. Means with different letters are significantly different; \* =  $P < 0.05$ , \*\* =  $P < 0.01$ , \*\*\* =  $P < 0.001$ , \*\*\*\* =  $P < 0.0001$ . The non-random assignment of plots to groups (treatments) violates assumptions required for hypothesis testing; results should be interpreted with caution.

REGULARITY OF STANDING WATER									
	NEVER	s.d.	LOW	s.d.	SOME	s.d.	HIGH	s.d.	
Acal_vir*	0.02	0.039 bc	0.02	0.048 bc	0.08	0.153 a	0.02	0.037 ac	
Achi_mil	0.00	0.000	0.09	0.089	0.08	0.256	0.00	0.000	
Agro_smi	0.67	1.093	0.78	1.547	0.31	0.582	0.17	0.287	
Alli_spe	0.03	0.125	0.00	0.000	0.00	0.000	0.00	0.000	
Andr_ger**	16.10	7.473 a	11.54	7.450 b	7.92	5.317 c	5.82	4.132 bc	
Andr_sco	3.17	4.156	2.08	2.494	1.98	2.189	1.30	2.385	
Andr_vir	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	
Aris_dic	0.00	0.000	0.00	0.000	0.55	2.464	0.00	0.000	
Aste_pil	1.01	3.152	0.92	3.874	0.12	0.276	0.10	0.224	
Bout_cur***	26.00	11.118 a	18.03	11.336 b	6.39	7.635 c	0.92	1.575 d	
Buch_dac	0.00	0.000	0.33	1.249	0.04	0.150	0.02	0.037	
Care_un1	0.05	0.172	0.07	0.227	0.15	0.550	0.10	0.224	
Care_un2	0.00	0.000	0.00	0.000	0.20	0.761	0.50	1.118	
Cirs_alt	0.06	0.187	0.00	0.000	0.00	0.018	0.00	0.000	
Cony_can	0.00	0.021	0.03	0.128	0.00	0.000	0.00	0.000	
Corn_dru	0.00	0.000	0.17	1.105	0.06	0.165	0.02	0.037	
Cron_cap	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	
Cype_spe	0.00	0.000	0.01	0.088	0.04	0.150	0.00	0.000	
Dale_pur	0.01	0.034	0.06	0.150	0.03	0.111	0.10	0.224	
Desm_ill	0.02	0.065	0.04	0.125	0.01	0.040	0.00	0.000	
Dica_sps	0.06	0.250	0.08	0.269	0.05	0.165	0.00	0.000	
Elae_ang	0.14	0.625	0.00	0.000	0.00	0.000	0.00	0.000	
Eleo_spe	0.00	0.000	0.07	0.442	0.00	0.000	0.00	0.000	
Erig_str	1.05	1.515	1.29	1.593	1.16	2.577	0.30	0.337	
Eupa_rug	0.30	1.250	0.02	0.089	0.06	0.180	0.00	0.000	
Euth_gym	0.01	0.029	0.00	0.029	0.18	0.864	0.10	0.224	
Fest_pra	0.96	3.557	0.00	0.029	0.10	0.272	0.02	0.037	
Gall_cul	0.14	0.625	0.00	0.000	0.00	0.000	0.00	0.000	
Gaur_bie	0.19	0.662	0.08	0.238	0.05	0.150	0.00	0.000	
Geum_ver	0.15	0.438	0.21	0.693	0.19	0.760	0.00	0.000	
Heli_ann	0.00	0.021	0.00	0.000	0.00	0.000	0.00	0.000	
Heli_max	0.14	0.624	0.30	0.719	0.22	0.656	0.03	0.047	
Junc_un1	0.00	0.000	0.07	0.442	0.02	0.126	0.00	0.000	
Juni_vir	0.00	0.021	0.00	0.015	0.00	0.000	0.00	0.000	
Lesp_vio	0.00	0.000	0.00	0.000	0.65	3.500	0.00	0.000	
Meli_sps	0.44	1.872	0.45	1.591	0.13	0.663	0.00	0.000	
Oxal_dil	0.01	0.029	0.01	0.025	0.01	0.034	0.00	0.000	
Pani_cap	0.00	0.000	0.10	0.472	0.15	0.571	0.00	0.000	
Pani_vir****	23.22	11.305 c	22.63	12.413 cd	40.19	21.178 b	60.27	8.207 a	
Phys_lon	0.03	0.125	0.02	0.091	0.01	0.030	0.00	0.000	
Poa_pra	1.18	3.530	0.60	2.014	0.33	0.789	0.73	1.306	
Popu_del	0.00	0.000	0.28	1.843	0.92	3.791	0.12	0.219	
Pycn_ten	0.03	0.126	0.08	0.299	0.02	0.109	0.02	0.037	
Rati_pin	0.05	0.172	0.04	0.150	0.14	0.651	0.00	0.000	
Rhus-aro	0.27	0.862	0.00	0.000	0.00	0.000	0.00	0.000	
Rhus_cop	0.00	0.000	0.66	4.348	0.25	1.346	0.00	0.000	
Rhus_gla	0.16	0.631	0.07	0.442	0.10	0.539	0.00	0.000	
Rubu_flg	0.05	0.172	0.01	0.088	0.02	0.108	0.00	0.000	
Scir-pen	0.00	0.000	0.00	0.000	0.02	0.108	0.00	0.000	
Soli_can	9.38	10.627	5.98	8.369	5.01	5.441	6.68	4.726	
Sorg_nut*	3.79	3.644 a	1.13	1.548 ab	2.84	4.438 ab	1.83	1.512 b	
Sphe_obt	0.09	0.205	0.17	0.624	0.48	1.430	0.13	0.256	
Spir_cer	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	
Spor_asp	0.17	0.630	0.60	2.149	0.39	1.428	0.02	0.037	
Teuc_can	0.00	0.000	0.00	0.015	0.00	0.000	0.00	0.000	
Toxi_rad	0.03	0.125	0.00	0.000	0.00	0.000	0.00	0.000	
Trip_dac	0.00	0.000	0.07	0.442	0.55	1.578	0.02	0.037	
Ulm_pum	0.00	0.021	0.00	0.000	0.00	0.000	0.00	0.000	



Appendix 4. Results of exploratory ANOVA of differences between mean cover values of species within plots grouped by level of mine refuse at the soil surface. Means with different letters are significantly different; \* =  $P < 0.05$ , \*\* =  $P < 0.01$ . The non-random assignment of plots to groups (treatments) violates assumption required for hypothesis testing; results should be interpreted with caution.

	LEVEL OF MINE REFUSE PRESENT					
	NONE	s.d.	SOME	s.d.	HIGH	s.d.
Acal_vir	0.02	0.063	0.07	0.138	0.03	0.067
Achi_mil	0.02	0.106	0.02	0.104	0.13	0.377
Agro_smi	0.53	1.169	0.69	1.395	0.59	0.502
Alli_spe	0.01	0.076	0.00	0.000	0.00	0.000
Andr_ger	11.51	8.699	10.21	4.497	11.70	6.037
Andr_sco	2.56	3.313	1.83	2.024	1.54	2.037
Andr_vir	0.00	0.000	0.00	0.017	0.00	0.000
Aris_dic*	0.00	0.000 b	0.09	0.522 b	1.50	4.243 a
Aste_pil	0.95	3.790	0.25	0.525	0.11	0.281
Bout_cur*	18.23	13.446 a	11.71	10.766 bc	8.42	7.098 ac
Buch_dac*	0.01	0.076 b	0.46	1.460 a	0.07	0.189 ab
Care_un1	0.06	0.207	0.16	0.540	0.07	0.189
Care_un2	0.05	0.391	0.19	0.726	0.00	0.000
Cirs_alt	0.02	0.115	0.00	0.017	0.00	0.000
Cony_can*	0.00	0.000 b	0.02	0.065 a	0.09	0.251 a
Corn_dru	0.13	0.944	0.04	0.158	0.01	0.031
Cron_cap**	0.00	0.000 b	0.00	0.000 b	0.01	0.031 a
Cype_spe	0.01	0.076	0.02	0.104	0.07	0.189
Dale_pur	0.04	0.130	0.05	0.146	0.01	0.031
Desm_ill	0.02	0.107	0.02	0.057	0.04	0.068
Dica_sps	0.05	0.228	0.05	0.148	0.16	0.406
Elae_ang	0.05	0.378	0.00	0.000	0.00	0.000
Eleo_spe	0.00	0.000	0.09	0.522	0.00	0.000
Erig_str*	0.93	1.974 b	1.57	1.773 a	1.09	1.465 ab
Eupa_rug	0.11	0.758	0.02	0.105	0.20	0.283
Euth_gym*	0.03	0.109 b	0.00	0.017 b	0.53	1.508 a
Fest_pra	0.37	2.170	0.04	0.145	0.02	0.063
Gall_cul	0.05	0.378	0.00	0.000	0.00	0.000
Gaur_bie	0.07	0.392	0.12	0.320	0.08	0.187
Geum_ver	0.18	0.638	0.10	0.224	0.48	1.316
Heli_ann	0.00	0.013	0.00	0.000	0.00	0.000
Heli_max	0.29	0.832	0.12	0.204	0.17	0.236
Junc_un1	0.00	0.000	0.09	0.522	0.08	0.220
Juni_vir	0.00	0.018	0.00	0.000	0.00	0.000
Lesp_vic	0.31	2.456	0.00	0.000	0.01	0.031
Meli_sps	0.30	1.273	0.21	1.046	0.97	2.734
Oxal_dil	0.00	0.018	0.01	0.033	0.03	0.047
Pani_cap	0.06	0.399	0.15	0.561	0.02	0.042
Pani_vir	28.16	18.636	35.84	18.040	22.60	14.663
Phys_lon	0.02	0.107	0.01	0.033	0.00	0.000
Poa_pra	0.52	2.144	0.67	2.154	1.51	2.443
Popu_del	0.53	2.948	0.24	1.304	0.00	0.000
Pycn_ten**	0.04	0.183 b	0.01	0.029 b	0.28	0.494 a
Rati_pin	0.05	0.163	0.02	0.104	0.40	1.131
Rhus_aro	0.10	0.530	0.00	0.000	0.00	0.000
Rhus_cop	0.48	3.716	0.00	0.000	0.83	2.357
Rhus_gla	0.06	0.384	0.19	0.726	0.00	0.000
Rubu fla	0.04	0.147	0.00	0.000	0.00	0.000
Scir_pen**	0.00	0.000 b	0.00	0.000 b	0.07	0.189 a
Soli_can**	6.56	7.919 b	4.26	6.204 b	13.70	11.412 a
Sorg_nut	2.34	3.018	1.80	2.738	3.08	5.842
Sphe_obt	0.23	1.016	0.21	0.572	0.40	0.938
Spir_cer**	0.00	0.000 b	0.00	0.000 b	0.01	0.031 a
Spor_asp	0.20	0.653	0.67	2.493	0.92	2.333
Teuc_can	0.00	0.000	0.00	0.017	0.00	0.000
Toxi_rad	0.01	0.076	0.00	0.000	0.00	0.000
Trip_dac	0.22	1.077	0.10	0.522	0.33	0.943
Ulmu_pum	0.00	0.013	0.00	0.000	0.00	0.000

Appendix 5. Results of exploratory ANOVA of differences between mean cover values of species within plots grouped by location within the reclamation area. Means with different letters are significantly different; \* =  $P < 0.05$ , \*\* =  $P < 0.01$ , \*\*\* =  $P < 0.001$ . The non-random assignment of plots to groups (treatments) violates assumption required for hypothesis testing; results should be interpreted with caution.

GROUPS BASED ON LOCATION						
	EDGE	s.d.	LOW LAND	s.d.	MOUND	s.d.
Acal_vir	0.04	0.090	0.05	0.118	0.01	0.032
Achi_mil	0.07	0.242	0.01	0.089	0.00	0.020
Agro_smi	0.44	1.139	0.48	0.632	0.98	1.821
Alli_spe	0.00	0.000	0.01	0.089	0.00	0.000
Andr_ger**	9.36	6.597 b	14.04	6.961 a	8.40	7.563 b
Andr_sco	2.46	3.101	2.55	3.344	1.40	0.953
Andr_vir	0.00	0.017	0.00	0.000	0.00	0.000
Aris_dic	0.49	2.322	0.00	0.000	0.00	0.000
Aste_pil**	1.81	4.973 a	0.12	0.299 b	0.03	0.118 b
Bout_cur*	12.04	12.610 b	15.22	13.264 ab	20.06	10.326 a
Buch_dac	0.26	1.268	0.10	0.460	0.12	0.588
Care_un1	0.11	0.270	0.10	0.460	0.05	0.163
Care_un2*	0.27	0.860 a	0.00	0.000 b	0.00	0.000 b
Cirs_alt	0.04	0.154	0.00	0.000	0.00	0.000
Cony_can	0.04	0.143	0.00	0.015	0.01	0.039
Corn_dru	0.26	1.267	0.02	0.090	0.00	0.000
Cron_cap	0.00	0.017	0.00	0.000	0.00	0.000
Cype_spe	0.04	0.141	0.01	0.089	0.00	0.000
Dale_pur	0.09	0.211	0.02	0.037	0.02	0.040
Desm_ill	0.04	0.109	0.01	0.047	0.03	0.118
Dica_sps	0.09	0.249	0.08	0.272	0.00	0.020
Elae_ang	0.00	0.000	0.07	0.447	0.00	0.000
Eleo_spe	0.00	0.000	0.00	0.000	0.12	0.588
Erig_str	0.67	0.874	1.73	2.620	0.75	0.789
Eupa_rug	0.19	1.016	0.04	0.151	0.03	0.118
Euth_gym	0.17	0.813	0.02	0.091	0.00	0.000
Fest_pra	0.15	0.545	0.44	2.531	0.00	0.000
Gall_cul	0.09	0.507	0.00	0.000	0.00	0.000
Gaur_bie	0.07	0.179	0.14	0.511	0.02	0.118
Geum_ver**	0.46	1.057 a	0.05	0.160 b	0.02	0.118 b
Heli_ann	0.00	0.017	0.00	0.000	0.00	0.000
Heli_max	0.28	0.655	0.20	0.703	0.20	0.597
Junc_un1	0.02	0.118	0.00	0.000	0.12	0.588
Juni_vir	0.00	0.017	0.00	0.000	0.00	0.020
Lesp_vio	0.58	3.294	0.00	0.000	0.00	0.000
Meli_sps	0.46	1.639	0.23	1.344	0.32	1.188
Oxal_dil	0.01	0.028	0.01	0.034	0.00	0.000
Pani_cap	0.01	0.024	0.06	0.221	0.24	0.828
Pani_vir**	35.13	19.440 a	32.00	18.842 a	19.76	11.862 b
Phys_lon	0.04	0.141	0.01	0.032	0.00	0.020
Poa_pra	0.55	1.419	1.10	3.041	0.01	0.027
Popu_del*	1.18	4.077 a	0.01	0.089 b	0.00	0.000 b
Pych_ten	0.06	0.224	0.07	0.262	0.00	0.000
Rati_pin**	0.20	0.629 a	0.00	0.000 b	0.02	0.118 b
Rhus_aro	0.00	0.000	0.14	0.625	0.00	0.000
Rhus_cop	1.09	5.105	0.00	0.000	0.00	0.000
Rhus_gla	0.18	0.706	0.08	0.454	0.00	0.000
Rubu_fla	0.05	0.170	0.01	0.089	0.00	0.000
Scir_pen	0.02	0.101	0.00	0.000	0.00	0.000
Soli_can***	8.48	9.361 a	7.65	8.275 a	1.64	2.422 b
Sorg_nut**	3.49	4.271 a	2.16	2.851 a	0.67	1.126 b
Sphe_obt	0.28	1.268	0.27	0.656	0.12	0.587
Spir_cer	0.00	0.017	0.00	0.000	0.00	0.000
Spor_asp*	0.31	1.350 b	0.12	0.465 b	1.06	2.798 a
Teuc_can	0.00	0.017	0.00	0.000	0.00	0.000
Toxi_rad	0.02	0.101	0.00	0.000	0.00	0.000
Trip_dac	0.18	0.717	0.31	1.262	0.00	0.000
Ulmu_pum	0.00	0.017	0.00	0.000	0.00	0.000

Appendix 6. Species, common name, code, mean percent cover, standard deviation, relative cover, frequency, relative frequency.

	SPECIES	CODE	COMMON NAME	LIFE FORM	MEAN PERCENT COVER	STD ERR	RELATIVE COVER	FREQUENCY	RELATIVE FREQUENCY
CUPRESSACEAE	Juniperus virginiana L.	Junivir	Red Cedar	NATIVE TREE	0.002	0.0138	0.003	1.94	0.181
Ulmaceae	Ulmus pumila L.	Ulmupum	Siberian Elm	ADVENTITIOUS TREE	0.001	0.0098	0.001	0.97	0.090
SALICACEAE	Populus deltoides Marsh.	Popudel	Cottonwood	NATIVE TREE	0.395	2.4070	0.528	4.85	0.452
ROSACEAE	Geum vernum (Raf.) T. & G. Rubus flagellaris Willd.	Geumver Rubufla	Spring Avens Northern Dewberry	NATIVE PERENNIAL FORB NATIVE SHRUB	0.180 0.023	0.6491 0.1159	0.240 0.031	18.45 3.88	1.719 0.362
MIKUSACEAE	Desmanthus illinoensis (Michx.) MacM.	Desm_ill	Illinois Bundle Flower	NATIVE PERENNIAL FORB	0.023	0.0916	0.031	10.68	0.995
FABACEAE	Dalea purpurea Vent. Lespedeza violacea (L.) Pers. Melilotus sps.	Dale_pur Lesp_vio Mill_sps	Purple Prairie Clover Prairie Lespedeza Sweet Clover	NATIVE PERENNIAL FORB* NATIVE PERENNIAL FORB ADVENTITIOUS BIENNIAL FORB	0.043 0.190 0.328	0.1304 1.9120 1.4175	0.057 0.254 0.438	18.45 1.94 11.65	1.719 0.181 1.086
ELAAGNACEAE	Elaeagnus angustifolia L.	Elae_ang	Russian Olive	ADVENTITIOUS SHRUB*	0.029	0.2941	0.039	0.97	0.090
ONAGRACEAE	Gaura longiflora Spach.	Gaur_bie	Large-flowered Gaura	NATIVE BIENNIAL FORB	0.089	0.3577	0.119	13.59	1.267
CORNACEAE	Cornus drummondii C. A. Mey.	Corn_dru	Rough-leaved Dogwood	NATIVE SHRUB	0.091	0.7395	0.122	7.77	0.724
EUFORBIACEAE	Acalypha virginica L. Croton capitatus Michx.	Acal_vir Crot_cap	Virginia Mercury Woolly Croton	NATIVE ANNUAL FORB NATIVE ANNUAL FORB	0.037 0.001	0.0955 0.0098	0.049 0.001	21.36 0.97	1.991 0.090

\* Indicates species planted or seeded during reclamation activities.

Appendix 6. Species, common name, code, mean percent cover, standard deviation, relative cover, frequency, relative frequency - continued.

SPECIES	CODE	COMMON NAME	LIFE FORM	MEAN PERCENT COVER	STD. ERR.	RELATIVE COVER	FREQUENCY	RELATIVE FREQUENCY
<b>ANACARDIACEAE</b>								
Rhus aromatica Ait.	Rhus_aro	Aromatic Sumac	NATIVE SHRUB*	0.058	0.4140	0.078	1.94	0.181
Rhus copallina L.	Rhus_cop	Shining Sumac	NATIVE SHRUB	0.359	2.9776	0.480	1.94	0.181
Rhus glabra L.	Rhus_gla	Smooth Sumac	NATIVE SHRUB	0.093	0.5069	0.124	3.88	0.362
Toxicodendron radicans (L.) G. Ktze.	Toxi_rad	Poison Ivy	NATIVE SHRUB	0.006	0.0588	0.008	0.97	0.090
<b>OXALIDACEAE</b>								
Oxalis dillenii	Oxal_dil	Yellow Wood Sorrel	NATIVE PERENNIAL FORB	0.009	0.0282	0.012	8.74	0.814
<b>SOLANACEAE</b>								
Physalis longifolia Nutt.	Phys_lon	Ground Cherry	NATIVE PERENNIAL FORB	0.017	0.0852	0.023	7.77	0.724
<b>LAMIACEAE</b>								
Pycnanthemum tenuifolium Schrad.	Pyc_ten	Slender Mountain Mint	NATIVE PERENNIAL FORB	0.050	0.2163	0.067	8.74	0.814
Teucrium canadensis L.	Teuc_can	Germander	NATIVE PERENNIAL FORB	0.001	0.0098	0.001	0.97	0.090
<b>ASTERACEAE</b>								
Achillea millefolium L.	Achi_mil	Yarrow	ADVENTITIOUS PERENNIAL FORB	0.030	0.1538	0.040	4.85	0.452
Aster pilosus Willd.	Aste_pil	Hairy Aster	NATIVE PERENNIAL FORB	0.658	2.9774	0.879	27.18	2.534
Cirsium altissimum (L.) Spreng.	Cirs_alt	Tall Thistle	NATIVE PERENNIAL FORB	0.014	0.0904	0.018	2.91	0.271
Conyza canadensis (L.) Cronq.	Cony_can	Horseweed	NATIVE ANNUAL FORB	0.015	0.0864	0.019	4.85	0.452
Erigeron strigosus Muhl. ex Willd.	Erig_str	Daisy Fleabane	NATIVE ANNUAL FORB	1.143	1.8955	1.526	82.52	7.692
Eupatorium rugosum Houtt.	Eupa_rug	White Snakeroot	NATIVE PERENNIAL FORB	0.089	0.5993	0.119	7.77	0.724
Euthamia gymnospermoides Greene	Euth_gym	Viscid Euthamia	NATIVE PERENNIAL FORB	0.063	0.4768	0.084	6.80	0.633
Gallardia cultivar	Gall_cul	Indian Blanket Flower	NATIVE BIENNIAL FORB CULTIVAR	0.029	0.2942	0.039	0.97	0.090
Helianthus annuus L.	Heli_ann	Common Sunflower	NATIVE ANNUAL FORB	0.001	0.0098	0.001	0.97	0.090
Helianthus maximiliani Schrad.	Heli_max	Maximilian Sunflower	NATIVE PERENNIAL FORB*	0.225	0.6637	0.301	32.04	2.986
Ratibida pinnata (Vent.) Barne.	Rati_pin	Greyhead Prairie Coneflower	NATIVE PERENNIAL FORB*	0.071	0.3767	0.095	7.77	0.724
Solidago canadensis L.	Soli_can	Canada Goldenrod	NATIVE PERENNIAL FORB	6.466	8.1962	8.633	97.09	9.050
<b>JUNCACEAE</b>								
Juncus sp.	Junc_unl	Rush	NATIVE FORB	0.036	0.3014	0.048	1.94	0.181

\* Indicates species planted or seeded during reclamation activities.

Appendix 6. Species, common name, code, mean percent cover, standard deviation, relative cover, frequency, relative frequency - continued.

SPECIES	CODE	COMMON NAME	LIFE FORM	MEAN PERCENT COVER	STD ERR	RELATIVE COVER	FREQUENCY	RELATIVE FREQUENCY
<b>CYPERACEAE</b>								
Carex sp. #1	Care_un1	Sedge	SEDGE	0.092	0.3486	0.123	13.59	1.267
Carex sp. #2	Care_un2	Sedge	SEDGE	0.088	0.5101	0.118	2.91	0.271
Cyperus sp.	Cype_spe	Umbrella Sedge	SEDGE	0.017	0.1009	0.023	2.91	0.271
Eleocharis sp.	Eleo_spe	Spikerush	SEDGE	0.029	0.2942	0.039	0.97	0.090
Scirpus pendulus Muhl.	Scir_pen	Bulrush	NATIVE PERENNIAL FORB	0.006	0.0588	0.008	0.97	0.090
<b>POACEAE</b>								
Agropyron smithii (Pursh) Scribn. & Sm.	Agro_smi	Western Wheat Grass	NATIVE PERENNIAL GRASS*	0.585	1.2058	0.782	68.93	6.425
Andropogon gerardii Vitman	Andr_ger	Big Blue Stem	NATIVE PERENNIAL GRASS*	11.125	7.4429	14.854	95.15	8.869
Andropogon scoparius Michx.	Andr_sco	Little Blue Stem	NATIVE PERENNIAL GRASS*	2.242	2.8984	2.993	75.73	7.059
Andropogon virginicus L.	Andr_vir	Broom Sedge	NATIVE PERENNIAL GRASS	0.001	0.0098	0.001	0.97	0.090
Aristida dichotoma Michx.	Aris_dic	Churchmouse Three-Awn	NATIVE PERENNIAL GRASS	0.160	1.3532	0.214	1.94	0.181
Bouteloua curtipendula (Michx.) Torr.	Bout_cur	Side Oats Grama	NATIVE PERENNIAL GRASS*	15.346	12.7488	20.488	90.29	8.416
Buchloe dactyloides (Nutt.) Engelm.	Buch_dac	Buffalo Grass	NATIVE PERENNIAL GRASS*	0.155	0.8431	0.207	7.77	0.724
Dicanthelium sps.	Dica_sps	Dichanthelium	NATIVE PERENNIAL GRASS	0.061	0.2308	0.082	11.65	1.086
Festuca pratensis	Fest_pra	Tall Fescue	NATIVE PERENNIAL GRASS	0.238	1.6937	0.318	9.71	0.905
Panicum capillare L.	Pani_cap	Common Witchgrass	NATIVE PERENNIAL GRASS	0.087	0.4423	0.117	8.74	0.814
Panicum virgatum L.	Pani_vir	Switch Grass	NATIVE PERENNIAL GRASS	30.062	18.6112	40.137	100.00	9.321
Poa pratensis L.	Poa_pra	Kentucky Blue Grass	ADVENTITIOUS PERENNIAL GRASS	0.651	2.1921	0.870	26.21	2.443
Scirgastrium nutans (L.) Nash	Sorg_nut	Indian Grass	NATIVE PERENNIAL GRASS*	2.237	3.3045	2.987	73.79	6.878
Sphenopholis obtusa (Michx.) Scribn.	Sphe_obt	Wedgrass	NATIVE PERENNIAL GRASS	0.238	0.8958	0.318	21.36	1.991
Sporobolus aspera (Michx.) Kunth	Spor_asp	Rough Dropseed	NATIVE PERENNIAL GRASS	0.412	1.6533	0.550	21.36	1.991
Tripsacum dactyloides (L.) L.	Trip_dac	Eastern Gamagrass	NATIVE PERENNIAL GRASS	0.191	0.9301	0.255	5.83	0.543
<b>LILIACEAE</b>								
Allium cepa	Alli_spe	Onion	NATIVE PERENNIAL FORB	0.006	0.0588	0.008	0.97	0.090
<b>ORCHIDACEAE</b>								
Spiranthes cernua (L.) Rich.	Spir_cer	Lady's Tresses	NATIVE PERENNIAL FORB	0.001	0.0098	0.001	0.97	0.090

\* Indicates species planted or seeded during reclamation activities.

Appendix 7. Species richness, N1 and N2 species diversity, and evenness by plot number and code.

PLOT NUMBER/ CODE		RICHNESS	N1 DIVERSITY	N2 DIVERSITY	EVENNESS
1	B6E	17	5.80	3.59	0.54
2	C6E	18	7.57	6.59	0.85
3	B5E	16	3.66	2.16	0.44
4	C5E	11	2.36	1.58	0.43
5	D5E	9	4.93	4.19	0.81
6	B4E	9	3.73	3.12	0.78
7	C4E	11	1.71	1.33	0.47
8	D4E	8	1.82	1.38	0.46
9	E4E	12	4.23	2.77	0.55
10	F4E	9	2.42	1.74	0.52
11	G4E	10	3.51	3.27	0.90
12	B3E	14	3.69	2.93	0.72
13	C3E	13	4.67	3.57	0.70
14	D3E	10	3.90	3.39	0.82
15	E3E	12	4.57	3.94	0.82
16	F3E	11	4.84	4.26	0.85
17	G3E	9	4.47	3.45	0.70
18	H3E	8	4.12	2.87	0.60
19	I3E	10	4.96	4.50	0.88
20	B2E	12	5.34	4.55	0.82
21	C2E	9	1.58	1.25	0.44
22	D2E	12	6.00	4.40	0.68
23	E2E	10	5.75	4.84	0.81
24	F2E	9	4.27	3.74	0.84
25	G2E	10	4.90	4.12	0.80
26	H2E	8	3.77	3.03	0.73
27	I2E	12	5.35	4.70	0.85
28	J2E	15	5.76	4.27	0.69
29	B1E	10	3.18	2.71	0.78
30	C1E	5	2.52	2.22	0.81
31	D1E	9	5.12	4.26	0.79
32	E1E	8	3.98	3.46	0.83
33	F1E	9	2.91	2.14	0.60
34	G1E	15	5.22	4.32	0.79
35	H1E	11	4.75	3.89	0.77
36	I1E	7	4.20	3.86	0.89

Appendix 7. Species richness, N1 and N2 species diversity, and evenness by plot number and code - continued.

PLOT NUMBER/ CODE		RICHNESS	N1 DIVERSITY	N2 DIVERSITY	EVENNESS
37	J1E	11	4.92	4.40	0.87
38	ABL	15	6.50	5.16	0.76
39	BBL	10	3.13	2.59	0.75
40	CBL	7	2.35	2.06	0.78
41	DBL	8	3.26	2.79	0.79
42	EBL	11	3.55	2.79	0.70
43	FBL	7	2.86	2.51	0.81
44	GBL	9	3.50	2.75	0.70
45	HBL	14	6.86	5.67	0.80
46	IBL	9	4.74	3.97	0.79
47	JBL	10	4.27	2.98	0.60
48	KBL	12	6.96	6.41	0.91
49	A1W	11	6.71	6.16	0.90
50	B1W	12	4.75	3.59	0.69
51	C1W	8	4.61	4.25	0.90
52	D1W	10	4.75	4.06	0.81
53	E1W	9	4.93	4.10	0.79
54	F1W	7	3.45	2.86	0.76
55	G1W	13	6.03	5.21	0.84
56	H1W	8	5.04	4.49	0.86
57	I1W	9	4.72	3.91	0.78
58	J1W	8	3.92	2.96	0.67
59	K1W	11	7.27	6.44	0.87
60	A2W	13	2.95	2.02	0.52
61	B2W	16	5.21	4.06	0.73
62	C2W	9	2.43	1.64	0.45
63	D2W	9	3.74	2.88	0.69
64	E2W	7	3.25	2.66	0.74
65	F2W	7	3.04	2.50	0.74
66	G2W	9	5.59	5.35	0.95
67	H2W	7	4.19	3.57	0.81
68	I2W	6	4.38	4.08	0.91
69	J2W	8	2.52	1.78	0.51
70	K2W	10	5.17	4.18	0.76
71	A3W	10	2.90	1.94	0.50
72	B3W	14	5.01	3.54	0.63

Appendix 7. Species richness, N1 and N2 species diversity, and evenness by plot number and code - continued.

PLOT NUMBER/ CODE	RICHNESS	N1 DIVERSITY	N2 DIVERSITY	EVENNESS
73 C3W	12	7.40	6.68	0.89
74 D3W	8	4.39	3.35	0.69
75 E3W	10	4.42	3.17	0.63
76 F3W	9	4.04	3.36	0.78
77 G3W	6	3.55	3.23	0.87
78 H3W	9	4.94	4.50	0.89
79 I3W	8	2.11	1.51	0.45
80 J3W	11	1.89	1.36	0.41
81 A4W	14	4.83	3.01	0.52
82 B4W	15	4.90	3.22	0.57
83 C4W	14	4.80	3.60	0.68
84 D4W	18	6.63	5.47	0.80
85 E4W	16	6.53	4.61	0.65
86 F4W	10	5.79	4.84	0.80
87 G4W	6	1.87	1.50	0.58
88 H4W	11	3.89	2.55	0.54
89 I4W	12	2.48	1.68	0.46
90 A5W	13	1.64	1.21	0.33
91 B5W	7	1.26	1.08	0.33
92 C5W	10	2.28	1.60	0.47
93 D5W	13	5.76	4.33	0.70
94 E5W	15	4.52	2.97	0.56
95 F5W	12	4.47	2.83	0.53
96 G5W	11	3.33	2.48	0.64
97 H5W	14	5.86	4.63	0.75
98 A6W	11	5.01	4.05	0.76
99 B6W	11	5.78	4.65	0.76
100 C6W	11	3.60	2.31	0.50
101 D6W	12	4.85	3.60	0.68
102 E6W	16	7.94	6.64	0.81
103 F6W	18	8.69	6.86	0.76



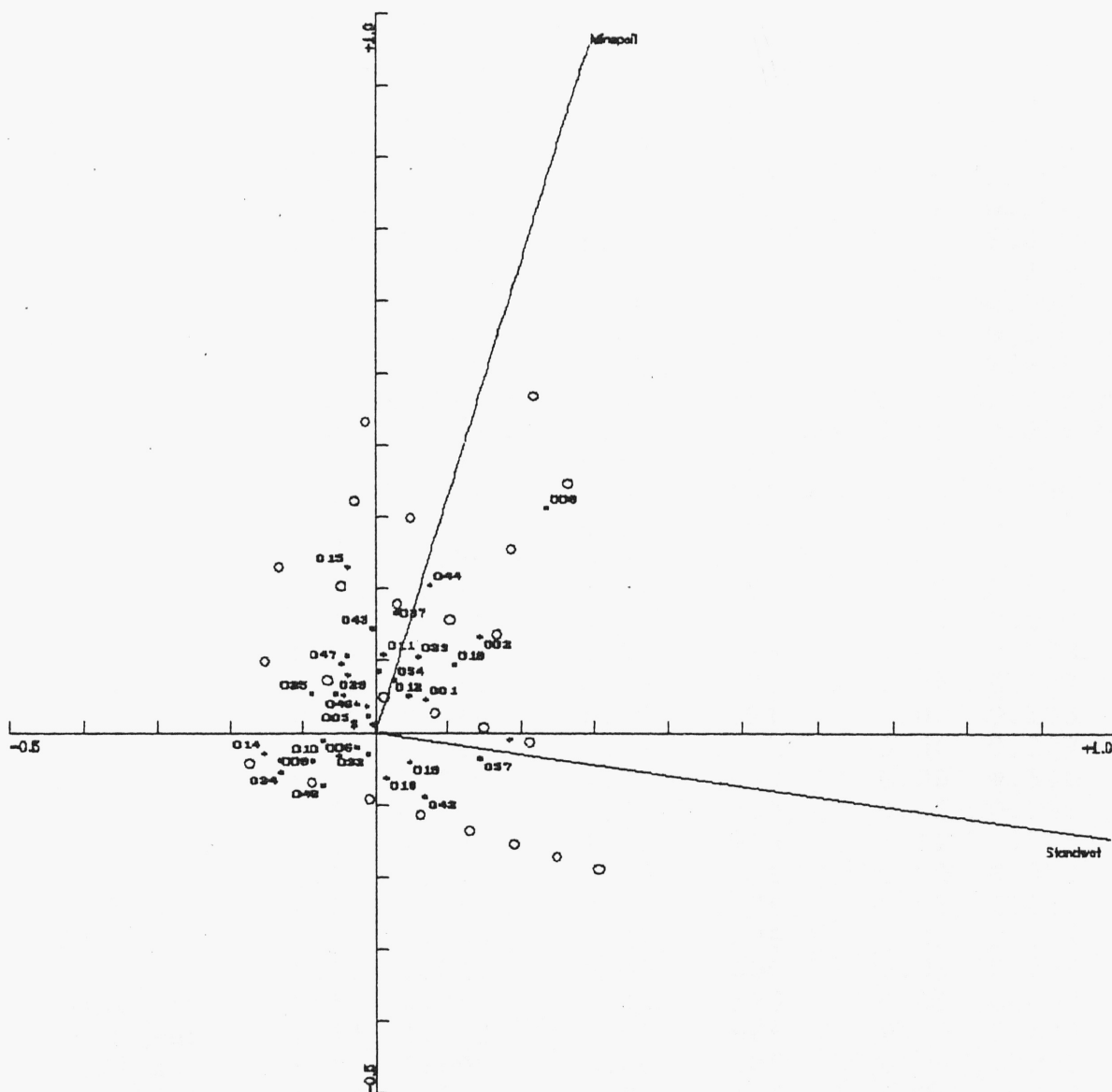
### Appendix 8. TWINSPAN default two-way matrix.

[illegible]

## Appendix 9. TWINSPAN variant two-way matrix.

[illegible]

Appendix 10. Ordination triplot of CCA-DEFAULT showing plots (sites), species, and environmental variables.



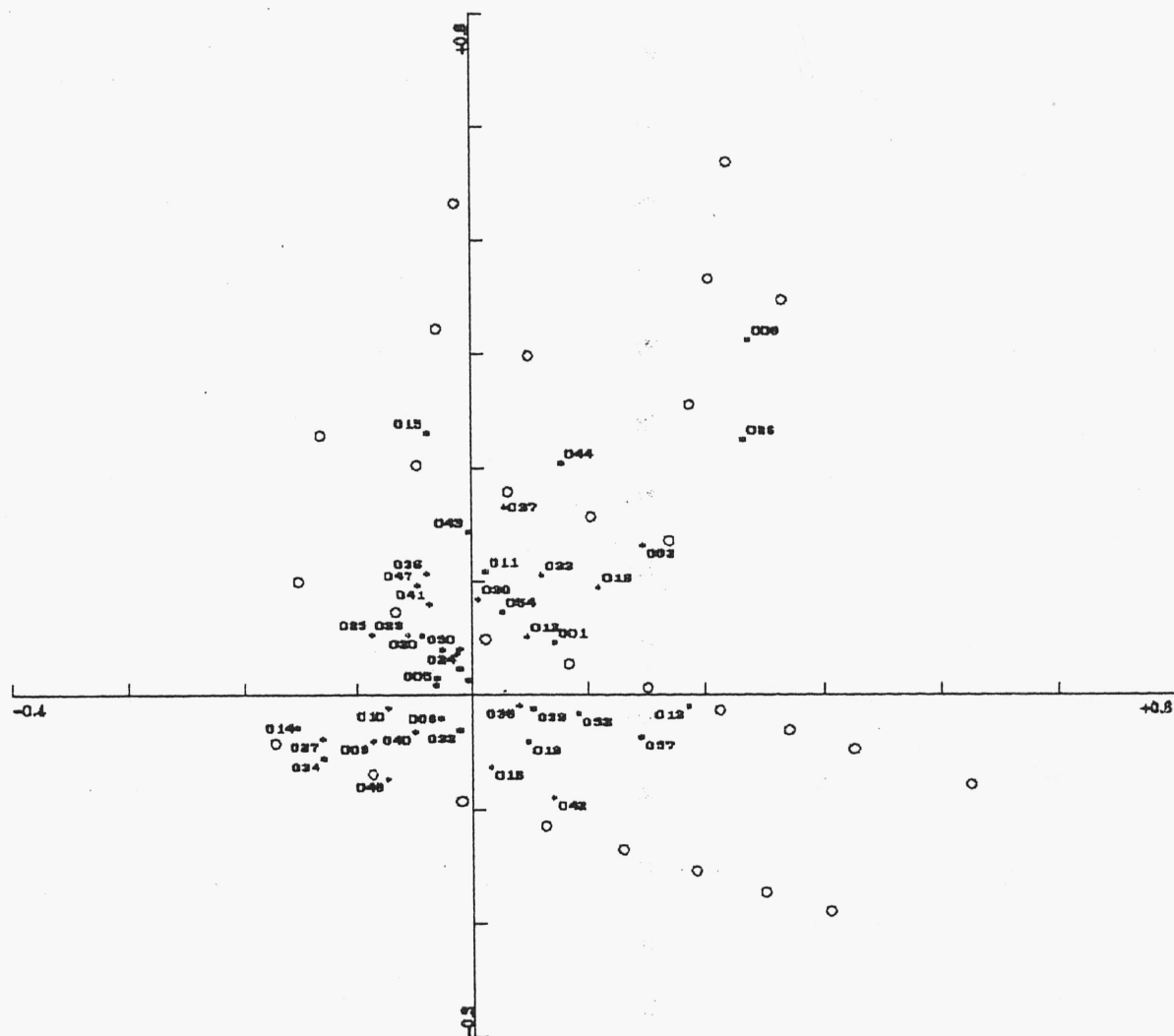
Appendix 11. Exploratory ANOVA of differences between mean cover of species in groups created through partitioning of CCA-DEFAULT ordination axes I and II. Means with different letters are significantly different; \* =  $P < 0.05$ , \*\* =  $P < 0.01$ , \*\*\* =  $P < 0.001$ . The non-random assignment of plots to groups (treatments) violates assumptions required for hypothesis testing, results should be interpreted with caution.

	IMPACT BY MINE REFUSE			IMPACT BY STANDING WATER			LOW IMPACT BY VARIABLES	
	mean	s.d.		mean	s.d.		mean	s.d.
Acal_vir **	0.09	0.175	a	0.07	0.113	a	0.01	0.034 b
Achi_mil	0.08	0.290		0.06	0.176		0.01	0.074
Agro_smi	0.44	0.461		0.16	0.224		0.76	1.452
Alli_spe	0.00	0.000		0.00	0.000		0.01	0.073
Andr_ger **	11.43	5.409	a	6.47	4.273	b	12.53	8.040 a
Andr_sco	1.33	1.708		1.55	1.939		2.68	3.264
Andr_vir	0.01	0.024		0.00	0.000		0.00	0.000
Aris_dic **	1.03	3.300	a	0.00	0.000	b	0.00	0.000 b
Aste_pil	0.13	0.249		0.11	0.221		0.96	3.681
Bout_cur***	8.66	6.560	b	3.53	6.935	c	20.73	11.988 a
Buch_dac *	0.45	0.984	a	0.06	0.176	ab	0.11	0.916 b
Care_un1	0.23	0.731		0.10	0.209		0.06	0.202
Care_un2 *	0.19	0.726	ab	0.29	0.895	a	0.00	0.000 b
Cirs_alt	0.01	0.024		0.00	0.000		0.02	0.112
Cony_can *	0.07	0.196	a	0.00	0.000	b	0.01	0.038 b
Corn_dru	0.05	0.170		0.02	0.050		0.12	0.918
Cron_cap	0.01	0.024		0.00	0.000		0.00	0.000
Cype_spe	0.04	0.145		0.03	0.128		0.01	0.073
Dale_pur	0.02	0.039		0.06	0.176		0.04	0.127
Desm_ill	0.04	0.086		0.00	0.021		0.02	0.105
Dica_sps	0.09	0.313		0.04	0.153		0.06	0.227
Elae_ang	0.00	0.000		0.00	0.000		0.05	0.366
Eleo_spe	0.00	0.000		0.00	0.000		0.05	0.366
Erig_str	1.33	1.597		1.11	2.904		1.11	1.515
Eupa_rug	0.15	0.260		0.03	0.128		0.09	0.733
Euth_gym	0.31	1.161		0.06	0.176		0.01	0.030
Fest_pra	0.09	0.200		0.12	0.299		0.31	2.103
Gall_cul	0.00	0.000		0.00	0.000		0.05	0.366
Gaur_bie	0.16	0.331		0.04	0.129		0.09	0.407
Geum_ver	0.35	1.013		0.02	0.066		0.19	0.626
Heli_ann	0.00	0.000		0.00	0.000		0.00	0.012
Heli_max	0.14	0.226		0.09	0.195		0.29	0.807

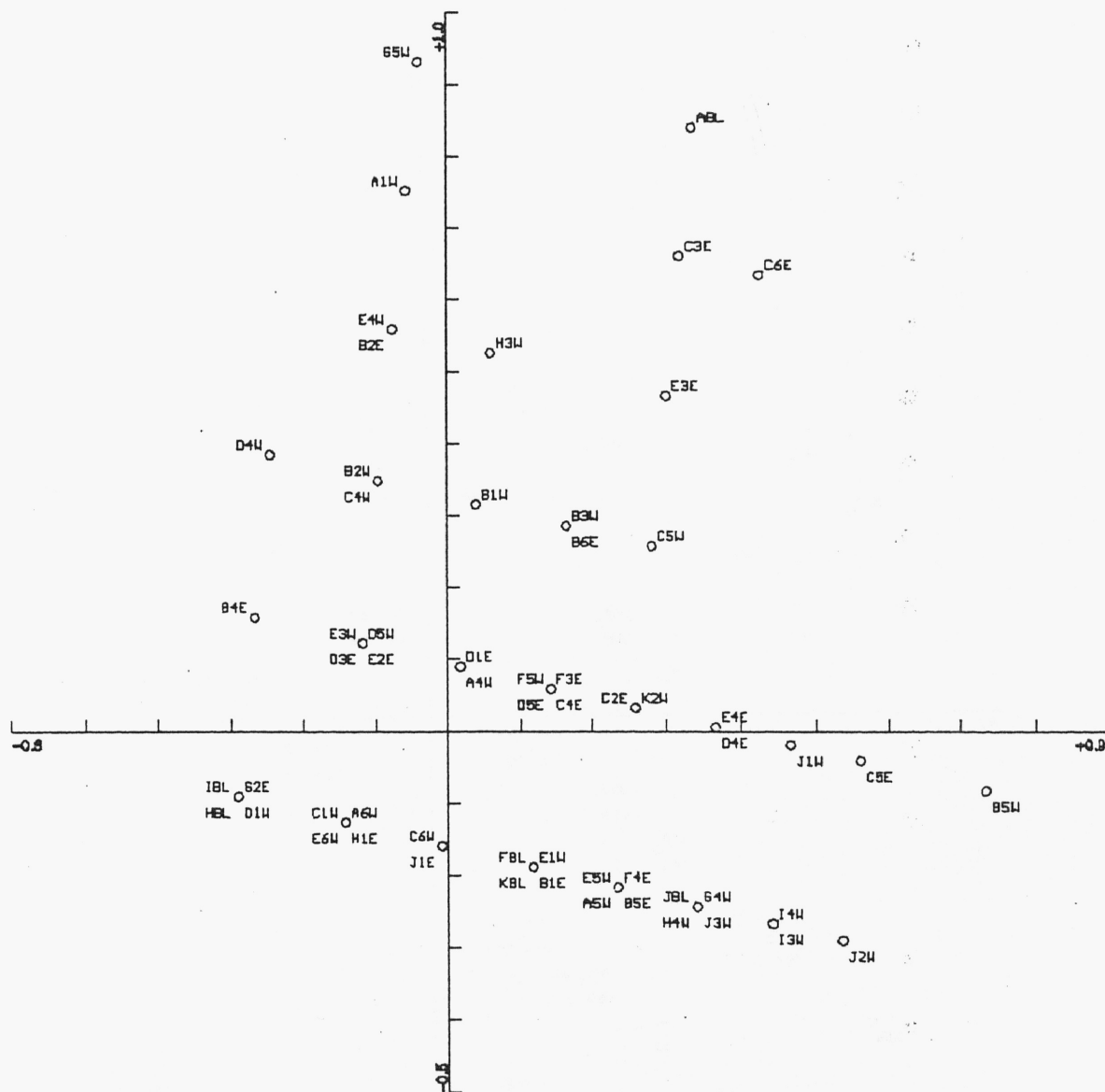
Appendix 11. Exploratory ANOVA of differences between mean cover of species in groups created through partitioning of CCA-DEFAULT ordination axes I and II. Means with different letters are significantly different; \* =  $P < 0.05$ , \*\* =  $P < 0.01$ , \*\*\* =  $P < 0.001$ . The non-random assignment of plots to groups (treatments) violates assumptions required for hypothesis testing, results should be interpreted with caution - continued.

	IMPACT BY MINE REFUSE			IMPACT BY STANDING WATER			LOW IMPACT BY VARIABLES	
	mean	s.d.		mean	s.d.		mean	s.d.
Junc_unl	0.04	0.169		0.00	0.000		0.05	0.366
Juni_vir	0.00	0.000		0.00	0.000		0.00	0.017
Lesp_vio	0.01	0.024		0.93	4.153		0.00	0.000
Meli_sps	0.96	2.468		0.18	0.787		0.22	1.161
Oxal_dil***	0.03	0.046	a	0.00	0.000	b	0.01	0.024
Pani_cap	0.05	0.146		0.04	0.150		0.11	0.540
Pani_vir***	27.14	16.452	b	53.24	17.795	a	23.40	12.518
Phys_lon	0.01	0.033		0.00	0.021		0.02	0.104
Poa_pra	1.36	2.273		0.41	0.983		0.55	2.406
Popu_del	0.00	0.000		1.34	4.465		0.19	1.527
Pycn_ten	0.16	0.394		0.03	0.128		0.03	0.163
Rati_pin	0.23	0.871		0.00	0.000		0.06	0.172
Rhus-aro	0.00	0.000		0.00	0.000		0.09	0.514
Rhus_cop	0.47	1.815		0.00	0.000		0.45	3.604
Rhus_gla	0.38	0.992		0.00	0.000		0.05	0.373
Rubu fla	0.00	0.000		0.00	0.000		0.04	0.143
Scir-pen	0.04	0.145		0.00	0.000		0.00	0.000
Soli_can	10.71	11.289		4.86	4.263		5.95	7.919
Sorg_nut	2.66	5.376		1.89	1.970		2.25	2.952
Sphe_obt	0.30	0.735		0.60	1.675		0.11	0.411
Spir_cer	0.01	0.024		0.00	0.000		0.00	0.000
Spor_asp	0.52	1.809		0.16	0.636		0.47	1.822
Teuc_can	0.00	0.000		0.00	0.000		0.00	0.012
Toxi_rad	0.00	0.000		0.00	0.000		0.01	0.073
Trip_dac	* 0.19	0.726	ab	0.65	1.772	a	0.05	0.366
Ulmu_pum	0.00	0.000		0.00	0.000		0.00	0.012

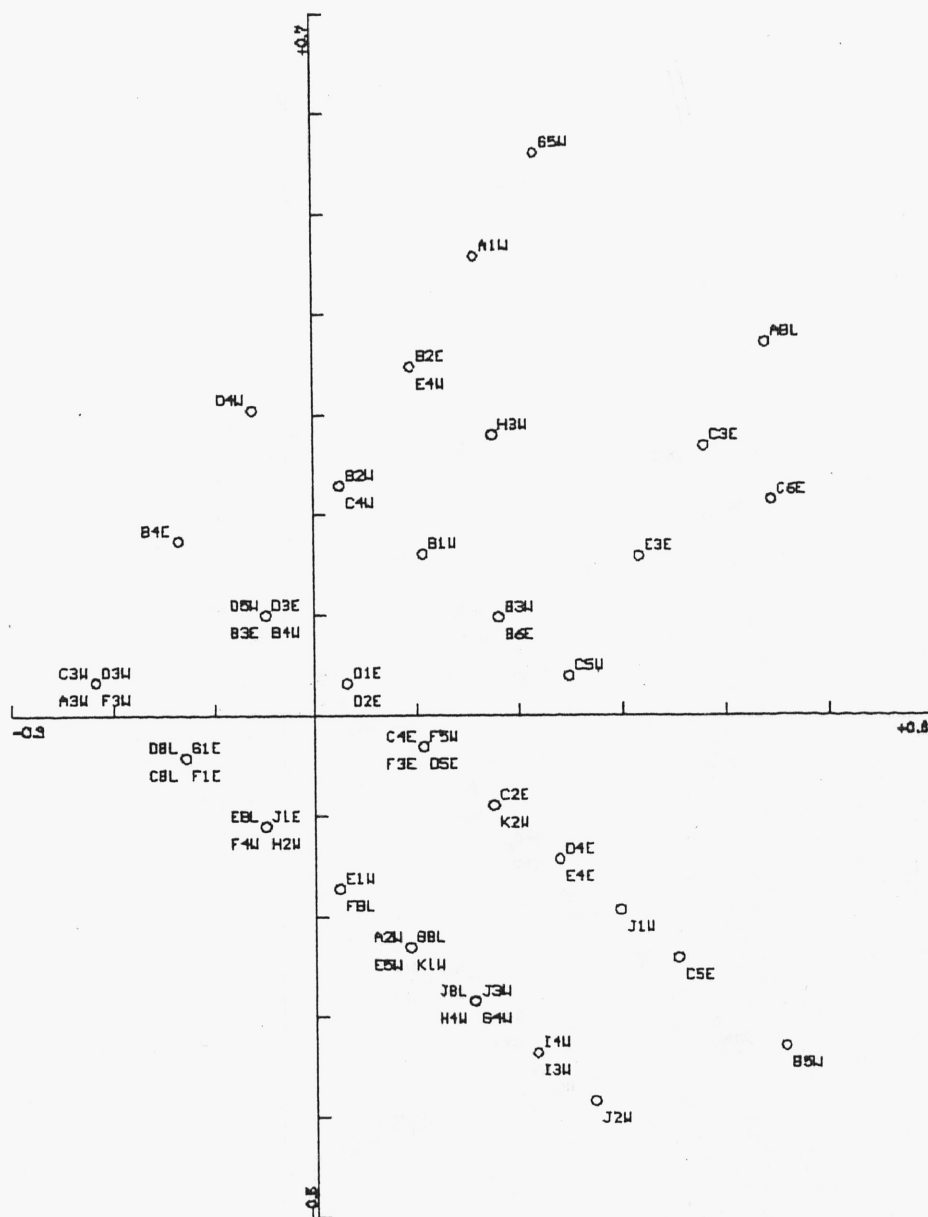
Appendix 12. Ordination biplot of plots (sites) and species.



Appendix 13. Ordination diagram of CCA-DOWN for plots.

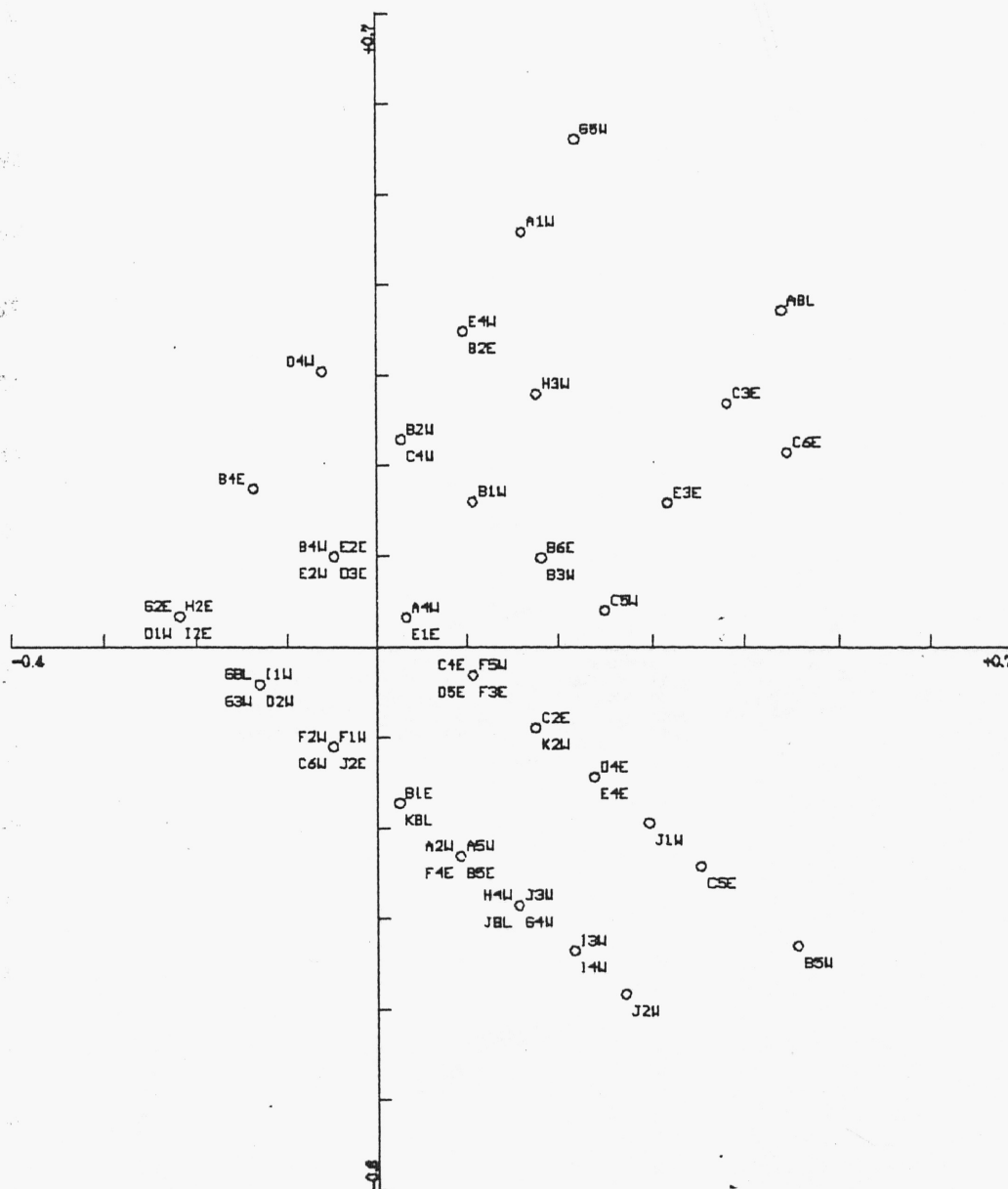


Appendix 14. Ordination diagram of CCA-PASSIVE for plots.

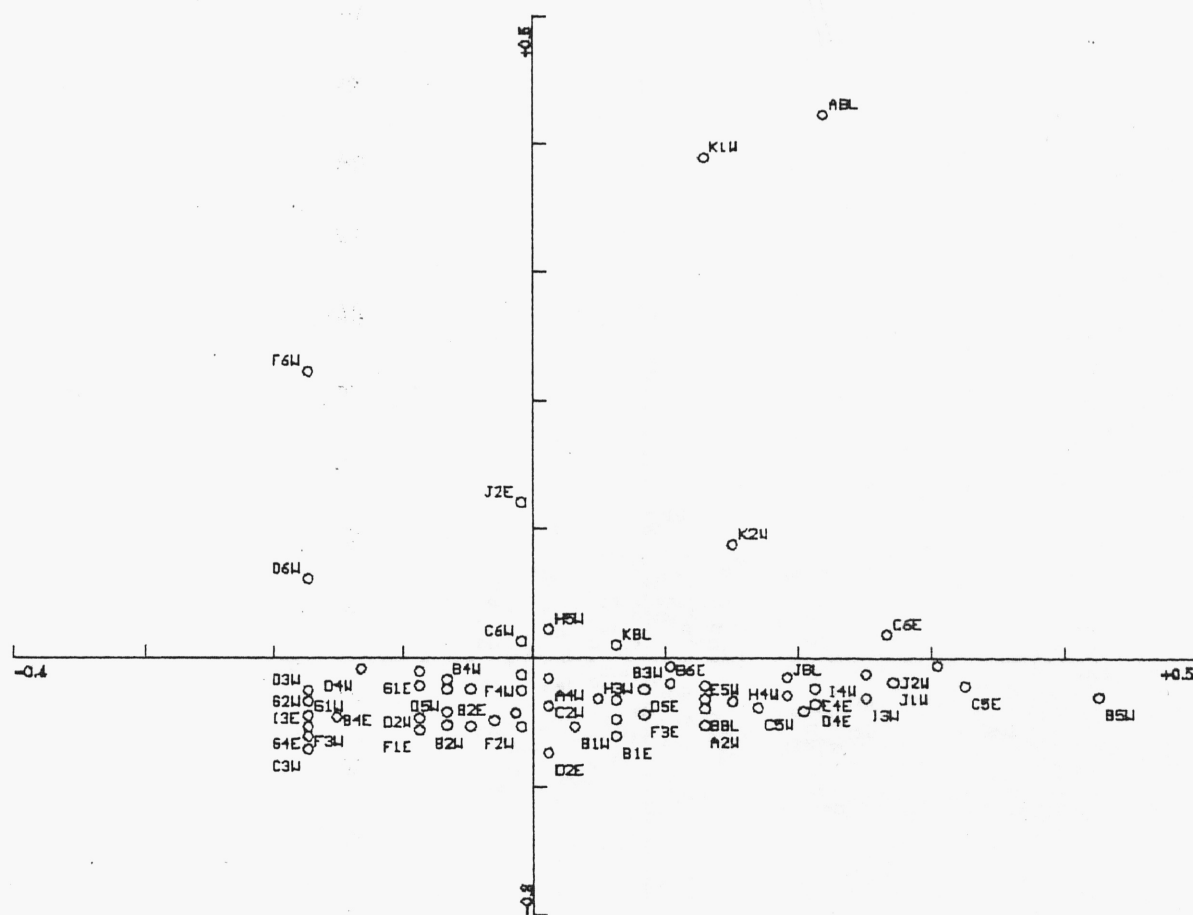




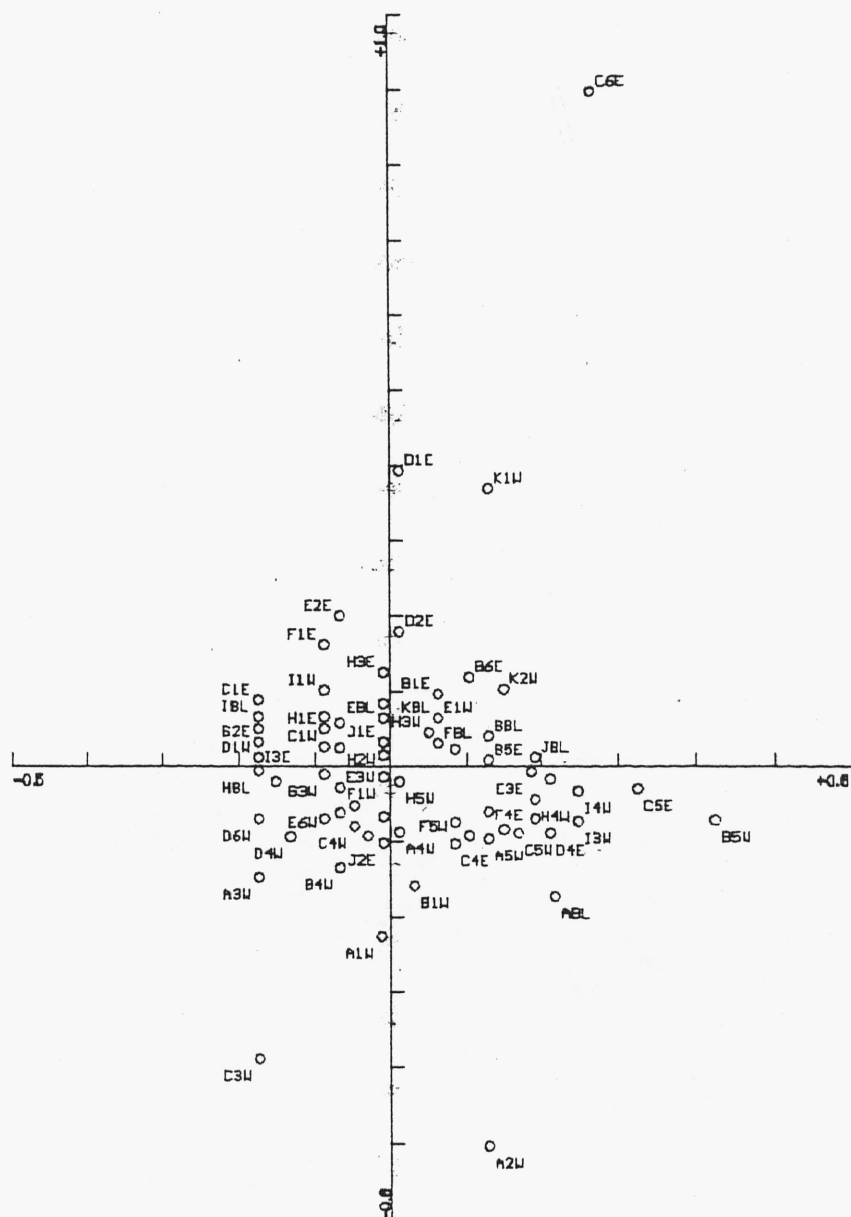
Appendix 15. Ordination diagram of CCA-OCTAVE for plots.



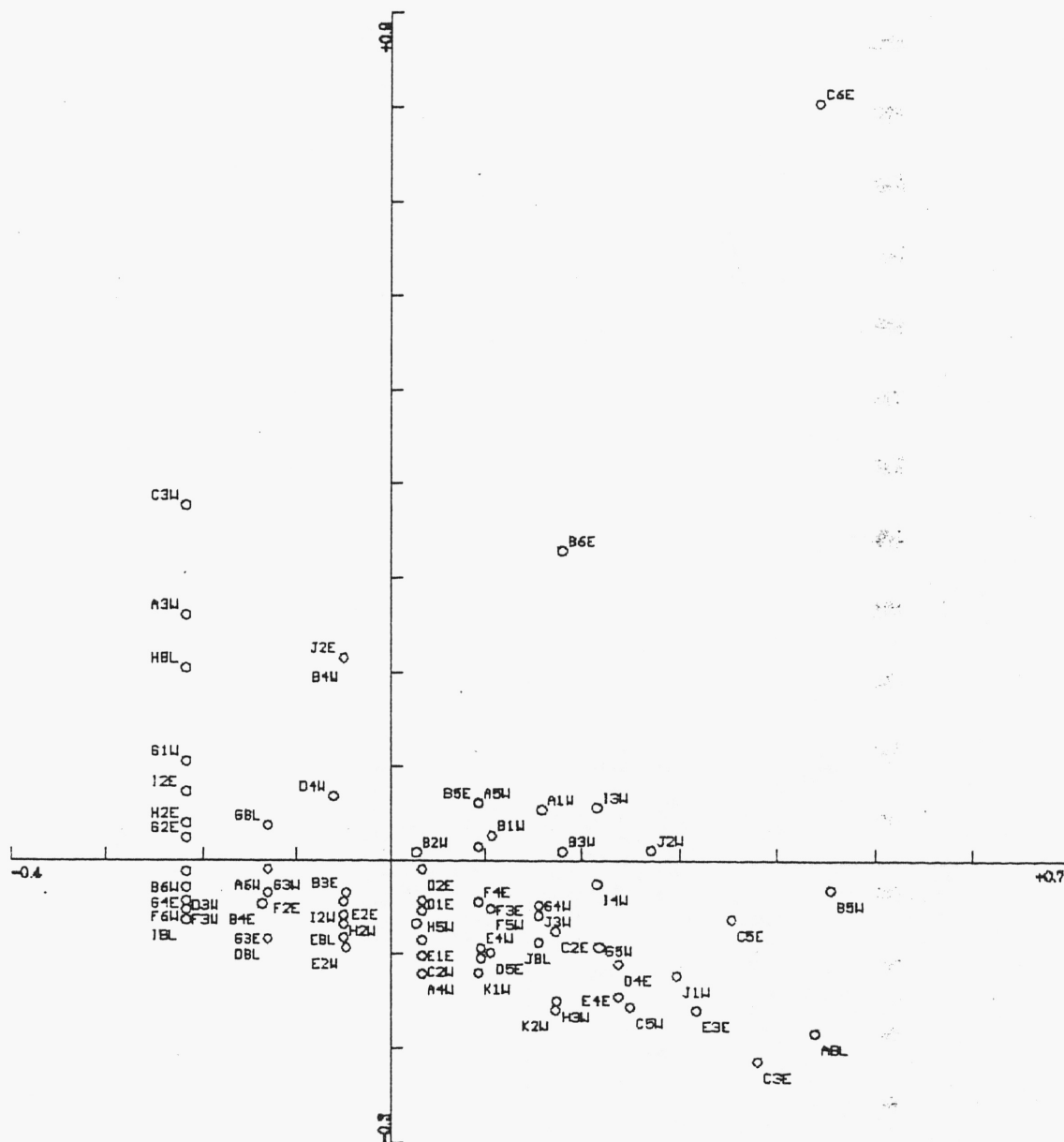
Appendix 16. Ordination diagram of axes 1 and 3 from CCA-DEFAULT for plots.



Appendix 17. Ordination diagram of axes 1 and 4 from CCA-DEFAULT for plots.



Appendix 18. Ordination diagram of axes 1 and 3 from CCA-PASSIVE for plots.



Appendix 19. Ordination diagram of axes 1 and 4 from CCA-PASSIVE for plots.

