EVALUATION OF CATTLE GRAZING EFFECTS ON FLORISTIC COMPOSITION IN EASTERN WASHINGTON VERNAL POOLS

by

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Abstract

Evaluation of Cattle Grazing Effects on Floristic Composition in Eastern Washington Vernal Pools

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Six vernal pools at the Marcellus Shrub-Steppe Preserve were compared with six pools in the adjacent DNR property to investigate differences in floristic composition between ungrazed and grazed vernal pools. In the spring of 1998 and 1999, presence/absence and cover data on vascular plant species were collected along permanent transects that crossed each pool. Pools were sampled twice during each field season, separated by a minimum of three weeks, to account for phenological differences. Relative elevation was surveyed along all transects and soil samples were collected in all study pools. Soil samples were analyzed for pH, organic matter content, and bulk density.

Soils in the grazed pools were significantly more compacted and more alkaline than soils in the ungrazed pools. No differences in organic matter content were detected between the sites, and there were no consistent differences in relative elevation of the pool basins. In both years, few basins held water by early-May, probably due to evaporation caused by the warm, dry weather conditions.

The frequency and/or cover of weed species was significantly greater in all zones of the grazed pools. The greatest differences in species presence was seen in the deepest portions of the pools, where the cover of the dominant sedges (*Eleocharis*) was lower and weed species was greater in the grazed pools. Evidence of livestock grazing on *Eleocharis* was observed in all of the grazed study pools. One rare species was recorded in the study, and it was found with low frequency and cover only in the ungrazed pools. Results of the multivariate analysis indicate that there is

separation of floristic composition between the ungrazed and grazed sites along axes that are correlated with the presence or absence of grazing.

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CHAPTER 1: INTRODUCTION

Vernal pools are seasonal wetlands, formed in shallow depressions where Mediterranean-type rainfall patterns prevail. The pools fill with fall and winter rains and retain water until the late spring or early summer when reduced precipitation and increased evapotranspiration rates lead to complete desiccation. From a botanical perspective, the most interesting feature of the vernal pool ecosystem is its well-developed and often highly diverse flora, which differs dramatically from the surrounding grassland or forest vegetation. Vernal pools are characterized as amphibious ecosystems, exhibiting winter-wet and summer-dry conditions, and it is precisely these ephemeral conditions that can result in the creation of a specialized, sometimes rare, and often highly endemic flora. To survive in a vernal pool, a species must be able to either tolerate a wide range of moisture conditions or to grow and reproduce within a short window of favorable conditions. Typically in these systems, annual species dominate. Their r-selected reproductive strategy enables proliferation in a rapidly-changing environment.

Given the structure of the pool basin, these ecosystems contain environmental gradients that strongly influence the spatial distribution of plant species. Within a pool there tends to be a continuous gradation from the deepest parts of the pool to the surrounding upland area. Along this topographic gradient, the physical environment changes (Lathrop 1976) and plant species composition and relative abundance changes along with it (Zedler 1987). From research conducted on vernal pools in other areas, the depth and duration of standing water is understood to be one of the most influential gradients affecting the distribution of plant species in the vernal pool ecosystem (Purer 1939, Lin, 1970, Zedler 1984, 1987). Plant species are believed to be arranged along the pool-to-margin topographic gradient according to their water inundation tolerance and responses. Other factors found to relate to species distributions in the pools exist in the soil (Lathrop 1976, Bauder 1987). Again, research conducted in other regions has shown that pH, salinity, organic matter content, soil moisture potential, soil oxygen, and texture vary along the pool topographic gradient, all of which are known to be important to plant growth.

Residential development and conversion of land for agricultural and range use are two direct threats to a vernal pool and ones that can completely obliterate the ecosystem. Other threats, less direct but not less important, include land management activities that alter surface and soil organic matter, soil bulk density, or other factors that threaten the physical integrity of the pool basin. One such management activity that may indirectly affect vernal pool ecology and, in doing so, may alter the native plant communities of the pools is cattle grazing. While no data on cattle grazing effects on vernal pool flora have yet been published, grazing activity in other ecosystems has been shown to decrease native plant species density and diversity (Rummell 1951, Szaro and Pase 1983) and increase the spread and establishment of exotic plant species (Mack 1981, D'Antonio and Vitousek 1992, Hobbs and Huenneke 1992, Young and Allen 1997).

The consequences of cattle grazing on vernal pool flora are particularly relevant to the pools of eastern Washington since many of them exist on public lands that are grazed. Given this present state of land use, the Washington Natural Heritage Program (WNHP) has ranked low elevation alkali vernal pools in the Columbia Basin with a Priority 2 protection status. This status is assigned to an ecosystem that either (1) contains rare or highly threatened species or (2) has an intermediate degree of threat and rarity or has little or no representation in the Natural Areas Preserve system (WDNR 1999). It is the second highest priority for state preservation and applies to the pools examined in this study.

Research conducted on vernal pools comes almost entirely from California, where the flora of pools and the environmental gradients influencing floristic composition and distribution have been well-described (Purer 1939; Jain 1976; Holland and Jain 1977; Schlising and Sanders 1982; Zedler 1984, 1987; Riefner and Pryor 1996). In the Pacific Northwest, vernal pools exist in eastern Oregon, eastern Washington, and southeastern Idaho (Bjork 1997), and little is known about the pool floristic structure and its antecedents. This research project was undertaken to build upon the current knowledge of eastern Washington vernal pool flora. Its purpose was to quantify the effects of cattle grazing on vernal pool plant communities and determine environmental gradients correlated with the spatial distribution of plants within the pool basin. Pools were studied in the Marcellus Shrub-Steppe Preserve and adjacent Washington Department of Natural Resources (DNR) land, both located within an area of about one-half square mile in Adams County, Washington. The Marcellus preserve, owned by The Nature Conservancy, has been fenced since 1986 and is not noticeably degraded by past grazing, which occurred there approximately 30 years ago (Schuller 1984). The DNR land contains pools of similar dimension and substrate to those on the preserve, but has been leased for cattle grazing since at least 1957

(D. Warriner, personal communication, 1998). Topography and soil type are very similar on the two sites as well, providing an ideal opportunity to isolate grazing as a disturbance and examine its effects on the pool flora.

Using both parametric statistics and ordination methods, the effects of grazing and patterns of species distribution and variation both within and among pools were investigated. Specific research questions include the following:

- What are the differences in plant species composition and distribution between ungrazed and grazed vernal pools?

- What environmental factors are correlated with the spatial distribution of plant species in vernal pools?

CHAPTER 2: LITERATURE REVIEW

With the exception of one study on Pacific Northwest vernal pools (Crowe et al. 1994), much of the published research on vernal pool plant communities comes from California. Given the similarities of vernal pool floristics between California and the Pacific Northwest, the California research, as it pertains to species composition, vegetation zonation, and within-pool environmental gradients, is presented below. Research on grazing effects from other geographic areas is also discussed.

SPECIES COMPOSITION

In one of the first published studies of vernal pool ecology, Purer (1939) described vascular plants common to the vernal pool flora. In general, she found perennial species present in the deeper portions of the pools and annuals predominating in shallower areas. She focused much of the study on temporal changes in species composition, reporting that there were distinct changes in the pool flora over the course of a growing season. Taxa occurring early in the season were *Callitriche*, *Juncus*, *Eleocharis*, *Isoetes*, and *Pilularia*, followed by individuals of *Downingia*, *Plagiobothrys*, and *Veronica*, which developed leaves and flowers above the water surface. When the soil dried, *Pogogyne* plants matured and late-flowering species, such as *Eryngium parishii*, began to develop. Numerous exotic species were found in the pools as well, some of which included *Juncus bufonius*, *Lepidium nitidum*, and *Plantago hookeriana*.

In describing the vascular plant communities of southern California vernal pools, Zedler (1987) first defined the vernal pool ecosystem as a "sequence of ecosystems rather than a single static type." He identified four distinct sequences—the wetting phase, aquatic phase, drying phase, and drought phase—and discussed plant species representative of each phase. Plants were found to occur primarily in two of the phases—aquatic and drying. The aquatic phase is defined as beginning when the soils become saturated and standing water accumulates. Species prominent in this phase were aquatic, belonging mostly to the following genera: *Isoetes*, *Pilularia*, *Marsilea*, *Callitriche*, *Eleocharis*, *Elatine*, and *Crassula*. In the drying phase, the vernal pool specialists emerged. This group of plants includes species that can spend part of their life as aquatics but that flourish when the pools dry (Zedler 1987), and thus are described as "amphibious." They often are the narrow endemics that define a vernal pool ecosystem. Some of the more common amphibious species observed by Zedler were *Pogogyne abramsii*, *Plagiobothrys* spp., *Psilocarphus* spp., *Downingia* spp., *Deschampsia danthonioides*, *Myosurus minimus*, and *Boisduvalia glabella*.

Lin (1970) studied the succession of plant species in vernal pools. He reported the seral sequence to have been initiated, following the first fall rains, by *Erodium* and *Lomatium* seedlings on the pool margins and *Callitriche* and *Tillaea* seedlings in the depressions. Soon after the pools had filled with water, the first species to produce reproductive structures was *Isoetes orcuttii*. Also at this time, seedlings of *Limnanthes*, *Downingia*, *Lilaea*, *Deschampsia*, and *Lythrum* began to emerge from the standing water, and annual grasses and forbs, including *Festuca*, *Bromus*, and *Juncus bufonius*, appeared on the pool margins. As the pools began to dry, around mid-March, individuals of *Lasthenia*, *Psilocarphus*, and *Navarretia* appeared and replaced the earlier-germinating species. By the end of April, seedlings of late-flowering species, such as *Eryngium*, *Calochortus*, *Eremocarpus*, *Grindelia*, and *Hemizonia*, began to dominate the flora. Lin also observed that with a reduction in rainfall the following growing season, the diversity of plants decreased and most species appeared depauperate. The sequence of succession, however, remained the same.

The first, and only, comprehensive look at vernal pool plant species composition in the Pacific Northwest was a botanical inventory of vascular plant species associated with vernal pools on the Columbia Plateau (Bjork 1997, 1999). The purpose of the inventory was to provide an initial characterization of vernal pools in this region. From 52 pools sampled, Bjork found many of the same genera that are characteristic of California vernal pools, including *Isoetes*, *Pilularia*, *Lilaea*, *Myosurus*, *Plagiobothrys*, *Navarretia*, and *Downingia*. He also recorded numerous rare species in undisturbed (i.e., ungrazed) vernal pools, eight of which had not previously been found in Washington (Table 2-1).

Cryptogams represent another component of the vernal pool flora, and one that has been little studied. A preliminary survey of cryptograms in southern California vernal pools showed a cryptogamic community dominated by cyanobacteria, bryophytes, and lichens and occupying

Table 2-1. Rare Species Found in Ungrazed Vernal Pools by Bjork (1997, 1998)

Species	Rarity Status
Callitriche marginata	New Washington record
Elatine rubella	New Washington record
Juncus hemiendytus var. *hemiendytus*	State List, Possibly Extinct or Extirpated Washington Taxa
Juncus uncialis	State List, Review 1
Mimulus suksdorfii	State List, Sensitive
Myosurus minimus ssp. *apus*	New Washington record, Federal Species of Concern
Parietaria hespera var. *hespera*	New Washington record
Pilularia americana	New Washington record
Scirpus saximontanus	New Washington record
Teucrium canadense	State List, Sensitive

zones similar to the vascular plants (Riefner and Pryor 1996). These communities form soil crusts in the pools (cryptogamic or microbiotic crusts), which are believed to contribute to nutrient cycling, soil aggregation and stability, and soil moisture storage. From the vascular plant's perspective, the presence of cryptogams may increase water availability and facilitate nutrient uptake, as well as provide favorable sites for seed germination (Harper and Pendleton 1993). In undisturbed vernal pools, cryptogamic crusts are often a prominent feature; pristine floras such as the Morro Bay region in San Luis Obispo County are known to support nearly 375 lichen taxa (Riefner and Pryor 1996).

VEGETATION ZONATION

One of the most visually striking aspects of the vernal pool flora is the apparent discontinuity of vegetation types along the center to upland topographic gradient which forms concentric bands, or zones, around the lowest point of the pool (Figure 2-1). This arrangement of plant species along the topographic gradient is believed to be largely influenced by the environmental conditions, such as depth and duration of standing water and soil characteristics, that also vary along the gradient.

There has been debate in the scientific community as to whether these zones are actually spatially-discrete assemblages of species that are apparent throughout the growing season or whether they form a continuous and variable distribution with overlapping growth ranges. Proponents of the former view (Lin 1970, Kopecko and Lathrop 1975, Schlising and Sanders 1982), though differing in some details, identify the existence of a higher zone dominated by annual grassland plant species, an intermediate zone or zones dominated by annual species tolerant of or requiring some degree of inundation, and a lower zone containing the most water-tolerant or water-requiring species.

Others have identified these patterns of plant distribution to be more temporally-defined than spatially-defined or to be a combination of both. Purer (1939) observed that no single species formed a pure stand in the pools she studied and that no group of pool species were regularly associated together. She identified the seasonal aspect as playing an important role in determining plant species composition, where different species germinate and flower in the pools at different times throughout a growing season.

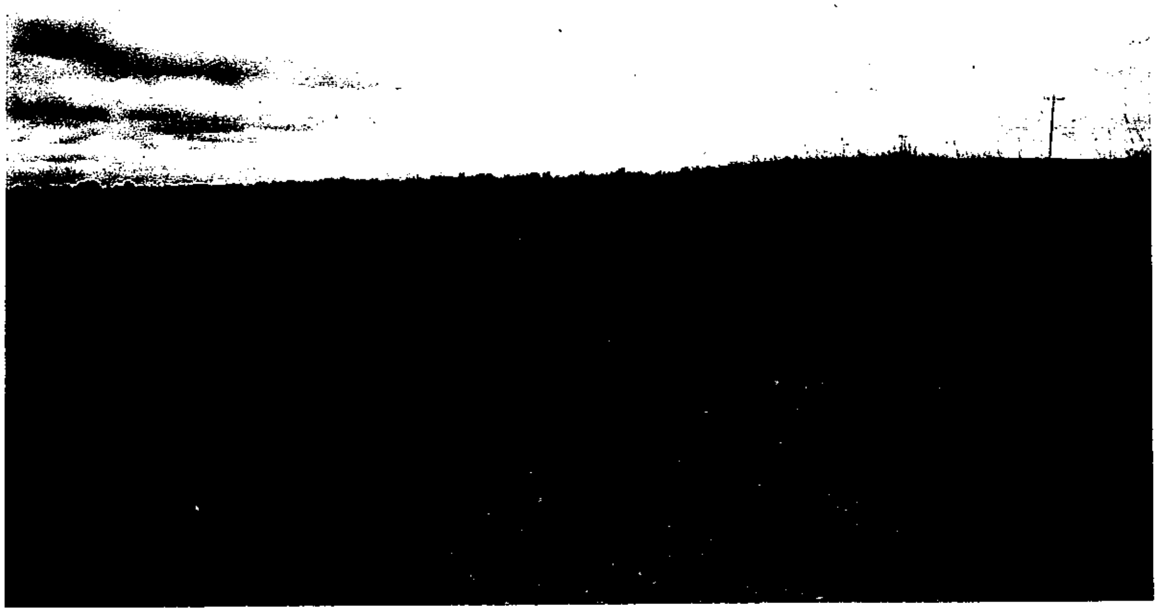


Figure 2-1. Vegetation zonation.

Zedler (1987) suggested that distinct groupings corresponding to zones did not exist. While there was a tendency towards spatial zonation in vernal pools, he noticed that species also existed well outside the zone in which they were most apparent. He illustrated this concept by graphing a water duration curve, the percentage of occurrence of a species as a function of the length of time water stood above it, for each species. Examination of the graphs for species seemingly dominant in a particular zone showed that all of the species occurred over a broad range of inundation conditions. Instead of viewing plant community distribution on a strictly spatial scale, where certain plants dominate certain elevations of the pool, Zedler proposed that vernal pools go through a sequence of dominant plants as the season progresses. For example, in Lin (1970) and Purer's (1939) work discussed above, it was not uncommon that the first species to become dominant in the pools was *Isoetes*, an herbaceous perennial; while the final dominants were annuals such as *Pogogyne abramsii*. In a study of vernal pools in San Diego, Zedler (1984) reported both spatial and temporal zonation patterns. Within the spatial zones, he observed species with different phenologies and concluded that a lack of competition may be enabling coexistence.

WITHIN-POOL GRADIENTS

Evidenced by the change in plant community composition along the pool topographic gradient, there exists a more or less continuous gradation from the deepest parts of the pool towards the surrounding nonpool vegetation along which the physical environment is changing. Some of the environmental factors in a vernal pool ecosystem that are important to plant growth and known to differ from the center to the margin of the pools include water duration, soil texture, soil structure, soil moisture during the growing season, and salinity/alkalinity (Zedler 1987).

Water Duration

Many vernal pool researchers agree that the duration of standing water in time and space plays a major role in affecting the occurrence and distribution of plants in the pool basin (Holland and Jain 1984, Zedler 1984 and 1987, Bauder 1987, Crowe et al. 1994). Support for this idea comes from research conducted on the distribution of plants along the moisture, or water duration, gradient in vernal pools on Kearny Mesa (Zedler 1984). Plant species abundance was sampled along transects that cut across pools, such that the entire range of inundation conditions within a pool was represented. Sampling occurred at 5-day intervals, and each area of a pool that had been exposed between sampling dates was considered a separate duration class. The frequency of each species within a particular duration class was then calculated and used as a measure of a species' water duration requirements or, alternatively, its tolerance to inundation. Results of this work showed that species with the lowest water duration class value were those found most commonly near the pool edge and rarely within the inundated portions of the pool, and, similarly, that species with the highest values occurred almost exclusively near the bottom of the pools.

Lin (1970) conducted greenhouse experiments on vernal pool seed germination in relation to depth of standing water. From soil samples collected from vernal pool basins in August, he placed the samples in a controlled environment and treated them with different levels of standing water. He found that the number and kinds of plants that germinated increased with decreasing standing water and that standing water of depth greater than 10 centimeters inhibited germination of all but the true aquatic species.

Bauder (1987) hypothesized that since pools differ in water retention and variability in water depth, differences among pools in species richness and the distribution of species would be expected. Following the example of Zedler (1984), she plotted the distribution of species against water duration classes and found that the pattern of distribution was similar to that observed when species presence was plotted against elevation. The "nonpool" species, including many exotic species, had peaks in the lower duration classes, while the "pool" species were found to tolerate either prolonged periods of inundation or greater depths of inundation. Bauder also found that pools with lower water retention abilities (i.e., shallow) or greater among-year variability in length of inundation were more likely to have larger populations of non-pool species, especially exotics, and lower abundances of the characteristic pool species.

Soil Properties

Bauder (1987) also examined the change in soil properties along the topographic gradient. In general, she described soils at the dry, higher end of the gradient as sandy loams, low in nutrients, and saturated with water for only brief periods in the winter months. Soils found at lower depths were described as clays or clay loams and were higher in nutrients. Lathrop (1976) also measured soil texture along the elevational gradient, finding all soils except those in the deepest parts of the pools to have a loam texture. Soils in the deepest pool zone were characterized as a clay loam.

In another study of the relationships between within-pool vegetation patterns and underlying soil conditions, surface soil texture became less clayey (loamier) towards the outer edge of the pools (Holland and Dains 1990). Also, near the pool margin, the duripan layer, a cement-like mineral soil horizon, was displaced upward, and the overlaying soil was shallower. While no consistent patterns in subsoil conditions were found beneath the vernal pools, there was an observable change in plant dominance that was correlated to soil thickness over the duripan layer, rather than to microtopographic position in the pool basin. The researchers concluded that variations in soil texture and soil moisture storage capacity may be important factors in influencing plant distribution in vernal pools.

In the only published study of vernal pools in eastern Washington, Crowe et al. (1994) examined the relationship between species distributions and soil characteristics within two vernal pools on the Marcellus Shrub-Steppe Preserve. In addition to describing vegetation zones and surveying topography, soils were collected in each of the zones and analyzed for pH; electrical conductivity; sodium, calcium, and magnesium ions; sodium absorption ratio; particle size; organic carbon; and water matric potential. Results indicated that plant groupings, having been separated into zones based on the presence of abundant species, were responding to changes in topography along the pool-to-upland gradient. While no significant relationships between soil properties and zonation were detected, some interesting findings were made. Finer particle sizes increased and sand fractions decreased from the outside to interior of the pool basins. Electrical conductivity decreased with increasing dryness of the soil through the spring and summer, and shallower soils in the centers of the pools were wetter during the wet season and drier during the dry season than were deeper soils.

Soil chemical characteristics, such as pH, salinity, and alkalinity, have also been discussed as influential factors in the distribution of vernal pool plants. While all of these characteristics are related, they each have a distinct meaning. The pH is a measure of the concentration of hydrogen ions in a soil, which determines whether a soil is acidic, neutral, or alkaline. Salinity is a soil property defined by the amount of soluble neutral salts in the soil (Munshower 1994), primarily chlorides, sulfates, and nitrates, which do not affect pH. The dry precipitate of saline soils often appears white (Kelley 1951). Related to salinity is alkalinity, which refers specifically to the content of exchangeable sodium in a soil (Munshower 1994). In highly alkaline, or sodic, soils, sodium ions accumulate on the exchange sites of clays and organic matter particles, replacing the cations previously there, such as calcium and magnesium, and decreasing their availability to plants. The pH of these soils often exceeds 8.5, providing an inhospitable environment to most plants (Brady and Weil 1999).

In vernal pools, Zedler (1987) found salinity and/or alkalinity to be higher in the center of a pool compared to the pool margin due to the evaporative concentration of salts. He suggested that salinity and/or alkalinity may be minimal at the margin in pools with subsurface drainage. Bauder (1987) recorded an increase in exchangeable sodium ions with decreasing elevation. In two eastern Washington vernal pools, electrical conductivity measures were below the salinity classification value of 2 deciSiemens per meter (Crowe 1990). A high measure of exchangeable sodium was found in a single area in one of the study pools, implying that sodic conditions are uncommon in these pools. Lathrop (1976) recorded a continuous increase in salinity along the edge to center topographic gradient, where salinity was greatest in the deeper portions of a pool. A non-continuous gradient of salinity was measured in vernal pools in northern California (Hobson and Dahlgren 1998). Electrical conductivity readings of the surface soil were highest in the pool basins, lowest in the pool rim (which corresponds to zone 2), and intermediate in the uppermost region of the pools. This latter finding is similar to the salinity gradient found in some tidal salt marshes (Jefferies et al. 1981, Mitsch and Gosselink 1986).

The organic matter content of a vernal pool soil may be another factor influencing plant distribution, given its role in nutrient cycling and contribution to soil structure. Crowe (1990) found that organic carbon values, an indirect measure of organic matter content, were greater in the outer pool zones than in the deeper center zones—a finding she attributed to the increased presence of fine-rooted perennial grasses along the pool margins. However, no significant differences in organic carbon contents were detected among pool zones.

INFLUENCES OF WEATHER CONDITION

In addition to the environmental gradients that exist within a pool, different weather conditions among years may impact the abundance and distribution of plant species. Pools with greater among-year variability in length of inundation have been found to support larger populations of exotic species and lower abundances of characteristic pool species than pools with less variability (Bauder 1987). Also, within the same pool, exotic species have been found to vary with the amount of seasonal rainfall (Bauder 1998). In dry years, upland annual weeds were able to disperse into the pool basin and became dominant there. In wet years many of the same weed species were excluded from the pool basin, limited by their intolerance to inundation.

Holland and Jain (1984) studied vernal pools during three years—a drought year, a year of average rainfall and temperature, and a year with abnormally high winter precipitation and a prolonged cool season. Species richness was found to vary with year, such that it was significantly greater in the two higher rainfall and cooler temperature years compared to the drought year. Species composition also varied among the years, as several grassland and exotic species grew in the pools during the drought year but were excluded from the same pools under average precipitation and temperature. Additionally, several characteristic vernal pool species, including *Downingia cuspidata, Pilularia americana*, *Gratiola ebracteata*, were not seen in the pools during the dry year, but were common and widespread in the other two years.

EFFECTS OF CATTLE GRAZING ON PLANT COMMUNITY STRUCTURE

Cattle were first brought to eastern Washington in 1834, after which time (in the 1880s) sheep farming developed, along with the rapid expansion of agriculture (Daubenmire 1970). Investigation of archeological evidence from the steppe region of Washington indicates that grazing ungulates were present in the region until they went extinct about 2,000 years ago (Daubenmire 1970), suggesting that the vegetation of this region has not been subject to heavy grazing pressure until somewhat recently.

Considerable research has been conducted in the area of livestock grazing effects on plant communities with little consensus reached. Much less research has been conducted on grazing effects in vernal pools and, to date, no data have been published (Barry 1998). Some of the more relevant studies on cattle grazing effects on plant community structure and composition are presented below.

In a review of the ecological costs of livestock grazing in western North America, the negative effects of grazing were categorized into three groups—alteration of species composition, disruption of ecosystem functioning, and alteration of ecosystem structure (Fleischner 1994). In terms of the former, some research has shown that grazing activity decreases native plant species density and diversity (Rummell 1951, Szaro and Pase 1983) and increases the spread and establishment of exotic plant species within native communities (Mack 1981, D'Antonio and Vitousek 1992, Hobbs and Huenneke 1992, Young and Allen 1997). In addition to effects on vascular plant community structure, grazing has been correlated with the loss of cryptogamic cover, as well as microbiotic species richness (Anderson et al. 1982). Not only does the loss of cryptogamic crust cover alter species composition, but it also has an adverse effect on ecosystem functioning. As mentioned above, cryptogamic soil crusts are believed to perform essential nitrogen fixation functions, increase soil stability, and increase soil water infiltration, much of which is lost with a degraded crust. Grazing is also believed to disrupt ecological succession processes, producing and maintaining early successional plant communities (Fleischner 1994). Effects on the physical structure of ecosystems, including deterioration of soil structure and porosity and increased erosion and soil compaction, have long been recognized by ecologists. Studies have shown grazing to alter ecosystem structure by removing soil litter (Schulz and Leininger 1990) and increasing soil compaction (Orr 1960, Bryant et al. 1972).

A widely-accepted model of disturbance effects, and one that is applied to livestock grazing, is the intermediate disturbance hypothesis (Grime 1973). This model proposes that moderate levels of grazing will reduce biomass of the dominant species, resulting in an increased availability of resources and the eventual establishment of a greater number of plant species, including both native and invasive (Grime 1973, Connell 1978). In a study of plant responses to overgrazing in the *Agropyron* bunchgrass prairie of southeastern Washington, Daubenmire (1940) noted an increased abundance in numerous species with increased grazing pressure. He also found other species that appeared to benefit from the early stages of grazing, where the competitive influence of "climatic climax dominants" was removed. Two of the species that increased under grazing, both of which were found in the Marcellus and DNR vernal pools, were *Sisymbrium altissimum* and *Madia exigua*.

In the grasslands of Colorado, Wyoming, Montana, and South Dakota, the effects of grazing and soil quality on native and exotic plant diversity were investigated (Stohlgren et al. 1999). Twenty-six long-term exclosure sites were included in the study, and grazing effects were examined at different ecological scales. Results of this work indicated that grazing had little effect on native species richness, as well as on the accelerated spread of exotic plant species, at landscape scales. At the one-meter-square scale, however, native species richness was significantly lower in the ungrazed enclosures than in grazed sites. Rather than grazing, this work suggests that soil characteristics, climate, and disturbances, such as rodent activity, insect outbreaks, intermittent fire, and occasional flooding, may instead be significantly affecting plant species diversity in Rocky Mountain grasslands.

Two projects have looked specifically at grazing effects in vernal pools—a demonstration project in Tehama County, California and a botanical inventory in eastern Washington. In the paper describing the demonstration project, Barry (1998) postulates that under a management regime of no grazing (i.e., the vernal pool landscape is fenced off completely from grazing livestock), the integrity of the native pool flora will be threatened. She reports on the findings of an on-going demonstration project that was established to study grazing effects. The project was initiated in 1993 and includes four pairs of pools, one grazed and one ungrazed, and two previously-grazed sites that had been ungrazed for 15 years. Preliminary results from five years of study suggest that the removal of livestock from the vernal pool can promote the spread of certain exotic annual species and that complete rest from grazing may alter the hydrology of the pools by increasing residual dry matter and altering soil structure. The author hypothesized that sustaining vernal pools as habitat for certain endangered pool species can be difficult in an ungrazed system since the presence of ubiquitous vernal pool perennials, such as *Eleocharis palustris*, can outcompete the endangered species. No discussion of yearly weather conditions was included in the paper.

As part of the botanical inventory of vernal pools located throughout the Columbia Plateau (Bjork 1997), plant species composition in two pools located on land not recently grazed by cattle and two others on grazed land were described and compared. Each grazed pool was found to support no rare species and approximately 20 percent nonnative species. The ungrazed pools, in contrast, supported an average of four rare species and approximately 10.5 percent nonnative species. The ratios of native to nonnative species was greater in the ungrazed pools.

CHAPTER 3. METHODS

STUDY SITE

Vernal pools were studied in the Marcellus Shrub-Steppe Preserve and adjacent Department of Natural Resources (DNR) land, both located within an area of about one-half square mile in Adams County, Washington (47°14'N, 118°24'E; T20N, R35E, Sec. 15; Figure 3-1). The Marcellus preserve, owned by The Nature Conservancy, has been fenced since 1986 and is not noticeably degraded by past grazing, which occurred there approximately 30 years ago (Schuller 1984). It covers 263 acres and is surrounded by wheat fields on three sides. To the west, the 300-acre DNR property neighbors the preserve, separated by a gravel road (Figure 3-2). The DNR land contains pools of similar dimension and substrate to those on the preserve, but has been leased for cattle grazing since at least 1957. From about 1980 to the present, the stocking density has been 6 acres per animal per month (D. Warriner, personal communication, 1998), with grazing occurring in the spring and summer months.

Two plant communities dominate the upland portions of the study sites—*Artemisia tridentata/Festuca idahoensis* (big sagebrush/Idaho fescue) and *Artemisia tripartita/Festuca idahoensis* (threetip sagebrush/Idaho fescue; Schuller 1984). The *Artemisia tridentata* association is the far more common of the two, but, on the Marcellus preserve, both are considered to be high quality examples. On the north end of the DNR parcel, there are large areas that are devoid of *Artemisia* and are dominated instead by *Bromus mollis* and *B. tectorum.* No such patches were observed on the preserve.

Soils on the study sites have been mapped as Roloff-Starbuck stoney silt loams (USDA 1967). The soils formed from a combination of glacial outwash that was derived from basalt and loess deposits containing some volcanic ash. Ash from the 1980 eruption of Mt. St. Helens is evident throughout the site. These soils have a rich mollic surface horizon and are approximately 120 centimeters in depth (Crowe 1990). Topography of the sites is mostly hummocky. The hummocks, described as Mima mounds, range from about 15 to 30 meters in diameter and about 0.5 to 2 meters in height and are composed of the Roloff soil. Areas in between the mounds consist mostly of the Starbuck soil. Basaltic outcrops are common.

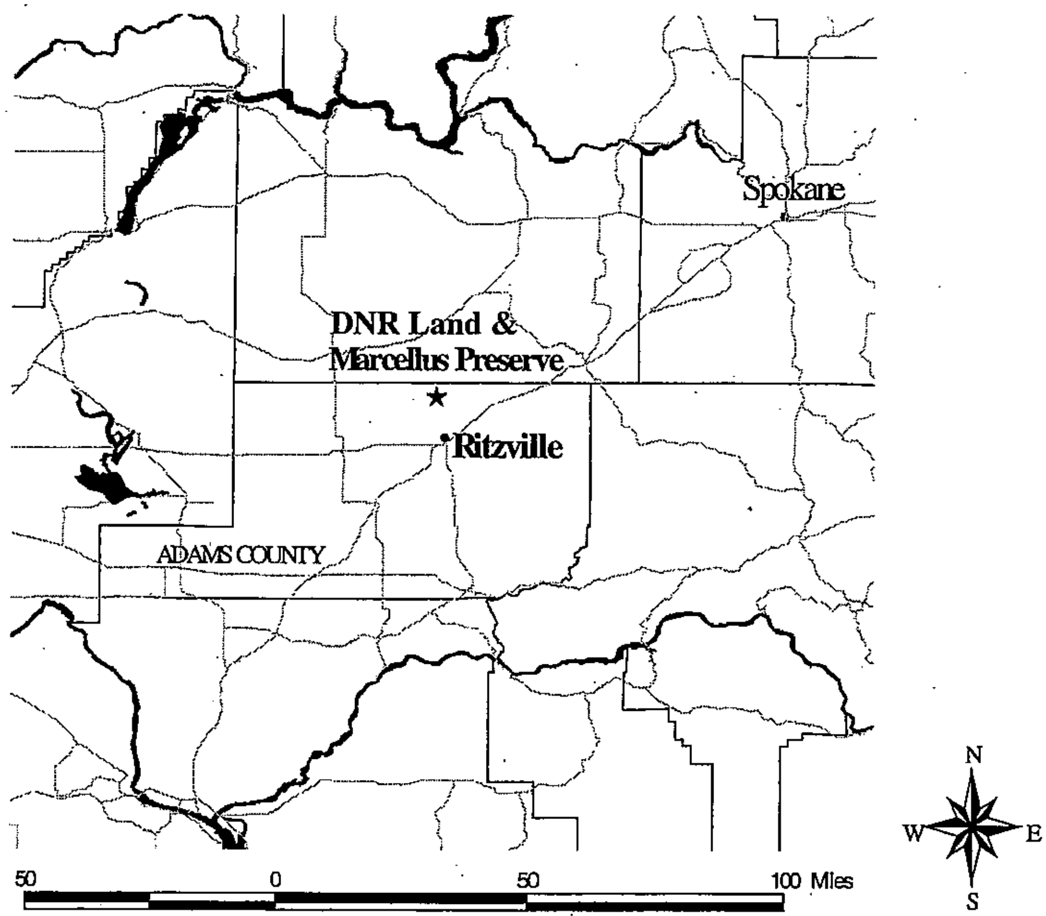


Figure 3-1. Location of the Marcellus Preserve in Adams County, Washington. The DNR property lies directly adjacent to, and west of, the preserve.

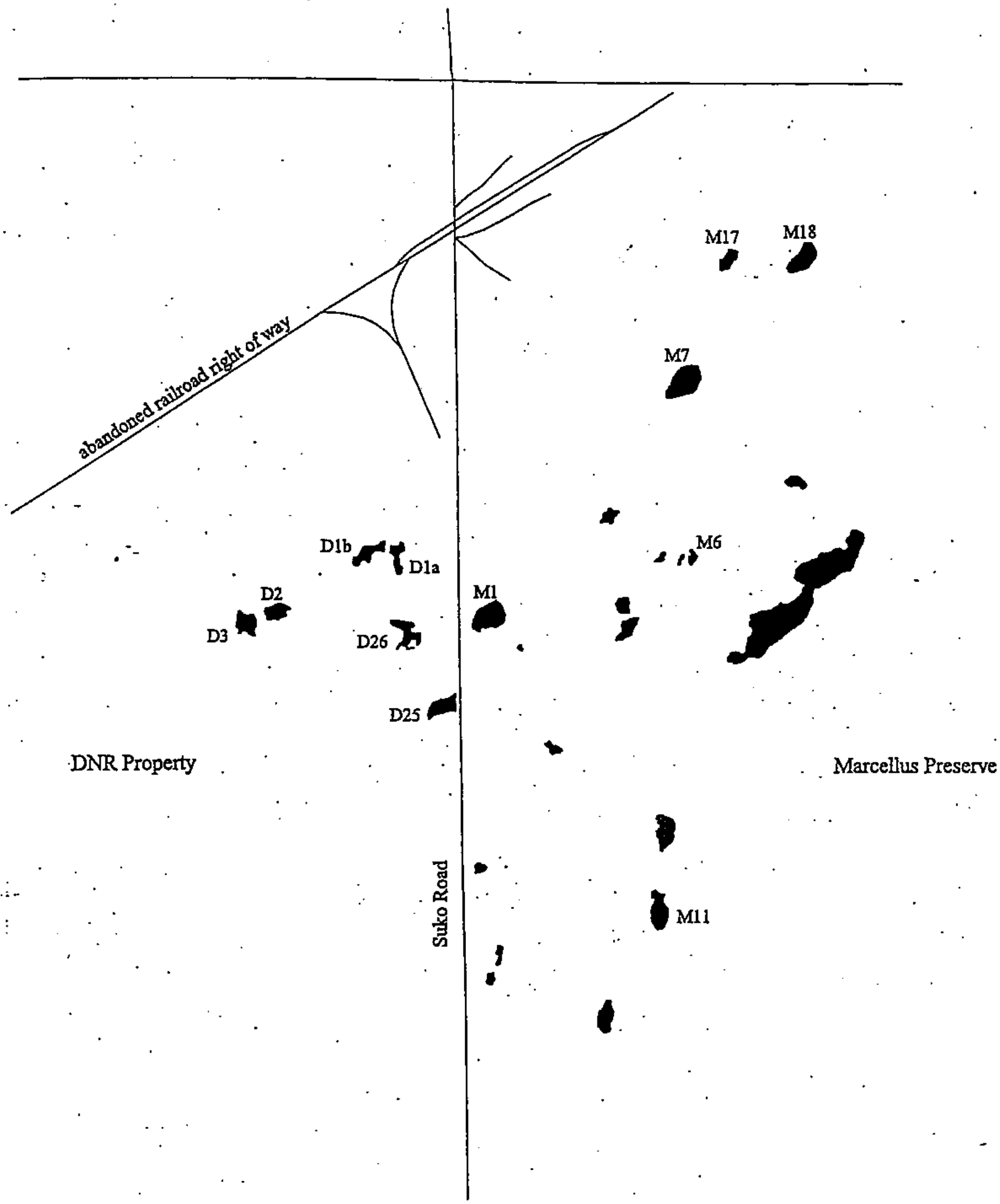


Figure 3-2. Location of vernal pools. Labeled pools are those included in the study.

The climate of the region is characterized by wet, moderately-cold winters and hot, dry summers. The mean temperature of the coldest month, January, ranges from about –5.5 and 1.5 degrees Celsius (°C), and the mean temperature of the warmest month, July, is between 18.5 and 24.5 °C (Daubenmire 1970). Precipitation is concentrated in the fall and winter months; monthly averages are highest in November and December and lowest in July and August. Average monthly precipitation in the winter month ranges from about 3 to 4.5 centimeters; in the summer months it ranges from 2 to less than 1.3 centimeters. Long-term monthly precipitation and temperature levels were recorded at the Ritzville 1SSE weather station and used to compare against conditions during the 1997-1998 and 1998-1999 field seasons.

The study site is part of the Channeled Scablands, a unique landscape in the Columbia Plateau physiographic province characterized by a series of deeply carved channels or "coulees." Formation of the scablands was the result of repeated catastrophic flooding during the Pleistocene (Bretz 1923). Glacial ice sheets created a dam near the Missoula Valley in Montana, behind which a vast lake of melt water was formed. Periodically the ice dam would break, resulting in massive floodwaters moving west. Prior to the last glaciation, the basaltic floor of the Plateau had been covered by thick layers of loess. Over the course of approximately 1,500 years, the melt waters carved through the soft loess deposits to the basalt, creating islands of loess existing in a system of "basalt-floored drainageways" (Daubenmire 1970). On the Plateau, vernal pools are found almost exclusively in and around the channels, where impervious basalt is exposed (Bjork 1997).

VEGETATION SAMPLING

In early-April 1998, all pools on the study sites were located and labeled with flagging tape attached to rebar poles. Pool identifiers begin with the letter "M" or "D," referring to its location on the Marcellus Preserve or DNR property, respectively, and end with a number. The sequence of pool numbers has no significance, and the numbers should be considered like names. For each pool located, 18 on Marcellus and 27 on the DNR land, size was approximated by measuring the lengths of its major and minor axis. Boundaries of the pools were delineated at the current year's high water mark, and measurements were made in the field using a 100-meter fiberglass tape. In addition to size, the pool's approximate shape (e.g., circular, elliptical, long and narrow), spatial arrangement of vegetation (i.e., zonal or azonal), percent cover of cobbles, and percent cover of bare ground were visually estimated (Appendix A).

From these data, pools were categorized into groups according to size and arrangement of vegetation. Size classes were small (10-34 m in length), medium (35-64 m in length), and large (>65 m in length), and patterns of vegetation distribution were categorized in two ways—zonal (described below) and azonal. Vegetation arranged in the azonal pattern was distributed in a more or less homogenous manner and did not form visibly-distinct bands. Species composition in these azonal pools also consisted primarily of upland species, with few to none of the characteristic vernal pool plants.

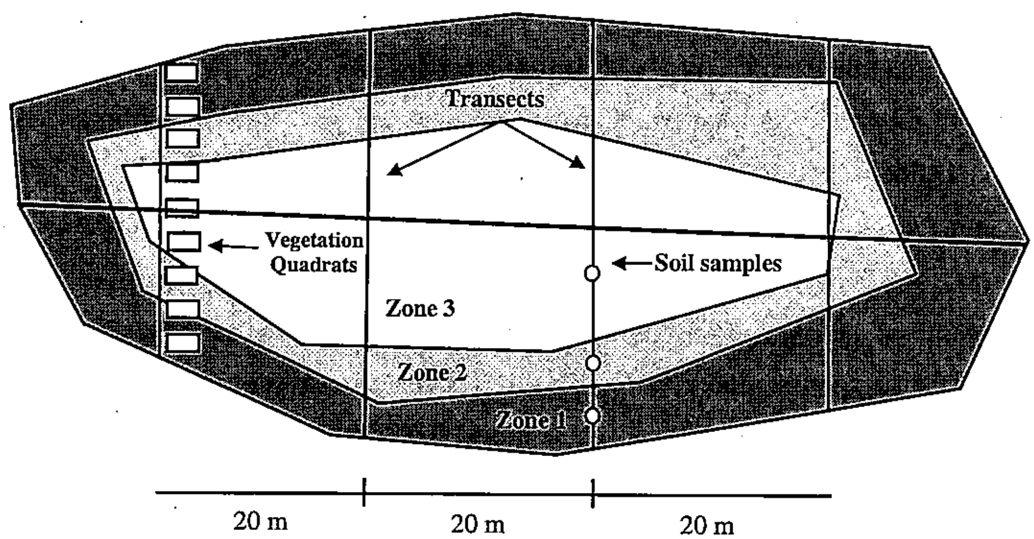
The objective of grouping the pools in this way was to minimize the influence of confounding variables such as size (Ebert and Balko 1987). Because most of the pools on the Marcellus Preserve fit into the medium-size category and the homogenous pools (also known as dry swales) contained few plant species characteristic of vernal pools, all of the six medium-sized pools with a zonal vegetation pattern on the Marcellus side were chosen for study. Pools on the DNR property were evaluated in a similar manner, and six of the medium-sized, zonal ones were randomly selected.

Once the number of pools to be sampled was known, a pilot study was conducted to determine both the minimum number of quadrats needed per pool and an appropriate quadrat size. To calculate this minimum sample size, the following equation was used: $n = ((Z_\alpha + Z_\beta)^2 (p_1q_1 + p_2q_2))/(p_2-p_1)^2$, where n=estimated necessary sample size, Z_α=Z-coefficient for the Type 1 error rate, Z_β= Z-coefficient for the Type 2 error rate, p_1=proportion of samples with a given species present at the ungrazed sample site, $q_1=1- p_1$, p_2=proportion of samples with species present at the grazed sample site, and $q_2=1- p_2$ (TNC 1997). From measurements taken in Marcellus and DNR pools, the values of p_1 and p_2 were 0.80 and 0.20, respectively, and the Type 1 and Type 2 error rates were 0.10. The number of quadrats calculated was 64, meaning that at least 64 quadrats needed to be sampled in each of the 12 pools.

To determine the most effective quadrat size for sampling, three different sizes were tested—20 x 50 cm (per Daubenmire 1959 and Bauder 1987), 50 x 50 cm, and 50 x 70 cm. On the basis of 10 samples in a pool, the number of species captured from each quadrat size were compared. Since there was no difference in number of species captured, the smallest quadrat size was selected because it was more likely to be contained within a given vegetation zone. The quadrat was constructed from PVC pipe material.

Permanent transects were established in the twelve study pools once the minimum sample size was determined. Beginning at one end of the major axis, they were located at regular intervals, usually 20 meters, perpendicular to the major axis (Figure 3-3) and perpendicular to the topographic gradient (see Appendix B for transect locations). The transects were arranged in this way to sample across all pool zones, though transects placed at either end of the pool tended to bisect only zone 1. Most pools had four transects, a few of the shorter ones had three or two.

Figure 3-3. Vegetation sampling scheme.



Transects were established at the pool-upland interface, the place where the upland vegetation ended and vernal pool vegetation began, and continued until they reached the other edge of the pool. This interface area was visible as the high water mark of that year. Each end was marked with rebar and labeled with the following information: pool number, transect number, and whether it was the beginning or end of the transect ("s" for start or "e" for end). The spatial coordinates of the transects were also recorded with GPS. It is important to note that, while the transects began and ended at the edge of the high water mark in 1998, being that they were permanent, in some of the pools they fell below the high water mark in 1999 when the pool sizes expanded. As is typical of most vernal pools, its size fluctuates from year to year depending on the amount of standing water it contains. In 1999 the size of the Marcellus and DNR pools was larger compared to the previous year when there was relatively less standing water in the pools.

In past studies of vernal pool flora (Lin 1970, MacDonald 1976), pools were subdivided on the basis of apparent zonation with sampling occurring only in the pre-established zones. This method limited observation of transitions in species composition between zones (Bauder 1987). To avoid this shortcoming, transects were placed along the entire length of the water duration gradient. Also, the sampling unit used, a 20 x 50-cm quadrat, was never larger than the zones of transition, which, in theory, should provide a more complete description of changes in plant community composition along the pool's elevational gradient.

For the purpose of associating the presence of a species with its placement in a pool, three zones were defined (see below). Rather than basing the delineations on dominant species, which has been shown to be an inaccurate metric (Zedler 1984, 1987), zones were defined as bands containing plants of similar growth form and microenvironmental conditions. All zones defined in this study existed within the pool basin below the high water mark and correspond closely to zones 2-4 of Bjork (1997). In a few of the pools, zonal boundaries were sharply defined. More commonly, however, there were areas of transition between zones where it was more difficult to assign the sampling quadrat to one zone or another. In these instances, a judgement call was made based on the percent cover of the most common plant growth form (e.g., whether the plants were primarily upland grasses and forbs or vernal pool annuals or aquatic sedges). For example, if more than half of the ground cover in the quadrat was composed of upland grasses and forbs, then that quadrat would be recorded as occurring in zone 1. If the ground cover of aquatic sedge (i.e., *Eleocharis* spp.) within a quadrat was greater than 50 percent, than that quadrat would be attributed to zone 3. These transitional areas between zones tended to be very narrow, falling within only one or two quadrats. Zonal boundaries shifted slightly between 1998 and 1999, but were defined in both years using the same criteria.

Zone 1 was the highest zone, which lay adjacent to the surrounding upland community. In the Marcellus and DNR pools, this zone often contained a high density and diversity of upland grasses and forbs (e.g., *Bromus* spp., *Poa scabrella*, *Elymus elymoides*, *Apera interrupta*, *Draba verna*, *Erigeron* spp.), as well as some of the more water-tolerant vernal pool species such as *Deschampsia danthonioides* and *Myosurus minimus*. Zone 2 was the intermediate portion of the pool, which contained plant species able to tolerate moderate periods of inundation (e.g., *Alopecurus saccatus*, *Navarretia leucocephala*, *Polygonum polygaloides*, *Plagiobothrys leptocladus*). In some of the pools, Zone 2 consisted almost entirely of bare ground, supporting minimal plant biomass. Zone 3 was the deepest part of the pool, where the most water-tolerant species were found. Within this zone the period of inundation was longest and the soil surface characteristics included desiccation fissures or large basalt cobbles. Species common in zone 3 were *Eleocharis macrostachya*, *Limosella aquatica*, *Gnaphalium palustre*, and *Boisduvalia glabella*.

In the first year, sampling began on May 8th and was completed on June 5th, 1998; in the second year, sampling began on May 3rd and ended June 8th, 1999. Presence/absence of plant species was recorded in quadrats along the transects. Standing at the "start" transect marker and facing towards the "end" marker, quadrats were placed on the right side of the transect, such that the 20-cm side was adjacent to it (Figure 3-4). The location of each quadrat along the transects was recorded so that the same locations would be re-sampled each year. Vegetation zone was also recorded for each quadrat. The spacing of quadrats along the transects was determined by the area of a particular zone. For example, in most pools zones 1 and 2 were relatively narrow, so quadrats were spaced 60 cm apart. In zone 3 (and occasionally zone 2), which tended to be wider than the other zones, quadrats were spaced 80 or 100 cm apart. Sampling intensity was adjusted by zone to have roughly equal numbers of samples per zone within a pool. The number of quadrats sampled in a pool ranged from 68 (in M6) to 131 (in D1b).

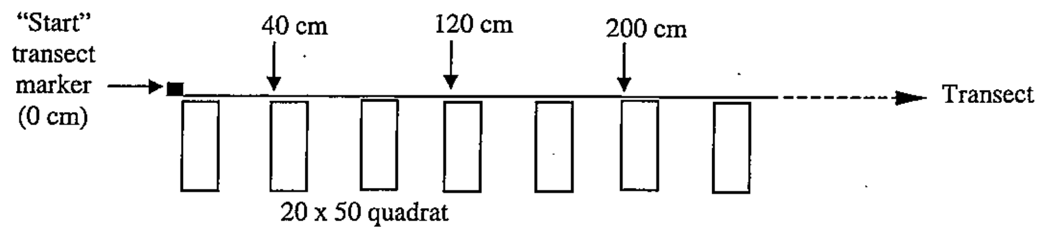
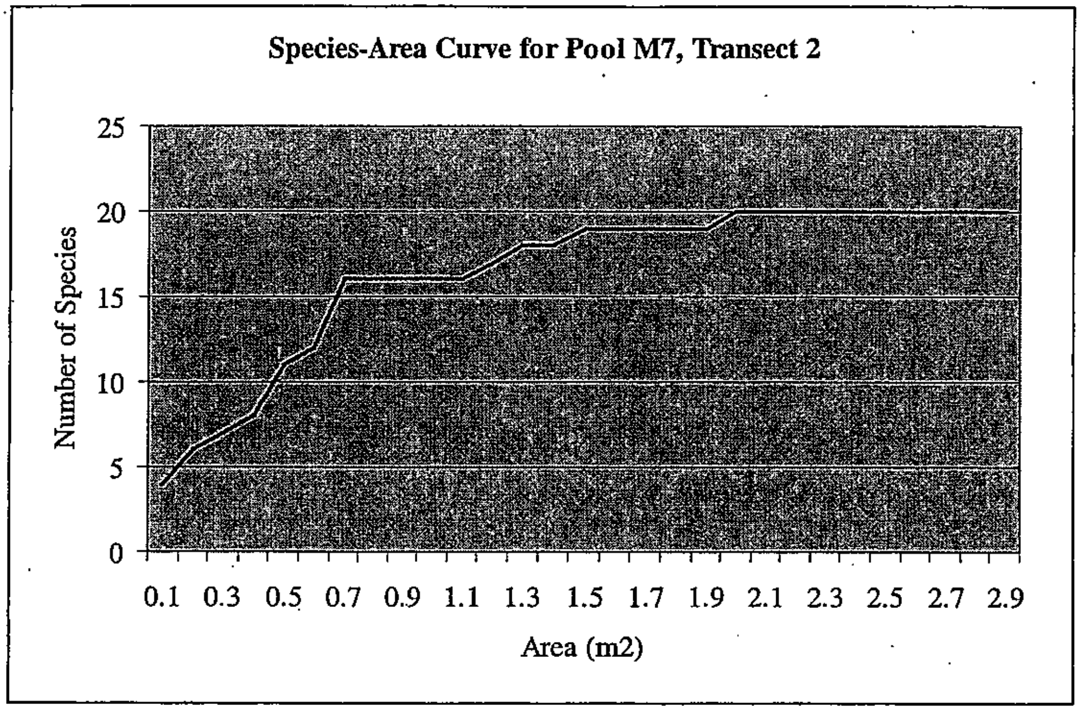


Figure 3-4. Arrangement of quadrats along a transect. Beginning at the "start" transect marker and facing the "end" marker, quadrats were placed on the right side of the transect. The location of each quadrat along the transect was recorded.

Species-area curves were created for a subset of transects to test if the number of samples measured in a pool was large enough to fully represent its species composition (see Figure 3-5 for two examples). In all instances, species richness reached an asymptote after about 20 quadrats.

Each pool was sampled twice, at least three weeks apart, to account for temporal variation in flowering. However, due to some early confusion in plant identification, data collected in the first sample period of 1998 are not included in the results of this study. Each pool was also inventoried for rare species by walking throughout the entire pool basin. The purpose of the inventory was to test the adequacy of the sample design and assess whether rare species, if present, were being recorded in the sampling efforts.

In 1999, the percent cover of individual species was measured along one of the permanent transects in each of the study pools. Selection of the transect was based on its representation of all vegetation zones in the pool. Thus, the transect was required to cut across all three (or two, in the case of pool M6b) vegetation zones. Using a 0.5 x 0.5-meter quadrat with 10 cm x 10-cm subdivisions, sampling was stratified such that 4 quadrats were measured in each vegetation zone. A random numbers table was used to locate sample points along the transect. Cover was visually estimated and recorded according to the Braun-Blanquet scale, where the range of cover values from 0 to 100 percent is partitioned into 6 classes—less than 1 percent, 1 to 5 percent, 6 to 25 percent, 26 to 50 percent, 51 to 75 percent, and 76 to 100 percent (Barbour et al. 1987).



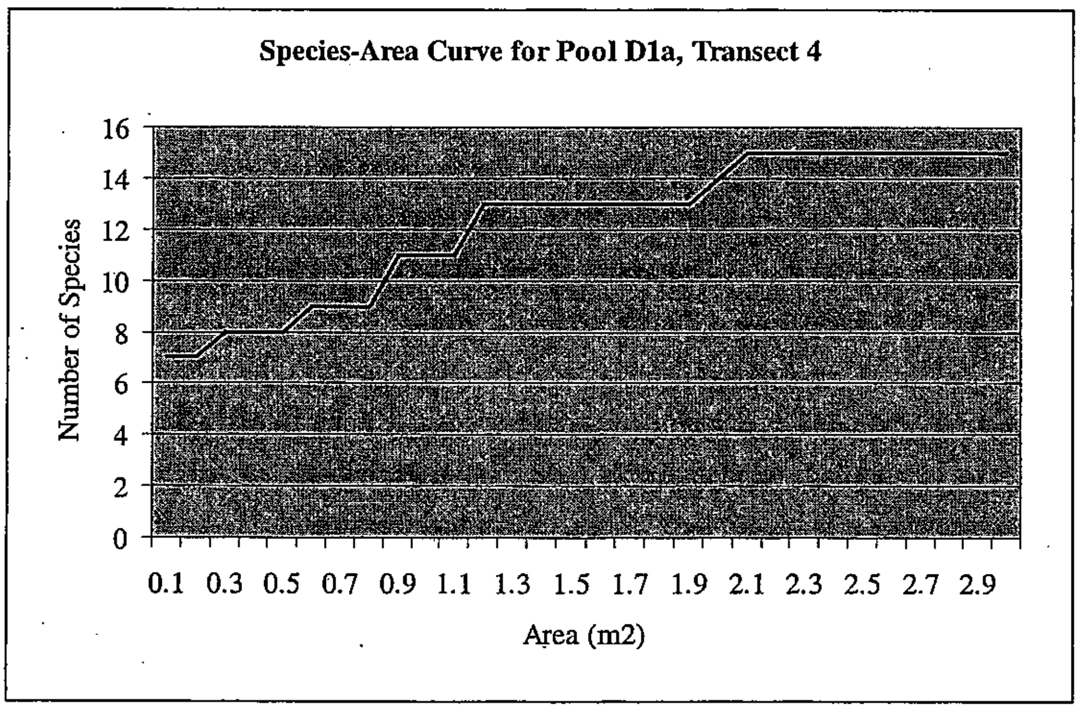


Figure 3-5. Species-area curves for selected transects.

ENVIRONMENTAL VARIABLES

Soil samples were collected in each zone of the pools and analyzed for pH, organic matter content, and bulk density. Within a pool, three samples were collected in each of two or three zones at random points along a transect, for a total of 6 or 9 samples. From all of the study pools, 99 soil samples were collected and analyzed. Soil pH was measured by inserting a calibrated pH meter electrode (Cole Palmer Model 05985-80) into a paste-like mixture of soil and distilled water. The percentage of organic carbon in the soil, an indirect measure of organic matter content, was measured with the Loss-On-Ignition method (Bartles 1996). Bulk density, the weight of the solid particles in a standard volume of soil, was measured by obtaining a known volume of soil (using a bulk density soil sampler), drying it to remove water, and weighing the dry mass. The weight of the soil is expressed in terms of its volume, as milligrams per cubic meter.

Relative elevations were measured at 2 or 3-meter intervals along all transects with a Topcon AT-G1 Auto Level mounted on a tripod and stadia rod. Before surveying, the auto level and tripod were placed at a fixed point just outside of the pool basin, the "zero" elevation position, and all measurements were made relative to that elevation. The height of the auto level was recorded first and then subtracted from each measurement taken along the transect. It is important to note that larger values of relative elevation refer to deeper portions of the pool (Figure 3-6). Relative elevation, as it was measured for this study, can not be viewed as absolute elevation since the position of the auto level was different at each pool. Rather, these values are taken as measures of pool depth that can be compared among the study pools.

In the DNR pools, grazing intensity was estimated by counting patches of dried bovine fecal material present in the pool basin and by visually categorizing microtopography, assumed to be affected by hoof prints, along transects as "very undulated, undulated, irregular, or flat." These data were later discarded from the study since no difference in grazing intensity was detected among pools. While it may be the case that there truly were no differences in grazing intensity among the DNR pools, it seems equally possible that the measures used were either too coarse and/or imprecise to detect small differences had they existed. For example, when the number of bovine fecal material patches was adjusted for pool area and analyzed for differences in grazing intensity among pools, the values of fecal patches per area, ranging from 0.02 to 0.005, were all very small and no significant differences were revealed. Had the stocking density on the site been greater, it is possible that differences among pools might have emerged using this metric of fecal patches per area. Additionally, the other method used to measure grazing intensity, visually categorizing microtopography, proved inadequate, as it was difficult to distinguish among the four categories in a consistent and quantifiable manner. In hindsight, a more effective approach would have been to actually measure microdepressional depths along the transects at randomly-selected locations.

DATA ANALYSIS

Differences in species frequency and percent cover between the ungrazed and grazed sites were analyzed using the software package SPSS, Version 8.0 (SPSS, Inc. 1998). A frequency and cover value for each species, or group of species, were calculated for a pool, then the mean value for the ungrazed pools was compared to the mean value for the grazed pools with a two-tailed t-test for equality of means (Zar 1996).

Frequency is defined as the percentage of plots containing a particular species in any abundance; percent cover refers to the area of ground within a quadrat that is occupied by the above-ground

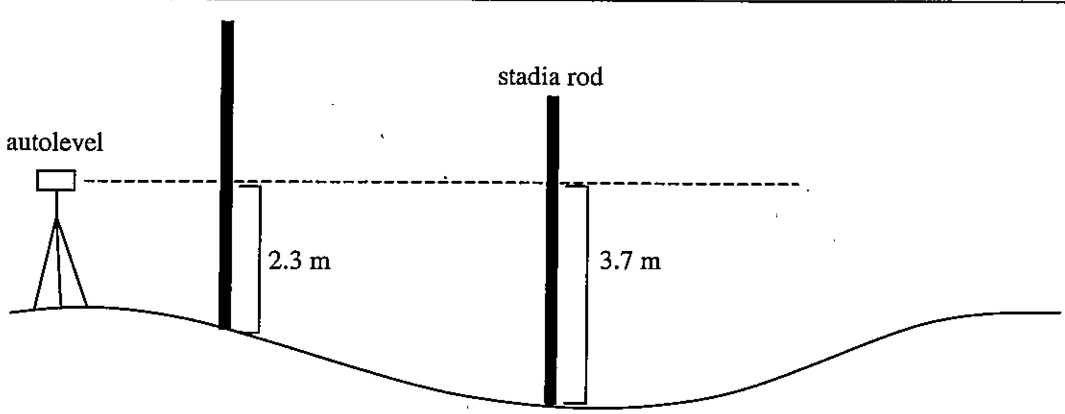


Figure 3-6. Measuring relative elevation. Note that larger values of elevation refer to deeper parts of the pool.

parts of a species. Multivariate analysis, described below, was used to analyze differences in community composition between the sites, as well as to investigate underlying environmental gradients that may be affecting the spatial distribution of plants in the pools. Data were classified using TWINSPAN and ordinated using DECORANA (McCune and Mefford 1997).

In addition to individual species, analyses were conducted on groups of species, including annuals, perennials, weeds, and nonweeds, to determine their frequency and cover by zone in the pools. A weed is defined in this study as a native or nonnative species that is capable of developing self-sustaining populations and becoming dominant and/or disruptive to the vernal pool ecosystem (Parker and Reichard 1998). Weed designations were based on ecological information provided in Hitchcock et al. (1969), USDA (1988), and Whitson et al. (1996).

Due to the large variability in floristic composition within a growing season, only data from the second sample periods of 1998 and 1999 were used in the classification and ordination analyses to reduce variation in the data attributable to environmental "noise." An analysis of temporal changes in floristic composition is presented separately.

Similar to the frequency and cover data, differences in environmental variables between the sites were analyzed with two-tailed t-tests for equality of means. The pH values were transformed to a negative logarithmic scale prior to analysis.

Classification

Two-way indicator species analysis (TWINSPAN), a method of divisive cluster analysis, was used to classify quadrats into discrete groups of similar species composition. Divisive classification methods begin with the entire set of samples and then divide it into smaller and smaller groups, or clusters, based on floristic similarity. Using reciprocal averaging, divisions are made until a specified minimum group size or maximum level of divisions is reached. A two-way table is generated where quadrats are arranged along an ordination axis, along with a dendrogram where the clusters are arranged. The relatedness of individual quadrats and/or clusters is depicted in their proximity to one another. In general, quadrats and quadrat groups that share similar floristic composition are located close together in the ordination space, while those that differ are located farther apart. Interpretation of the output necessitates knowledge of the ecological system from which the data were collected to determine which of the groupings make ecological sense. Species weights were not assigned in this analysis.

Ordination

Detrended correspondence analysis (DCA), a method of indirect gradient analysis, was used to examine the distribution of sample plots along (unknown) environmental gradients. The method involves the process of reciprocal averaging whereby species ordination scores are averages of the sample (or quadrat) ordination scores, and reciprocally, sample ordination scores are averages of the species scores (Gauch 1982). The ordination process looks for the largest source of variation in the data and draws an axis, Axis 1, through it. The second axis, Axis 2, represents the second largest source of variation, the third axis represents the next greatest variation in the data, and so on. The end product of the process is a multi-dimensional scatter plot in which the distances between samples or species on the graph are taken as a measure of their degree of similarity. Like the classification output, points close together represent quadrats that are similar in species composition or species that are similar in their distribution within the quadrats. Thus two species occurring with exactly the same abundance in the same quadrats would occupy the same point on the graph.

Each axis in DCA, like all methods of correspondence analysis, has a corresponding eigenvalue (λ). This value ranges from 0 to 1 and measures the spread of, or variation in, species scores along an axis. In other words, it provides a measure of the importance of the ordination axis in explaining the total variation of the data. The first axis has the largest eigenvalue, the second axis has the second largest eigenvalue, and so on. An eigenvalue over 0.5 often denotes a good separation of species along an axis (ter Braak 1995).

Although DCA is a method of indirect gradient analysis, it is possible to show the relationship between a set of environmental variables and the floristic data using a joint plot. Joint plots are created with a second matrix of environmental variables that is overlaid directly onto the species ordination. Vectors representing the environmental variables may be drawn in the ordination space, such that the angle and line of the vector tells the direction and strength of the relationship. Correlation coefficients are calculated to describe the relationship between each environmental variable and the sample scores associated with the axis. Only variables with a coefficient of determination (r^2) greater than 0.200 appear on the graph as a vector.

Environmental variables used in the joint plot analysis include relative elevation (assumed to be positively correlated with depth or duration of standing water), soil pH, soil organic matter content, soil bulk density, and grazing. This last variable is not considered as a gradient, but instead represents a condition—whether grazing occurred or did not occur. For construction of the environmental matrix, it is important to recognize that individual soil samples and measures of elevation were not taken for each individual quadrat. Within a pool, soil samples were instead collected by zone and the measurements of pH, organic matter content, and bulk density were then applied to all quadrats in that zone. A similar approach was taken when assigning relative elevation to each quadrat. Since elevation was measured at 2 or 3-meter intervals along the transects, extrapolations were made for quadrats located between the measured points.

Canonical correspondence analysis and the associated Monte Carlo permutation test were used to examine the relationship between species distributions and the measured environmental variables (ter Braak 1987). The null hypothesis of the Monte Carlo test is that there is no relationship between the species and environmental matrices. Canonical correspondence analysis is a direct gradient analysis technique, which differs from DCA, an indirect gradient analysis technique, by constraining the ordination axes to be linear combinations of the measured environmental variables. Variation in the community, therefore, can be directly related to variation in known environmental variables. Testing for significant relationships between ordination axes and environmental variables can not be done with DCA since the environmental matrix is not used to create the ordination axes. In a DCA joint plot, the vectors, which correspond to environmental gradients, are overlaid onto a pre-existing ordination plot. The software, CANOCO for Windows Version 4.0, was used for the analysis (ter Braak and Smilauer 1998).

CHAPTER 4. RESULTS

A total of 3,504 plots were sampled during two field seasons and analyzed for differences in species composition. In the second year of study, 134 plots were sampled for percent cover of species. Results of analyses of the vegetation and environmental data, along with a comparison of weather conditions over the course of the study, are presented below. Statistical significance was detected at α=0.10.

YEARLY PRECIPITATION AND TEMPERATURE

Comparison of the long-term average precipitation and temperature with 1997-1998 and 1998-1999 seasonal values reveal above-average precipitation and temperatures in 1998 and above-average precipitation and below-average temperature in 1999 (Figures 4-1 and 4-2). In 1997-1998, total precipitation in the winter months was 6.33 inches, 0.52 inches above average; in the spring, precipitation was also 15 percent above average—3.39 inches compared to 2.87 inches. Temperature in both the winter and spring was higher than average, by 3 degrees Fahrenheit (°F) in the winter and 1.1 °F in the spring. In 1998-1999, precipitation levels in the winter months were consistently greater than the long-term averages, but in the spring months were well below them. Total precipitation in the winter was 8.69 inches, almost three inches more than average for those months, and in the spring was 1.38 inches, about 1.5 inches below average. Temperature was 3.15 °F higher than average in the winter and 1.7 °F lower in the spring months.

For the vernal pools, 1998 appeared to be a dry year. In early-March 1998, when the study was initiated, all pools were completely dry except for pools M7 and D2, which contained a very small amount of water. By mid-April, surface soil in all of the pools was visibly dry. In contrast, in the spring of 1997, when precipitation was 57 percent above average and temperature about 2 percent below average, the pools were inundated well into June and July (C. Bjork, personal communication, 1998).

In the following field season, there was a greater amount of precipitation in the winter, both compared to the winter of 1998 and the long-term average, and the pools retained water longer into the spring. The high water mark of the pools was also clearly extended beyond the transect

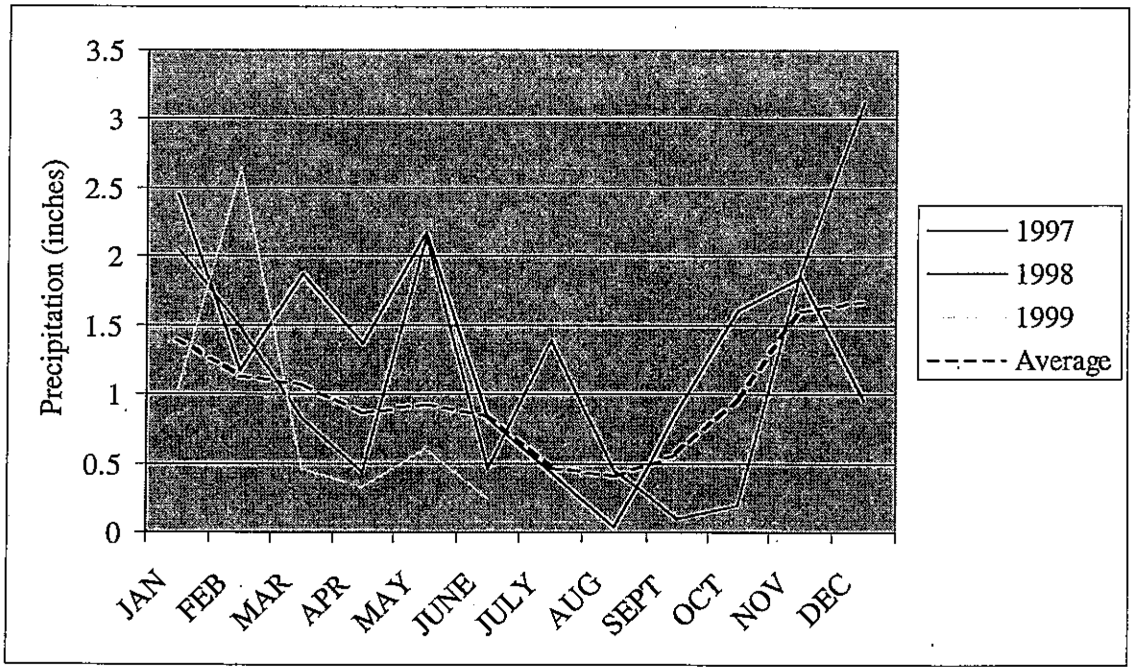


Figure 4-1. Monthly total precipitation (in inches) recorded at the Ritzville 1SSE weather station. Average precipitation is the long-term average, from 1948 to the present.

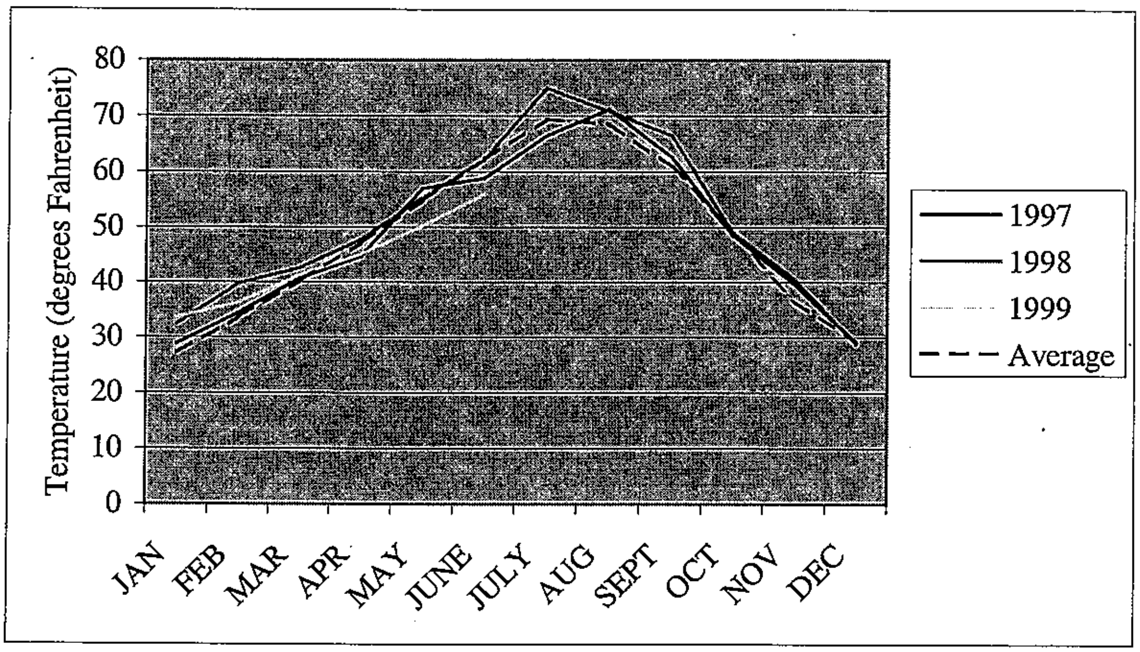


Figure 4-2. Monthly average temperature (degrees Fahrenheit) recorded at the Ritzville 1SSE weather station. Average temperature is the long-term average, from 1948 to the present.

markers. In mid-April while collecting GPS data of transect locations, some of the transect markers, about 10 inches tall, were almost entirely submerged. By May 3rd, most pools were still moist but dry enough to begin sampling, with the exception of M1 and D3. The pools retaining water longest in 1998 were not the same ones holding water longest in 1999, when conditions were wetter.

The Palmer Drought Severity Index (PDSI) can also be used to describe the meteorological conditions of the study years. The PDSI is a drought index which responds to weather conditions that have been abnormally dry or abnormally wet. The index value is calculated from precipitation and temperature data, as well as the local available water content of the soil, and ranges from 4.0 or more (extremely wet) to –4.0 or less (extreme drought). The PDSI values for eastern Washington (state division 8) ranged from 7.81 to 4.62 in 1996 and most of 1997, indicating extreme wet conditions in the region (Table 4-1). In November 1997, the PDSI value decreased considerably and remained below 1.0 throughout both field seasons. This index, when considered along with the precipitation and temperature data, suggests that although rainfall was above average in some of the winter and spring months of 1998, the elevated temperatures, and thus increased rates of evapotranspiration, are likely responsible for the dry conditions.

ENVIRONMENTAL VARIABLES

The bulk density measurements for the ungrazed pools ranged from 0.70 to 1.43 mg/m^3; in the grazed pools the range was 1.06 to 1.46 mg/m^3. Mean values were 1.11 ± 0.25 mg/m^3 and 1.29 ±

Table 4-1. Palmer Drought Severity Index Values for Washington, State Division 8.

Month	1996	1997	1998	1999
January	4.80	7.81	-0.62	-1.61
February	5.63	7.38	-0.49	-1.31
March	5.23	6.89	-0.70	-1.77
April	5.13	6.56	-1.04	-2.23
May	5.52	6.72	-0.65	-2.28
June	5.65	6.77	-1.08	-2.67
July	6.04	7.12	-0.77	-2.65
August	5.21	6.54	-1.15	-2.36
September	4.62	6.03	-1.49	-2.68
October	4.76	6.21	-1.87	no data
November	5.40	-0.22	-1.56	no data
December	7.35	-1.01	-1.46	no data

0.14 mg/m^3 for the ungrazed and grazed pools, respectively (Table 4-2). A typical medium-textured mineral soil may have a bulk density of 1.25 mg/m^3. Comparison of these values using a two-tailed t-test for equality of the means showed a significant difference between them (p=0.07).

Organic matter (OM) content in the ungrazed pools ranged from 0.8 to 3.4 percent. Mean values, by zone, for all of the ungrazed pools were 1.46 ± 0.33 percent in zone 1, 1.58 ± 0.38 percent in zone 2, and 2.05 ± 0.27 percent in zone 3. A similar range of values was found in the grazed pools, where OM content ranged from 0.9 to 3.6 percent. Mean values by zone in the grazed pools were 1.65 ± 0.24 percent in zone 1, 1.84 ± 0.67 percent in zone 2, and 1.88 ± 0.30 percent in zone 3. Within both sites, OM content increased with increasing depth of the pool. This may be a function of OM content generally being higher in fine-textured soils (Brady and Weil 1999).

A comparison of OM content by zone using a two-tailed t-test for equality of the means indicated no significant differences between the sites (Table 4-2). A one-way analysis of variance (ANOVA) conducted on OM content showed a significant difference among zones in all of the study pools (p=0.07). Post-hoc analysis of this result, using the Tukey's Honestly Significant Difference test, reveals a difference in OM content between zones 1 and 3.

Table 4-2. Statistical Comparison of Environmental Variables

Soil Characteristic	Mean Value in Ungrazed Pools	Mean Value in Grazed Pools	P-value
Bulk Density	**1.11**	**1.29**	**0.070**
Organic Matter	1.68	1.78	0.488
Organic Matter, Zone 1	1.46	1.65	0.299
Organic Matter, Zone 2	1.58	1.84	0.418
Organic Matter, Zone 3	2.04	1.88	0.418
ANOVA, Organic Matter Among Zones			**0.070***
pH	**6.21**	**6.91**	**0.000**
pH, Zone 1	6.44	6.75	0.215
pH, Zone 2	**6.22**	**6.99**	**0.011**
pH, Zone 3	**5.91**	**7.03**	**0.022**
ANOVA, pH Among Zones			0.718

*Post-hoc analysis shows difference in OM between zones 1 and 3.
Bolded text indicates a significant difference (α=0.10).
See Appendix C for individual values.

Measurements of pH ranged from 5.23 to 7.07 in the ungrazed pools and from 5.67 to 8.19 in the grazed pools. Mean values by zone in the ungrazed pools were 6.44 ± 0.37 in zone 1, 6.22 ± 0.38 in zone 2, and 5.91 ± 0.41 in zone 3. In the grazed pools, mean values were 6.75 ± 0.42 in zone 1, 6.99 ± 0.52 in zone 2, and 7.03 ± 0.70 in zone 3. Comparisons between the sites were made by zone, again using a two-tailed t-test for equality of means, with significant differences showing in zone 2 (p=0.011) and zone 3 (p=0.022, Table 4-2). When pH was compared between the sites without accounting for zone, a highly significant difference was found (p=0.000). The difference in pH among zones was tested with a one-way ANOVA, revealing no significant difference.

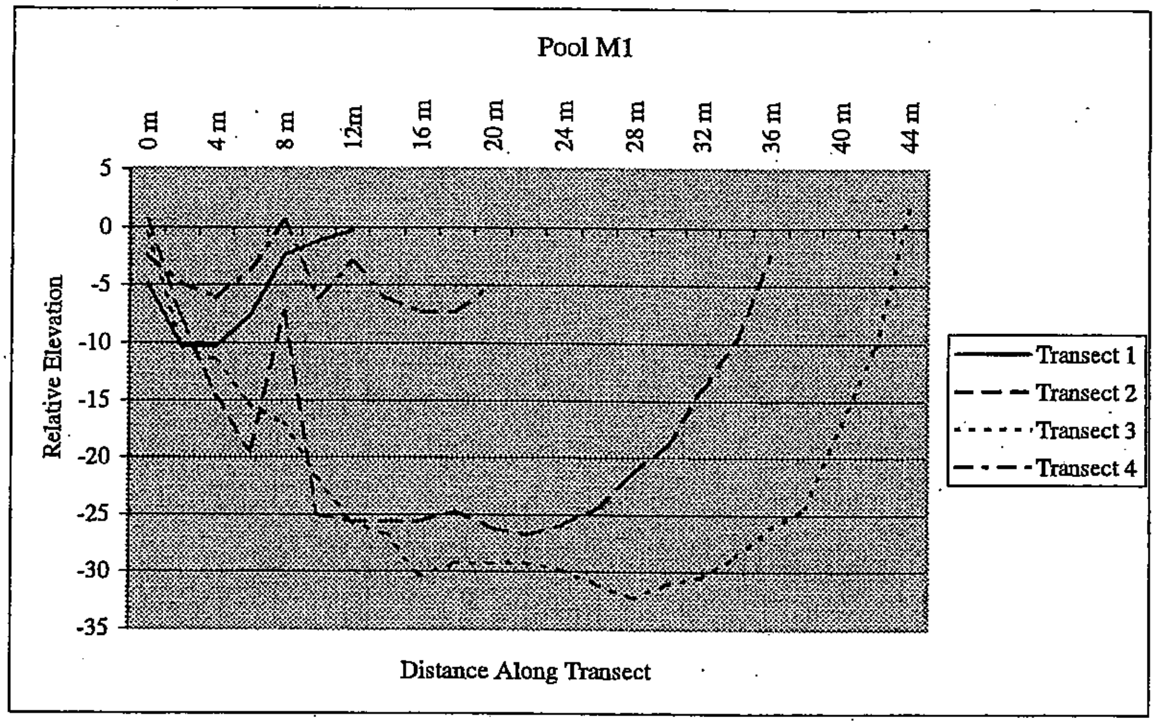
Relative elevation of the pools are shown graphically in Figure 4-3. D25 was the deepest of all the study pools, where the elevation along transect 3 approached -70 cm; D3 and D26 were the most shallow. The shallowest of the ungrazed pools was M17, which was about 25 cm shallower than the deepest ungrazed pool, M18. Greater differences were seen among the grazed pools, where elevations ranged from approximately 30 cm in D25 and 15 cm in D26 to almost -70 cm in D25. Three of the ungrazed pools had regions of hummocks within the pools basin—D2, D3, and D26. Overall, there does not appear to be a marked difference in depth between pools in the two sites.

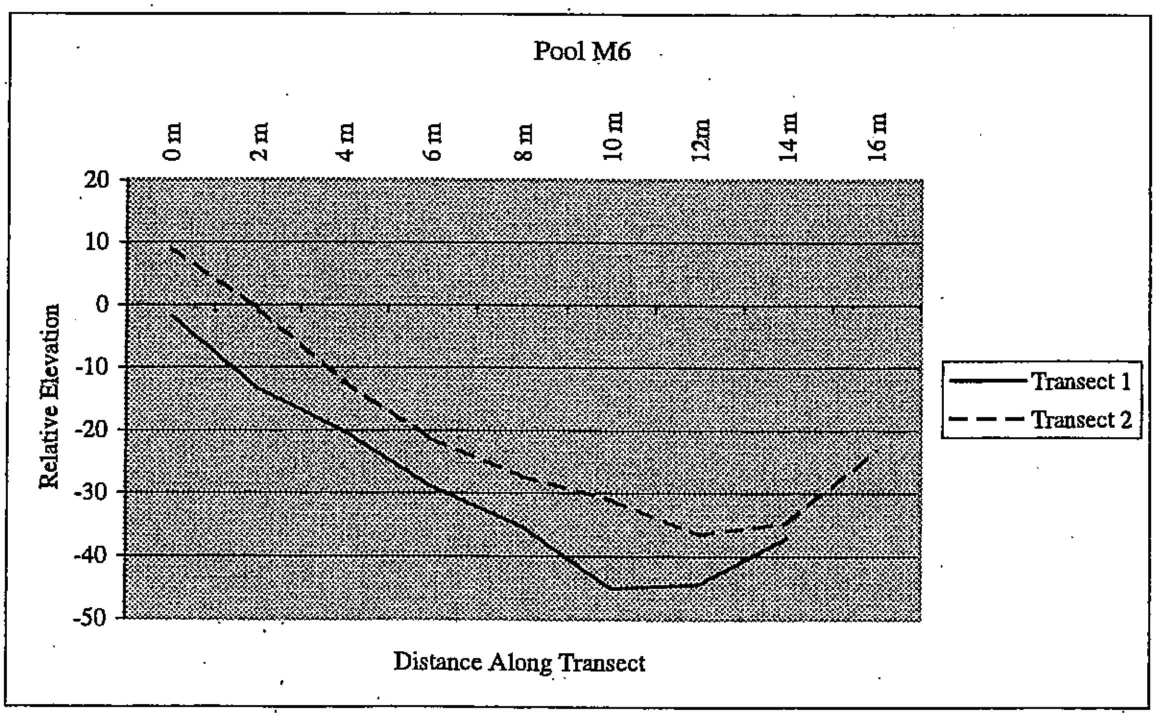
SPECIES COMPOSITION, 1998

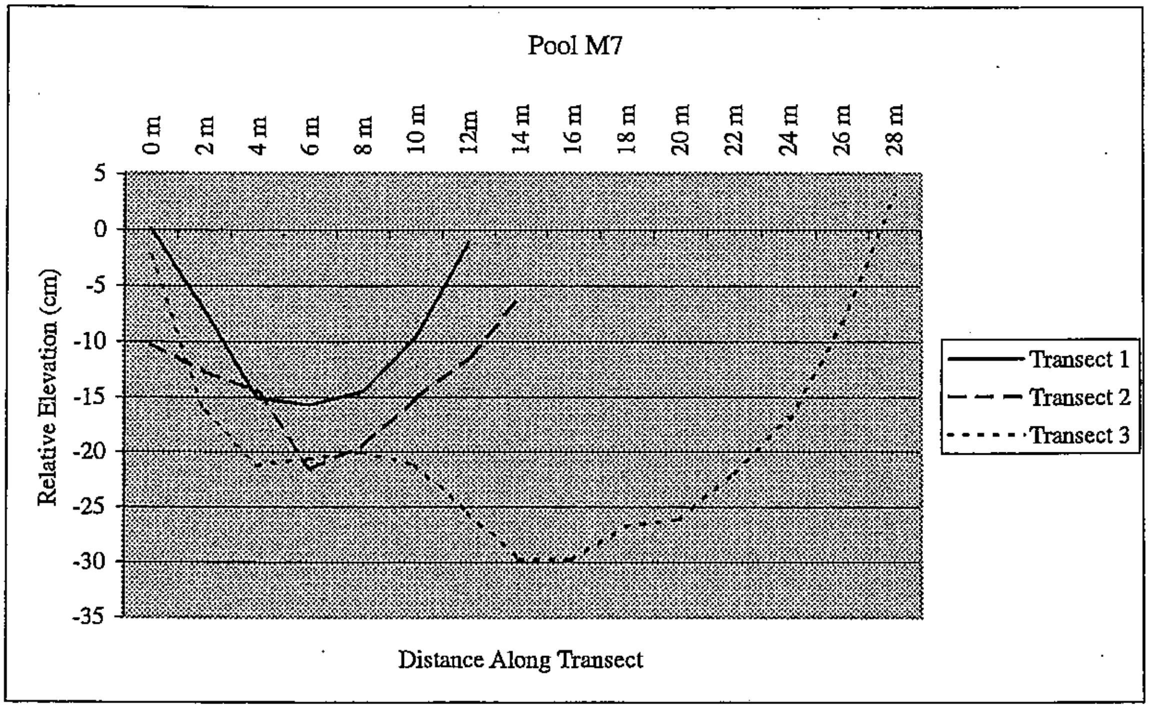
In 1998, the dominant species in all of the pools was the native graminoid, *Deschampsia danthonioides*, which was recorded with high frequency (>50 percent) in almost every zone of every pool. Other species recorded with relatively high frequency in all zones included *Myosurus minimus* spp. *minimus*, *Navarretia leucocephala*, and *Plagiobothrys leptocladus*. All of these species are vernal pool endemics. (See Appendix D for frequency values for all species.)

Numerous weeds were sampled in the ungrazed and grazed pools. As mentioned previously, a weed is defined here as a native (N) or nonnative (NN) species that is capable of developing self-sustaining populations and becoming dominant and/or disruptive to the vernal pool ecosystem. The following species were considered to be weeds according to this definition and were recorded from the study pools: *Apera interrupta* (NN), *Bromus japonicus* (NN), *Bromus mollis* (NN), *Bromus tectorum* (NN), *Cirsium arvense* (NN), *Conyza canadensis* (N), *Epilobium paniculatum*

Figure 4-3. Relative elevation (cm) of vernal pools measured along transects.






Pool M7
0 m
2 m
4 m
6 m
8 m
10 m
12m
14 m
16 m
18 m
20 m
22 m
24 m
26 m
28 m
5
0
-5
-10
-15
-20
-25
-30
-35
Relative Elevation (cm)
Transect 1
Transect 2
Transect 3
Distance Along Transect

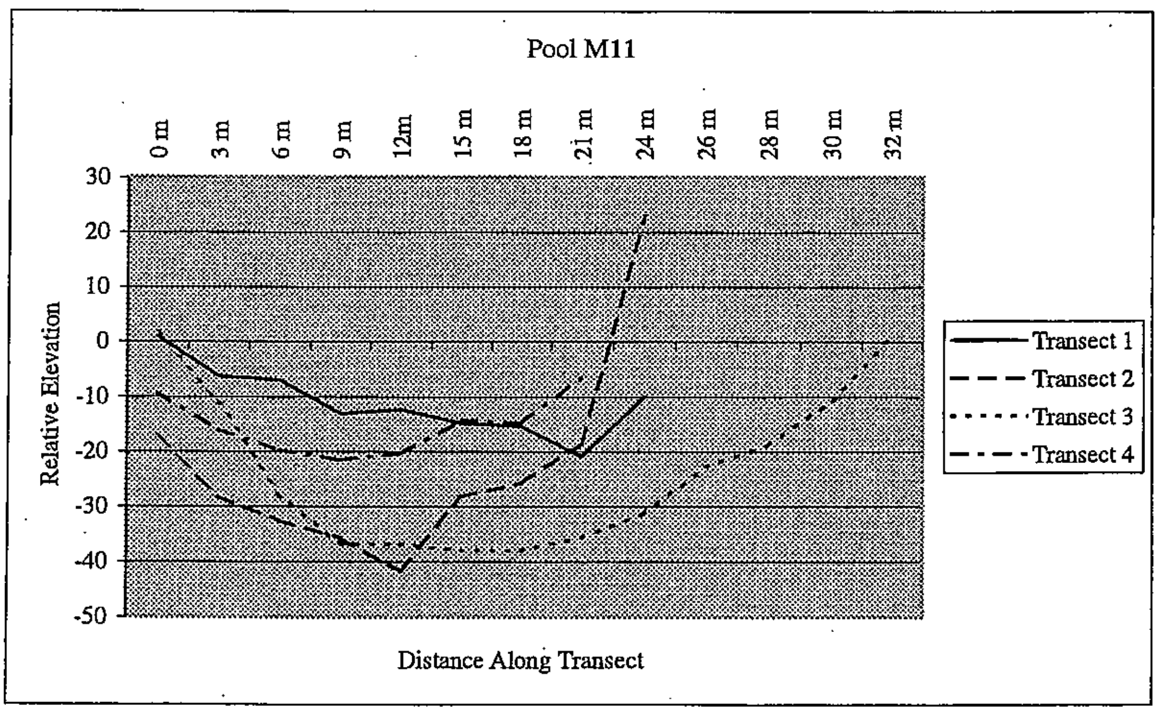
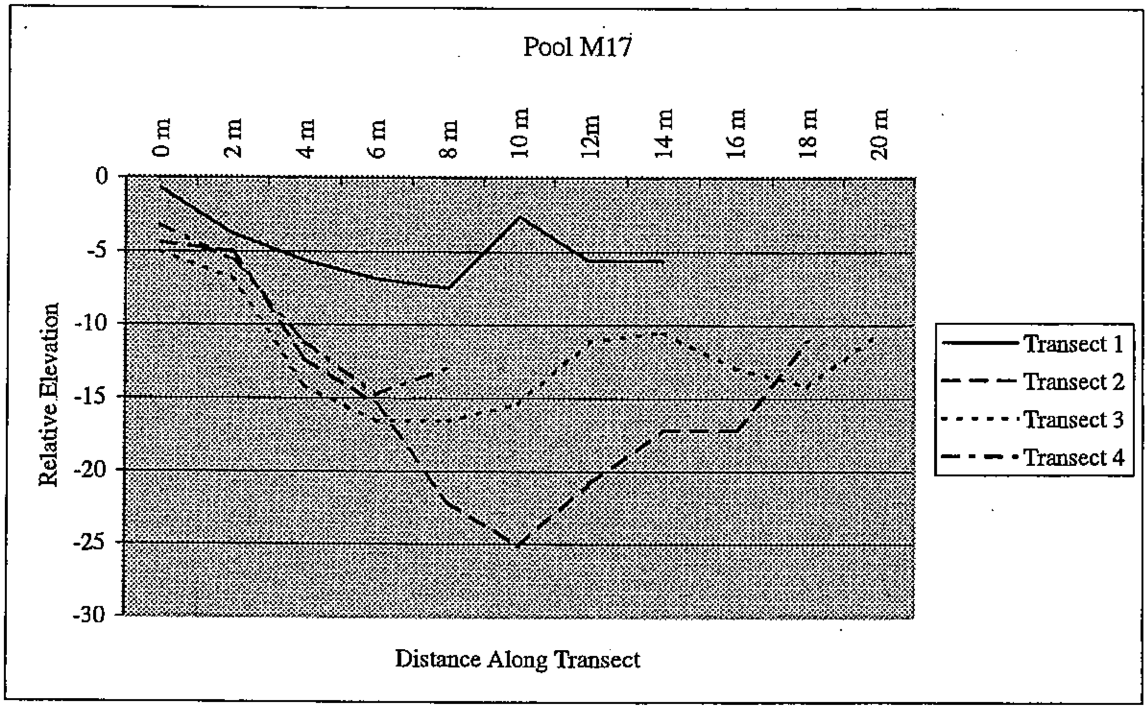

Pool M11
0 m
3 m
6 m
9 m
12m
15 m
18 m
21 m
24 m
26 m
28 m
30 m
32 m
30
20
10
0
-10
-20
-30
-40
-50
Relative Elevation
Transect 1
Transect 2
Transect 3
Transect 4
Distance Along Transect

Figure 4-3 (cont.)



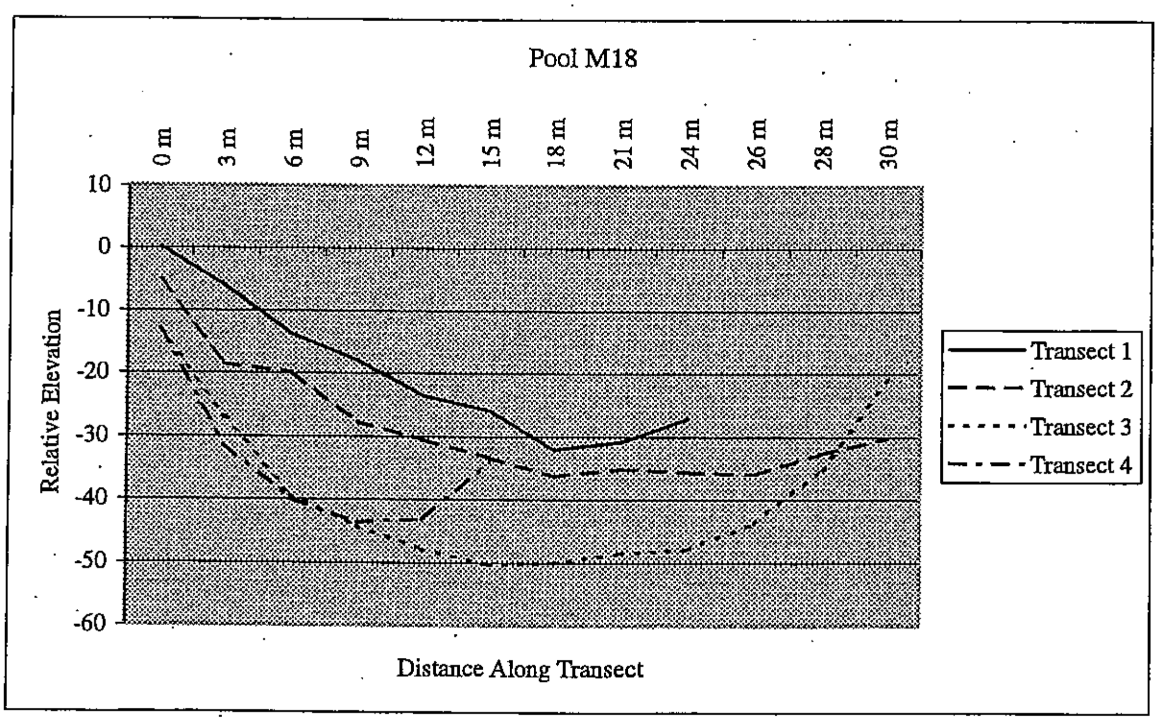
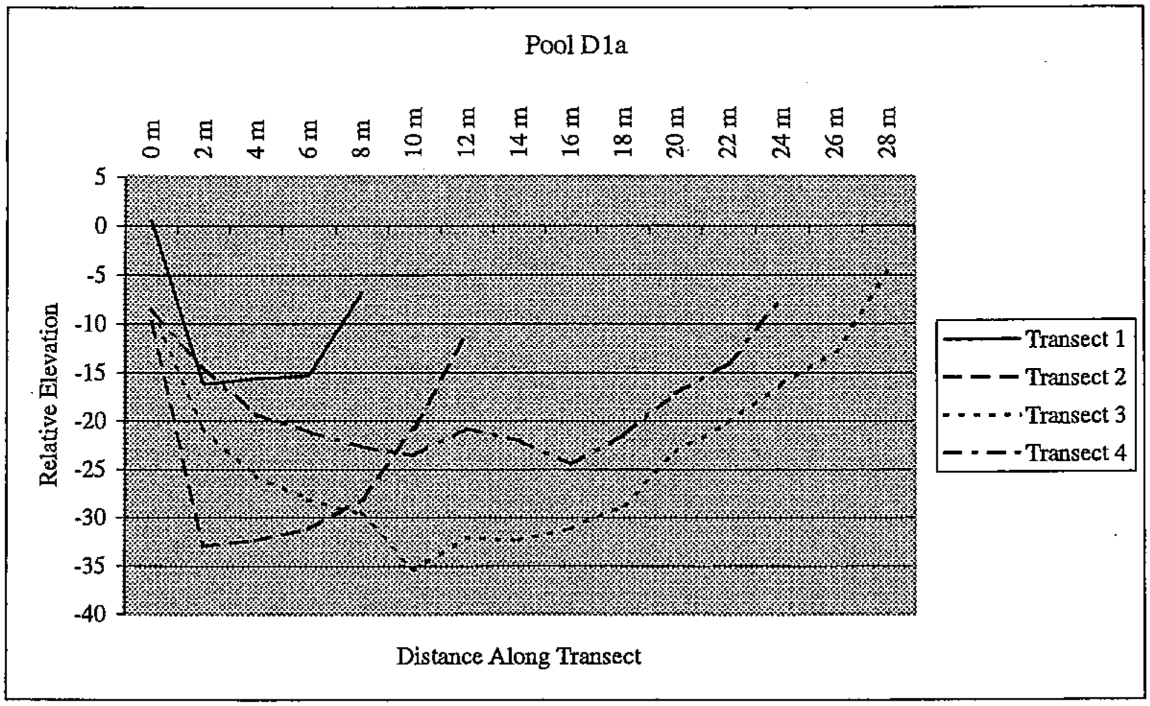
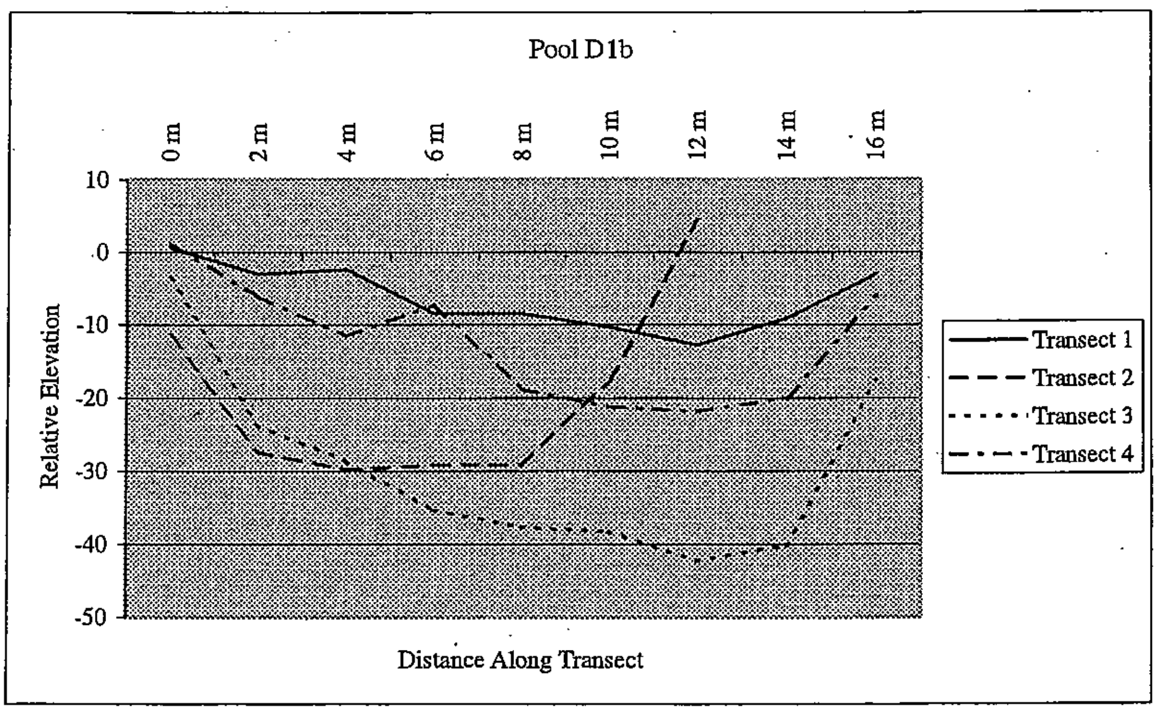
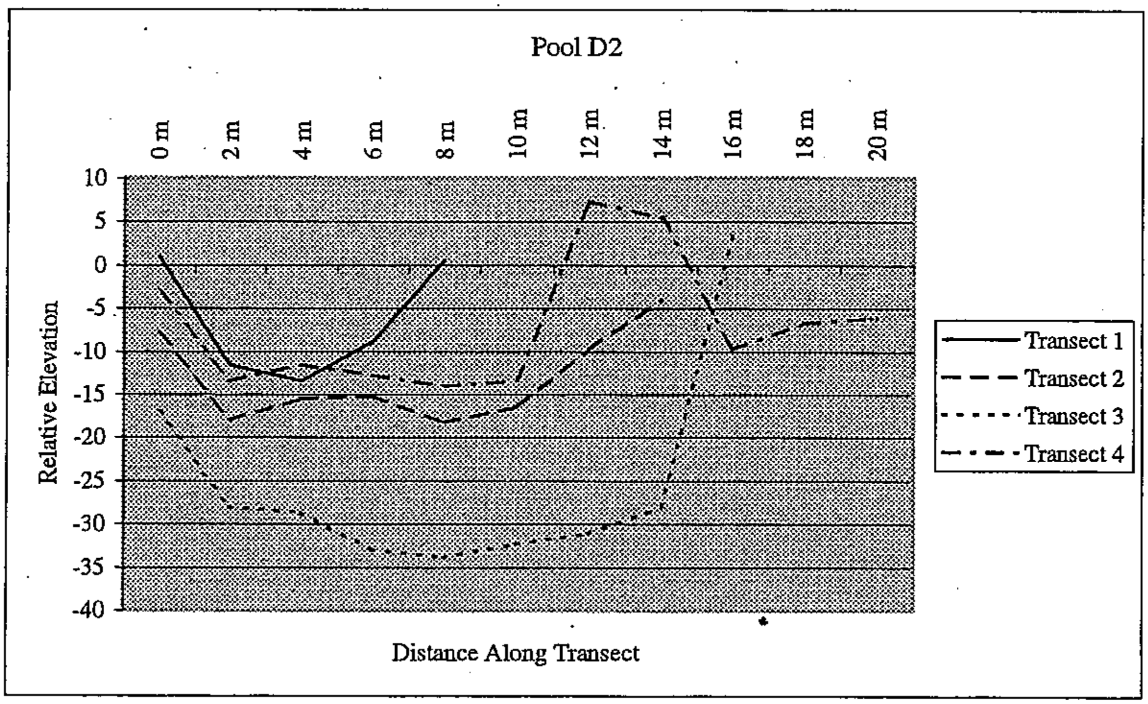
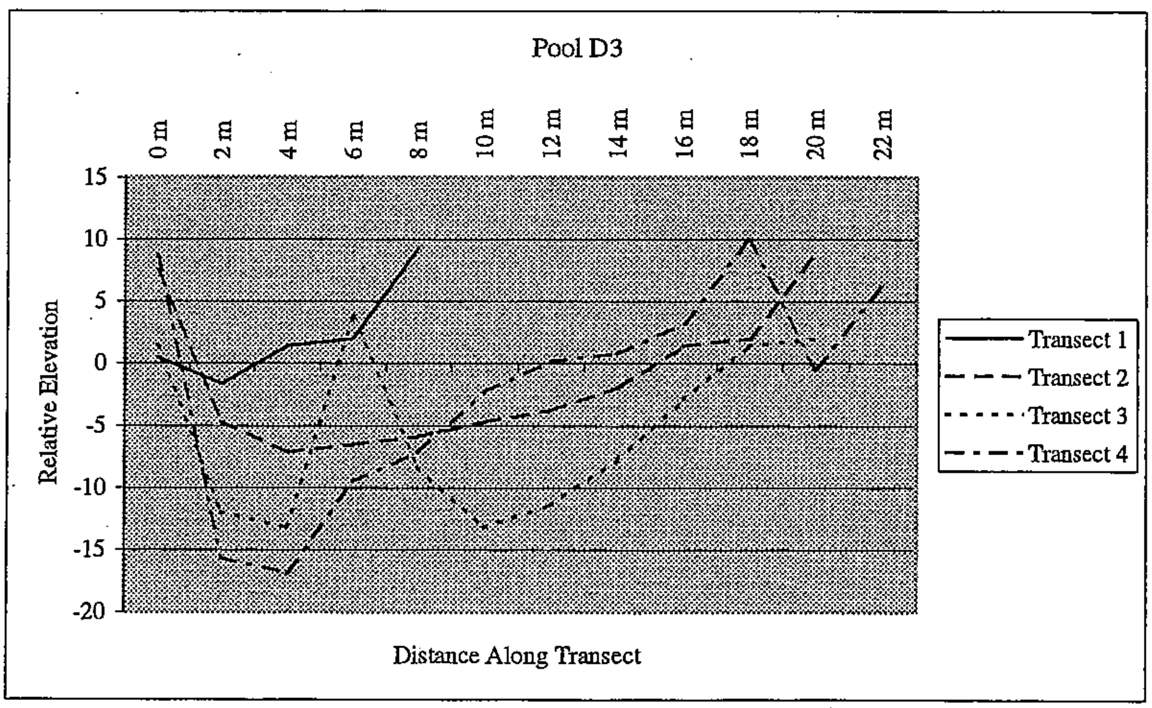


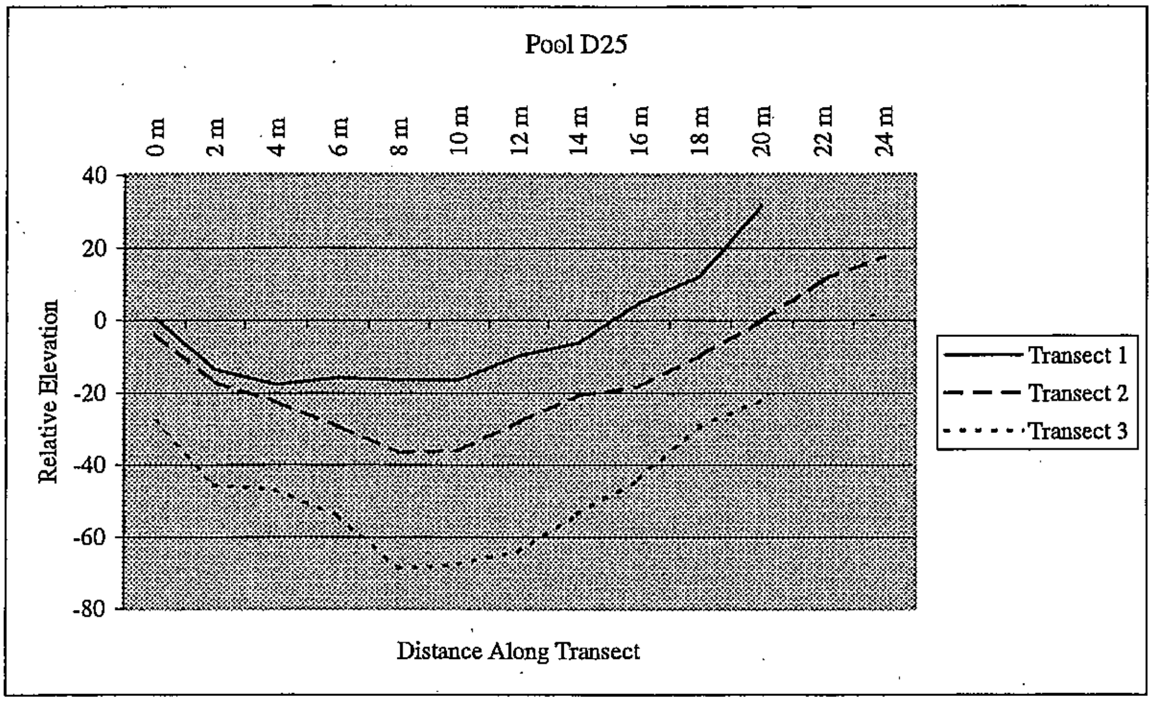
Figure 4-3 (cont.)

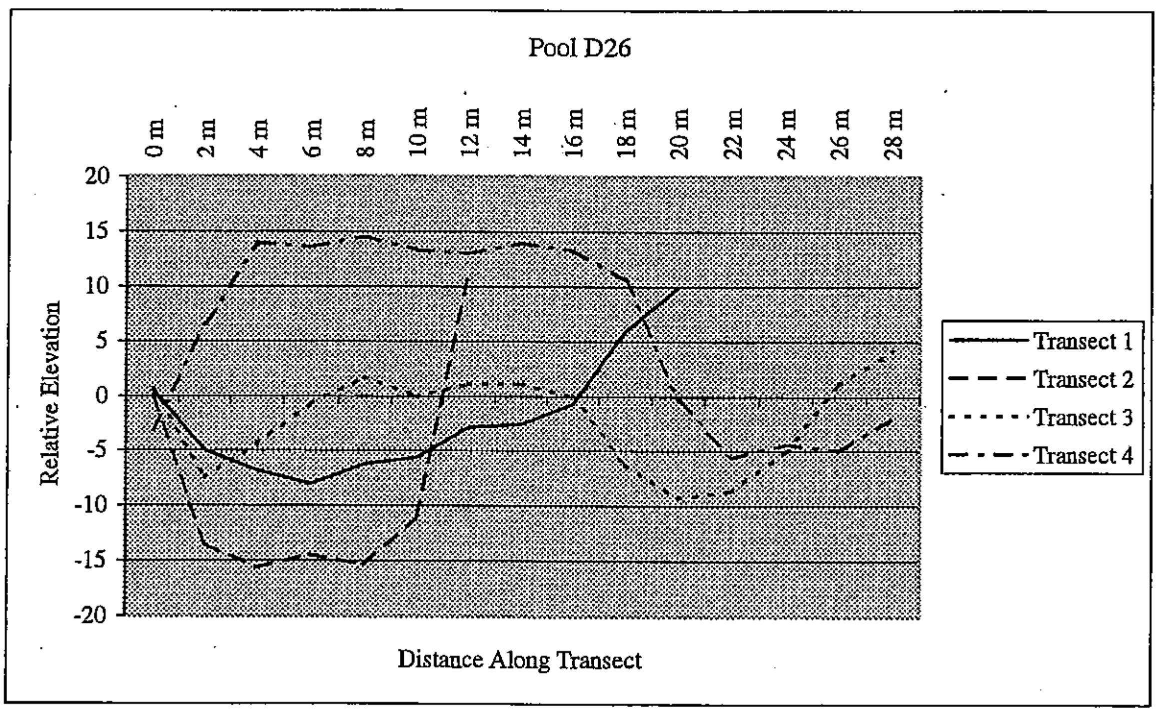





Pool D2
0 m
2 m
4 m
6 m
8 m
10 m
12 m
14 m
16 m
18 m
20 m
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Relative Elevation
Distance Along Transect
Transect 1
Transect 2
Transect 3
Transect 4


Pool D3
0 m
2 m
4 m
6 m
8 m
10 m
12 m
14 m
16 m
18 m
20 m
22 m
15
10
5
0
-5
-10
-15
-20
Relative Elevation
Distance Along Transect
Transect 1
Transect 2
Transect 3
Transect 4


Pool D25
0 m
2 m
4 m
6 m
8 m
10 m
12 m
14 m
16 m
18 m
20 m
22 m
24 m
40
20
0
-20
-40
-60
-80
Relative Elevation
Distance Along Transect
Transect 1
Transect 2
Transect 3


Pool D26
0 m
2 m
4 m
6 m
8 m
10 m
12 m
14 m
16 m
18 m
20 m
22 m
24 m
26 m
28 m
20
15
10
5
0
-5
-10
-15
-20
Relative Elevation
Distance Along Transect
Transect 1
Transect 2
Transect 3
Transect 4

(N), *Gnaphalium palustre* (N), *Holosteum umbellatum* (NN), *Juncus bufonius* (N), *Lactuca serriola* (NN), *Lepidium perfoliatum* (NN), *Lotus purshiana* (N), *Myosotis micrantha* (NN), *Plantago patagonica* (N), *Polygonum aviculare* (NN), *Sisymbrium altissimum* (NN), *Spergularia diandra* (NN), and *Taraxacum officinale* (NN).

Considering all of the species sampled in the ungrazed pools, both weedy and nonweedy, those most frequent in zone 1 were *Achillea millefolium*, *Allium geyeri*, *Apera interrupta*, *Draba verna*, *Epilobium paniculatum*, *Grindelia nana*, *Lactuca serriola*, *Lomatium grayi*, *Montia linearis*, and *Polygonum polygaloides* (Table 4-3). Within zone 2, frequently-occurring species included *Alopecurus saccatus*, *Epilobium paniculatum*, *Grindelia nana*, *Lactuca serriola*, *Montia linearis*, *Polygonum aviculare*, *Psilocarphus brevissimus*, and *Veronica peregrina*. The presence of the aquatic sedge, *Eleocharis macrostachya*, characterized zone 3 of the pools. Other species occurring frequently in this portion of the pools, excluding the ubiquitous ones mentioned above, were *Grindelia nana*, *Lactuca serriola*, and *Psilocarphus brevissimus*.

In the grazed pools, species most frequent in zone 1 were *Agoseris heterophylla*, *Agrostis diegoensis*, *Allium geyeri*, *Bromus mollis*, *Bromus tectorum*, *Draba verna*, *Epilobium paniculatum*, *Juncus bufonius*, *Lactuca serriola*, *Lepidium perfoliatum*, *Lomatium grayi*, *Madia exigua*, *Polygonum aviculare*, and *Polygonum polygaloides* (Table 4-3). Species occurring with high frequency in zone 2 were *Allium geyeri*, *Alopecurus saccatus*, *Boisduvalia glabella*, *Eleocharis macrostachya*, *Epilobium paniculatum*, *Juncus bufonius*, *Lactuca serriola*, *Polygonum aviculare*, *Polygonum polygaloides*, *Psilocarphus brevissimus*, and *Veronica peregrina*. Similar to the ungrazed pools, but to a lesser extent (i.e., 46 percent), *Eleocharis macrostachya* was abundant in zone 3 of the grazed pools. Other species present in this zone were *Alopecurus saccatus*, *Boisduvalia glabella*, *Epilobium paniculatum*, *Juncus bufonius*, *Lactuca serriola*, *Polygonum aviculare*, *Polygonum polygaloides*, *Psilocarphus brevissimus*, and *Veronica peregrina*.

Six species were found only in ungrazed pools—*Bromus japonicus* (weedy annual grass), *Elymus elymoides* (upland grass), *Idahoa scapigera* (upland annual), *Montia dichotoma* (wetland species), *Myosurus minimus* ssp. *apus* (rare vernal pool specialist, see below), and *Phlox gracilis* (annual grassland species common to Columbia Basin vernal pools). Species recorded only from the grazed pools were *Agrostis diegoensis* (upland grass), *Carex douglasii* (alkali-tolerant sedge), *Cirsium arvense* (weedy perennial), *Erigeron peregrina* (upland composite), *E. pumilus* (upland composite), *Festuca idahoensis* (dominant upland grass), *Myosurus apetalus* (vernal pool specialist, this species was found in the ungrazed pools in 1999), and *Plantago patagonica* (annual weed).

Only one rare species was encountered—*Myosurus minimus* ssp. *apus*. Though not presently designated in the state of Washington nor federally listed, *M. minimus* ssp. *apus* is considered by the U.S. Fish and Wildlife Service as a Species of Concern (CDFG 1999). It was sampled in zone 2 of pool M18, occurring with low frequency (1.9 percent; Appendix D). *M. minimus* ssp.

Table 4-3. Mean Frequency of Common Species in Ungrazed and Grazed Pools, 1998.

	Zone 1		Zone 2		Zone 3	
Species	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**
Achillea millefolium	9.7	8.8	2.4	0	0	2.8
Agoseris heterophylla	14.8	36.3	2.5	12.5	0	4.8
Agrostis diegoensis	0	33.4	0	18.6	0	19.0
Allium geyeri	14.8	22.0	14.0	22.5	2.7	22.1
Alopecurus saccatus	11.6	1.5	42.6	29.3	62.0	9.2
Apera interrupta*	40.2	24.2	17.5	4.5	7.2	1.0
Boisduvalia glabella	0	3.2	5.6	26.0	12.9	37.1
Bromus mollis	11.0	24.7	0	5.0	0	1.4
Bromus tectorum	2.3	12.9	2.7	4.6	0	7.0
Deschampsia danthonioides	94.8	83.9	72.8	76.2	41.7	53.4
Draba verna	34.2	26.2	0.6	6.5	0	5.6
Eleocharis macrostachya	2.2	12.7	32.1	25.8	89.5	40.8
Epilobium paniculatum	48.1	42.8	32.8	16.8	8.1	25.0
Grindelia nana	47.1	24.3	37.1	22.1	6.0	12.4
Juncus bufonius	2.4	20.7	6.3	28.9	0	15.4
Lactuca serriola	65.5	41.8	32.7	17.9	9.2	21.6
Lepidium perfoliatum	0	17.4	1.0	7.8	0	5.6
Lomatium grayi	17.0	16.3	7.1	2.9	0	0
Madia exigua	1.9	23.2	2.5	5.8	0	1.4
Montia linearis	10.0	0	20.4	0	1.9	1.4
Myosurus minimus ssp. *minimus*	45.5	38.6	40.0	51.7	21.7	32.4
Navarretia leucocephala	38.2	45.2	28.9	47.0	18.2	26.2
Plagiobothrys leptocladus	17.5	66.7	28.1	69.0	42.8	49.4
Polygonum aviculare	9.4	28.8	25.5	39.4	11.5	43.6
Polygonum polygaloides	44.6	19.6	36.8	34.9	15.5	19.6
Psilocarphus brevissimus	4.0	5.9	20.8	34.4	59.0	50.5
Veronica peregrina	22.8	15.0	27.8	27.3	12.0	33.9

*Weedy species in bold.

apus was also observed in pool M7, in very small numbers, but was not recorded in any of the sample plots.

DIFFERENCES IN SPECIES COMPOSITION, 1998

Two-tailed t-tests for equality of means were conducted to compare the mean frequency of species in each zone of the ungrazed and grazed pools (see Appendix E). Because of multiple comparisons, the true alpha level is greater than the nominal alpha level. Within zone 1 of the study pools, species that occurred with significantly greater frequency in the ungrazed pools were *Elymus elymoides* (p=0.069), *Lactuca serriola* (p=0.052), *Montia dichotoma* (p=0.026), *M. linearis* (p=0.058), and *Sisymbrium altissimum* (p=0.039, Table 4-4). Of these species, *L. serriola* and *S. altissimum* are considered weedy. Also within zone 1, species more frequent in the grazed pools were *Agoseris heterophylla* (p=0.087), *Agrostis diegoensis* (p=0.072), *Bromus tectorum* (p=0.03), *Juncus bufonius* (p=0.092), *Lepidium perfoliatum* (p=0.035), *Madia exigua* (p=0.034), *Plagiobothrys leptocladus* (p=0.001), and *Polygonum aviculare* (p=0.08). Differences in weed species frequencies in zone 1 are illustrated in Figure 4-4. Within zone 2, the one species significantly more frequent in the ungrazed pools was *Apera interrupta* (p=0.087; Figure 4-5); species occurring more frequently in zone 2 of the grazed pools were *Agoseris heterophylla* (p=0.051), *Draba verna* (p=0.075), *Holosteum umbellatum* (p=0.083), and *Plagiobothrys leptocladus* (p=0.004). Zone 3 differences involved *Alopecurus saccatus* and *Eleocharis macrostachya*, which were significantly more frequent in the ungrazed pools (p=0.039 and 0.10, respectively) and *Polygonum aviculare*, which was more frequent in the grazed pools (p=0.05). Weed species frequencies in zone 3 are shown in Figure 4-6.

Other differences in species composition between the sites were seen in the presence of *Downingia yina*, *Lotus purshiana*, and *Juncus bufonius*. *Downingia yina*, a characteristic vernal pool species, was more abundant in zone 1 of the grazed pools—occurring in 0.33 percent of plots in the ungrazed pools versus 3.42 percent in the grazed pools—and more abundant in zones 2 and 3 of the ungrazed pools (4.02 vs. 0.63 percent zone 2 and 8.12 vs. 0 percent in zone 3).

Table 4-4. Significant Differences in Species Frequency, 1998.

Location	Species with Significantly Greater Frequency Relative to Pools in the Other Site (e.g. ungrazed pools zone 1 vs. grazed pools zone 1)
Ungrazed Pools, Zone 1	*Elymus elymoides*, ***Lactuca serriola*****, *Montia dichotoma*, *M. linearis*, ***Sisymbrium altissimum***.
Ungrazed Pools, Zone 2	***Apera interrupta***.
Ungrazed Pools, Zone 3	*Alopecurus saccatus*, *Eleocharis macrostachya*.
Grazed Pools, Zone 1	*Agoseris heterophylla*, *Agrostis diegoensis*, ***Bromus tectorum***, ***Juncus bufonius***, ***Lepidium perfoliatum***, *Madia exigua*, *Plagiobothrys leptocladus*, ***Polygonum aviculare***.
Grazed Pools, Zone 2	*Agoseris heterophylla*, *Draba verna*, ***Holosteum umbellatum***, *Plagiobothrys leptocladus*.
Grazed Pools, Zone 3	***Polygonum aviculare***.

*Weedy species in bold.

Lotus purshiana, a weedy species, was very common in zones 1 and 2 of pools D2 and D3 and was non-existent in the other study pools (with the exception of M17, zone 1). Pools D2 and D3 are located in close proximity to one another (see Figure 3-2). *Juncus bufonius*, another weedy species, exhibited significant differences between the sites in zone 1, and it also occurred much more frequently in zones 2 and 3 of the grazed pools, especially pool D3.

SPECIES COMPOSITION, 1999

In the second year of the study, three species were present with high frequency in nearly all zones of all pools—*Deschampsia danthonioides*, *Myosurus minimus* ssp. *minimus*, and *Plagiobothrys leptocladus*—though *D. danthonioides* was not as prevalent as it was in 1998 and was more restricted to zones 1 and 2 of the pools. *Navarretia leucocephala* was also very abundant in the pools, with the exception of D25 where it was not recorded at all. Weeds sampled in the pools included most of those sampled in 1998, along with a few others—*Echinochloa crusgalli*, *Ranunculus testiculatus*, *Sonchus asper*, and *Tragopogon dubius*. (See Appendix D for frequency values for all species.)

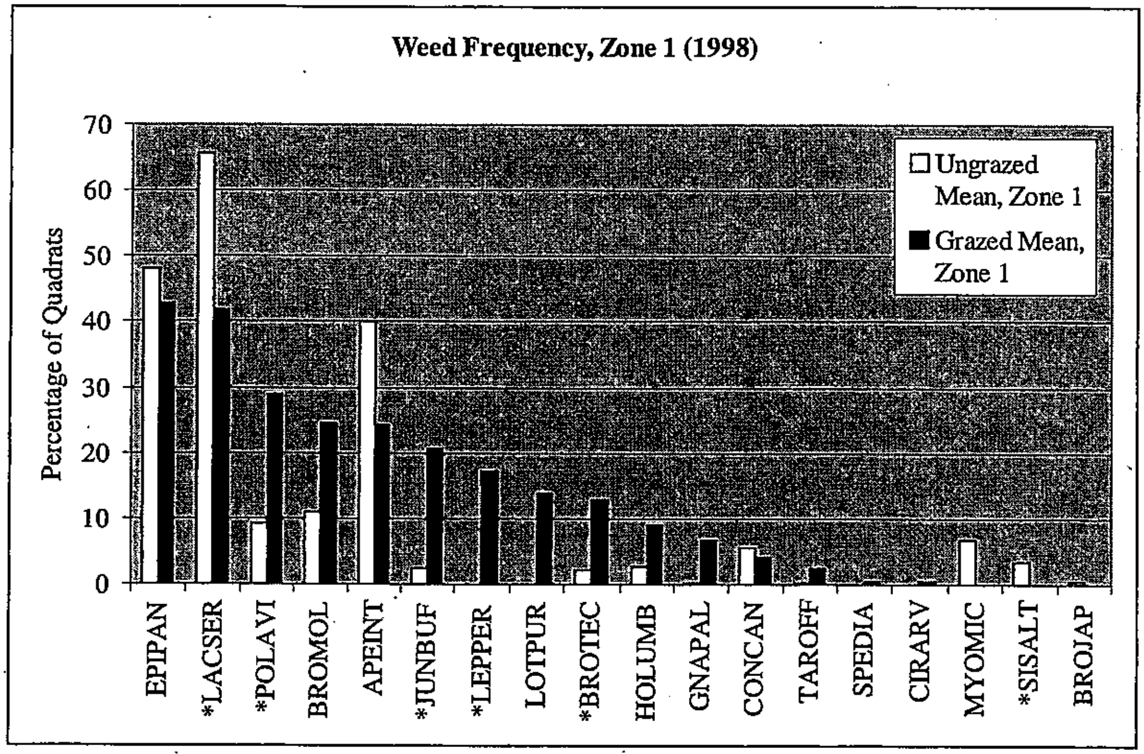


Figure 4-4. Frequency of weed species in zone 1 of ungrazed and grazed pools, 1998 data. Asterisks denote a significant difference (p<0.10).

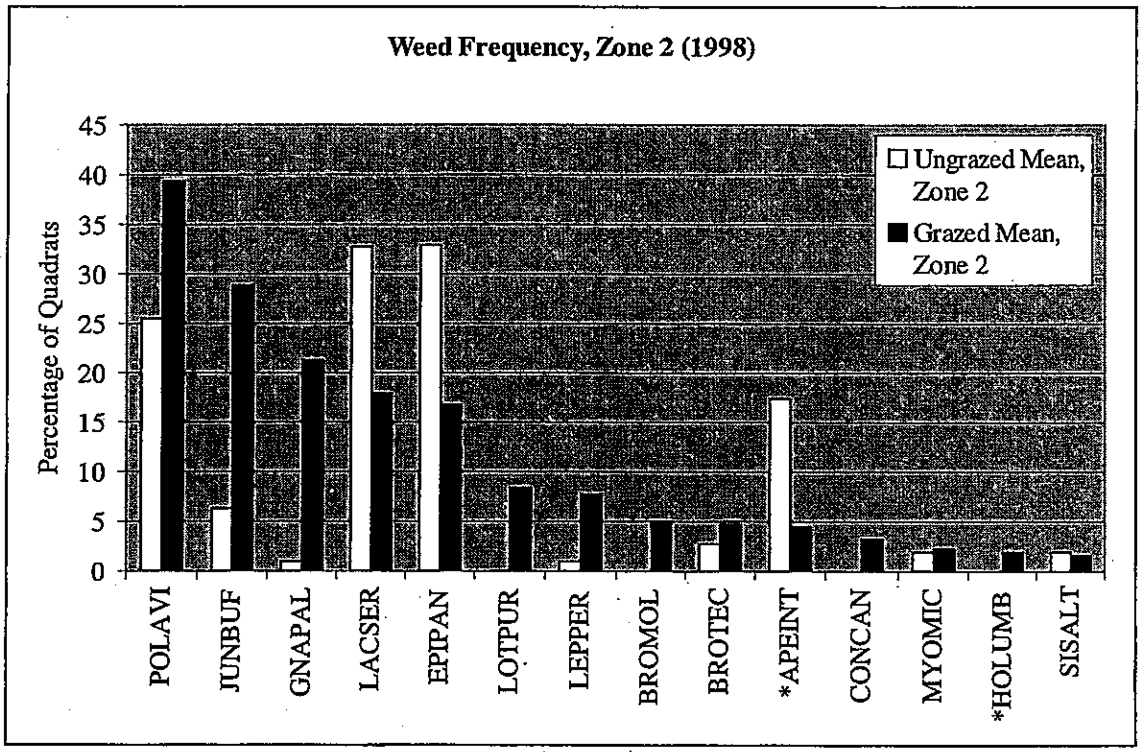


Figure 4-5. Frequency of weed species in zone 2 of ungrazed and grazed pools, 1998 data. Asterisks denote a significant differences ($p<0.10$).

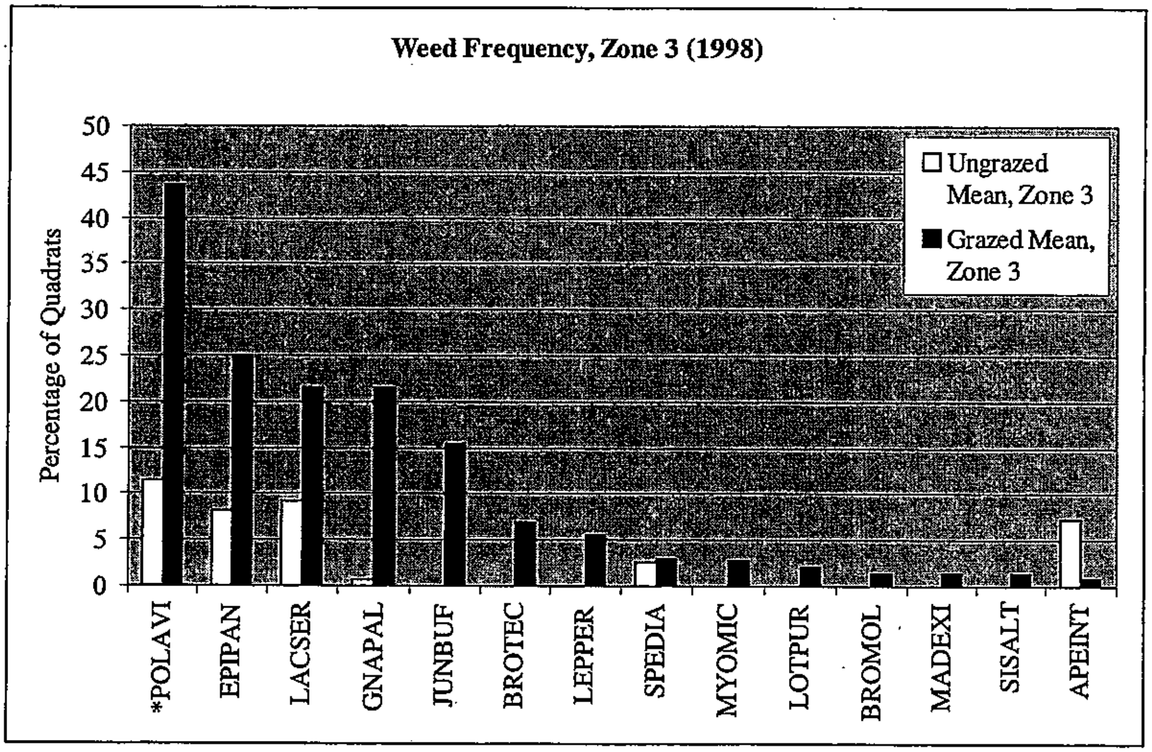


Figure 4-6. Frequency of weed species in zone 3 of ungrazed and grazed pools, 1998 data. Asterisks denote a significant difference ($p<0.10$).

In this year, dominant species in zone 1 of the ungrazed pools were *Allium geyeri*, *Apera interrupta*, *Draba verna*, *Epilobium paniculatum*, *Grindelia nana*, *Lactuca serriola*, *Montia dichotoma*, *M. linearis*, and *Veronica peregrina* (Table 4-5). In zone 2, common species were *Allium geyeri*, *Alopecurus saccatus*, *Apera interrupta*, *Gnaphalium palustre*, *Grindelia nana*, *Lactuca serriola*, *Montia dichotoma*, *Montia linearis*, *Polygonum aviculare*, *Polygonum polygaloides*, *Psilocarphus* sp., and *Veronica peregrina*. Two species of *Eleocharis*, *E. acicularis* and *E. macrostachya*, were identified in the pools during this field season, the latter of which was much more prevalent in zone 3 of the pools than the former. *Eleocharis acicularis* characterized zone 3 of pool M7 and was also found with relatively high frequency in M1 and M18. In addition to *E. macrostachya*, which was the dominant species in zone 3 of most ungrazed pools, *Boisduvalia glabella*, *Gnaphalium palustre*, *Grindelia nana*, *Lactuca serriola*, and *Psilocarphus* sp., were found with some regularity in zone 3. *Limosella aquatica*, *Polygonum aviculare*, *Polygonum polygaloides*, and *Veronica peregrina* also occurred in zone 3 of the ungrazed pools, but to a lesser extent.

In the grazed pools, species most prevalent in zone 1 were *Agoseris heterophylla*, *Allium geyeri*, *Apera interrupta*, *Bromus mollis*, *Draba verna*, *Epilobium paniculatum*, *Lactuca serriola*, *Lepidium perfoliatum*, *Lomatium grayi*, *Madia exigua*, and *Polygonum aviculare* (Table 4-5). Within zone 2, *Allium geyeri*, *Boisduvalia glabella*, *Draba verna*, *Eleocharis macrostachya*, *Epilobium paniculatum*, *Gnaphalium palustre*, *Juncus bufonius*, *Lactuca serriola*, and *Polygonum aviculare* were the dominant species; and within zone 3, *Boisduvalia glabella*, *Eleocharis macrostachya*, *Gnaphalium palustre*, *Juncus bufonius*, and *Polygonum aviculare* were common.

Species found only the ungrazed pools in 1999 were *Artemisia tridentata* (dominant upland shrub), *Clarkia pulchella* (upland forb), *Collomia linearis* (upland forb), *Conyza canadensis* (annual weed), *Danthonia unispicata* (upland grass), *Downingia yina* (vernal pool endemic), and *Myosurus minimus* ssp. *apus* (rare vernal pool endemic). Species sampled only in grazed pools included *Carex douglasii* (alkali-tolerant sedge), *Erigeron pumilus* (upland forb), *Festuca* sp.(upland grass), *Hesperochiron pumilus* (upland forb), *Lotus purshiana* (annual weed), *Plantago patagonica* (annual weed), *Ranunculus testiculatus* (annual weed), *Sonchus asper* (annual weed), and *Taraxacum officinale* (perennial weed).

Table 4-5. Mean Frequency of Common Species in Ungrazed and Grazed Pools, 1999.

	Zone 1		Zone 2		Zone 3	
Species	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**	**Ungrazed**	**Grazed**
Agoseris heterophylla	11.9	18.5	1.2	4.8	0	0
Allium geyeri	21.5	22.1	9.5	21.7	7.8	20.9
Alopecurus saccatus	8.7	0.5	30.7	2.9	23.8	0.5
Apera interrupta	22.7	26.4	11.5	7.5	1.7	0
Boisduvalia glabella	0.3	0.4	10.0	18.6	6.0	22.7
Bromus mollis	8.9	18.1	3.8	6.1	0	0
Deschampsia danthonioides	59.2	41.3	43.7	35.4	13.2	8.9
Draba verna	71.3	54.6	15.3	15.6	0	0.8
Eleocharis acicularis	0	0.5	0	0.9	14.0	2.5
Eleocharis macrostachya	0.7	11.8	26.9	25.3	67.6	40.6
Epilobium paniculatum	4.6	40.6	16.1	19.9	0.2	2.7
Gnaphalium palustre	0	0.1	17.5	21.7	33.6	38.4
Grindelia nana	30.0	10.2	23.3	4.1	10.6	15.6
Juncus bufonius	0.8	6.5	1.1	23.9	0	22.9
Lactuca serriola	27.4	44.7	13.9	21.6	3.5	6.0
Lepidium perfoliatum	0.6	21.9	0	2.8	0	0.4
Limosella aquatica	0	0	2.5	0.6	5.0	5.2
Lomatium grayi	18.3	24.9	5.2	5.7	3.6	0.8
Madia exigua	5.3	11.3	0.3	3.4	0	0.5
Montia dichotoma	47.4	11.8	19.0	2.6	0	0
Montia linearis	34.3	9.7	32.6	5.9	4.1	0
Myosurus minimus ssp. *minimus*	65.9	60.1	72.0	40.2	36.8	21.8
Navarretia leucocephala	25.5	33.9	23.3	20.6	14.4	9.7
Plagiobothrys leptocladus	31.8	59.2	50.9	55.5	32.3	33.0
Polygonum aviculare	3.0	17.6	16.4	40.0	2.2	51.4
Polygonum polygaloides	21.7	1.3	28.9	1.1	3.2	0.4
Psilocarphus sp.	1.8	1.0	7.8	6.6	10.6	12.1
Veronica peregrina	20.8	6.4	19.5	8.5	7.5	1.2

*Weedy species in bold.

Myosurus minimus ssp. *apus* was, again, the only rare species found in the study pools. Numerous individuals were found in zones 1 (6.8 percent), 2 (22.1 percent) and 3 (20 percent) of M7. It was noticeably more prevalent than in the previous year but was not recorded nor observed in pool M18, as it had been the previous year.

DIFFERENCES IN SPECIES COMPOSITION, 1999

Two-tailed t-tests for equality of means were again conducted to compare the mean frequency of species, by zone, between the sites (see Appendix E). As with the 1998 data, because of multiple comparisons, the true alpha level is greater than the nominal alpha level. Within zone 1 of the pools, species occurring with significantly greater frequency in the ungrazed pools were

Deschampsia danthonioides (p=0.051), *Montia dichotoma* (p=0.012), *M. linearis* (p=0.083), *Phlox gracilis* (p=0.057), and *Polygonum polygaloides* (p=0.051, Table 4-6). Species that occurred with significantly greater frequency in zone 1 of the grazed pools were *Lactuca serriola* (p=0.09), *Lagophylla ramosissima* (p=0.069), *Lepidium perfoliatum* (p=0.023), *Plagiobothrys leptocladus* (p=0.007), *Polygonum aviculare* (p=0.041), and *Taraxacum officinale* (p=0.045). Of these six species, four are weeds (Figure 4-7). Within zone 2, species more frequent in the ungrazed pools were *Alopecurus saccatus* (p=0.081), *Downingia yina* (p=0.101), *Grindelia nana* (p=0.033), *Montia dichotoma* (p=0.082), *M. linearis* (p=0.081), *Myosurus minimus* ssp. *minimus* (p=0.094), *Polygonum polygaloides* (p=0.019), and *Veronica peregrina* (p=0.036); while species more frequent in the grazed pools were the weeds, *Juncus bufonius* (p=0.01), *Polygonum aviculare* (p=0.115), *Sonchus asper* (p=0.083), and *Tragopogon dubius* (p=0.069; Figure 4-8). In zone 3, there were no species that were significantly more frequent in the ungrazed pools. There were, however, two weed species that were more frequent in zone 3 of the grazed pools—*Juncus bufonius* (p=0.087) and *Polygonum aviculare* (p=0.055; Figure 4-9).

Table 4-6. Significant Differences in Species Frequency, 1999.

Location	**Species with Significantly Greater Frequency Relative to Pools in the Other Site (e.g. ungrazed pools zone 1 vs. grazed pools zone 1)**
Ungrazed Pools, Zone 1	*Deschampsia danthonioides, Montia dichotoma, M. linearis, Phlox gracilis, Polygonum polygaloides.*
Ungrazed Pools, Zone 2	*Alopecurus saccatus, Downingia yina, Grindelia nana, Montia dichotoma, M. linearis, Myosurus minimus* ssp. *minimus, Polygonum polygaloides, Veronica peregrina.*
Ungrazed Pools, Zone 3	none.
Grazed Pools, Zone 1	***Lactuca serriola*****, *Lagophylla ramosissima*, ***Lepidium perfoliatum***, *Plagiobothrys leptocladus*, ***Polygonum aviculare***, ***Taraxacum officinale***.
Grazed Pools, Zone 2	***Juncus bufonius***, ***Polygonum aviculare***, ***Sonchus asper***, ***Tragopogon dubius***.
Grazed Pools, Zone 3	***Juncus bufonius***, ***Polygonum aviculare***.

*Weedy species in bold.

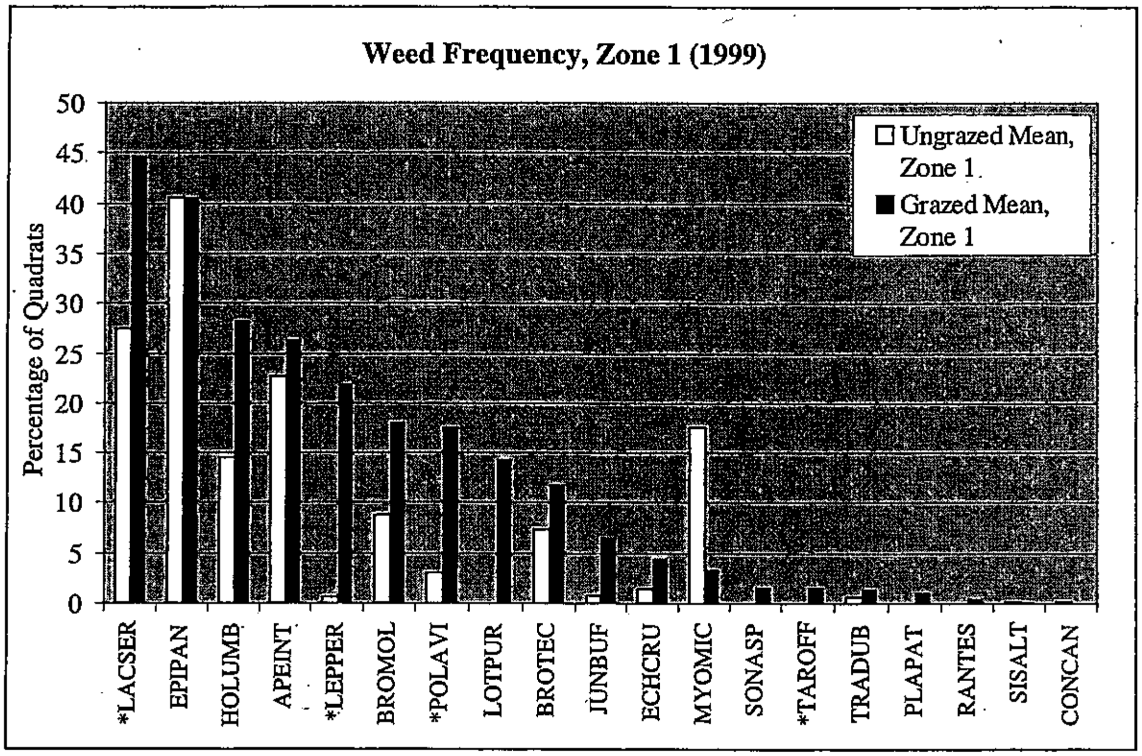


Figure 4-7. Frequency of weed species in zone 1 of ungrazed and grazed pools, 1999 data. Asterisks denote a significant difference (p<0.10).

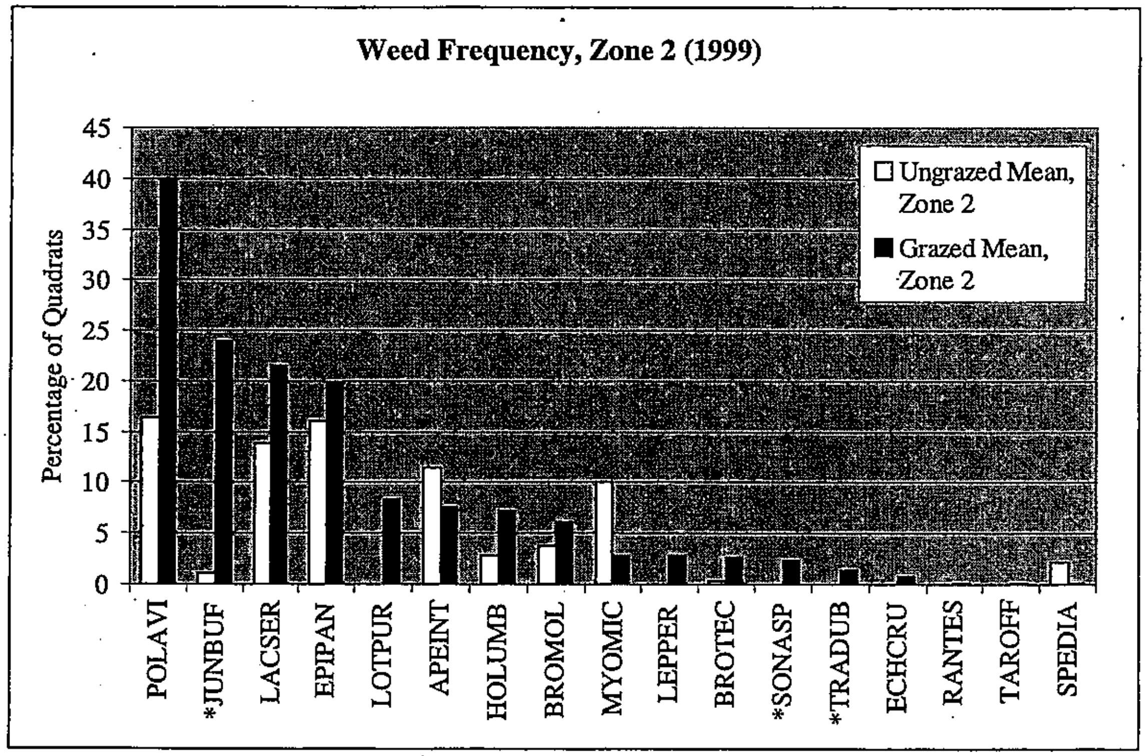


Figure 4-8. Frequency of weed species in zone 2 of ungrazed and grazed pools, 1999 data. Asterisks denote a signficiant difference (p<0.10).

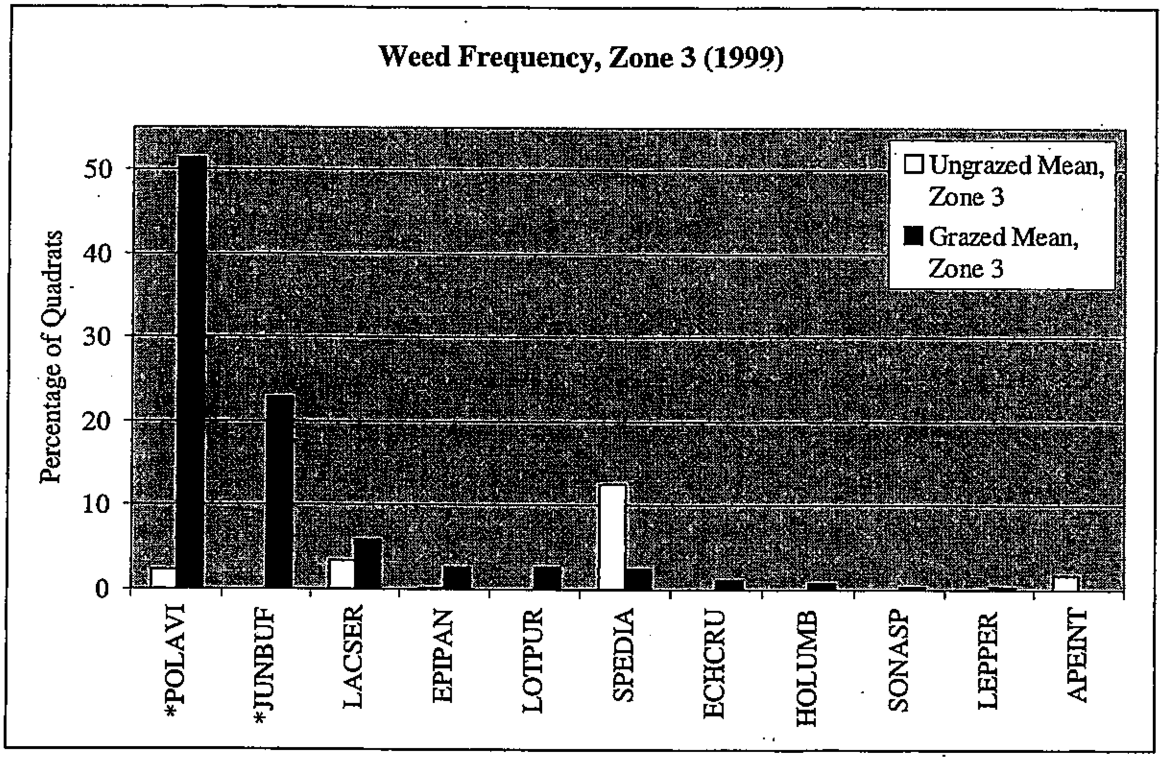


Figure 4-9. Frequency of weed species in zone 3 of ungrazed and grazed pools, 1999 data. Asterisks denote a significant difference ($p<0.10$).

TEMPORAL CHANGES IN SPECIES COMPOSITION

The following discussion pertains only to data collected in the 1999 field season since data from the first sample period of 1998 were discarded.

Some of the first species to germinate in the pools were, not surprisingly, those found primarily in zone 1 of the pools. The most common of these species included *Bromus mollis*, *B. tectorum*, *Draba verna*, *Epilobium paniculatum*, *Holosteum umbellatum*, *Montia dichotoma*, and *M. linearis*. Two species, *Myosurus apetalus* and *Ranunculus testiculatus*, were observed in the pools only during the first sample period, at which time both had already gone to seed. When sampling began in early May, very few species were present and/or recognizable in the deep, center portions of the pools. Certain perennial species were clearly present, such as *Grindelia nana* and *Eleocharis* sp., but many of the annuals were too small to be identified.

An additional 24 species were identified in the second sampling period. By late-May and early-June, the diminutive annuals of zones 2 and 3 were large enough to be recognized, and many of the upland and vernal pool grasses and composites present in zones 1 and 2 had flowered. Species recorded in the second sample period that were not recorded in the first included *Agoseris heterophylla*, *Apera interrupta*, *Castilleja tenuis*, *Collomia linearis*, *Downingia yina*, *Elymus elymoides*, *Erigeron pumilus*, *Juncus bufonius*, *Lagophylla ramosissima*, and *Sonchus asper*. Other vernal pool annuals that had germinated in the first sample period but not yet flowered were *Boisduvalia glabella*, *Deschampsia danthonioides*, *Limosella aquatica*, and *Navarretia leucocephala*. A congener of this last species, *N. intertexta*, was sampled in many of the pools in 1998 but was not recorded at all in 1999. This may be explained by the fact that *N. intertexta* flowers later in the season than *N. leucocephala* and thus was missed in the 1999 field season, when the vernal pool flora generally germinated and flowered later compared to 1998.

SPECIES RICHNESS

A total of 58 species were identified in 1998—51 in the Marcellus pools and 54 in the DNR pools. In 1999, 69 species were identified—this time with 59 species in the Marcellus pools and 63 in the DNR pools. Species recorded in the pools in 1999 that were not observed in 1998 were *Boisduvalia densiflora*, *Clarkia pulchella*, *Collomia linearis*, *Echinochloa crusgalli*, *Grindelia* sp., *Hesperochiron pumilus*, *Lomatium macrocarpum*, *L. triternatum*, *Ranunculus testiculatus*, *Sonchus asper*, *Tragopogon dubius*, and two unknown grasses. Of these species, one is considered a vernal pool specialist (*B. densiflora*), four are weeds (*E. crusgalli*, *R. testiculatus*, *S. asper*, *T. dubius*), and three are common shrub-steppe plants (*C. pulchella*, *H. pumilus*, *L. macrocarpum*).

To test for between-site differences in species richness, the number of species recorded in a quadrat was averaged for each individual pool and then compared by site. In 1998, the mean number of species per quadrat in the ungrazed pools was 5.89 ± 0.94 and in the grazed pools was 7.14 ± 0.55. In 1999, these values were 7.55 ± 0.66 in the ungrazed pools and 7.1 ± 1.2 in the grazed pools. A two-tailed t-test for equality of means showed that the grazed quadrats had a significantly greater number of species per quadrat than the ungrazed quadrats in 1998. No such difference was detected in 1999. Mean richness per quadrat values for individual pools are provided in Table 4-7.

Table 4-7. Mean Species Richness per Quadrat, 1998 and 1999.

Pool	Total Species	Weed Species	Nonweed Species	Annual Species	Perennial Species
1998:					
M1	4.47	1.03	3.47	3.97	1.02
M6b	6.5	2.15	4.30	4.45	1.06
M7	5.47	0.53	4.93	4.07	1.01
M11	7.25	1.96	5.30	6.17	1.00
M17	5.9	0.97	4.90	4.47	0.99
M18	5.73	1.12	4.63	4.80	0.97
D1a	7.53	1.77	5.80	6.67	0.97
D1b	6.74	1.09	5.65	5.85	0.95
D2	7.23	1.74	5.50	6.70	0.99
D3	6.23	1.75	4.43	5.17	1.03
D25	7.63	2.53	5.10	5.87	1.03
D26	7.48	1.42	6.00	6.40	0.94
1999:					
M1	6.50	1.32	5.17	3.96	0.53
M6b	8.50	2.20	6.35	5.70	1.25
M7	7.47	1.00	6.43	4.00	1.51
M11	7.47	1.60	5.87	4.53	0.96
M17	7.93	1.13	6.80	4.80	1.12
M18	7.43	1.37	6.03	4.43	0.98
D1a	8.40	2.73	5.63	5.57	0.83
D1b	7.45	2.65	4.85	5.20	0.74
D2	8.10	2.93	5.17	5.43	0.67
D3	5.20	1.50	3.70	2.33	0.88
D25	6.20	2.33	3.87	2.93	1.23
D26	7.25	2.25	4.95	4.75	0.99

A similar approach was taken to assess differences in weed, nonweed, annual, and perennial species richness per quadrat between the two sites (Table 4-8). Comparisons using two-tailed t-tests for equality of means revealed a significantly greater number of nonweed and annual species

Table 4-8. Differences in Species Richness per Quadrat, 1998 and 1999.

Species Group	Mean, Ungrazed Pools	Mean, Grazed Pools	P-value
1998:			
Total Species	**5.8**	**7.1**	**0.018**
Total Species, Zone 1	**6.9**	**7.9**	**0.034**
Total Species, Zone 2	5.9	7.0	0.275
Total Species, Zone 3	4.5	6.1	0.182
Weed Species	1.3	1.7	0.218
Weed Species, Zone 1	1.9	2.4	0.206
Weed Species, Zone 2	1.2	1.5	0.519
Weed Species, Zone 3	**0.4**	**1.3**	**0.079**
Nonweed Species	**4.6**	**5.4**	**0.040**
Nonweed Species, Zone 1	4.9	5.5	0.240
Nonweed Species, Zone 2	4.7	5.5	0.270
Nonweed Species, Zone 3	4.1	4.8	0.439
Annual Species	**4.7**	**6.1**	**0.005**
Annual Species, Zone 1	5.6	6.7	0.111
Annual Species, Zone 2	4.7	6.1	0.116
Annual Species, Zone 3	3.5	5.2	0.133
Perennial Species	1.0	0.9	0.275
Perennial Species, Zone 1	1.3	1.1	0.676
Perennial Species, Zone 2	1.2	0.9	0.378
Perennial Species, Zone 3	1.0	0.9	0.816
1999:			
Total Species	7.6	7.1	0.441
Total Species, Zone 1	8.1	7.9	0.821
Total Species, Zone 2	7.6	6.7	0.247
Total Species, Zone 3	6.6	6.3	0.785
Weed Species	**1.4**	**2.4**	**0.005**
Weed Species, Zone 1	**1.8**	**3.0**	**0.028**
Weed Species, Zone 2	**1.4**	**2.3**	**0.019**
Weed Species, Zone 3	**0.9**	**1.6**	**0.002**
Nonweed Species	**6.1**	**4.7**	**0.004**
Nonweed Species, Zone 1	**6.4**	**4.8**	**0.037**
Nonweed Species, Zone 2	**6.2**	**4.5**	**0.008**
Nonweed Species, Zone 3	5.7	4.7	0.237
Annual Species	4.6	4.4	0.756
Annual Species, Zone 1	6.0	5.8	0.851
Annual Species, Zone 2	4.8	4.0	0.231
Annual Species, Zone 3	2.4	2.5	0.885
Perennial Species	1.1	0.9	0.309
Perennial Species, Zone 1	1.1	1.1	0.902
Perennial Species, Zone 2	0.8	0.7	0.716
Perennial Species, Zone 3	1.2	0.8	0.116

*Significant differences in bold.

in the grazed quadrats in 1998, as well as a significantly greater number of weeds per quadrat in the grazed pools in 1999. The number of nonweed species per quadrat was significantly greater in the ungrazed pools in 1999. Looking at these differences by zone, the grazed pools had a significantly greater number of weed species per quadrat in zone 3 in 1998 and in all zones in 1999. Nonweed species richness was significantly greater in zones 1 and 2 of the ungrazed pools in 1999.

The mean number of species per quadrat was also compared between years using a two-tailed t-test for equality of means (Table 4-9). In the ungrazed pools, both total species and nonweed species richness per quadrat was significantly greater in 1999 than in 1998. In the grazed pools, the number of weed species was significantly greater in 1999, while the number of nonweed and annual species was greater in 1998.

Using data from both years, frequency distributions were used to compare the number of weed and nonweed species in each of the sample quadrats. Results indicated that, when considering the entire data set, quadrats in the grazed pools tended to have higher weed species richness than ungrazed quadrats (Figure 4-10). The opposite trend was found in the frequency distribution plot of nonweed species where grazed quadrats consistently had a lower diversity of nonweed species than ungrazed quadrats (Figure 4-11).

Table 4-9. Between-Year Differences in Species Richness per Quadrat.

Species Group	1998	1999	P-value
Ungrazed Pools:			
Total Species	**5.9**	**7.6**	**0.005**
Weed Species	1.3	1.4	0.653
Nonweed Species	**4.6**	**6.1**	**0.001**
Annual Species	4.7	4.6	0.843
Perennial Species	1.0	1.1	0.718
Grazed Pools:			
Total Species	7.1	7.1	0.943
Weed Species	**1.7**	**2.4**	**0.038**
Nonweed Species	**5.4**	**4.7**	**0.093**
Annual Species	**6.1**	**4.4**	**0.018**
Perennial Species	0.9	0.9	0.302

*Significant differences in bold.

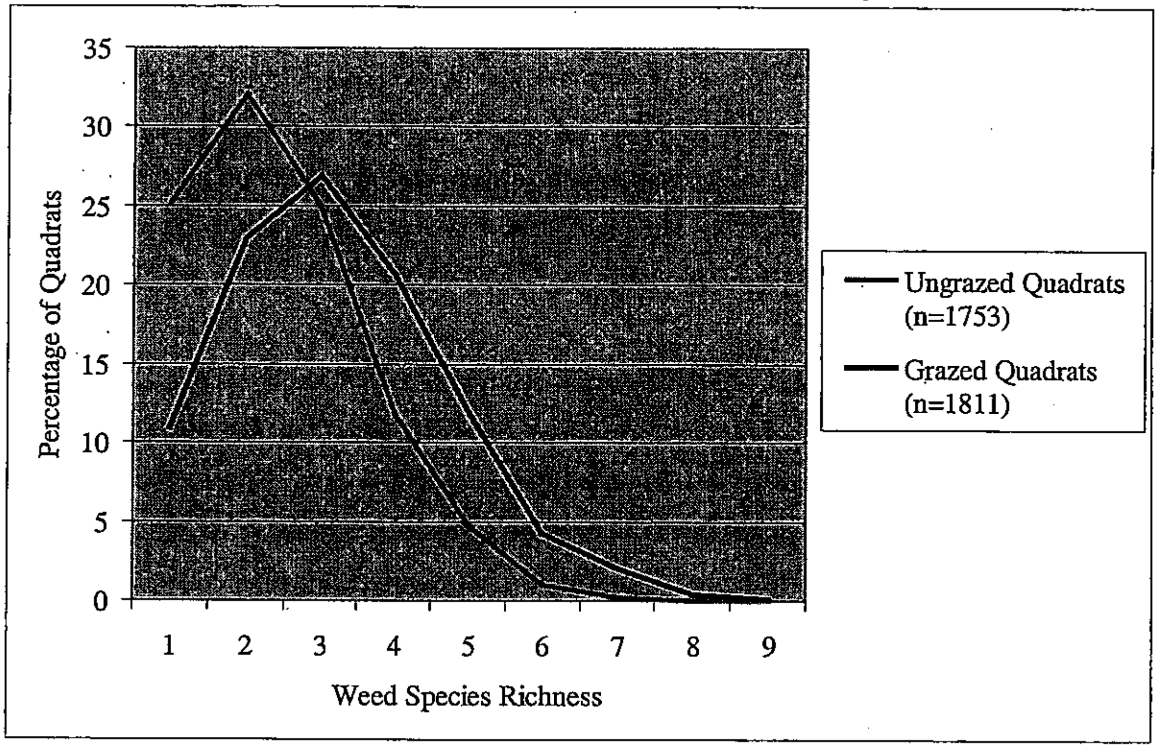


Figure 4-10. Frequency distribution of weed species in ungrazed and grazed pools.

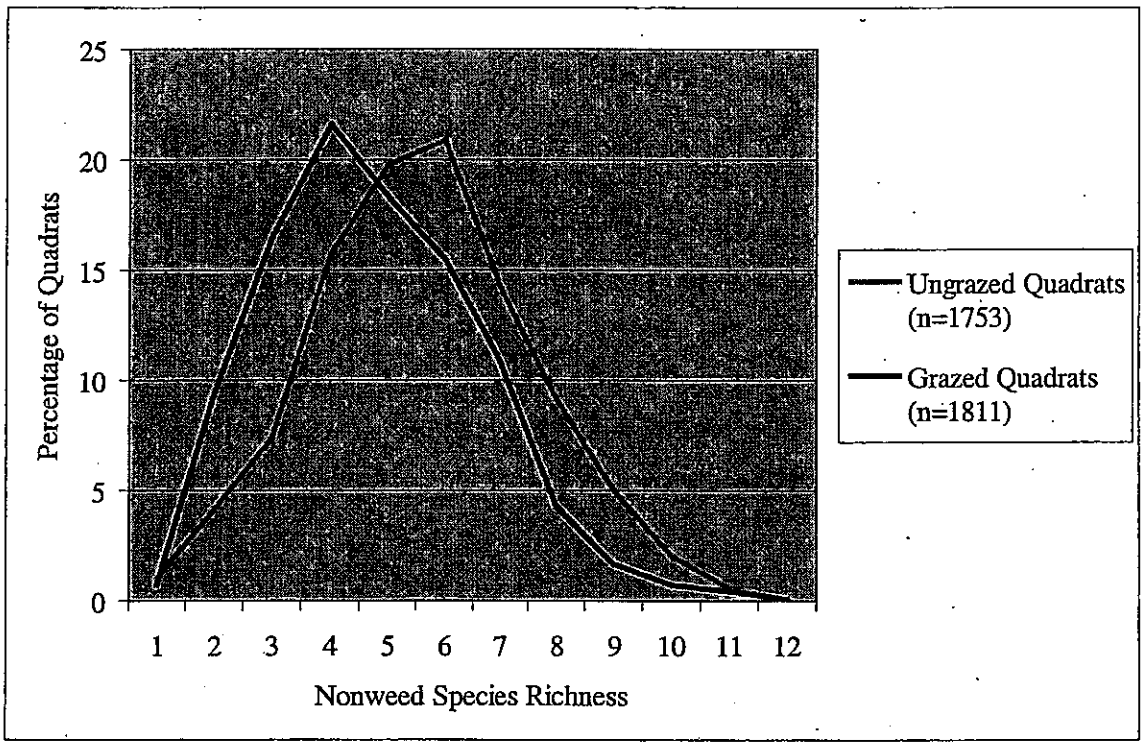


Figure 4-11. Frequency distribution of nonweed species in ungrazed and grazed pools.

FREQUENCY OF SPECIES GROUPS

The frequency of particular species groupings were compared with two-tailed t-test for equality of means between the two sites. The species groups include annuals, perennials, vernal pool indicators (i.e., characteristic vernal pool species), weeds, nonweeds, annual weeds, annual nonweeds, perennial weeds, and perennial nonweeds. To calculate these frequencies for each zone of each pool, the number of plots in which at least one annual (perennial, weed, nonweed, etc.) species was present was divided by the total number of plots in a given zone of a given pool. Thus, the number of individual annual (perennial, weed, nonweed, etc.) species is not considered in this analysis. Frequencies are expressed here as the percentage of plots in which a particular type of species (e.g., annual, perennial) was present. Species comprising the vernal pool indicator group included *Boisduvalia densifolia*, *B. glabella*, *Downingia yina*, *Myosurus apetalus*, *M. minimus* ssp. *minimus*, *M. minimus* ssp. *apus*, *N. leucocephala*, *Polygonum polygaloides*, and *Psilocarphus* sp. These species were selected as indicators based on descriptions as species or genera "being largely restricted to vernal pools" provided in Zedler (1987). Additional information was provided in Bjork (1997).

In both years, the frequency of weed species was significantly greater in the grazed pools than the ungrazed pools (see Table 4-10 for means and p-values). Also in both years, the frequency of annual weeds in zone 3 and perennial weeds in zone 1 was significantly greater in the grazed pools. Other differences are: in 1998, the frequency of perennial species was higher in the ungrazed pools and, in 1999, the frequency of annual weeds in zone 2 of the grazed pools was greater than in the ungrazed pools. No significant differences were found in the frequency of annual, nonweed species, and vernal pool indicator species, as well as in the frequency of annual nonweeds and perennial nonweeds.

SPECIES COVER

Plagiobothrys leptocladus, *Holosteum umbellatum* (weed), *Juncus bufonius* (weed), and *Lepidium perfoliatum* (weed) all had a greater percent cover in zone 1 of the grazed pools relative to zone 1 of the ungrazed pools, with the former being significant at the 0.10 α-level (Figure 4-12). The ungrazed pools had significantly greater cover of *Grindelia nana*, *Montia linearis*, and *Elymus elymoides*; and relatively greater cover of *Veronica peregrina*, *Montia dichotoma*, and *Polygonum polygaloides*.

Table 4-10. Statistical Comparison of the Frequency of Species Groups.

Species Group	Mean Percent in Ungrazed Pools	Mean Percent in Grazed Pools	P-value
1998:			
Annual Species	96.18	99.13	0.268
Perennial Species	**80.21**	**63.4**	**0.056**
Weed Species	**60.94**	**81.66**	**0.026**
Nonweed Species	99.42	99.81	0.527
Vernal Pool Indicator Species	71.97	78.17	0.699
Annual Weed Species, Zone 1	87.42	92.88	0.376
Annual Weed Species, Zone 2	67.57	76.18	0.543
Annual Weed Species, Zone 3	**32.96**	**78.05**	**0.043**
Annual Nonweed Species, Zone 1	98.63	99.2	0.728
Annual Nonweed Species, Zone 2	97	98.33	0.652
Annual Nonweed Species, Zone 3	91.46	96.15	0.547
Perennial Weed Species, Zone 1	**0.33**	**2.88**	**0.081**
Perennial Weed Species, Zone 2	0	0	n/a
Perennial Weed Species, Zone 3	0	0.95	0.391
Perennial Nonweed Species, Zone 1	76.37	68.32	0.495
Perennial Nonweed Species, Zone 2	71.92	59.68	0.458
Perennial Nonweed Species, Zone 3	92.86	72.4	0.409
1999:			
Annual Species	92.43	93.47	0.816
Perennial Species	73.6	58.2	0.185
Weed Species	**77.5**	**90.95**	**0.031**
Nonweed Species	100	100	1.000
Vernal Pool Indicator Species	70.17	60.62	0.511
Annual Weed Species, Zone 1	77.33	88.67	0.289
Annual Weed Species, Zone 2	**49.77**	**77.62**	**0.078**
Annual Weed Species, Zone 3	**19.4**	**71.3**	**0.003**
Annual Nonweed Species, Zone 1	100	90.65	0.148
Annual Nonweed Species, Zone 2	96.38	91.48	0.253
Annual Nonweed Species, Zone 3	72.9	73.15	0.988
Perennial Weed Species, Zone 1	**0**	**1.52**	**0.024**
Perennial Weed Species, Zone 2	0	0.4	0.147
Perennial Weed Species, Zone 3	0	0	n/a
Perennial Nonweed Species, Zone 1	70.37	61.63	0.490
Perennial Nonweed Species, Zone 2	58.73	56.57	0.872
Perennial Nonweed Species, Zone 3	97.18	67.9	0.117

Bolded text indicates a significant difference (α=0.10).

In zone 2 of the pools, species having a significantly greater percent cover in the grazed pools included *Deschampsia danthonioides*, *Plagiobothrys leptocladus*, *Polygonum aviculare* (weed), and *Juncus bufonius* (Figure 4-13). Also within this zone, *Myosurus minimus* ssp. *minimus* had a significantly greater cover in the ungrazed pools, along with *Montia linearis* and *Spergularia diandra* (weed).

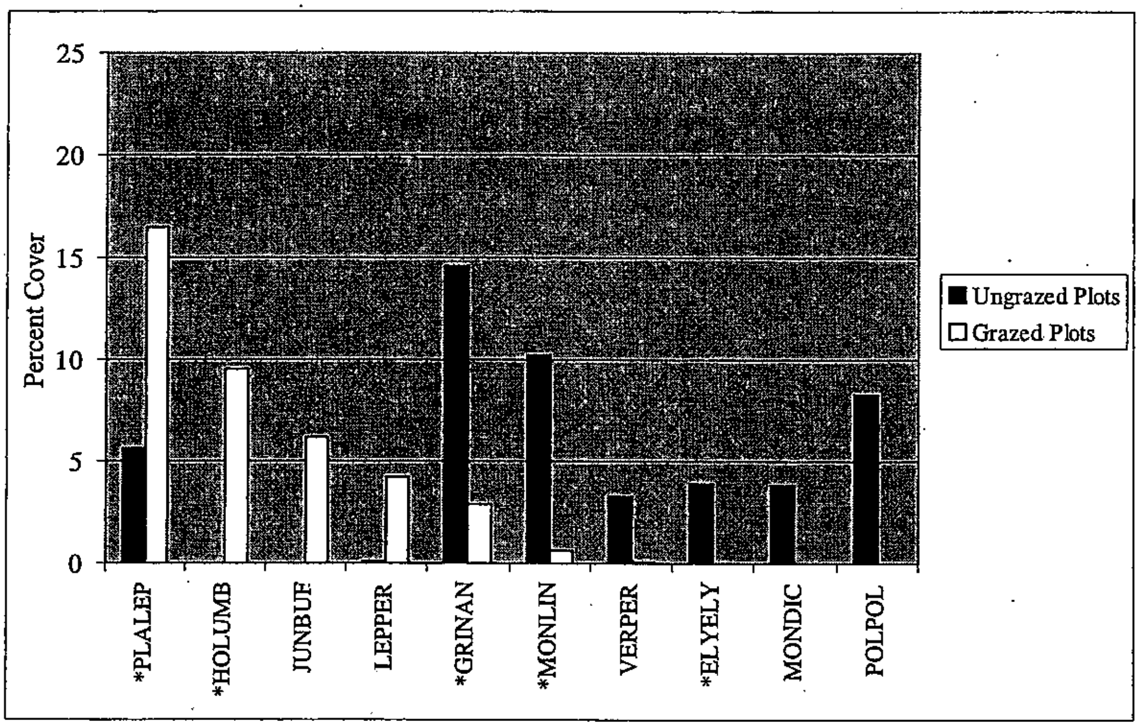


Figure 4-12. Differences in percent cover of species in zone 1. Astericks denote a significant difference ($p<0.10$) in percent cover between the ungrazed and grazed pools.

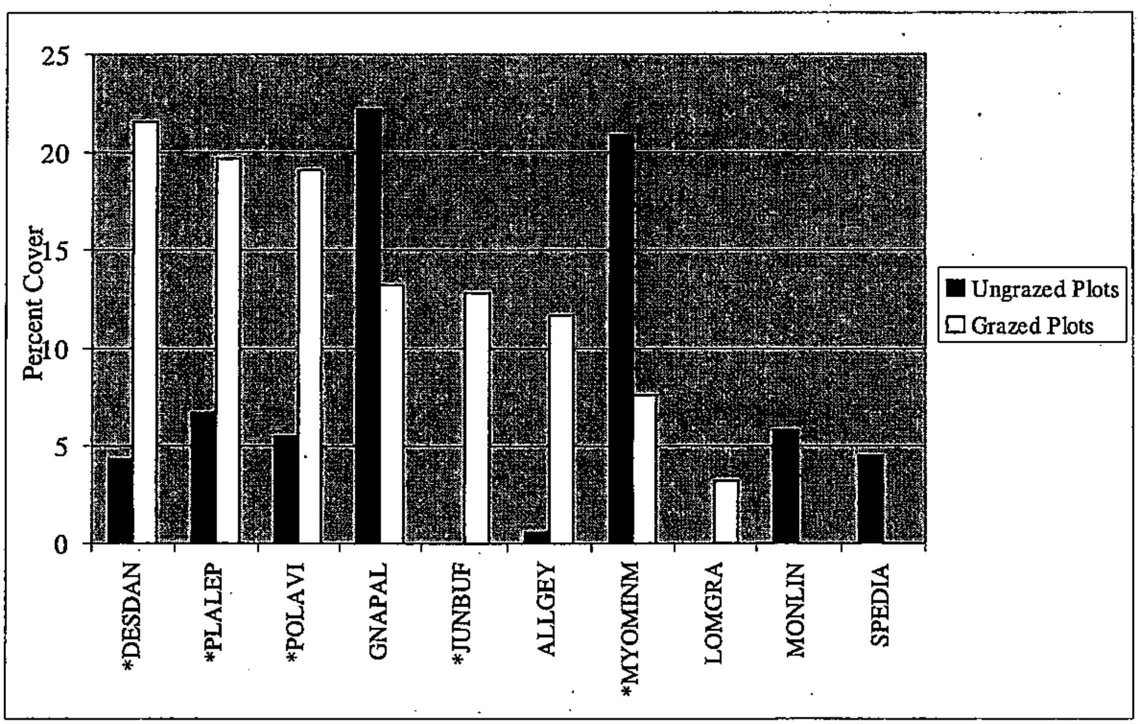


Figure 4-13. Differences in percent cover of species in zone 2. Astericks denote a significant difference (p<0.10) in percent cover between the ungrazed and grazed pools.

In zone 3, grazed pools supported a significantly greater cover of *Polygonum aviculare*, while the ungrazed pools showed a significantly greater cover of *Eleocharis macrostachya* (Figure 4-14). Ungrazed pools also had a greater cover of *Eleocharis acicularis* and *Alopecurus saccatus*; grazed pools also had a greater cover of *Gnaphalium palustre* (weed) and *Sonchus asper* (weed). A list of cover values for all of the species samples is provided as Appendix F.

CLASSIFICATION, 1998

The two-way table shows an arrangement of plots from left to right along what appears to be the topographic gradient in the pools. Relative elevation is assumed to be correlated with duration of standing water. Plots located towards the left side of the table were those found in zone 1, those in the center were in zone 2, while plots on the right side of the table were found in zone 3. From the TWINSPAN analysis, eight community types have been identified and are displayed in Figure 4-15. The community types, their position in the pools, and location by site are described below.

On the far left of the dendrogram is a cluster of 56 plots (Group A in Figure 4-15) separated from other plots by the presence of *Artemisia ludoviciana* and *Montia linearis*. Plots in this group come almost entirely from pool M6 and correspond to zone 1. There are a few plots from M1, M11, and D3 also in this group, but essentially this group is particular to M6. Other species important in this group are *Deschampsia danthonioides* and the weeds, *Apera interrupta*, *Epilobium paniculatum*, and *Lactuca serriola*.

The second group identified is also the largest, comprising 429 plots (Group B). This group is also a zone 1 community type but was present in all pools. Nonweedy species indicative of this group are *Draba verna*, *Deschampsia danthonioides*, *Navarretia leucocephala*, *Plagiobothrys leptocladus*, and *Agrostis diegoensis*. Prevalent weedy species include *Epilobium paniculatum*, *Lactuca serriola*, and *Apera interrupta*. This can be considered the "typical" zone 1 community type of the Marcellus and DNR pools.

The next identifiable community type, Group C, is another large group consisting of 335 plots and one that is comprised of plots in almost equal proportions from both sites. This group represents the "typical" zone 2 community type. Dominant species include many characteristic vernal pools species, such as *Deschampsia danthonioides*, *Alopecurus saccatus*, *Psilocarphus*

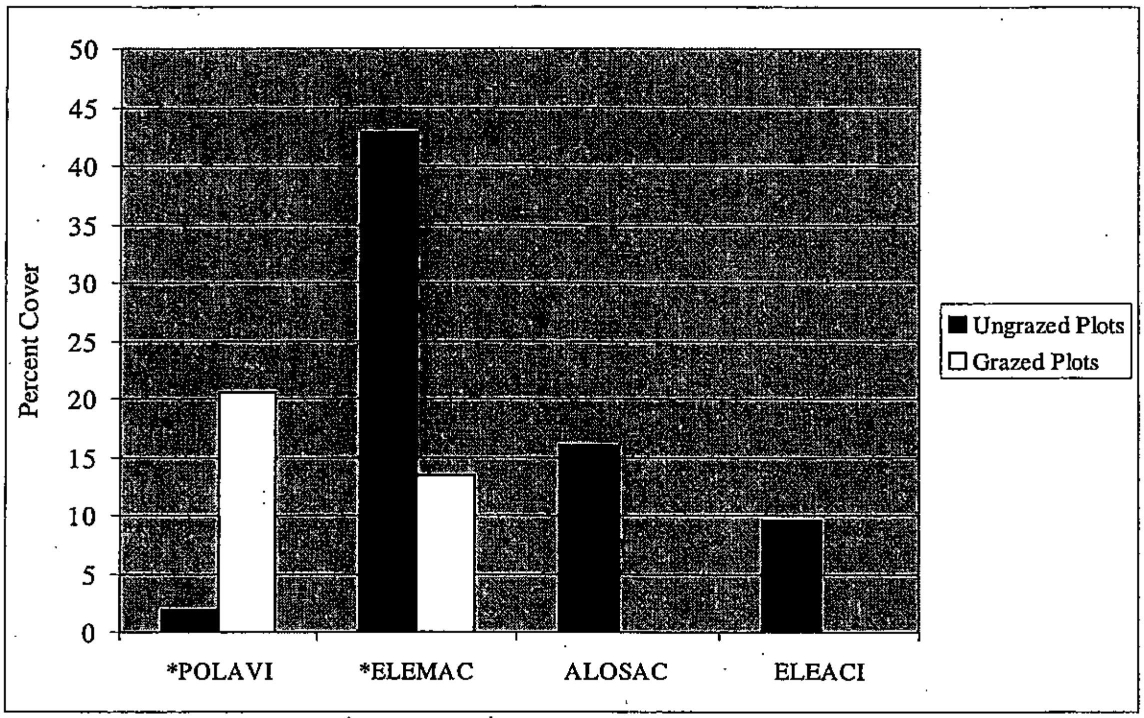


Figure 4-14. Differences in percent cover of species in zone 3. Astericks denote a significant difference (p<0.10) in percent cover between the ungrazed and grazed pools.

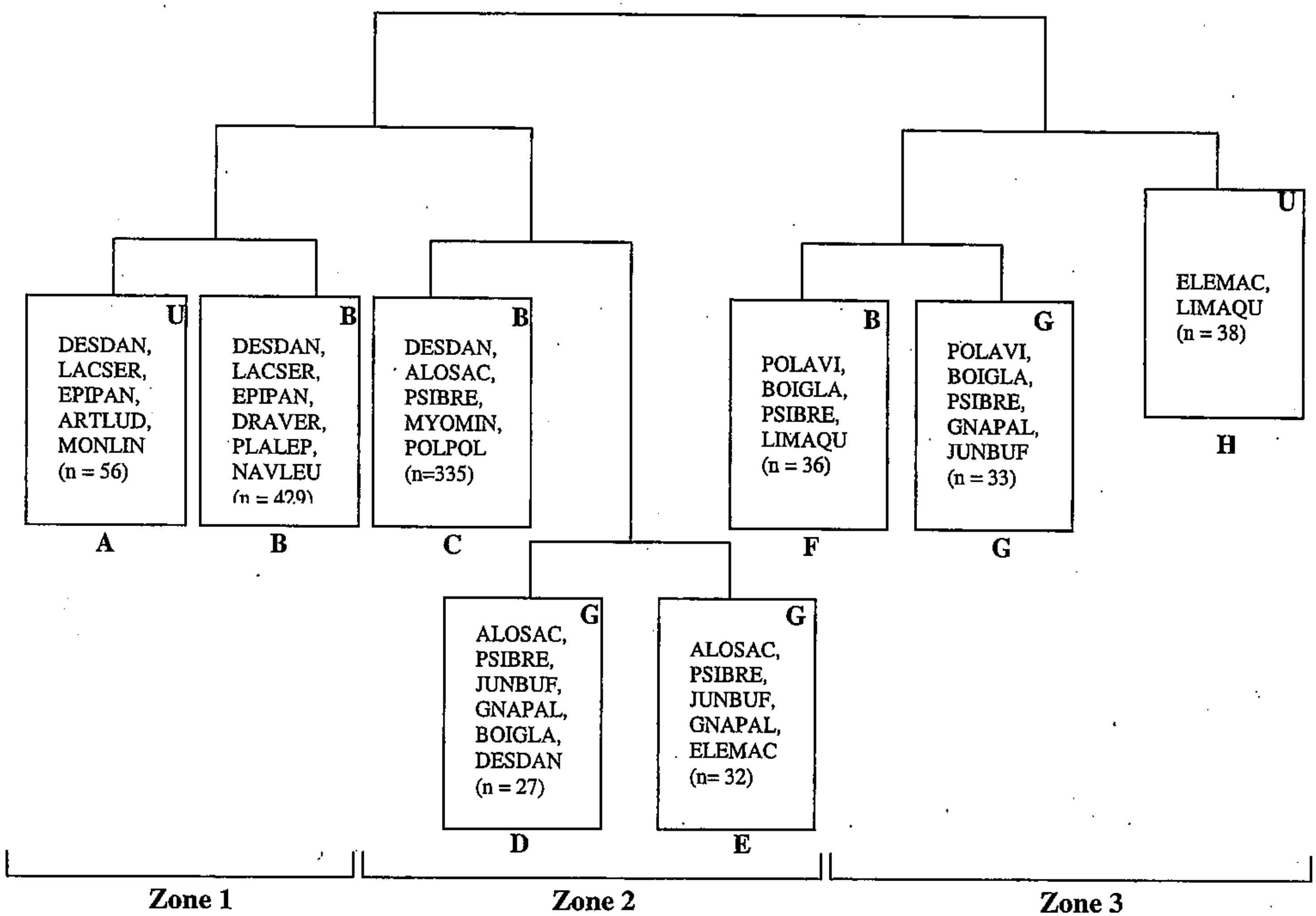


Figure 4-15. TWINSPAN dendrogram for 1998 data. Eight community types have been identified. (U=community type comprised of mostly ungrazed quadrats, G=mostly grazed quadrats, B=both types of quadrats represented.)

brevissimus, *Myosurus minimus* ssp. *minimus*, *Polygonum polygaloides*, *Plagiobothrys leptocladus*, and *Navarretia leucocephala*. Although weedy species tend not to be as prevalent in this assemblage compared with the zone 1 groups, *Polygonum aviculare* does have some importance. *Eleocharis macrostachya* is also present in this group, but only in a smaller cluster of Marcellus pool plots. The plots containing *E. macrostachya* come primarily from Marcellus pools M7, M11, M17, and M18.

Two other variations of the zone 2 community type, Groups D (n=27) and E (n=32), are found almost exclusively in the DNR pools. Plots from pools D26 and D3 comprise Group D, and plots from pools D25 and D3, with the exception of four plots from the Marcellus pools, comprise Group E. The communities separate out in the analysis due to the presence of *Juncus bufonius*, *Polygonum aviculare*, and *Gnaphalium palustre*. It is the presence of *Deschampsia danthonioides*, *Boisduvalia glabella*, and *Psilocarphus brevissimus* and absence of *Eleocharis macrostachya* that distinguishes Group D from Group E.

The last three groups occur to the right side of the first-level division and represent variations of the zone 3 community type. These plots were separated in the TWINSPAN analysis due to the presence of *Boisduvalia glabella* and *Limosella aquatica* and absence of *Deschampsia danthonioides*. The first, Group F, consists of 36 plots which were almost all from pools M1 and D2. Species that define this community type are *Psilocarphus brevissimus*, *Boisduvalia glabella*, *Cuscuta californica*, *Limosella aquatica*, and the weedy *Polygonum aviculare*. Group G is similar to F in species composition, but separated from it due to the presence of *Juncus bufonius*, *Gnaphalium palustre*, *Grindelia nana*, and *Plagiobothrys leptocladus*. Only plots from DNR pools (D2, D3, and D25) comprise Group G.

The third zone 3 community consists entirely of ungrazed plots (n=38). Almost all plots contain *Eleocharis macrostachya*, along with *Limosella aquatica* to a lesser extent. *Spergularia diandra*, *Psilocarphus brevissimus*, and *Boisduvalia glabella* also occur in this group. The fewest number of species are present in this community type.

ORDINATION, 1998

The DCA analysis of 1998 plots shows a strong gradient along axis 1, which has an eigenvalue (λ) of 0.439 (Figure 4-16). Examination of the placement of both quadrats and species along axis 1 suggests that it represents a topographic gradient. Species and quadrats on the left side of the axis are those which occurred in zone 1 of the pools, while species and quadrats on the right are those from zone 3. There is a clear gradation of species along this axis from those most abundant in zone 1 to those most abundant in zone 2 to those most abundant in zone 3. Species that were somewhat ubiquitous in the pool basins, such as *Deschampsia danthonioides* and *Myosurus minimus* ssp. *minimus*, are placed around the midpoint of the axis. There is no clear separation of the ungrazed versus grazed quadrats along axis 1 (Figure 4-17).

Separation of the ungrazed and grazed quadrats is more noticeable along axes 2 (λ=0.238) and 3 (λ=0.201), suggesting that these axes represent the grazing condition (Figures 4-17 and 4-18). Within the ordination space, ungrazed quadrats are clustered around the higher end of axis 2, while the grazed plots occur more towards the lower end of the axis. There is, however, a great deal of overlap between the two sites. Separation of the quadrats from the two sites is more clearly defined along axis 3, but the quadrats become less separated as one moves along axis 1. Looking at the arrangement of species along axis 2, there appears to be some grouping according to their presence in the ungrazed and grazed pools (Figure 4-19). Species that occur more frequently or only in the grazed pools tend to be located on the left side of the axis, while species more prevalent in the ungrazed pools tend to be on the right. Exceptions to this statement are *Carex douglasii* and *Festuca idahoensis*, which occur towards the far right of the axis and were found only in the DNR pools. The position of species relative to axis 3 shows no clear patterns in terms of grazing. Species occurring exclusively or more frequently in the grazed pools (e.g., *Erigeron pumilus*, *Gnaphalium palustre*, *Madia exigua*, *Holosteum umbellatum*, *Lepidium perfoliatum*, *Agrostis diegoensis*) are located along most of the length of the axis, as are species occurring exclusively or more frequently in the ungrazed pools (e.g., *Apera interrupta*, *Danthonia unispicata*, *Lactuca serriola*, *Polygonum polygaloides*, *Alopecurus saccatus*, *Downingia yina*, *Eleocharis macrostachya*).

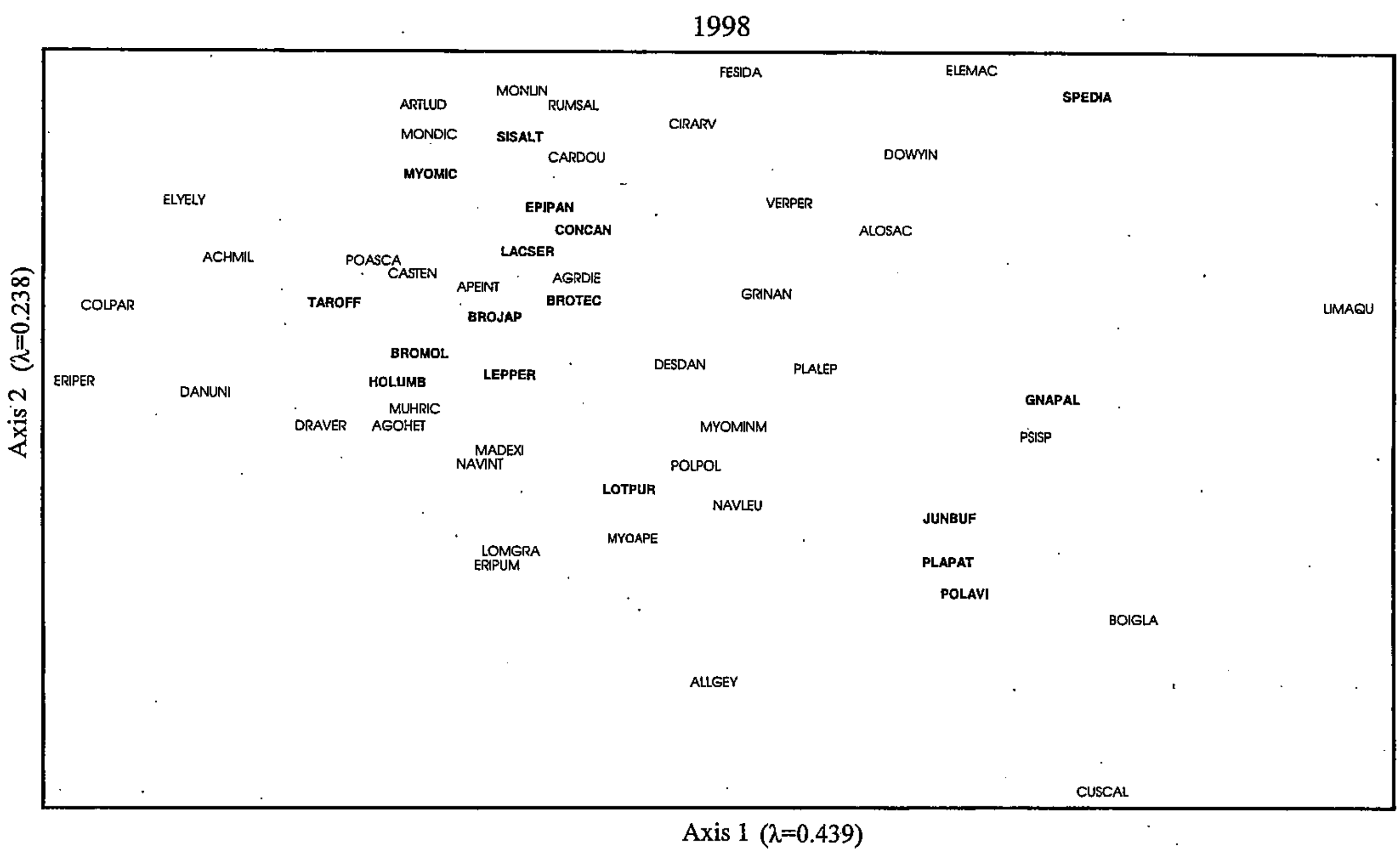
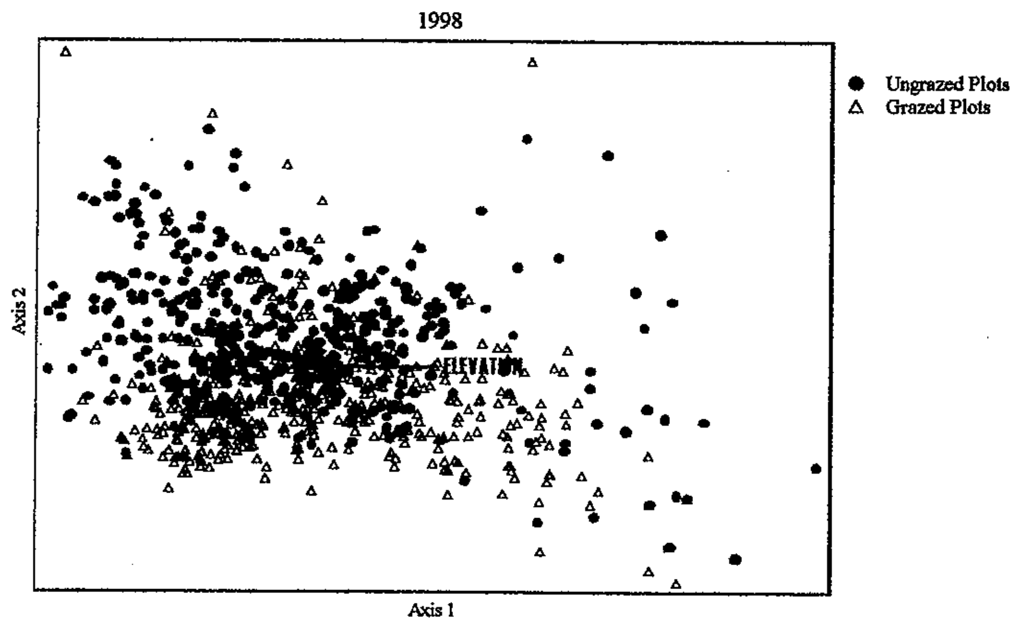


Figure 4-16. DCA ordination plot of species, 1998 data. Weedy species are bolded. Species abbreviations are constructed from the first three letters of the genus name and the first three letters of the specific epithet. A list of abbreviations is presented in Appendix D.



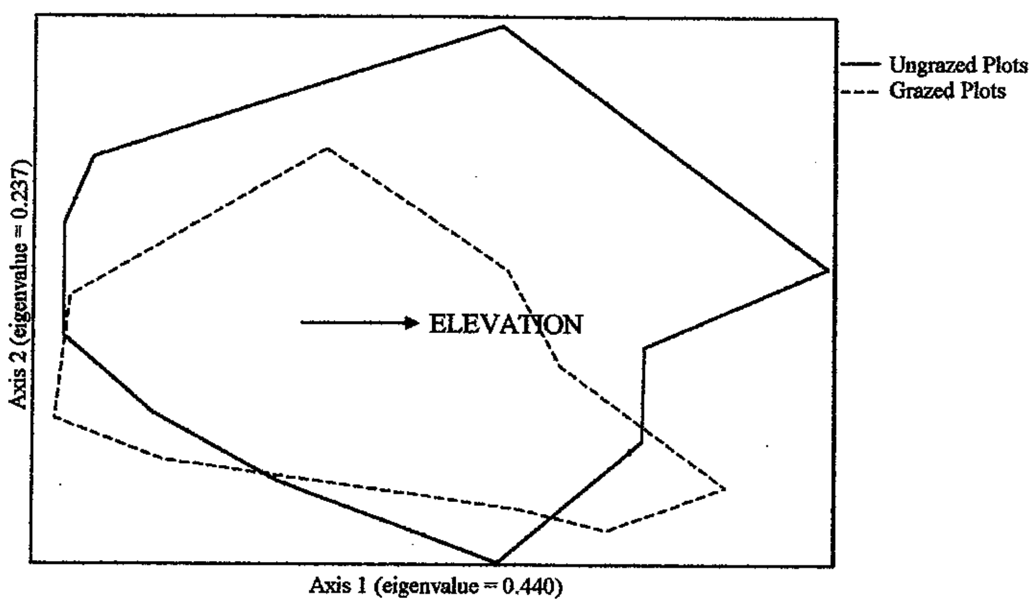


Figure 4-17. DCA joint plot of axes 1 and 2, 1998 data. Points on upper graph represent individual quadrats.

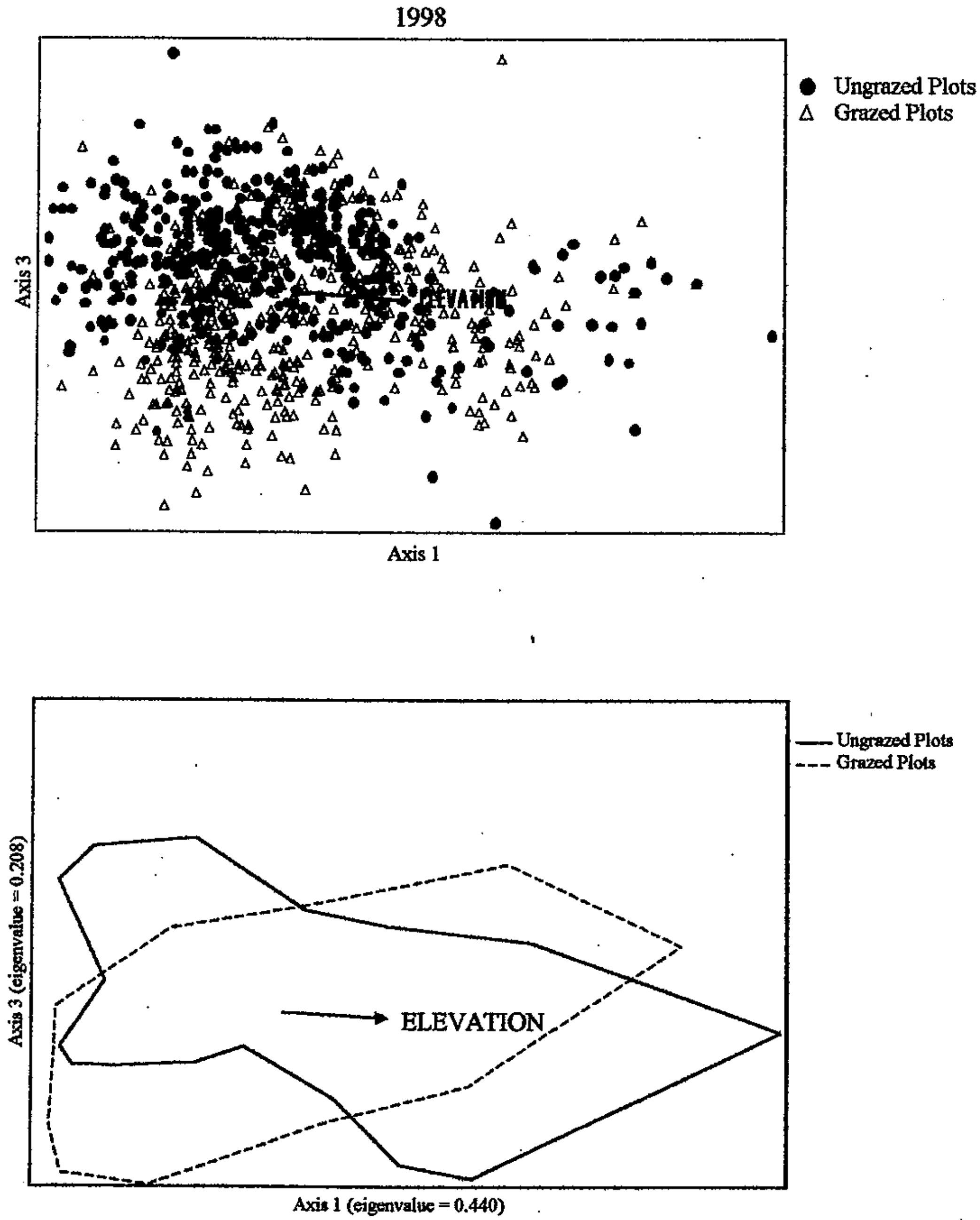


Figure 4-18. DCA joint plot of axes 1 and 3, 1998 data. Points on upper graph represent individual quadrats.

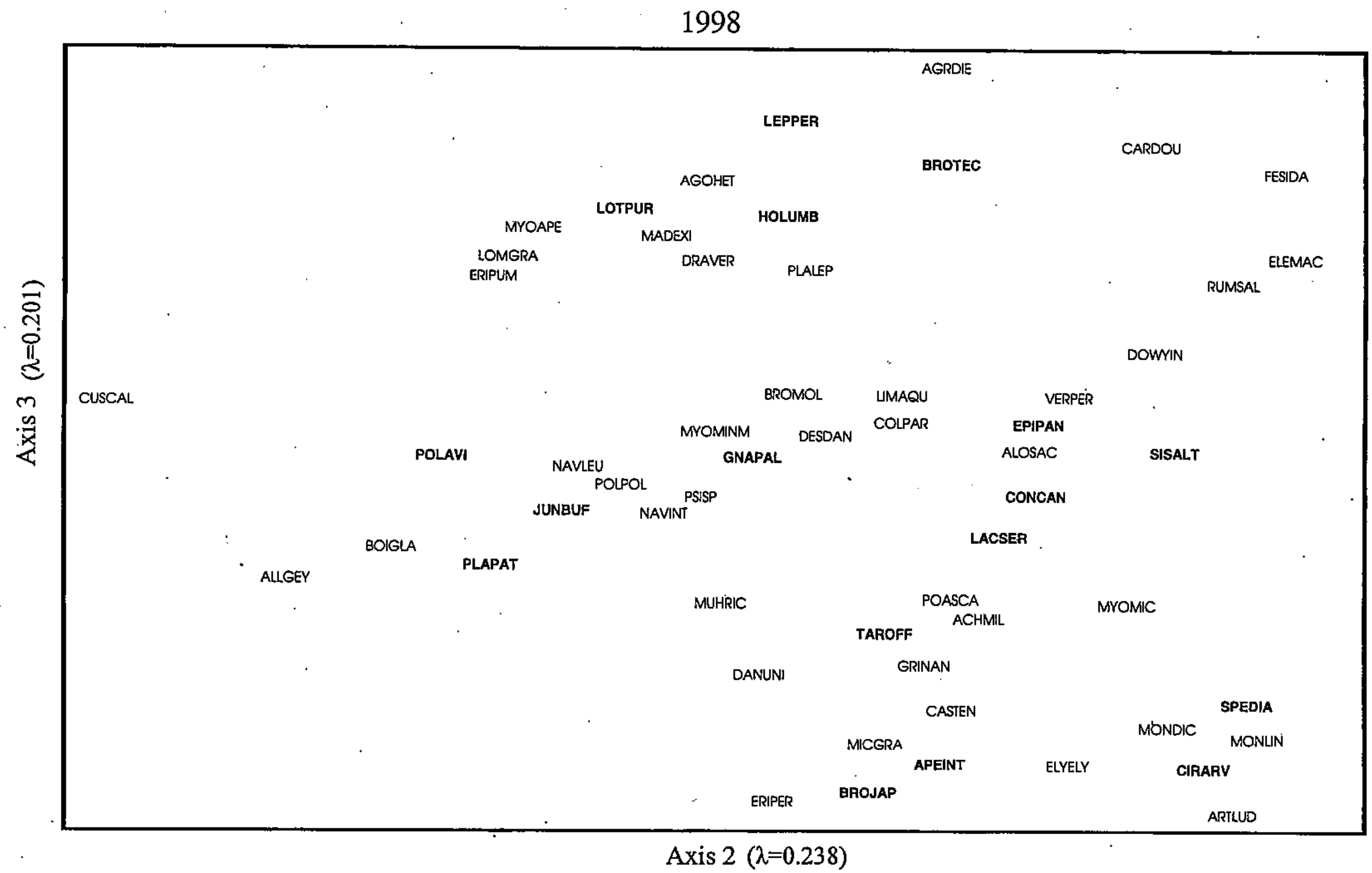


Figure 4-19. DCA ordination plot of species, 1998 data. Weedy species are bolded. Species abbreviations are constructed from the first three letters of the genus name and the first three letters of the specific epithet. A list of abbreviations is presented in Appendix D.

The arrangement of species along axis 2 suggests that it may also represent a gradient of salinity in the pools (Figure 4-19). Species that are known to be tolerant of alkali, such as *Eleocharis macrostachya* (Hitchcock et al. 1969, Rothrock and Wagner 1975), *Spergularia diandra* (Hitchcock et al. 1969), and *Apera interrupta*, *Carex douglasii*, and *Plagiobothrys leptocladus* (Bjork 1997), appear on the right side of the axis, while one species known to be intolerant, *Polygonum aviculare* (Foderaro and Ungar 1997, Khan and Ungar 1998), is plotted on the left side. The salinity tolerance of the other species on the graph are unknown, and soil salinity was not measured in this study so differences between the sites can not be confirmed.

When the environmental variables (i.e., elevation, pH, organic matter, bulk density, grazing) are overlaid onto the ordination, only elevation was plotted as a vector (Figures 4-17 and 4-18). This variable is shown to have a strong and direct relationship with axis 1, where relative elevation increases (i.e., the pool becomes deeper) from left to right or, alternatively, from zone 1 to zone 3. The correlation coefficient between elevation and axis 1 is 0.66 (Table 4-11). Although, the condition of grazing did not appear at all on the joint plot, it is fairly well correlated with axis 2 (r=-0.48). Grazing shows little relationship to both axis 1 (r =0.02) and axis 3 (r =-0.09).

From the canonical correspondence analysis, the Monte Carlo permutation tests (99 permutations) showed significant species-environment correlations for the first two axes (p=0.01) and a nonsignificant correlation for the third axis (p=1.00). The species-environment correlation for axis 1 was 0.73 and for axis 2 was 0.75.

CLASSIFICATION, 1999

Seven community types were identified from the 1999 TWINSPAN results. Similar to the 1998 data, quadrats were arranged in the two-way table along the upland-to-center topographic gradient of the pools. On the left side of the table are quadrats from zone 1, farther right on the

Table 4-11. Correlations between DCA Axis Scores and Environmental Variables, 1998.

Ordination Axis	Elevation	Grazing
Axis 1	0.66	0.02
Axis 2	-0.07	-0.48
Axis 3	-0.19	-0.09

table are quadrats from zone 2, and at the far right are quadrats from zone 3. The relationship of the community types to one another is shown in Figure 4-20 and each is described below.

On the far left of the dendrogram, is a cluster of 61 quadrats that were unlike any of the nearly 1300 samples collected (Group A in Figure 4-20). This group is composed entirely of quadrats from pool D25, with the exception of three from D1b and two from M6. The quadrats are identified as a separate zone 1 community type due to overriding presence of *Eleocharis macrostachya* along with numerous weedy species that are typical of the zone 1 community (e.g., *Apera interrupta*, *Bromus mollis*, *Bromus tectorum*, *Epilobium paniculatum*, and *Lactuca serriola*). In almost all of the other pools, the aquatic *E. macrostachya* is a clear indicator of zone 3, but in D25, there is no such relationship. This species is present throughout the pool basin, extending from the deeper portions upward to the upland-pool interface.

The second zone 1 community type to separate out in the analysis (Group B) occurred almost entirely in the ungrazed pools. This group consists of 123 quadrats and is defined by the association of *Deschampsia danthonioides*, *Draba verna*, *Montia linearis*, *Collinsia parviflora*, and several weedy species—*Apera interrupta*, *Epilobium paniculatum*, *Myosotis micrantha*, and *Lactuca serriola*.

The third zone 1 community type, Group C, comprises one of the largest groups of quadrats (n=307) and occurred about equally on the two sites. Within this community, many of the weedy species abundant in zone 1 were present, but some of the zone 2 vernal pool species occurred as well. Group C can be considered a transitional community type between zones 1 and 2 and is defined by the presence of *Deschampsia danthonioides*, *Navarretia leucocephala*, *Plagiobothrys leptocladus*, and *Myosurus minimus* ssp. *minimus*, as well as some weedy species—*Apera interrupta*, *Epilobium paniculatum*, and *Lactuca serriola*. *Polygonum aviculare* begins to appear much more substantially in this group.

Moving towards the right of the dendrogram, two zone 2 community types were identified. The first type, Group D, is composed to a large degree by ungrazed quadrats. Of the 295 quadrats in this group, only 53, or approximately 18 percent, were from grazed pools. The underlying assemblage of species in this community type include *Deschampsia danthonioides*, *Myosurus*

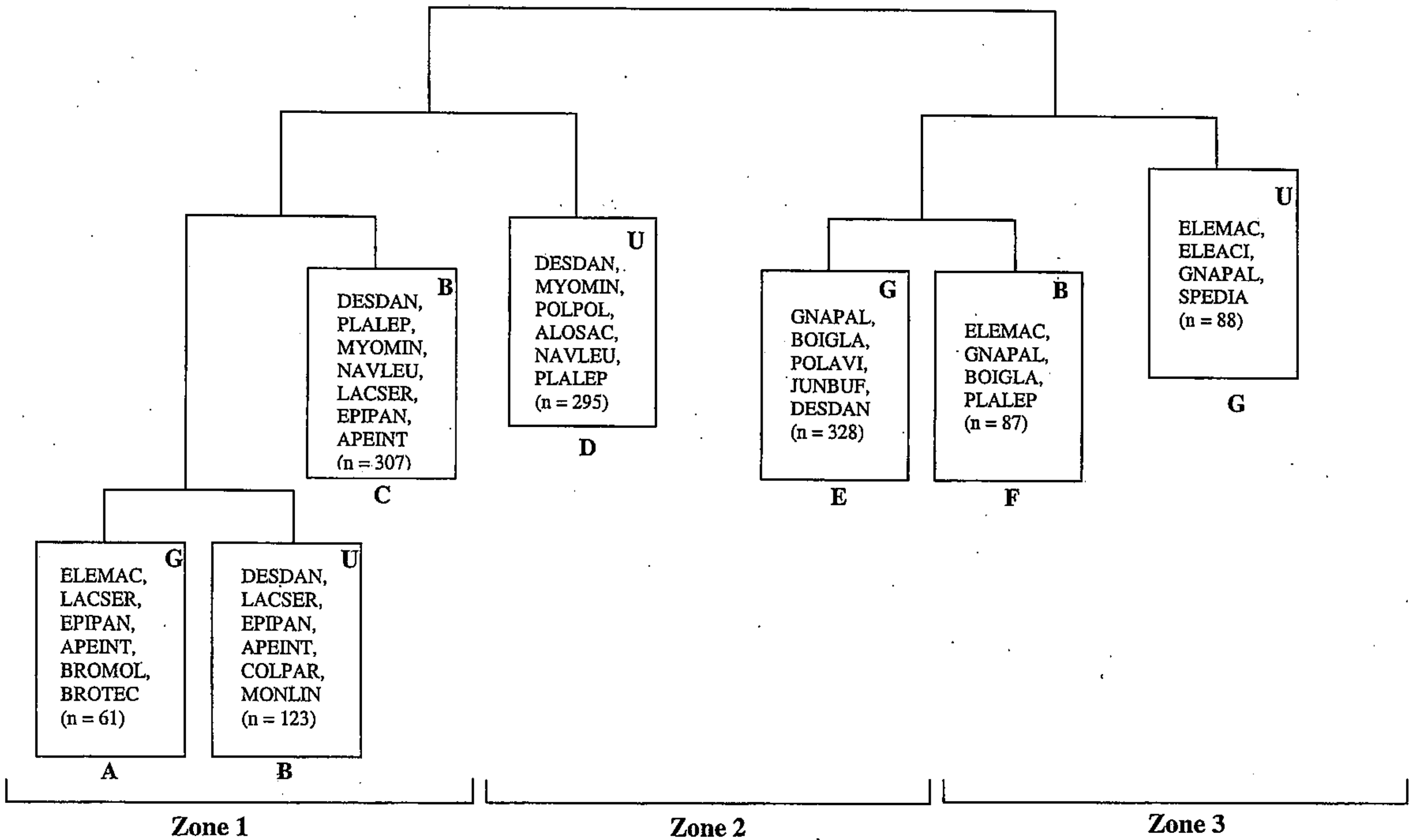


Figure 4-20. TWINSPAN dendrogram for 1999 data. Seven community types have been identified. (U=community type comprised of mostly ungrazed quadrats, G=mostly grazed quadrats, B=both types of quadrats represented.)

minimus ssp. *minimus*, *Polygonum polygaloides*, *Alopecurus saccatus*, *Navarretia leucocephala*, and *Plagiobothrys leptocladus*. Weedy species were much less prevalent in this community type. The large majority of grazed quadrats in this group are clumped on the far right side of the two-way table (within this defined community type). They seem to be set off from the other quadrats on the basis of three weedy species—*Juncus bufonius*, *Lotus purshiana*, and *Sonchus asper*.

The second zone 2 community type (Group E) occurs just to the right of the first-level division of the data. It is another large group (n=328) and was found almost exclusively in the grazed pools. Based on the species composition of this group, it may be considered a zone 2-3 transitional community type. Dominant species, those occurring in almost all of the quadrats, include *Gnaphalium palustre*, *Boisduvalia glabella*, *Juncus bufonius*, and *Polygonum aviculare*. Other important species are *Deschampsia danthonioides*, *Navarretia leucocephala*, and *Plagiobothrys leptocladus*. A few of the quadrats contained *Eleocharis macrostachya* and/or *Eleocharis acicularis*.

The last two community types identified in this analysis can be considered zone 3 communities. The first, Group F, had nearly equal representation from both sites (n=87). *Eleocharis macrostachya* occurred in all but a few quadrats, and other frequently-occurring species were *Gnaphalium palustre*, *Boisduvalia glabella*, and *Plagiobothrys leptocladus*. *Juncus bufonius* occurred in almost all of the grazed quadrats of this group, and none of the ungrazed quadrats. The second zone 3 community type, Group G, was composed of almost all ungrazed quadrats. *E. macrostachya* is again dominant in this community, with other important players being *E. acicularis*, *Gnaphalium palustre*, and *Spergularia diandra*. *Juncus bufonius* occurred in only 2 of the 88 quadrats in this group, both of which were from grazed pools. *Polygonum aviculare* was present in only 4 quadrats.

ORDINATION, 1999

Plotting the 1999 data in a DCA ordination yielded higher eigenvalues for the first two axes compared to the previous year's data. The eigenvalue of axis 1 was 0.548, and the position of quadrats and species along the axis clearly indicated that it represents the elevational gradient in the pools (Figure 4-21). The greater spread of species and plots along axis 1 in 1999 is likely the result of increased amounts of water in the pools, and thus increased niche availability, compared to that in the drier year of 1998. The joint plot of environmental variables provides additional evidence for the relationship between axis 1 and elevation, as seen in Figure 4-22. The elevation vector is directly parallel to axis 1, indicating a strong relationship, and the correlation coefficient between axis 1 and elevation is 0.50 (Table 4-12). No other measured environmental variable are well-correlated with axis 1. Similar to the 1998 data, there is no clear separation of ungrazed versus grazed plots along the first axis (Figure 4-22).

Also similar to the 1998 DCA output, the distribution of species along axis 2 (λ=0.285) suggests that it may represent a salinity gradient (Figure 4-23). Species tolerant of alkali, *Eleocharis macrostachya*, *Eleocharis acicularis* (Rothrock and Wagner 1975, Kroh and Schein 1981), *Spergularia diandra*, *Carex douglasii*, *Apera interrupta*, and *Plagiobothrys leptocladus*, are located from the far right side of the axis into the center portion, while *Polygonum aviculare* is located on the far left. Again, the alkali tolerances of the other species on the plot are unknown. The position of quadrats relative to the axis also indicates separation along a salinity gradient (Figure 4-24). Quadrats from zone 2 of the pools appear on the far left of axis 2, next to them are quadrats from zone 1, while zone 3 quadrats fall on the far right. This positioning of quadrats is similar to that described by Hobson and Dahlgren (1998) where salinity was greatest in the lowest region of the pool (zone 3), intermediate at the upper edge (zone 1), and lowest in the middle region (zone 2).

The only measured environmental variable that was well-correlated with axis 2 was grazing (r=-0.40; Table 4-12), suggesting that axis 2 could represent a complex gradient of grazing, salinity, and possibly other soil characteristics. In addition to the numerical correlation with grazing, the separation of ungrazed versus grazed quadrats along this axis is apparent (Figure 4-25).

Table 4-12. Correlations between DCA Axis Scores and Environmental Variables, 1999.

Ordination Axis	Elevation	Grazing	Organic Matter	pH	Bulk Density
Axis 1	0.50	0.09	0.24	-0.18	0.02
Axis 2	-0.17	-0.40	0.29	-0.22	-0.18
Axis 3	-0.05	-0.50	-0.26	-0.46	-0.37

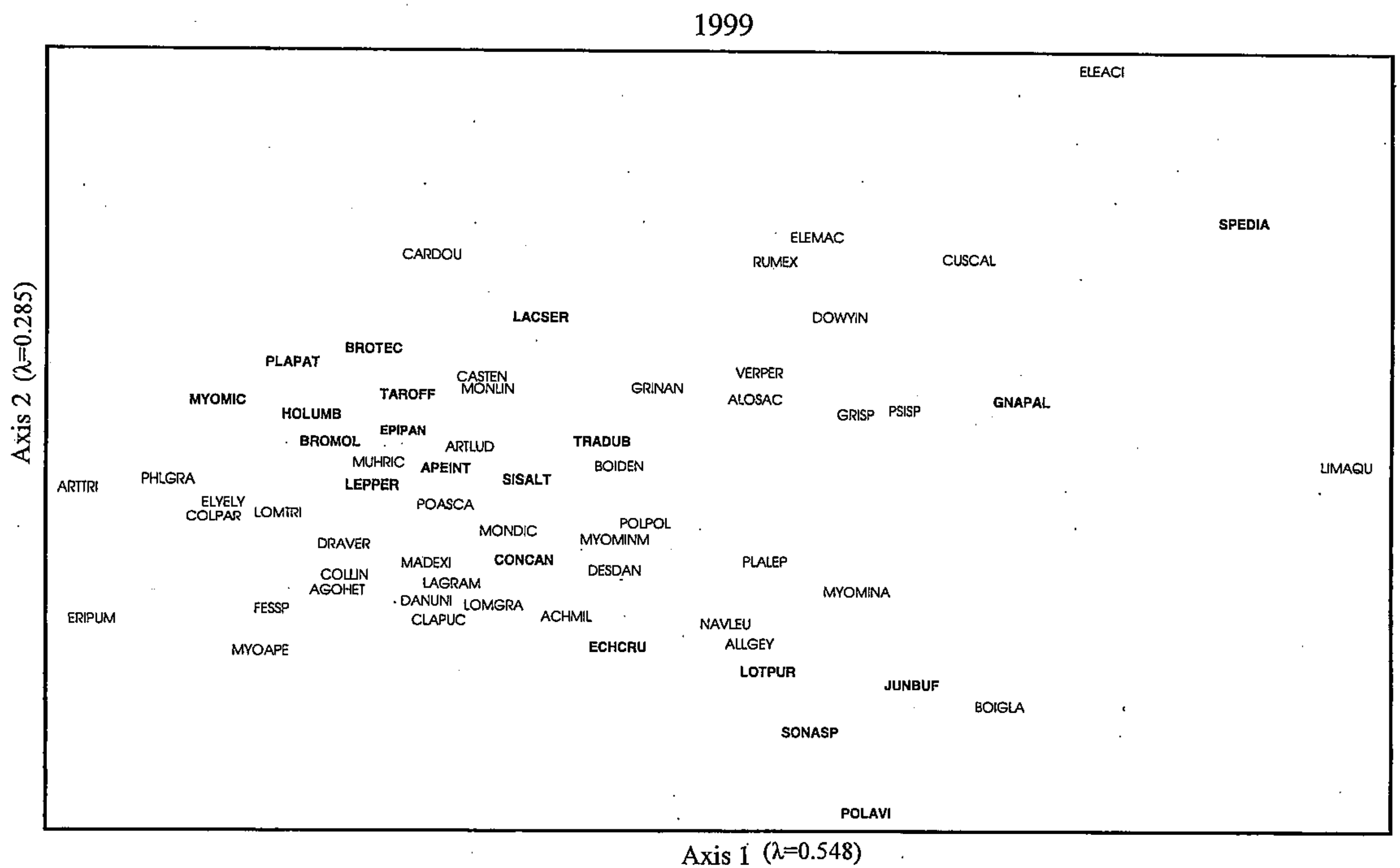


Figure 4-21. DCA ordination plot of species, 1999 data. Weedy species are bolded. Species abbreviations are constructed from the first three letters of the genus name and the first three letters of the specific epithet. A list of abbreviations is presented in Appendix D.

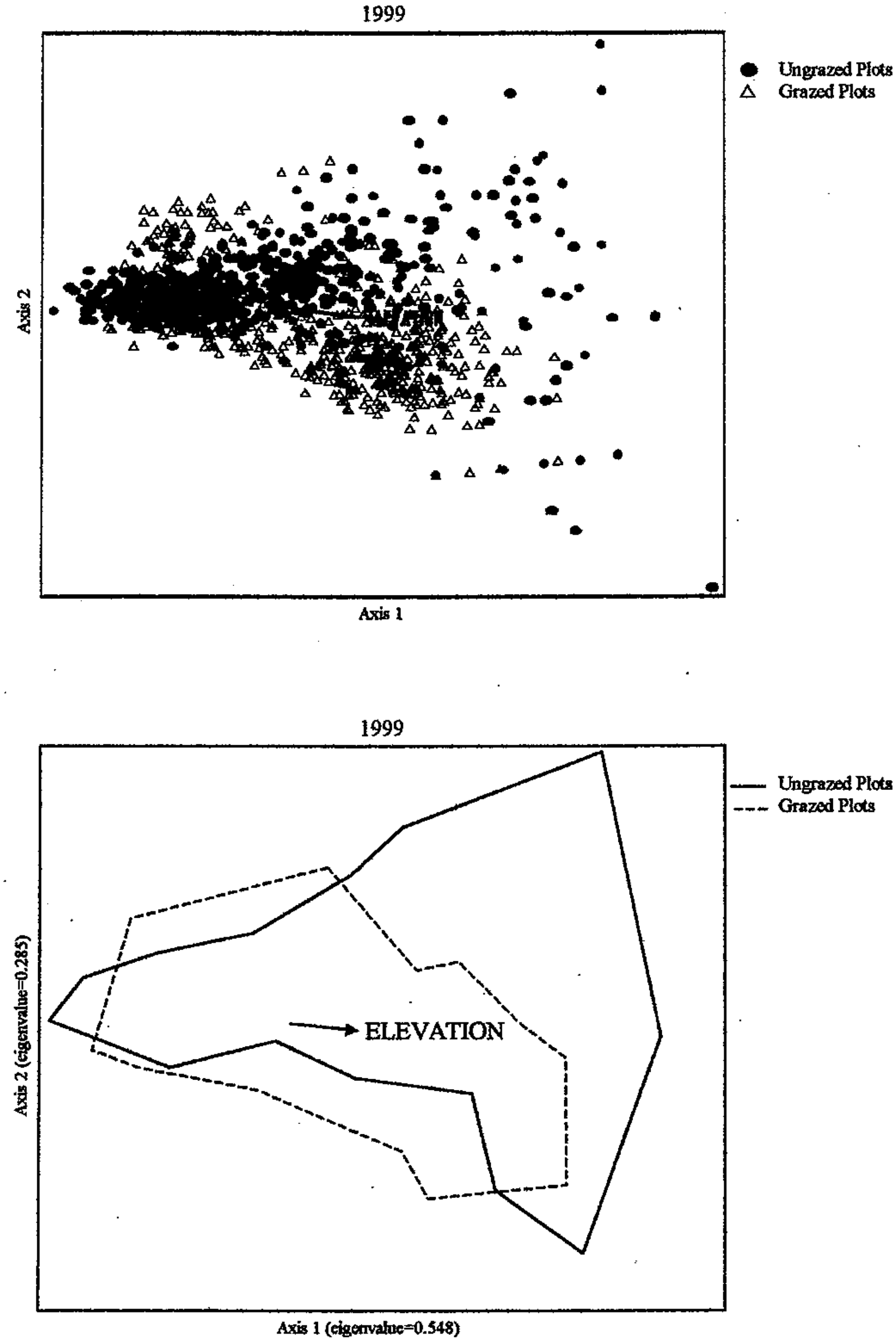


Figure 4-22. DCA joint plot of axes 1 and 2, 1999 data. Points on upper graph represent individual quadrats.

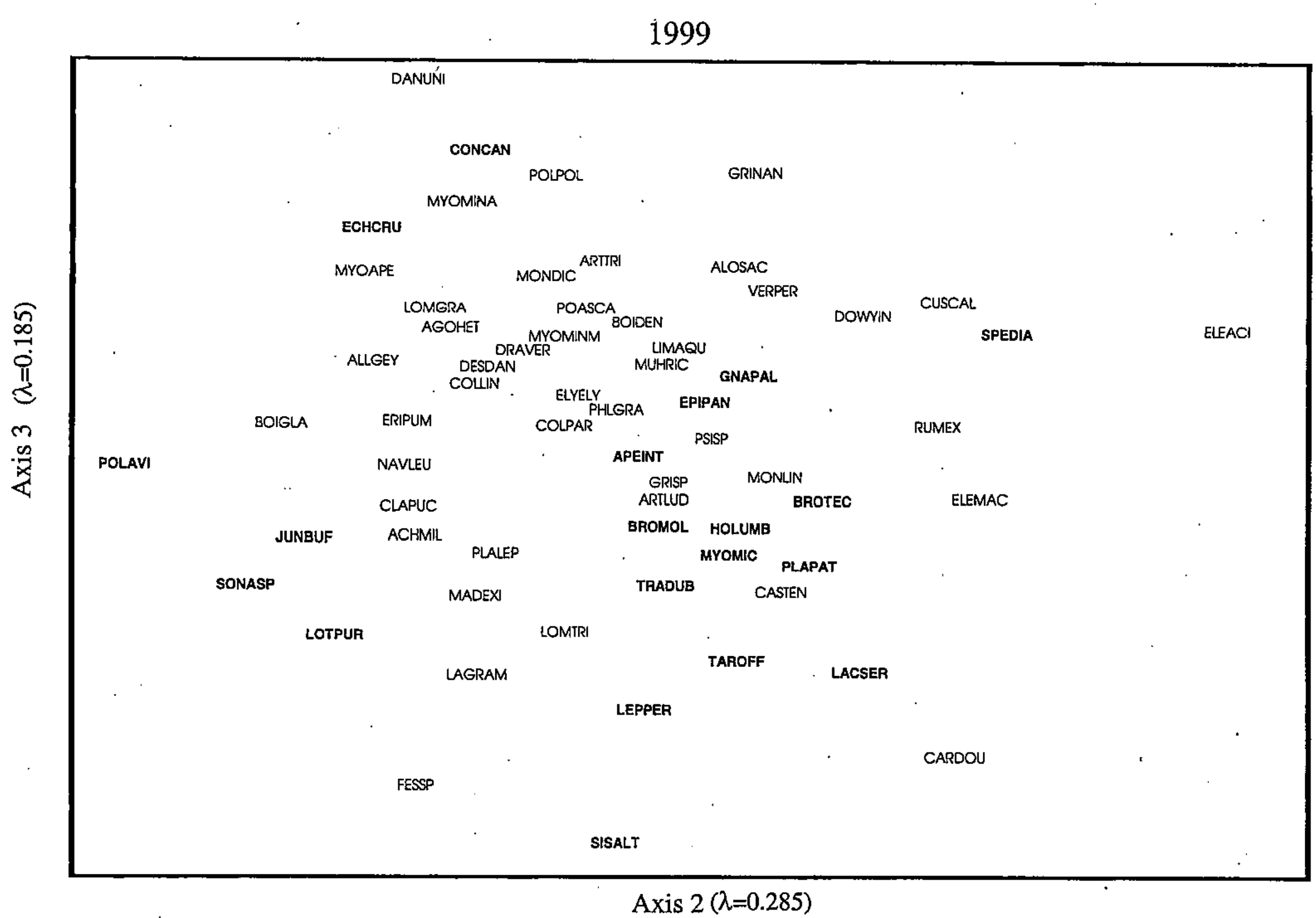


Figure 4-23. DCA ordination plot of species, 1999 data. Weedy species are bolded. Species abbreviations are constructed from the first three letters of the genus name and the first three letters of the specific epithet. A list of abbreviations is presented in Appendix D.

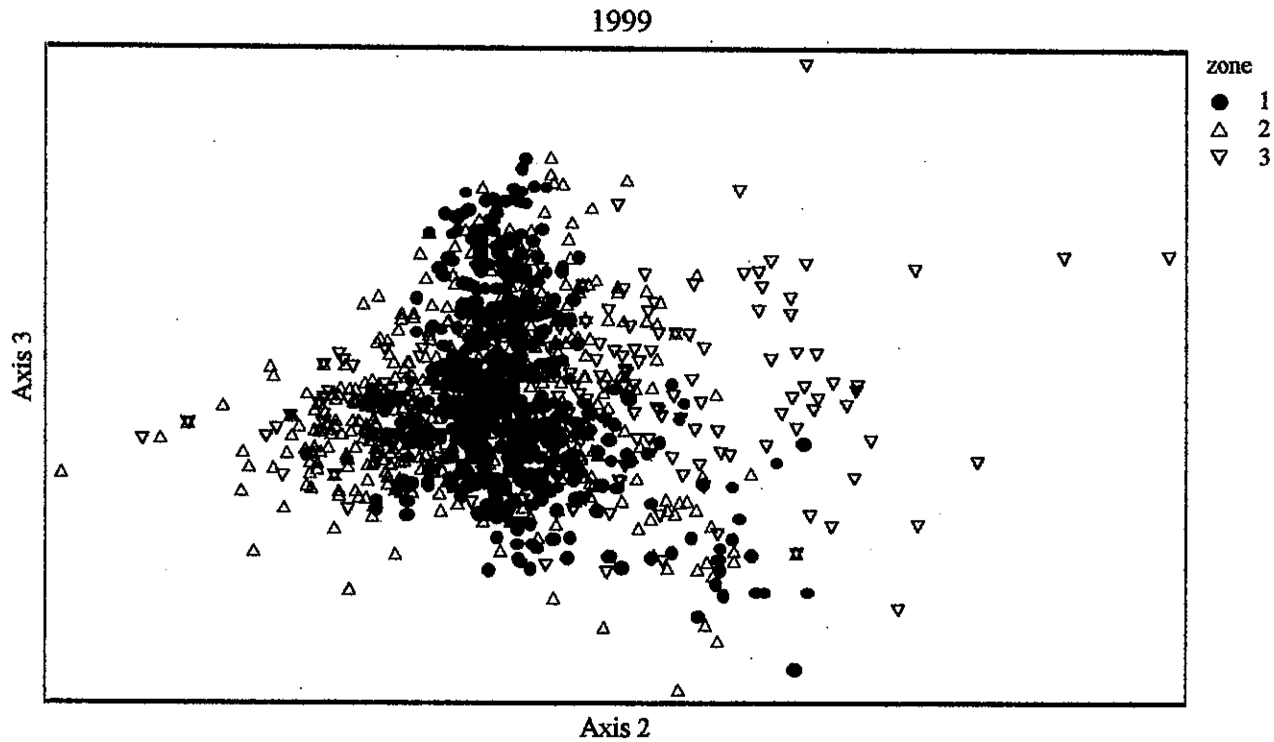


Figure 4-24. DCA ordination plot of quadrats, 1999 data. Symbols represent the zone in which the quadrat was present.

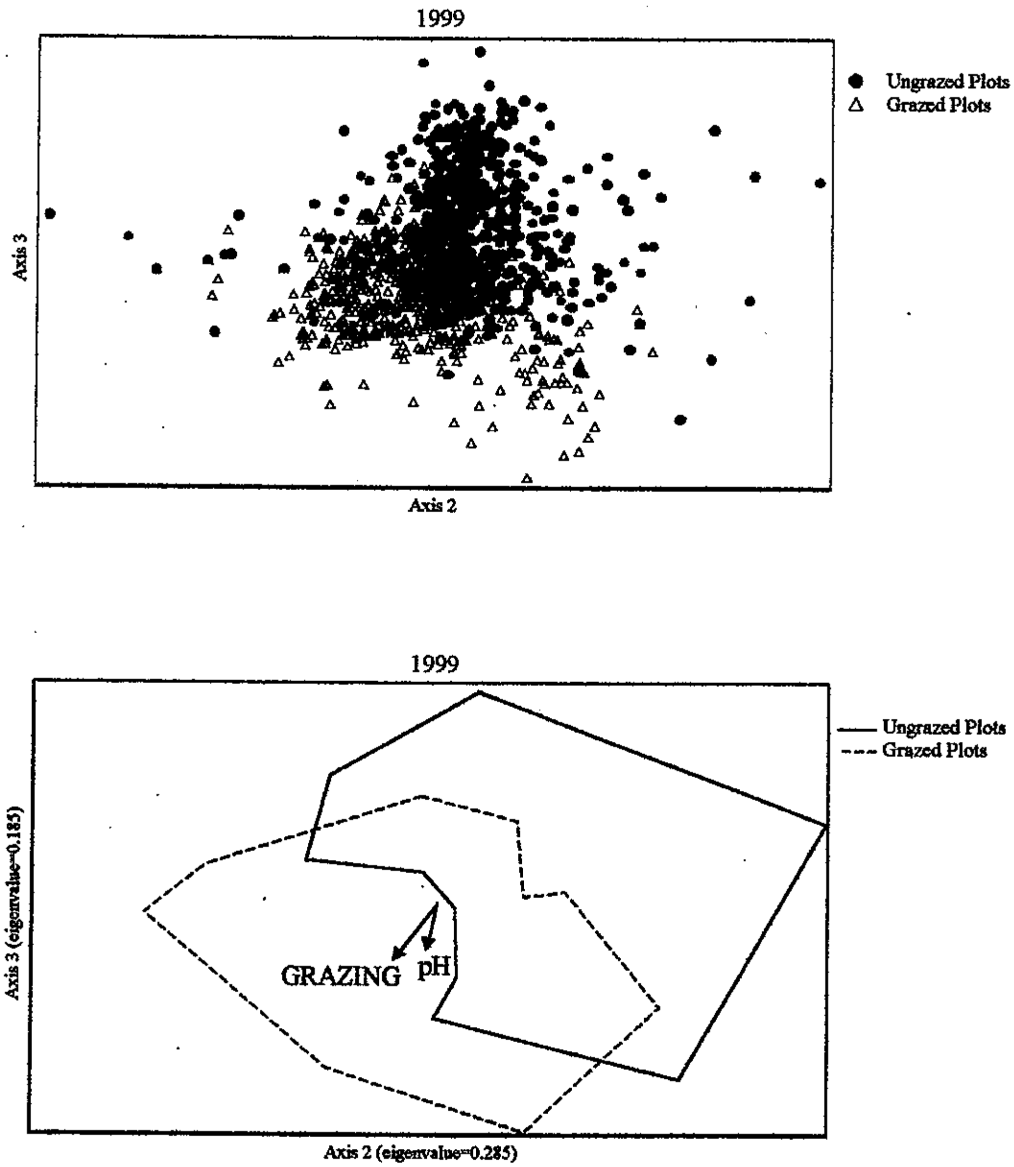


Figure 4-25. DCA joint plot of axes 2 and 3, 1999 data. Points on upper graph represent individual quadrats.

The relationship between grazing and axis 3 (λ=0.185) is stronger than it is for axis 2, seen both in the high correlation coefficient between them (r=-0.50) as well as the clear separation of ungrazed and grazed plots (Figure 4-26). The position of the grazing vector in the joint plot further illustrates its relationship with axis 3, where grazing increases, from absent (0) to present (1), towards the grazed plots. Also evident in this graph is the relationship of pH to axis 3 (r=-0.46), where pH increases in the direction of the grazed plots. The position of species along this axis further suggests that it represents a grazing condition (Figure 4-23). Species located along the lower portion of axis 3 (e.g., *Festuca* sp., *Carex douglasii*, *Lepidium perfoliatum*, *Taraxacum officinale*, *Lactuca serriola*, *Sonchus asper*, *Juncus bufonius*, *Tragopogon dubius*) are those found either entirely or with substantially greater frequency in the grazed pools compared to the ungrazed pools. The one exception to the previous statement is *Sisymbrium altissimum*, which is located at the extreme end of axis 3 but occurs more frequently in the ungrazed pools. At the upper end of the axis are those species that occur either entirely or with much greater frequency in the ungrazed pools—*Danthonia unispicata*, *Conyza canadensis*, *Polygonum polygaloides*, *Grindelia nana*, *Alopecurus saccatus*, *Myosurus apetalus*, *Downingia yina*, *Cuscuta californica*. Again, there is one exception, as *Echinochloa crusgalli* occurs with slightly greater frequency in the grazed pools than in the ungrazed pools.

The CCA Monte Carlo permutation tests (99 permutations) yielded a significant species-environment correlation for all three axes (p=0.01). The species-environment correlation value for axis 1 was 0.65, for axis 2 was 0.82, and for axis 3 was 0.67.

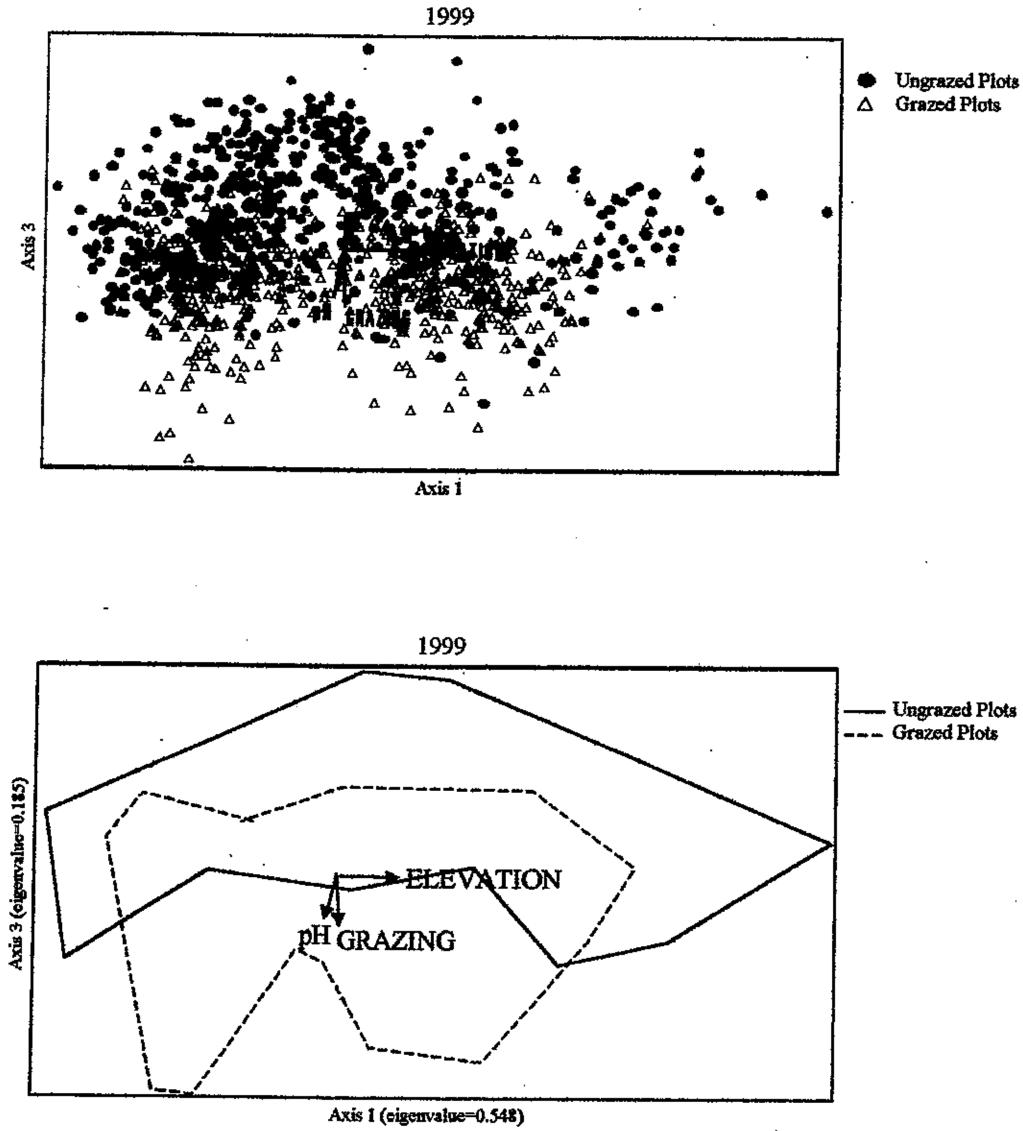


Figure 4-26. DCA joint plot of axes 1 and 3, 1999 data. Points on upper graph represent individual quadrats.

CHAPTER 5. DISCUSSION

DIFFERENCES IN SPECIES ABUNDANCES AND ENVIRONMENTAL VARIABLES

Results of this analysis indicate that there are measurable differences in floristic composition between the ungrazed and grazed vernal pools, as well as differences in environmental condition. Bulk density differed significantly between the sites, such that surface soils were more compacted in the grazed pools. This finding corresponds to personal observations of trampled soils in the grazed pools, noticeable by the hoof prints and undulated microtopography.

The other environmental variable that differed statistically between the sites was pH, which was higher in all zones of the grazed pools. It has been shown in other studies that urine deposition on soil can increase pH levels to 8.0 or greater (Doak 1952, Somda et al. 1997) and keep the pH elevated for prolonged periods. The rise in pH is believed to reflect the high pH of the urine itself, which is due to the release of hydroxide ions during the hydrolysis of urea and its high salt content (Monaghan and Barraclough 1992). Other researchers (Dormaar and Willms 1998) have suggested that an increased pH in a grazed system can be used as an indicator of soil loss, since with increased grazing pressure, the depth of the soil profile decreases, resulting in carbonates being closer to the soil surface. According to their reasoning, a high pH value may be an indicator of disturbed conditions.

Another explanation for the increased pH in the grazed pools involves the cryptogamic crust. Although this aspect of the pool flora was not included in the study, it has been documented previously that grazing degrades the cryptogamic soil crust in desert ecosystems (Anderson et al. 1982). A large component of these crusts is lichens, which produce acidic substances that are released into the soil as they decompose (Vare et al. 1995). Thus, a reduction in cryptogamic crust cover in the grazed pools could be contributing to an increased pH. This hypothesis requires further investigation.

Similar to the findings of Crowe (1990), organic matter (OM) content did not vary significantly among zones. Crowe also reported OM content to be highest in zone 1, which was attributed to the presence of fine-rooted perennial grasses along the pool margins. In contrast to her findings, however, in this study, OM content was highest in zone 3 and lowest in zone 1. One explanation for this result relates to the increased amounts of clay in the soil in zone 3 compared to zone 1 (Lathrop 1976, Bauder 1987, Holland and Dains 1990). Soil that has a high clay content can bind organic matter, stabilizing it and slowing the rate of decomposition. Also, soils in zone 3 are saturated longer, which further slows the decomposition process. Another explanation for the discrepancy may relate to the fact that only two pools were investigated in the Crowe study. It is possible that two pools is too-small of a sample size to adequately characterize zonal soil conditions.

In all zones and in both years, the frequency of weed species considered collectively was consistently greater in the grazed pools. Two exceptions were *Lactuca serriola* and *Apera interrupta*, common upland species that were more frequent in the ungrazed pools in 1998. The weed species that showed the greatest differences in frequency between the sites were *Juncus bufonius* and *Polygonum aviculare*, the latter of which is common in overgrazed pastures throughout the intermountain west and is often used as an indicator of a degraded landscape (Meerts and Garnier 1996, Whitson et al. 1996). *Juncus bufonius* is also common in disturbed environments, but not necessarily in over-grazed sites. When examining differences in weed species together as a group, the frequency of weeds was greater in both years in the grazed pools. When further considering zone and life history, annual weeds were more prevalent in zones 2 and 3 and perennial weeds were more frequent in zone 1 of the grazed pools. Differences in species cover were similar to differences in species frequency where the percent cover of many weed species was greater in the grazed pools. Again, two of the weeds showing large differences in cover between the sites were *Juncus bufonius* and *Polygonum aviculare*. The analysis of cover data also showed that percent cover of the dominant sedges, *Eleocharis macrostachya* and *E. acicularis*, was reduced in the grazed pools. In addition to frequency and cover, the number of weedy species tended to be higher in grazed quadrats. In particular, the mean number of weed species per quadrat in zone 3 was significantly greater in both years in the grazed pools.

Mechanisms that have been proposed to explain the increased spread of weedy species in a grazed landscape include livestock dispersing weed seeds in fur and dung, opening up habitat for weedy species that thrive in disturbed areas, and reducing competition from native species by eating them (Fleischner 1994). It may be the case that, for the vernal pools on the DNR property, all three mechanisms are acting concurrently. As described earlier, there were areas on the DNR land between the pools where the *Artemisia tridentata*/*Festuca idahoensis* association was replaced by a monoculture of *Bromus tectorum*, an invasive pasture grass. *B. tectorum* is a common weed on rangelands that is believed to have spread throughout western North America as a result of excessive grazing (Mack 1981, Young and Longland 1996). Mechanisms for its spread include both a passive dispersal system by adhesion to animals and active dispersal by native granivores. In zone 1 of the grazed vernal pools, *B. tectorum* was significantly more frequent than in the ungrazed pools. Not surprisingly, it has been able to spread into the outer limits of the pool basin from the surrounding environment.

The latter two mechanisms for exotic species spread proposed by Fleischner (1994), opening up habitat and reducing competition for weedy species by selectively consuming natives, may be the ones operating in the deeper parts of the pools. Within one week of nine head of cattle being released on the DNR property (mid-June 1999) and in all of the grazed study pools, almost all stems of the native sedges were bitten off. In addition to *Eleocharis*, grazing was apparent on the native *Allium geyeri* but not on any of the diminutive vernal pool specialists. The percent cover of *Eleocharis* was substantially reduced in the grazed pools, suggesting that grazing may be creating more open space into which the highly-competitive weed species are spreading in zone 3 of the grazed pools than in the comparable region of the ungrazed pools. Two of the weed species that seem to take particular advantage of the reduced *Eleocharis* cover in zone 3 are *Juncus bufonius* and *Polygonum aviculare*, neither of which appeared to be favored by the grazers.

While the frequency of individual weed species and weeds as a group tended to be higher in the grazed pools, most of these same weeds were also present in the ungrazed pools. Recruitment of weeds into the ungrazed pools may be a consequence of the preserve existing in a matrix of agricultural lands that themselves have been disturbed and colonized by weeds. In fact, most of the weed species found in the vernal pools are described as weeds of croplands (Whitson et al. 1996). Vectors of dispersal between the wheat fields, the fenced preserve, and DNR land are numerous, including wind and many species of birds.

The presence of the same weeds in the ungrazed pools may also be explained by their not-too-distant history of grazing. The practice of livestock grazing occurred on the preserve until approximately 30 years ago (Schuller 1984), which may be have contributed to the current abundance of weeds. It is possible that the Marcellus pools represent a transitional stage of recovery from grazing disturbance, where native species frequency is increasing and the weedy species are still present, as opposed to a purely "ungrazed" condition. A greater difference in floristic composition between grazed and ungrazed pools might have been detected if pools with no history of grazing had been used to compare against the grazed pools on the DNR land.

Bauder (1987, 1998) observed a negative relationship between the duration of standing water and presence of weedy species. Data from this study support Bauder's finding when the presence of upland weed species (i.e., *Apera interrupta*, *Bromus mollis*, *Bromus tectorum*, *Cirsium arvense*, *Conyza canadensis*, *Epilobium paniculatum*, *Holosteum umbellatum*, *Lepidium perfoliatum*, *Myosotis micrantha*, *Plantago patagonica*, *Sisymbrium altissimum*, and *Taraxacum officinale*) is compared between years. In 1998 when conditions in the pools were comparatively dry, the frequency of approximately 83 percent of these species was higher in zone 2 and/or zone 3 than in 1999. In other words, when standing water levels were greater and longer in duration, upland weeds were excluded from the deeper portions of the pool basin. Exceptions to this finding were *Holosteum umbellatum* and *Taraxacum officinale*, which were both just slightly more frequent in the lower zones in 1999.

The analysis of differences in rare species frequency and cover between the two sites proved inconclusive. Since only one rare species was found in each of the two years, although it was only found in some of the ungrazed pools, conclusions about grazing effects on rare plants can not be made with certainty. The year before this study was initiated, several rare species were observed in the Marcellus pools, all of which were absent in the DNR pools (Bjork 1997), leading to the conclusion that rare species were being excluded from the grazed pools. In consideration of this finding, following sampling, all pools were thoroughly inventoried for rare species to ensure that they were truly not present (i.e., not missed during sampling). Results of the inventory showed that species recorded by Bjork in 1997 were indeed not present in the pools in the 1998 and 1999 field seasons. The difference in rare species may be attributed to the weather, or more specifically, to the extremely wet conditions in the spring of 1997 and much drier conditions of 1998 and 1999. Zedler (1987) has suggested that the cycle of regional weather patterns is reflected in patterns of species germination and distribution in vernal pools and other work has shown that species with a narrow range of germination requirements fail to produce seedlings in dry years (Bauder 1987). Given the relatively dry conditions of the pools in the two field seasons comprising this study, it is therefore not surprising that many of the rare, water-requiring species found in the Marcellus pools in the spring of 1997 were not observed in the following years.

When one considers Bjork's (1997) observations of rare species in ungrazed and grazed pools, it appears that grazing may be excluding these species since five were found in the ungrazed pools, with none in the grazed pools. If this is indeed the case, then it is in contrast to statements made by Barry (1998) that sustaining vernal pools as habitat for endangered species would be more difficult in an ungrazed ecosystem. To support this conclusion, she cites another study (Crampton 1959) that found the presence of vernal pool perennials, such as *Eleocharis macrostachya*, restricted the density of two rare species. Clearly, more work is needed to clarify the issue of grazing effects on rare vernal pool species.

SPECIES DISTRIBUTION PATTERNS AND ENVIRONMENTAL GRADIENTS

In the TWINSPAN analysis, in both years, divisions among clusters were often made at a point where grazed plots were located on one side of the division and ungrazed plots on the other. In other words, there was a large degree of separation of community types by site. Most of the community types, such as the zone 2 community distinguished by the presence of *Juncus bufonius*, *Polygonum aviculare*, and *Gnaphalium palustre* in the DNR pools and the *Eleocharis macrostachya-Limosella aquatica* zone 3 community in the Marcellus pools, were found only in one site or the other, suggesting that floristic composition within community types differed more between the sites than within. Two of the pools, however, contained community types that were particular only to them—the zone 1 community type dominated by *Eleocharis macrostachya* in D25 and the zone 1 community type dominated by *Artemisia ludoviciana* and *Montia linearis* in M6.

Pool D25, more so than M6, was noticeably different in species composition from all the others included in the study. *Eleocharis macrostachya*, *Apera interrupta*, and *Lactuca serriola* were present in almost all of the quadrats sampled, from zone 1 to zone 3, and the standing crop biomass was significantly greater than in the other pools. Relative elevation in this pool was especially deep in the zone 3 area but was otherwise comparable in the other portions and did not appear to be one of the pools that held water late into the season. Organic matter content, pH, and bulk density all were slightly greater than in the other pools, but also did not differ significantly. Given the factors included in this study, there was no measured reason why D25 so differed in species composition and distribution. One possible explanation might lie in its geographic position. This pool was located immediately adjacent to Suko Road, the narrow gravel road that separated to the two sites, which might be causing an even greater disturbance to the pool flora than just grazing alone. Increased levels of sedimentation and biological and/or chemical contamination and greater access by human visitors may all be factors contributing to its current state. A more in-depth analysis of soil physical and chemical characteristics, as well as other means of disturbance, might help identify influential environmental gradients in the pool that have not yet been recognized.

The DCA analysis further identified differences in species composition between the sites, showing clear separation of grazed and ungrazed quadrats along two ordination axes. It also showed several environmental gradients were correlated with the distribution of species. The most influential environmental gradient in the pools was the topographic gradient, which was assumed to be correlated with a gradient of standing water duration, which influenced species distributions equally in the two sites. There was little separation of grazed versus ungrazed quadrats along this first axis. In the 1999 data, the presence of a grazing condition was apparent in the separation of quadrats along axes 2 and 3 and was further illustrated in a joint plot where axes 2 and 3 each had a relatively high correlation with grazing. Separation of quadrats by sites was also evident along axes 2 and 3 in the 1998 data but the correlations between the axes and grazing were much lower than in 1999.

Comparing the DCA plots between the two years, the eigenvalue for axis 1 was greater in the 1999 data indicating a stronger gradient of elevation. Although the eigenvalues of two different datasets are not directly comparable, this result seemed to reflect what was observed in the pools. Prior to data analysis, it was believed that there would be a stronger influence of elevation on species distribution in 1999 when conditions were wetter. The expectation was that prolonged periods of inundation would limit species dispersal to narrower elevational bands in the pools based on their water-tolerance. In 1998, many species, both "pool" and "nonpool," were able to spread throughout the pool basins, unrestricted by standing water. Numerous species were ubiquitous both within and among pools and there was much species overlap in the distribution. Many of the vernal pool species that require prolonged periods of standing water for germination and would be restricted to only the deepest portions of the pool basin (and were observed in the same pools by Bjork in 1997), such as *Callitriche marginata*, *Elatine rubella*, and *Pilularia americana*, were not present in 1998. In contrast, in 1999 when pools were slightly wetter, species distributions were more confined to certain elevations, resulting in a more distinct banding pattern in the pools.

If the pools were not grazed until the very end of the 1999 field season, why then was there greater separation of the ungrazed and grazed plots in the 1999 data than in 1998? One explanation might relate back to the difference in weather conditions between the two years. In 1999 when conditions were wetter, species richness increased in the pools with a larger number of weed and vernal pool species recorded in the field. In 1998 when fewer species were present, more species were shared between the two sites, resulting in a greater similarity in species composition between the sites. In the DCA analysis, then, separation of the quadrats by site was not as pronounced in the 1998 data since there was less difference overall in floristic composition than was seen the following year. This finding is consistent with others that have found soil fertility and water availability to overshadow grazing effects in many areas (Hongo et al. 1995, Stohlgren et al. 1998).

Another environmental parameter that may be influencing species composition and/or distribution in the pools is salinity. From the arrangement of species and quadrats along axis 2, salinity was identified as another potentially influential gradient in the pools. However, since salinity was not measured as part of this study, no conclusive statements about its effect on species distribution can be made. Zedler (1987) and Lathrop (1976) have reported that salinity is an important environmental gradient in the vernal pool ecosystem and one that decreases in a continuous manner from the deep, center portions of the pool towards the surrounding upland. In the Marcellus and DNR pools, however, salinity seemed to be greatest in the deep parts of the pools, lowest in the areas corresponding to zone 2, and intermediate in the outer zone. Salinity levels were highest in the deepest parts of the pools due to the evaporative concentration of salts remaining on the surface soil as the pools dry. One reason for salinity being greater in zone 1 compared to zone 2 may be that frequent periods of drought are causing high salt concentrations in the soil. In zone 2 where there is standing water, salts may be leached from the soil or suspended in the standing water and drawn down and concentrated in the lower zone as the pool dries. Evidence of a salinity gradient was more apparent in the 1999 data than in 1998, possibly due to differences in moisture conditions.

Studies of vernal pool ecology should be conducted over multiple years. As has been illustrated in this study and others, the vernal pool flora is greatly influenced by current and past weather conditions. Species that germinate in a relatively wet year may not do so in a dry year, and species that can disperse into the pool basin in a dry year may be restricted in a wet year. Also, since the pool flora is dominated by annuals, the distribution of plants varies each year depending, to a large degree, on what is available in the seed bank. To get an accurate sense of the "normal" ecosystem structure and functioning of a vernal pool, one must follow it over several years. Prior to initiating this study, conditions in the pools were very wet, and numerous rare, amphibious, and aquatic plants germinated. During the two years of this study, one was relatively dry and the other represented moderate or average moisture conditions. To detect additional plant species, especially the rare ones, and possibly observe greater differences between the ungrazed and grazed pools, this study would have benefited from the inclusion of data from at least one wet year.

MANAGEMENT RECOMMENDATIONS

Results of this research indicate that the greatest difference in floristic composition between the ungrazed and grazed pools is shown by the presence of weed species in the grazed pools. For many individual species, as well as weeds as a group, the frequency and percent ground cover were significantly greater in the grazed pools. To remove annual invasive species at other sites, prescriptions for vernal pool management have included late-spring burning, selective weeding, herbicide applications, mowing, and re-engineering of pool hydrology (Clark et al. 1998). Many of these management practices have been implemented in vernal pool ecosystems where the flora was severely degraded and dominated by invasive species. Since this is not the situation with the grazed pools examined here—the frequency and cover of native species was much greater than that of weed species—a less intrusive management regime is recommended. An appropriate first step towards recovery of the grazed pool flora may be to remove the source of disturbance. This can involve either cessation of livestock grazing on the land parcel altogether or exclusion of the grazers just from the vernal pools. If the pools on the Marcellus Preserve represent partially-recovered pools after 30 years of no grazing and the grazing history of the two sites was similar up until that point, then chances are that the DNR pools would recover in the same way.

However, recovery of the currently-grazed pools may take more time than those on the preserve since the shrub-steppe community on the DNR land is noticeably more degraded by weedy species. These species serve as a source of plant material that, over time, has developed a foothold in portions of the vernal pools. For this reason it may not be possible to just remove livestock from the pools; instead it may be necessary to actively restore the surrounding shrub-steppe to a more native-dominated association.

A program of long-term vegetation monitoring should be implemented on both sites. Changes in the presence and abundance of weedy species, annuals, perennials, characteristic vernal pool species, and rare species should be recorded and compared between the sites. Vernal pools on other sites, especially those with no history of livestock grazing, should also be monitored and used as a reference example of pristine pool conditions.

FUTURE RESEARCH

Given the exploratory nature of the multivariate analyses applied to these data, some of the relationships observed between species distribution and environmental gradients can not be interpreted as causal in nature. Gradient analysis and ordination techniques are methods for data reduction and exploration, which then should lead to hypothesis generation and testing. The methods are descriptive in nature and facilitate the formulation of ideas about possible causal relationships between variation in the vegetation and environment.

Based on species patterns observed in this study, hypotheses for future testing should include the following:

- There are distinct differences in zonal community types between ungrazed and grazed pools and these differences are defined mostly by the presence of weed species.

- Floristic composition between the ungrazed and grazed pools differs due to effects caused by livestock grazing.

- Duration of standing water is the environmental gradient that most influences species composition and distribution in the eastern Washington vernal pool ecosystem. Secondary gradients include salinity, grazing, and pH.

Results of this study have also led to additional questions that should be investigated in future vernal pool studies. These questions include:

- What is the nature and extent of the cryptogamic crust layer present in the ungrazed and grazed vernal pools? Is it disturbed? What are the effects of grazing on the crusts in a vernal pool?

- What are the effects of grazing on rare vernal pool species?

- What are the effects of different degrees of grazing intensity on the pool flora? Is there some minimum level of grazing intensity that has no measureable effect?

- Are there other disturbances to the pool flora that were not measured in the current study (e.g., fire history, sedimentation from road)? What are they and what are their effects on the pool flora?

The answers to these and other questions will provide a more complete understanding of vernal pool ecology in eastern Washington and the effects of livestock grazing on the pool flora.

CONCLUSIONS

The objectives of this research were to address the following two questions: (1) what are the differences in plant species composition and distribution between the ungrazed and grazed vernal pools and (2) what environmental factors are correlated with the spatial distribution of plant species in the pools. These questions were posed to investigate the effects, if any, that cattle grazing was having on the vernal pool flora.

Data collected during two field seasons (1998 and 1999) indicate that there were measurable differences in floristic composition between the two sites. Most notably, there was a significantly greater frequency and percent cover of weed species in all zones of the grazed pools, as well as a tendency for increased weed species richness in grazed quadrats. The greatest differences in weed species presence and richness were found in zone 3 of the pools, where two weed species in particular–*Juncus bufonius* and *Polygonum aviculare*–were much more abundant and widespread in the grazed pools. While both of these species are common in disturbed sites, *P. aviculare* is considered to be an indicator of overgrazed conditions. In addition to the increase in weed species cover in zone 3 of the grazed pools, the percent cover of *Eleocharis macrostachya* and *E. acicularis*, the sedges characteristic of zone 3, was significantly reduced. These species seemed to be preferred by the cattle as forage material and were visibly grazed in all of the DNR study pools. Thus, it appears that grazing on the elemental sedges in zone 3 of the pools is reducing their cover, creating open spaces for the spread of water-tolerant annual weeds.

While the presence of weeds tended to be greater in the grazed pools, most of these same weeds were also present in the ungrazed pools. Recruitment of weeds into the ungrazed pools probably does not reflect any direct disturbance by cattle; rather it may be a consequence of the preserve existing in a matrix of agricultural lands that have been disturbed and colonized by weeds, as well as the continued annual inundation of the pools that is itself a form of disturbance. The presence of weeds in the ungrazed pools may also be explained by their not-too-distant history of grazing. The practice of livestock grazing was stopped on the preserve approximately 30 years ago, which may be have contributed to the current abundance of weeds. So, it is possible that the Marcellus pools represent a transitional stage of recovery from grazing disturbance, rather than a purely "ungrazed" condition.

No strong conclusions about differences in the frequency and cover of rare vernal pool plant species can be made from the results of this study, primarily because only one species was encountered. Before initiating the study, the expectation was that rare species were being excluded from the grazed pools. This belief was based on a 1997 inventory of some of the Marcellus and DNR pools that documented several rare species in the Marcellus pools and none in the DNR pools. The difference among years in rare species presence may be attributed to variations in precipitation and temperature, where conditions were exceptionally wet in the spring of 1997 and much drier in 1998 and 1999. Since many of the rare vernal pool plant species tend to be more aquatic in nature (e.g., *Callitriche marginata*, *Elatine rubella*, *Pilularia americana*), it is likely that the relatively dry conditions encountered during this study inhibited their germination and growth.

Analysis of the measured environmental variables showed that soils in the grazed pools were significantly more compacted and had a higher pH than soils in the ungrazed pools. No differences in organic matter content and relative elevation along transects were found.

In the two-way indicator species analysis, community types separated to a large degree by site. Most of the community types identified in the analysis were found only in one site or the other, suggesting that floristic composition within community types differed more between the sites than within. Two of the pools, however, contained community types that were particular only to them—the zone 1 community type dominated by *Eleocharis macrostachya* in D25 and the zone 1 community type dominated by *Artemisia ludoviciana* and *Montia linearis* in M6.

Results of the detrended correspondence analysis suggest that the topographic gradient, assumed to be related to depth and duration of standing water, is the most influential gradient affecting the spatial distribution of plant species in the vernal pool ecosystem. The arrangement of quadrats and species along DCA axis 1 illustrate a smooth transition from zone 1 to zone 2 to zone 3. Grazing was well correlated with both ordination axes 2 and 3, and along these axes there was a clear separation of ungrazed and grazed plots. This result suggests, and is worthy of future testing, that the dissimilarity in floristic composition between the sites may be causally related to grazing occurring in one site and not the other. Other environmental variables seemingly correlated with ordination axes 2 and 3 are salinity and pH. The CCA Monte Carlo permutation tests revealed significant species-environment relationships for the first two axes in 1998 and all three axes in 1999.

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APPENDIX A: Pool Descriptions

Bolded text refers to pools included in study.

Pool	Zones	Length (m)	Width (m)	Approx. Shape	Percent Cover Cobble	Percent Bare Ground	Description of Vegetation
Marcellus Preserve Pools:							
M1	**3**	**64**	**45**	**circular**	**15, most in zone 2**	**60**	**Distinct zones, standing water, sparse vegetation in center**
M2	1 or 2	11	7	circular	1, scattered in center	<1	Fairly uniform vegetation, even ground coverage, Deschampsia dense within outer zone
M3a	1 or 2	48	27	elliptic	2 to 4, one small clump by end of major axis	<1	Somewhat uniform vegetation, lush, Deschampsia, Allium, Achillea
M3b	1	25	23	circular	<1	<1	Somewhat uniform vegetation, lush, Deschampsia, Allium, Achillea
M4	1	39	19	mostly circular, narrow at ends	5, 3 small patches, some scattered	<1	Artemisia, poor quality
M5	2	23	11	elliptic, widest in center	20, 2 clumps, SW end	1 to 2	Artemisia, moss on rock (not clumps), weeds, other upland species
M6a	2	20	7	elliptic	6 to 7, scattered	<1	Moss covering rock, Artemisia
M6b	**2**	**30**	**18**	**elliptic, irregular**	**10, mostly in center**	**2 to 3**	**Artemisia on outside, clumped vegetation**
M7	**3 or 4**	**68**	**23**	**elliptic**	**10, most in center**	**5 to 8**	**Fairly lush, Lomatium**
M8	2	40	28	elliptic, irregular	10, close to side that juts out	1 to 3	A lot of upland species, scrubby
M9a	1 or 2	97	70	elliptic, circular	<1	<1	Lush, fairly dense, homogenous +/-
M9b	2	325	59	elliptic, irregular	1 to 5	20	Sparce vegetation in center, bare ground, clumps of weed
M10	1 or 2	62	30	widely elliptic	<1	<1	Large clumps of Rumex, lush

Pool	Zones	Length	Width	Approx. Shape	Percent Cover Cobble	Percent Bare Ground	Description of Vegetation
M11	3	75	27	elliptic, narrow in center	2 to 3	8	Two small patches of bare ground, small cobbles
M12	2	62	30	circular, oblong	<1	<1	Fairly uniform vegetation
M13a	1	22	15	circular	5, scattered	<1	Artemisia and Deschampsia in pool
M13b	2	35	5	narrowly elliptic	5, clumped in small patch, outer edge	<1	Uniform coverage, Deschampsia, Allium
M14	1	22	18	circular	<1	<1	Homogeneous, Artemisia and grasses dominant
M15	1	32	25	circular	<1	<1	Less homogenous than M14, Artemisia abundant, clumps of large Artemisia
M16	1 or 2	27	17	somewhat circular	5, scattered, one small clump by end of major axis	2 to 3, small areas	Upland species, Deschampsia, Achillea, poor quality, moss
M17	3	43	19	elliptic	20, 3 small patches, some very large cobbles	8, patch along one side of major axis	Eleocharis in zone 2, bare earth in center, mixed vegetation on outside, Deschampsia, Allium, Lactuca, Lomatium
M18	3	63	34	elliptic	5, small, mostly scattered over bare ground, some in outer zones	20, patch slightly off center	Eleocharis in center, mixed vegetation along outside, Deschampsia, good condition
Pools on DNR Property:							
D01a	3	54	9	elliptic, narrow at center	5, spread out mostly in bare patches	15 to 20 in 3 patches	Large patch of Eleocharis, other vegetation uniform
D01b	3	72	20	mostly round, narrow tip at end	20, one spread-out patch, one dense patch	<1	Artemisia in cobble patch, dense
D02	2	43	24	circular	50, spread out over bare ground	80, in center	Circular zones, narrow vegetation zones

Pool	Zones	Length	Width	Approx. Shape	Percent Cover Cobble	Percent Bare Ground	Description of Vegetation
D03	2	53	30	mostly circular	30, mostly on bare ground, some scattered	40, slightly off center	Band of Eleocharis, low weeds
D04	2	17	19	almost circular	70, large cobbles	5, among cobbles	Little vegetation around cobbles
D05	1	44	17	elliptic, long	5, scattered on outside	<1	Artemisia, weeds, Lomatium
D06	1 or 2	40	28	elliptic, wide in center	30, scattered	5	Fairly uniform, vegetation around cobbles
D07	1	63	17	elliptic	<1	<1	Lush, weedy, not much obvious vernal pool vegetation
D08	2	96	22	elliptic	8, scattered	2 to 3	Artemisia, Lomatium, average quality, better than D7
D09	3	108	44	wide elliptic	80, very large cobbles, mostly in center, standing water	5 to 10	Eleocharis around center, among cobbles, low species diversity
D10	2	50	19	mostly round, narrow tip at end	50, spread out throughout zones	10, in center	Eleocharis in center
D11	Note: D11 is excluded from study because it is not located on DNR land.						
D12	Note: D12 is excluded from study because it is not located on DNR land.						
D13	1	92	20	elliptic	<1	<1	Very weedy. Not much vernal pool vegetation
D14	1	34	21	oblong	1 to 2, scattered	<1	Artemisia, Achillea, Taraxacum, Eleocharis in patches
D15	1	43	16	elliptic	5, scattered	<1	Artemisia on outside, Eleocharis in center, Taraxacum
D16	1	52	32	oblong	<1	<1	Artemisia scattered throughout, lush, no real zones apparent

Pool	Zones	Length	Width	Approx. Shape	Percent Cover Cobble	Percent Bare Ground	Description of Vegetation
D17	1	32	12	elliptic, oblong	<1	<1	Camas, Taraxacum, lush, weedy
D18	2	33	25	circular	<1	2 to 3	Artemisia, Eleocharis in patches
D19	1	36	22	circular	<1	2 to 3	Artemisia, Camas-both scattered, no distinct zones, Eleocharis
D20	1	34	23	circular	<1	2 to 3	Artemisia, Eleocharis, no distinct zones, more patchy
D21	2	109	17	elliptic, narrow at center	70, mostly [ ] in center, some scattered thruout	50, in center, some Eleocharis	Some Artemisia among cobbles, Eleocharis in center, zonation
D22	2	28	20	circular	<1	5, one patch on edge	Thick spike-rush in center
D23	3	137	36	wide elliptic	60, clumped, mostly in center, also on center deges	20 to 30	Eleocharis in center on bare ground, band of mixed vegetation along outside
D24	3	95	75	irregular, mostly circular	20 to 25, in patches	15 to 20, roughly corresponds to cobbles	Eleocharis mixed with cobble, mixed vegetation along edge
D25	**2 or 3**	**51**	**25**	**oblong**	**<1**	**15, close to road, in deepest part of pool**	**Many weeds throughout, also densely concentrated in some areas**
D26	**3**	**64**	**50**	**irregularly circular**	**5 to 10, mostly clumped in center**	**5 to 10**	**Somewhat uniform vegetation with patches of bare ground, Eleocharis in center around cobble**
D27	1 or 2	25	21	circular	<1	2 to 3 at one end	Artemisia at one end, grasses, Taraxacum
D28				elliptic	20, scattered at one end, large, none in south	<1	Patch of Eleocharis in center, uniform coverage, some Artemisia

APPENDIX B. Transect Locations.

Pool M1. Transect Locations Along Major Axis.

From west end of pool (closest to Suko Road):	
Transect 1	3 meters
Transect 2	23 meters
Transect 3	43 meters
Transect 4	63 meters

Pool M6. Transect Locations Along Major Axis.

From south end of pool:	
Transect 1	10 meters
Transect 2	20 meters

Pool M7. Transect Locations Along Major Axis.

From west end of pool (far side of fence):	
Transect 1	3 meters
Transect 2	23 meters
Transect 3	43 meters

Pool M11. Transect Locations Along Major Axis.

From south end of pool:	
Transect 1	6 meters
Transect 2	26 meters
Transect 3	46 meters
Transect 4	66 meters

Pool M17. Transect Locations Along Major Axis.

From north end of pool (away from fence):	
Transect 1	6 meters
Transect 2	20 meters
Transect 3	30 meters
Transect 4	40 meters

Pool M18. Transect Locations Along Major Axis.

From north end of pool:	
Transect 1	4 meters
Transect 2	8 meters
Transect 3	28 meters
Transect 4	50meters

Pool D1a. Transect Locations Along Major Axis.

From south end of pool (away from fence):	
Transect 1	2 meters
Transect 2	22 meters
Transect 3	42 meters
Transect 4	52 meters

Pool D1b. Transect Locations Along Major Axis.

From north end of pool (closest to fence):	
Transect 1	5 meters
Transect 2	25 meters
Transect 3	45 meters
Transect 4	65 meters

Pool D2. Transect Locations Along Major Axis.

From south end of pool:	
Transect 1	3 meters
Transect 2	10 meters
Transect 3	27 meters
Transect 4	43 meters

Pool D3. Transect Locations Along Major Axis.

From south end of pool:	
Transect 1	10 meters
Transect 2	20 meters
Transect 3	30 meters
Transect 4	40 meters

Pool D25. Transect Locations Along Major Axis.

From west end of pool (away from road):	
Transect 1	6 meters
Transect 2	26 meters
Transect 3	46 meters

Pool D26. Transect Locations Along Major Axis.

From east end of pool:	
Transect 1	10 meters
Transect 2	20 meters
Transect 3	30 meters
Transect 4	40 meters

APPENDIX C. Soil Data.

pH

Pool	Zone	pH	pH	pH	mean pH
M1	1	6.73	6.95	6.69	6.79
M1	2	6.48	6.77	6.68	6.64
M1	3	5.87	6.62	6.54	6.34
M6	1	6.9	6.62	6.72	6.75
M6	2	6.38	5.65	6.07	6.03
M7	1	6.21	6.24	6.33	6.26
M7	2	6.16	5.89	6.39	6.15
M7	3	5.58	5.85	5.93	5.79
M11	1	6.53	6.76	7.07	6.79
M11	2	6.73	6.77	6.67	6.72
M11	3	6.31	6.12	6.43	6.29
M17	1	5.8	6.09	6.28	6.06
M17	2	5.78	5.92	5.56	5.75
M17	3	5.23	5.41	5.43	5.36
M18	1	6.11	6.08	5.83	6.01
M18	2	6.06	6.01	5.98	6.02
M18	3	5.58	5.57	6.16	5.77
D1a	1	7.32	7.33	7.21	7.29
D1a	2	6.97	7.12	6.92	7.00
D1a	3	7.03	7.11	7.36	7.17
D1b	1	6.85	7.32	7.47	7.21
D1b	2	6.7	6.72	6.89	6.77
D2	1	6.01	6.28	6.5	6.26
D2	2	6.64	6.78	6.25	6.56
D2	3	6.38	6.16	5.67	6.07
D3	1	6.35	6.64	6.12	6.37
D3	2	6.89	6.85	6.64	6.79
D3	3	7.29	6.93	7.17	7.13
D25	1	6.3	6.94	6.84	6.69
D25	2	7.81	8.04	8.19	8.01
D25	3	7.92	7.47	7.88	7.76
D26	1	6.73	6.52	6.8	6.68
D26	2	6.75	6.99	6.62	6.79

Organic Matter Content

Pool	Zone	Pre-Ignition Wgt	Post-Ignition Wgt	OM Content
M1	1	88	86.5	1.5
M1	1	86.2	85.4	0.8
M1	1	84.5	83.6	0.9
M1	2	90	88.7	1.3
M1	2	86.3	85.4	0.9
M1	2	83.9	83	0.9
M1	3	89.1	85.7	3.4
M2	3	85.6	84.2	1.4
M3	3	85.2	82.9	2.3
M6	1	88	86.3	1.7
M6	1	89.7	88.4	1.3
M6	1	89.1	87.6	1.5
M6	2	88.7	86.3	2.4
M6	2	90.4	88.7	1.7
M6	2	91	89.3	1.7
M7	1	89.7	88.4	1.3
M7	1	90.6	89.3	1.3
M7	1	91.4	90	1.4
M7	2	88.9	87.5	1.4
M7	2	91	90.1	0.9
M7	2	90.1	88.6	1.5
M7	3	90.8	89.2	1.6
M7	3	90.3	88.6	1.7
M7	3	91.1	89.4	1.7
M11	1	90	88.1	1.9
M11	1	90.6	89.5	1.1
M11	1	90.2	89.1	1.1
M11	2	91.2	89.8	1.4
M11	2	90	88.5	1.5
M11	2	90.3	88.7	1.6
M11	3	91.2	89.1	2.1
M11	3	88.3	86.3	2
M11	3	88.6	87	1.6
M17	1	90.8	89.7	1.1
M17	1	90.6	89.3	1.3
M17	1	89.8	87.9	1.9
M17	2	90.6	89.5	1.1
M17	2	90.6	88.2	2.4
M17	2	89.5	87.1	2.4
M17	3	90.3	88.6	1.7
M17	3	89.7	87.1	2.6
M17	3	90.6	88.3	2.3
M18	1	90.6	88.9	1.7
M18	1	88.8	87.1	1.7
M18	1	91.9	89.1	2.8
M18	2	88.5	86.1	2.4
M18	2	90.8	89.2	1.6
M18	2	90.8	89.5	1.3
M18	3	88.3	86.8	1.5

Pool	Zone	Pre-Ignition Wgt	Post-Ignition Wgt	OM Content
M18	3	91.2	88.7	2.5
M18	3	91.4	89.1	2.3
D1a	1	89.6	88.5	1.1
D1a	1	91.3	89.2	2.1
D1a	1	89.5	87.8	1.7
D1a	2	88.4	87.3	1.1
D1a	2	90.3	88.7	1.6
D1a	2	91.5	90.1	1.4
D1a	3	90.8	89.9	0.9
D1a	3	91	89.1	1.9
D1a	3	90.8	89.1	1.7
D1b	1	89.8	88.8	1
D1b	1	91.2	89.7	1.5
D1b	1	89.9	88.6	1.3
D1b	2	91.4	90.3	1.1
D1b	2	90	88.2	1.8
D1b	2	90.7	88.8	1.9
D2	1	91	89.6	1.4
D2	1	90.9	89.3	1.6
D2	1	91.1	89.4	1.7
D2	2	90.8	89.3	1.5
D2	2	91.9	90.8	1.1
D2	2	91.9	90.2	1.7
D2	3	89.4	86.8	2.6
D2	3	90.9	89.4	1.5
D2	3	91.1	88.9	2.2
D3	1	87	84.9	2.1
D3	1	88.5	86.3	2.2
D3	1	89.1	87.5	1.6
D3	2	90.3	88.8	1.5
D3	2	89.1	87.5	1.6
D3	2	90.2	88.7	1.5
D3	3	90.3	88.8	1.5
D3	3	88.2	85.7	2.5
D3	3	88.2	86.8	1.4
D25	1	91.4	90	1.4
D25	1	90.3	89	1.3
D25	1	90.5	88.4	2.1
D25	2	90.1	86.5	3.6
D25	2	91.5	88.5	3
D25	2	89.6	86.8	2.8
D25	3	91.4	88.4	3
D25	3	91.2	89.4	1.8
D25	3	89	87.4	1.6
D26	1	91.1	89.2	1.9
D26	1	90	88.2	1.8
D26	1	90.2	88.4	1.8
D26	2	90.4	88.5	1.9
D26	2	91.2	89.1	2.1
D26	2	90.3	88.3	2

Bulk Density

Pool	Sample Weight (mg)	Volume (m3)	Bulk Density (mg/m3)
M6	43.6	46.14	0.94
M6	31.5	45.24	0.70
M6	56.7	45.24	1.25
M1	39.6	47.14	0.84
M1	59.3	46.14	1.29
M1	56.3	45.24	1.24
M7	58.3	45.24	1.29
M7	66.1	46.14	1.43
M7	48.2	46.14	1.04
D1a	67.9	47.14	1.44
D1a	56.8	45.24	1.26
D1a	70.9	47.14	1.50
D1b	52.7	47.14	1.12
D1b	63.9	45.24	1.41
D1b	66.6	46.14	1.44
D2	59.5	46.14	1.29
D3	58.3	45.24	1.29
D3	55	45.24	1.22
D3	60.7	45.24	1.34
D25	53.8	45.24	1.19
D25	60.2	45.24	1.33
D25	49.9	47.14	1.06
D26	56.1	45.24	1.24
D26	51.2	47.14	1.09
D26	66.1	45.24	1.46

APPENDIX D. Species Frequency Data, 1998 and 1999.

Species List of Abbreviations:

ACHMIL	Achillea millefolium
AGOHET	Agoseris heterophylla
AGRDIO	Agrostis diegoensis
ALLGEY	Allium geyeri
ALOSAC	Alopecurus saccatus
APEINT	**Apera interrupta**
ARTLUD	Artemisia ludoviciana
ARTTRI	Artemisia tridentata
BOIDEN	Boisduvalia densiflora
BOIGLA	Boisduvalia glabella
BROJAP	**Bromus japonicus**
BROMOL	**Bromus mollis**
BROTEC	**Bromus tectorum**
CARDOU	Carex douglasii
CASTEN	Castilleja tenuis
CIRARV	**Cirsium arvense**
CLAPUC	Clarkia pulchella
COLLIN	Collomia linearis
COLPAR	Collinsia parviflora
CONCAN	**Conyza canadensis**
CUSCAL	Cuscuta californica
DANUNI	Danthonia unispicata
DESDAN	Deschampsia danthonioides
DOWYIN	Downingia yina
DRAVER	Draba verna
ECHCRU	**Echinochloa crusgalli**
ELEACI	Eleocharis acicularis
ELEMAC	Eleocharis macrostachya
ELYELY	Elymus elymoides
EPIPAN	**Epilobium paniculatum**
ERIPER	Erigeron peregrina
ERIPUM	Erigeron pumilus
FESIDA	Festuca idahoensis
FESSP	Festuca sp.
GNAPAL	**Gnaphalium palustre**
GRINAN	Grindelia nana
GRINSP	Grindelia sp.
HESPUM	Hesperochiron pumilus
HOLUMB	**Holsteum umbellatum**
JUNBUF	**Juncus bufonius**
LACSER	**Lactuca serriola**
LAGRAM	Lagophylla ramosissima
LEPPER	**Lepidium perfoliatum**
LIMAQU	Limosella aquatica
LOMGRA	Lomatium grayi
LOMMAC	Lomatium macrocarpum
LOMTRI	Lomatium triternatum
LOTPUR	**Lotus purshiana**
MADEXI	Madia exigua
MONDIC	Montia dichotoma
MONLIN	Montia linearis
MUHRIC	Muhlenbergia richardsonis
MYOAPE	Myosurus apetalus
MYOMIC	**Myosotis micrantha**
MYOMINA	Myosurus minimus ssp. apus
MYOMINM	Myosurus minimus ssp. minimus
NAVINT	Navarretia intertexta
NAVLEU	Navarretia leucocephala
PHLGRA	Phlox gracilis
PLALEP	Plagiobothrys leptocladus
PLAPAT	**Plantago patagonica**
POASCA	Poa scabrella
POLAVI	**Polygonum aviculare**
POLPOL	Polygonum polygaloides
PSIBRE	Psilocarphus brevissimus
PSISP	Psilocarphus sp.
RANTES	**Ranunculus testiculatus**
RUMSAL	Rumex salicifolius
SISALT	**Sisymbrium altissimum**
SONASP	**Sonchus asper**
SPEDIA	**Spergularia diandra**
TAROFF	**Taraxacum officinale**
TRADUB	**Tragopogon dubius**
VERPER	Veronica peregrina

*Weedy species in bold.

Frequency of Species by Zone, 1998 Data-Sample Period 2

	M1 zone 1	M1 zone 2	M1 zone 3	M6 zone 1	M6 zone 2	M7 zone 1	M7 zone 2	M7 zone 3	M11 zone 1	M11 zone 2	M11 zone 3	M17 zone 1	M17 zone 2	M17 zone 3	M18 zone 1	M18 zone 2	M18 zone 3
No. Plots	124	61	32	86	20	63	43	43	87	22	65	79	62	24	96	52	56
ACHMIL	1.6	0	0	34.9	10	6.3	0	0	9.2	0	0	0	0	0	2.1	0	0
AGOHET	0.8	0	0	1.2	0	3.2	0	0	8	9.1	0	13.9	0	0	29.2	1.9	0
AGRDIO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALLGEY	13.7	4.9	0	0	0	20.6	27.9	0	31	0	0	26.6	46.8	12.5	0	0	0
ALOSAC	17.7	9.8	0	0	0	34.9	74.4	83.7	4.6	45.5	84.6	15.2	82.3	95.8	11.5	73.1	50
APEINT	1.6	0	0	46.5	10	14.3	4.7	0	34.5	31.8	4.6	139	4.8	16.7	13.5	9.6	0
ARTLUD	0	0	0	74.4	90	0	0	0	2.3	0	0	0	0	0	0	0	0
ARTTRI	0	0	0	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0
BOIGLA	0	14.8	21.9	0	0	0	0	0	0	0	0	0	0	8.3	0	0	5.4
BROJAP	0	0	0	0	0	0	0	0	1.1	0	0	0	0	0	0	0	0
BROMOL	7.3	0	0	20.9	5	3.2	0	0	9.2	0	0	0	0	0	12.5	0	0
BROTEC	10.5	0	0	1.2	0	0	0	0	1.1	4.5	0	1.3	1.6	0	14.6	5.8	0
CARDOU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CASTEN	2.4	0	0	0	0	0	0	0	19.5	4.5	1.5	2.5	1.6	0	0	0	0
CIRARV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COLPAR	0	0	0	5.8	0	0	0	0	8	0	0	0	0	0	11.5	0	0
CONCAN	4	0	0	3.5	5	4.8	0	0	10.3	0	0	0	0	0	0	0	0
CUSCAL	0	0	0	0	0	0	2.3	0	0	0	0	0	0	0	0	0	0
DANUNI	0	0	0	0	0	12.7	0	0	6.9	0	0	0	0	0	0	0	0
DESDAN	93.5	13.1	0	87.2	55	98.4	83.7	58.1	96.6	95.5	50.8	100	91.9	29.2	96.9	76.9	35.7
DOWYIN	0.8	0	0	0	0	0	0	0	0	13.6	29.2	0	0	0	0	3.8	0
DRAVER	49.2	1.6	0	19.8	0	50.8	0	0	33.3	0	0	39.2	0	0	68.8	0	0
ELEMAC	0	13.1	96.9	2.3	55	0	9.3	58.1	3.4	59.1	96.9	2.5	33.9	87.5	9.4	63.5	83.9
ELYELY	0	0	0	14	5	1.6	0	0	4.6	0	0	2.5	0	0	3.1	0	0
EPIPAN	67.7	13.1	0	64	75	33.3	0	0	70.1	63.6	35.4	55.7	8.1	0	51	38.5	0
ERIPER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ERIPUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FESIDA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GNAPAL	0	0	0	0	0	0	0	0	0	4.5	1.5	0	0	0	1	0	0
GRINAN	21.8	0	0	22.1	10	85.7	62.8	32.6	62.1	22.7	3.1	63.3	79	20.8	51	36.5	8.9
HOLUMB	9.7	0	0	2.3	0	0	0	0	4.6	0	0	0	0	0	2.1	1.9	0
JUNBUF	4	0	0	1.2	5	6.3	0	0	1.1	18.2	3.1	0	0	0	0	0	0

	M1 zone 1	M1 zone 2	M1 zone 3	M6 zone 1	M6 zone 2	M7 zone 1	M7 zone 2	M7 zone 3	M11 zone 1	M11 zone 2	M11 zone 3	M17 zone 1	M17 zone 2	M17 zone 3	M18 zone 1	M18 zone 2	M18 zone 3
LACSER	70.2	13.1	0	58.1	65	31.7	0	2.3	66.7	63.6	33.8	48.1	17.7	41.7	66.7	19.2	14.3
LEPPER	0.8	0	0	3.5	0	0	0	0	0	4.5	0	0	0	0	0	0	0
LIMAQU	0	63.9	56.3	0	0	0	0	0	0	0	0	0	0	0	0	0	16.1
LOMGRA	0.8	0	0	0	0	69.8	16.3	9.3	4.6	0	0	17.7	17.7	0	11.5	0	0
LOTPUR	0	0	0	0	0	0	0	0	0	0	0	10.7	0	0	0	0	0
MADEXI	8.1	0	0	1.2	0	3.2	0	0	3.4	9.1	0	1.3	0	0	3.1	1.9	0
MONDIC	0.8	0	0	14	45	3.2	0	0	14.9	0	0	2.5	0	0	1	1.9	0
MONLIN	41.9	0	0	19.8	65	11.1	2.3	0	21.8	18.2	15.4	13.9	4.8	0	9.4	13.5	0
MUHRIC	0	0	0	29.1	30	12.7	0	0	12.6	4.5	0	19	1.6	0	4.2	0	0
MYOAPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYOMIC	8.1	0	0	4.7	0	0	0	0	21.8	9.1	0	0	0	0	2.1	0	0
MYOMINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.9	0
MYOMINM	79	19.7	0	11.6	45	68.3	37.2	16.3	28.7	90.9	75.4	54.4	27.4	4.2	69.8	57.7	28.6
NAVINT	0	0	0	0	0	0	0	0	11.5	9.1	0	0	0	0	0	0	0
NAVLEU	78.2	14.8	0	4.7	0	42.9	60.5	41.9	14.9	31.8	38.5	53.2	53.2	20.8	44.8	38.5	28.6
PHLGRA	0	0	0	0	0	0	0	0	4.6	0	0	0	0	0	0	0	0
PLALEP	40.3	9.8	3.1	2.3	5	39.7	27.9	41.9	19.5	36.4	20	20.3	72.6	66.7	16.7	50	32.1
PLAPAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POASCA	11.3	0	0	8.1	0	1.6	0	0	5.7	0	0	0	0	0	2.1	0	0
POLAVI	14.5	49.2	12.5	0	0	14.3	23.3	0	1.1	9.1	13.8	0	11.3	4.2	1	13.5	10.7
POLPOL	35.5	4.9	0	1.2	0	68.3	51.2	14	6.9	54.5	38.5	60.8	46.8	0	79.2	63.5	33.9
PSIBRE	16.9	36.1	21.9	0	0	4.8	23.3	48.8	0	18.2	38.5	3.8	12.9	41.7	0	19.2	55.4
RUMSAL	5.6	1.6	0	4.7	5	0	0	0	0	0	0	0	0	0	0	0	0
SISALT	9.7	0	0	3.5	0	0	0	0	6.9	9.1	0	1.3	0	0	5.2	0	0
SPEDIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.1
TAROFF	0	0	0	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0
VERPER	71	4.9	0	14	50	17.5	9.3	2.3	16.1	36.4	53.8	34.2	11.3	0	16.7	25	5.4

Frequency of Species by Zone, 1998 Data-Sample Period 2

	D1a zone 1	D1a zone 2	D1a zone 3	D1b zone 1	D1b zone 2	D2 zone 1	D2 zone 2	D2 zone 3	D3 zone 1	D3 zone 2	D3 zone 3	D25 zone 1	D25 zone 2	D25 zone 3	D26 zone 1	D26 zone 2
No. Plots	107	39	29	115	35	56	45	47	80	63	49	47	56	48	65	120
ACHMIL	1.9	0	0	13.9	0	3.6	0	0	3.8	0	0	6.4	0	12.5	7.7	0
AGOHET	10.3	10.3	0	26.1	5.7	35.7	0	0	10	0	0	4.3	12.5	6.3	20	2.5
AGRDIO	2.8	5.1	0	48.7	5.7	21.4	24.4	4.3	0	0	0	27.7	28.6	25	0	0
ALLGEY	18.7	56.4	86.2	7.8	28.6	16.1	0	0	46.3	33.3	6.1	0	0	0	26.2	26.7
ALOSAC	0	15.4	3.4	3.5	65.7	12.5	62.2	8.5	2.5	1.6	0	0	3.6	16.7	27.7	41.7
APEINT	20.6	2.6	0	0	0	0	0	0	25	1.6	2	0	0	0	32.3	8.3
ARTLUD	0	0	0	0	14.3	23.2	8.9	0	10	9.5	20.4	4.3	0	2.1	4.6	2.5
ARTTRI	0.9	0	0	0	5.7	0	0	0	0	0	0	0	0	0	0	0
BOIGLA	0	2.6	17.2	0	11.4	0	8.9	66	16.3	57.1	38.8	0	0	0	6.2	23.3
BROJAP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BROMOL	31.8	12.8	0	9.6	0	3.6	0	0	3.8	0	0	8.5	7.1	2.1	10.8	0
BROTEC	35.5	2.6	0	19.1	0	25	4.4	0	2.5	0	0	19.1	25	33.3	3.1	0
CARDOU	0	0	0	0	0	0	0	0	0	0	0	21.3	0	8.3	0	0
CASTEN	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIRARV	0.9	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
COLPAR	0	0	0	1.7	0	3.6	2.2	0	0	0	0	0	0	0	0	0
CONCAN	0	0	0	1.7	0	3.6	0	0	0	0	0	10.6	12.5	4.2	0	2.5
CUSCAL	0	0	0	0	0	0	0	29.8	0	0	0	0	0	0	0	1.7
DANUNI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.6	0
DESDAN	99.1	89.7	93.1	99.1	94.3	98.2	95.6	12.8	71.3	55.6	10.2	23.4	16.1	60.4	93.8	99.2
DOWYIN	0	0	0	0	0	0	2.2	0	0	0	0	0	0	0	0	3.3
DRAVER	41.1	5.1	0	40	8.6	83.9	17.8	0	11.3	0	0	2.1	10.7	27.1	21.5	0.8
ELEMAC	7.5	43.6	3.4	2.6	2.9	0	8.9	14.9	10	0	44.9	72.3	80.4	97.9	0	10.8
ELYELY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EPIPAN	58.9	20.5	10.3	52.2	11.4	26.8	4.4	0	23.8	3.2	0	48.9	44.6	87.5	23.1	5.8
ERIPER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0
ERIPUM	8.4	0	0	0.9	0	0	0	0	0	0	0	2.1	0	0	0	0
FESIDA	0	0	0	0	0	0	0	0	0	0	0	2.1	1.8	0	0	0
GNAPAL	1.9	0	0	0	0	8.9	4.4	0	6.3	28.6	36.7	12.8	17.9	6.3	0	8.3
GRINAN	0	0	0	0.9	0	0	0	0	43.8	39.7	38.8	68.1	71.4	14.6	10.8	18.3
HOLUMB	17.8	2.6	0	10.4	2.9	28.6	0	0	0	0	0	4.3	3.6	2.1	0	0
JUNBUF	11.2	23.1	0	0.9	2.9	17.9	28.9	10.6	52.5	88.9	61.2	27.7	8.9	0	4.6	10

	D1a zone 1	D1a zone 2	D1a zone 3	D1b zone 1	D1b zone 2	D2 zone 1	D2 zone 2	D2 zone 3	D3 zone 1	D3 zone 2	D3 zone 3	D25 zone 1	D25 zone 2	D25 zone 3	D26 zone 1	D26 zone 2
LACSER	51.4	15.4	3.4	49.6	11.4	50	22.2	2.1	17.5	1.6	4.1	51.1	46.4	70.8	33.8	13.3
LEPPER	26.2	12.8	0	26.1	0	28.6	24.4	0	2.5	0	0	17	5.4	14.6	0	0
LIMAQU	0	0	0	0	0	0	0	72.3	0	0	0	4.3	16.1	0	0	2.5
LOMGRA	14	7.7	0	40.9	0	23.2	2.2	0	3.8	0	0	0	0	0	18.5	8.3
LOTPUR	0	0	0	0	0	71.4	42.2	4.3	12.5	3.2	2	0	0	0	0	0
MADEXI	47.7	17.9	0	22.6	2.9	25	6.7	0	2.5	0	0	2.1	0	2.1	7.7	1.7
MONDIC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MONLIN	0.9	0	0	3.5	0	7.1	0	2.1	0	0	0	0	0	8.3	3.1	0
MUHRIC	0	0	0	0	0	3.6	0	0	1.3	0	0	0	0	2.1	7.7	0
MYOAPE	4.7	23.1	0	3.5	0	0	0	0	0	0	0	0	0	0	0	0
MYOMIC	0.9	2.6	0	0	0	0	0	0	0	0	0	2.1	8.9	4.2	0	0
MYOMINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYOMINM	86	79.5	86.2	64.3	85.7	44.6	82.2	10.6	47.5	20.6	10.2	2.1	7.1	25	61.5	63.3
NAVINT	0	0	0	7	0	0	2.2	0	3.8	0	0	0	0	0	23.1	10
NAVLEU	72.9	66.7	62.1	21.7	8.6	85.7	88.9	10.6	45	31.7	6.1	2.1	1.8	12.5	66.2	73.3
PHLGRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLALEP	81.3	53.8	31	87	71.4	60.7	93.3	29.8	66.3	79.4	46.9	91.5	37.5	87.5	60	60
PLAPAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8
POASCA	2.8	0	0	0.9	0	1.8	0	0	8.8	1.6	0	0	1.8	0	0	0
POLAVI	23.4	33.3	44.8	5.2	17.1	28.6	44.4	68.1	46.3	69.8	49	55.3	50	8.3	23.1	25.8
POLPOL	29.9	35.9	37.9	22.6	45.7	12.5	60	8.5	0	0	0	6.4	0	0	15.4	34.2
PSIBRE	2.8	33.3	58.6	0.9	20	7.1	48.9	66	36.3	73	55.1	0	0	2.1	27.7	60
RUMSAL	0	0	0	0	0	0	0	0	0	0	0	14.9	5.4	4.2	0	0
SISALT	0	0	0	0	0	0	0	0	0	0	0	0	10.7	2.1	0	0
SPEDIA	0	0	0	0	0	0	0	0	1.3	0	6.1	0	0	0	0	0
TAROFF	1.9	0	0	1.7	0	0	0	0	6.3	0	0	2.1	0	0	0	0
VERPER	0.9	0	0	0	2.9	21.4	46.7	8.5	15	11.1	28.6	29.8	37.5	91.7	24.6	30

Frequency of Species by Zone, 1999 Data

	M1 zone1	M1 zone 2	M1 zone 3	M6 zone1	M6 zone 2	M7 zone1	M7 zone 2	M7 zone 3	M11 zone1	M11 zone 2	M11 zone 3	M17 zone1	M17 zone 2	M17 zone 3	M18 zone1	M18 zone 2	M18 zone 3
No. Plots	94	88	74	70	66	88	86	30	112	22	92	122	56	28	86	70	70
ACHMIL	3.2	1.1	0	51.4	13.6	10.2	0	0	8.9	0	0	1.6	0	0	9.3	0	0
AGOHET	2.1	0	0	7.1	1.5	5.7	1.2	0	2.7	0	0	13.1	0	0	40.7	4.3	0
ALLGEY	11.7	5.7	0	0	0	39.8	9.3	3.3	30.4	0	0	42.6	37.5	35.7	4.7	4.3	0
ALOSAC	6.4	5.7	0	0	1.5	18.2	32.6	23.3	0.9	13.6	9.8	24.6	83.9	85.7	2.3	47.1	0
APEINT	40.4	2.3	0	22.9	13.6	6.8	1.2	0	42	40.9	8.7	11.5	5.4	0	12.8	5.7	0
ARTLUD	0	0	0	38.6	57.6	0	0	0	0.9	0	0	0	0	0	0	0	0
ARTTRI	0	0	0	1.4	0	0	0	0	0.9	0	0	0	0	0	0	0	0
BOIDEN	4.3	0	0	0	0	0	0	0	0.9	18.2	1.1	13.1	8.9	0	3.5	17.1	0
BOIGLA	1.1	30.7	9.5	0	0	0	5.8	3.3	0.9	9.1	10.9	0	0	3.6	0	14.3	2.9
BROMOL	9.6	0	0	12.9	21.2	0	0	0	5.4	0	0	0.8	0	0	24.4	1.4	0
BROTEC	11.7	0	0	8.6	1.5	2.3	0	0	7.1	0	0	1.6	0	0	12.8	0	0
CARDOU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CASTEN	2.1	0	0	0	0	0	0	0	5.4	22.7	2.2	0	0	0	0	0	0
CLAPUC	0	0	0	0	1.5	0	0	0	0	0	0	0.8	0	0	0	0	0
COLLIN	1.1	0	0	0	0	0	0	0	6.3	0	0	0	0	0	0	0	0
COLPAR	0	0	0	58.6	30.3	3.4	0	0	48.2	0	0	2.5	0	0	29.1	1.4	0
CONCAN	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0
CUSCAL	0	2.3	0	0	0	1.1	1.2	33.3	0	0	2.2	0	0	0	0	0	10
DANUNI	0	0	0	0	0	17	0	0	0	0	0	5.7	0	0	2.3	1.4	0
DESDAN	81.9	28.4	0	40	42.4	50	31.4	30	50	50	10.9	75.4	55.4	25	58.1	54.3	0
DOWYIN	1.1	2.3	2.7	0	0	0	5.8	26.7	0	0	0	0	0	0	0	4.3	0
DRAVER	78.7	3.4	0	55.7	53	61.4	1.2	0	84.8	13.6	0	54.1	8.9	0	93	11.4	0
ECHCRU	0	0	0	0	0	0	0	0	0	0	0	8.2	0	0	0	0	0
ELEACI	0	0	25.7	0	0	0	0	10	0	0	0	0	0	0	0	0	34.3
ELEMAC	0	0	78.4	0	25.8	2.3	14	0	1.8	45.5	94.6	0	23.2	82.1	0	52.9	82.9
ELYELY	0	0	0	17.1	10.6	3.4	0	0	3.6	0	0	1.6	0	0	1.2	0	0
EPIPAN	13.8	0	0	62.9	54.5	31.8	3.5	0	31.3	22.7	1.1	44.3	7.1	0	59.3	8.6	0
ERIPUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FESSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GNAPAL	0	42	25.7	0	3	0	18.6	66.7	0	9.1	29.3	0	17.9	17.9	0	14.3	28.6
GRINAN	20.2	6.8	0	0	28.8	80.7	55.8	13.3	39.3	22.7	10.9	15.6	7.1	14.3	24.4	18.6	14.3
GRISP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.2	10	2.9

	M1 zone1	M1 zone 2	M1 zone 3	M6 zone1	M6 zone 2	M7 zone1	M7 zone 2	M7 zone 3	M11 zone1	M11 zone 2	M11 zone 3	M17 zone1	M17 zone 2	M17 zone 3	M18 zone1	M18 zone 2	M18 zone 3
HESPUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HOLUMB	21.3	0	0	14.3	16.7	8	0	0	40.2	0	0	0	0	0	3.5	0	0
JUNBUF	1.1	4.5	0	0	0	1.1	2.3	0	0	0	0	2.5	0	0	0	0	0
LACSER	27.7	0	0	42.9	39.4	18.2	4.7	0	24.1	22.7	17.4	21.3	3.6	0	30.2	12.9	0
LAGRAM	8.5	1.1	0	0	0	3.4	0	0	1.8	4.5	1.1	0	0	0	0	0	0
LEPPER	1.1	0	0	1.4	0	0	0	0	0.9	0	0	0	0	0	0	0	0
LIMAQU	0	13.6	16.2	0	0	0	1.2	3.3	0	0	0	0	0	0	0	0	5.7
LOMGRA	0	0	0	0	0	68.2	11.6	0	0.9	0	0	19.7	19.6	17.9	20.9	0	0
LOMMAC	0	0	0	0	0	9.1	1.2	0	0	0	0	0	0	0	0	0	0
LOMTRI	0	0	0	0	0	0	0	0	0	0	0	1.6	0	0	1.2	0	0
LOTUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MADEXI	5.3	0	0	2.9	0	0	0	0	17.9	0	0	3.3	1.8	0	2.3	0	0
MONDIC	40.4	12.5	0	47.1	53	67	9.3	0	28.6	0	0	47.5	23.2	0	53.5	15.7	0
MONLIN	51.1	8	0	68.6	65.2	2.3	0	0	55.4	68.2	20.7	20.5	14.3	0	8.1	40	0
MUHRIC	0	1.1	0	1.4	0	1.1	0	0	12.5	0	0	4.1	0	0	8.1	0	0
MYOAPE	0	0	0	4.3	9.1	25	10.5	13.3	6.3	0	0	6.6	0	0	0	0	0
MYOMIC	12.8	0	0	38.6	39.4	0	4.7	0	43.8	9.1	0	2.5	0	0	8.1	7.1	0
MYOMINA	0	0	0	0	0	6.8	22.1	20	0	0	0	0	0	0	0	0	0
MYOMINM	95.7	50	5.4	35.7	59.1	53.4	50	40	57.1	95.5	38	88.5	94.6	89.3	65.1	82.9	11.4
NAVLEU	74.5	17	0	4.3	0	12.5	33.7	40	6.3	18.2	2.2	36.9	33.9	28.6	18.6	37.1	1.4
PHLGRA	0	0	0	20	6.1	4.5	0	0	6.3	0	0	4.1	0	0	19.8	0	0
PLALEP	56.4	27.3	5.4	24.3	21.2	14.8	48.8	43.3	30.4	63.6	18.5	39.3	71.4	85.7	25.6	72.9	8.6
PLAPAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POASCA	6.4	3.4	0	2.9	3	1.1	0	0	10.7	0	0	1.6	0	0	3.5	0	0
POLAVI	16	58	5.4	0	0	1.1	11.6	0	0.9	4.5	4.3	0	7.1	0	0	17.1	1.4
POLPOL	19.1	34.1	0	0	3	28.4	34.9	6.7	0.9	9.1	2.2	51.6	33.9	7.1	30.2	58.6	0
PSISP	4.3	6.8	5.4	2.9	0	0	4.7	23.3	0.9	9.1	6.5	1.6	1.8	10.7	1.2	24.3	7.1
RANTES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUMEX	0	0	0	0	4.5	0	0	0	0	0	0	0	0	0	0	0	0
SISALT	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0
SONASP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPEDIA	0	0	20.3	0	0	0	0	10	0	0	0	0	0	0	0	12.9	32.9
TAROFF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRADUB	2.1	0	0	0	0	1.1	0	0	0.9	0	0	0	0	0	0	0	0
VERPER	37.2	13.6	1.4	14.3	18.2	22.7	16.3	3.3	1.8	31.8	22.8	44.3	12.5	0	4.7	24.3	10

Frequency of Species by Zone, 1999 Data

	D1a zone1	D1a zone 2	D1a zone 3	D1b zone1	D1b zone 2	D2 zone1	D2 zone 2	D2 zone 3	D3 zone1	D3 zone 2	D3 zone 3	D25 zone1	D25 zone 2	D25 zone 3	D26 zone1	D26 zone 2
No. Plots	98	88	56	188	74	22	90	62	20	172	28	74	78	16	30	228
ACHMIL	7.1	2.3	0	9	1.4	40.9	2.2	0	0	9.3	0	2.7	2.6	0	13.3	0.4
AGOHET	19.4	15.9	0	19.7	8.1	31.8	1.1	0	5	0	0	8.1	2.6	0	26.7	0.9
ALLGEY	11.2	46.6	82.1	5.9	21.6	27.3	8.9	1.6	35	27.3	0	0	0	0	53.3	25.9
ALOSAC	0	1.1	1.8	0.5	9.5	0	1.1	0	0	0.6	0	2.7	0	0	0	5.3
APEINT	3.1	0	0	48.4	25.7	18.2	0	0	30	1.2	0	28.4	12.8	0	30	5.3
ARTLUD	0	0	0	1.1	20.3	27.3	5.6	0	0	0.6	0	2.7	1.3	0	13.3	0.4
ARTTRI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BOIDEN	0	0	0	0	0	0	0	0	10	1.7	0	0	0	0	0	0.9
BOIGLA	2	20.5	35.7	0.5	14.9	0	17.8	37.1	0	26.2	17.9	0	0	0	0	32
BROMOL	45.9	21.6	0	17.6	0	4.5	0	0	0	0.6	0	20.3	12.8	0	20	1.8
BROTEC	6.1	3.4	0	7.4	0	22.7	0	0	0	0	0	35.1	12.8	0	0	0
CARDOU	0	0	0	1.1	0	0	0	0	0	0	0	5.4	16.7	0	0	0
CASTEN	0	0	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0
CLAPUC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COLLIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COLPAR	1	0	0	13.8	1.4	27.3	1.1	0	0	0	0	1.4	0	0	6.7	0
CONCAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CUSCAL	0	0	0	0	0	0	8.9	9.7	0	0	0	0	0	0	0	1.3
DANUNI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DESDAN	44.9	50	35.7	49.5	41.9	40.9	45.6	0	50	16.9	0	18.9	16.7	0	43.3	41.2
DOWYIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAVER	71.4	36.4	1.8	74.5	23	81.8	3.3	1.6	0	0	0	43.2	29.5	0	56.7	1.3
ECHCRU	0	0	0	0	0	0	0	4.8	0	0	0	27	5.1	0	0	0
ELEACI	0	0	3.6	0	5.4	0	0	0	0	0	0	2.7	0	6.3	0	0
ELEMAC	1	27.3	32.1	0	8.1	0	2.2	11.3	5	5.8	100	64.9	92.3	18.8	0	15.8
ELYELY	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
EPIPAN	64.3	46.6	10.7	55.9	31.1	31.8	0	0	5	0	0	43.2	41	0	43.3	0.4
ERIPUM	0	0	0	8.5	8.1	0	0	0	0	0	0	0	0	0	0	0
FESSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.3	0
GNAPAL	0	13.6	23.2	0.5	10.8	0	25.6	40.3	0	36.6	46.4	0	7.7	43.8	0	36
GRINAN	0	0	0	2.1	0	0	0	0	25	4.1	0	24.3	14.1	62.5	10	6.6
GRISP	0	0	0	0	0	0	1.1	0	5	7	10.7	0	0	0	0	0

	D1a zone1	D1a zone 2	D1a zone 3	D1b zone1	D1b zone 2	D2 zone1	D2 zone 2	D2 zone 3	D3 zone1	D3 zone 2	D3 zone 3	D25 zone1	D25 zone 2	D25 zone 3	D26 zone1	D26 zone 2
HESPUM	0	0	0	0.5	0	4.5	0	0	0	0	0	0	0	0	0	0
HOLUMB	32.7	30.7	1.8	32.4	1.4	45.5	0	1.6	0	0	0	48.6	11.5	0	10	0
JUNBUF	5.1	27.3	17.9	0	9.5	9.1	28.9	11.3	20	45.9	50	1.4	9	12.5	3.3	22.8
LACSER	45.9	25	8.9	42.6	17.6	59.1	5.6	1.6	5	2.3	7.1	62.2	75.6	6.3	53.3	3.5
LAGRAM	37.8	10.2	3.6	20.7	9.5	27.3	0	0	0	0	0	0	3.8	0	13.3	0
LEPPER	40.8	8	0	36.2	0	27.3	0	1.6	0	0	0	20.3	9	0	6.7	0
LIMAQU	0	0	1.8	0	0	0	2.2	6.5	0	0	0	0	0	12.5	0	1.3
LOMGRA	15.3	14.8	0	49.5	0	31.8	10	3.2	20	1.2	0	2.7	0	0	30	7.9
LOMMAC	0	0	0	1.1	0	0	0	0	0	0	0	0	0	0	0	0
LOMTRI	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3.3	0
LOTUS	0	0	0	0	0	86.4	48.9	0	0	1.2	10.7	0	0	0	0	0
MADEXI	20.4	13.6	1.8	22.3	2.7	13.6	0	0	0	0	0	1.4	3.8	0	10	0.4
MONDIC	0	0	0	1.1	0	63.6	13.3	0	0	0.6	0	2.7	1.3	0	3.3	0.4
MONLIN	7.1	0	0	6.4	2.7	27.3	3.3	0	0	0	0	4.1	28.2	0	13.3	1.3
MUHRIC	0	0	0	0	0	9.1	0	0	0	0	0	4.1	0	0	3.3	0
MYOAPE	1	0	0	13.8	0	4.5	0	0	0	0.6	0	2.7	0	0	0	0
MYOMIC	8.2	8	0	2.1	0	0	0	0	0	0	0	6.8	9	0	3.3	0
MYOMINA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYOMINM	92.9	93.2	80.4	81.4	75.7	40.9	30	3.2	50	9.3	3.6	18.9	5.1	0	76.7	28.1
NAVLEU	48	26.1	28.6	5.9	8.1	72.7	44.4	6.5	10	9.9	3.6	0	0	0	66.7	35.1
PHLGRA	0	0	0	0	0	0	0	0	0	0	0	2.7	0	0	0	0
PLALEP	71.4	58	42.9	60.1	47.3	77.3	76.7	29	40	55.8	53.6	9.5	35.9	6.3	96.7	59.2
PLAPAT	0	0	0	1.1	0	4.5	0	0	0	0	0	1.4	0	0	0	0
POASCA	0	0	0	0.5	0	13.6	0	0	5	2.9	0	0	0	0	6.7	0
POLAVI	20.4	55.7	73.2	9	58.1	40.9	74.4	66.1	15	18	3.6	0	11.5	62.5	20	22.4
POLPOL	0	1.1	0	0	0	4.5	4.4	1.6	0	0	0	0	0	0	3.3	0.9
PSISP	6.1	5.7	21.4	0	4.1	0	10	16.1	0	9.9	10.7	0	0	0	0	9.6
RANTES	0	0	0	0.5	0	0	0	0	0	0	0	2.7	1.3	0	0	0
RUMEX	0	0	0	0	0	0	0	0	0	0	0	0	2.6	0	0	0
SISALT	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
SONASP	0	1.1	1.8	0.5	0	9.1	5.6	0	0	1.7	0	0	0	0	0	6.1
SPEDIA	0	0	0	0	0	0	0	9.7	0	1.2	0	0	0	0	0	0
TAROFF	1	0	0	2.1	0	0	0	0	0	0	0	2.7	1.3	0	3.3	0
TRADUB	0	2.3	0	1.1	4.1	4.5	1.1	0	0	0	0	0	1.3	0	3.3	0
VERPER	5.1	2.3	0	0	1.4	22.7	22.2	4.8	0	5.2	0	4.1	5.1	0	6.7	14.9

APPENDIX E. Summary of Species Frequency T-tests, 1998 and 1999.
1998, Sample Period 2
[Significant differences ($p<0.10$) in bold.]

Species	Weed - N-0, Y-1	Annual(0)/ Perennial(1)	Ungrazed Mean, Zone 1	Grazed Mean, Zone 1	P	Ungrazed Mean, Zone 2	Grazed Mean, Zone 2	P	Ungrazed Mean, Zone 3	Grazed Mean, Zone 3	P
ACHMIL	0	1	9.72	8.85	0.866	2.38	0.00	0.363	0.00	2.78	0.391
AGOHET	0	0	14.83	36.32	**0.087**	2.50	12.50	**0.051**	0.00	4.18	0.391
AGRDIE	0	1	0.00	33.38	**0.072**	0.00	18.63	0.106	0.00	18.95	0.323
ALLGEY	1	0	14.78	21.95	0.412	13.97	22.45	0.501	2.66	22.05	0.445
ALOSAC	0	1	11.62	1.47	0.166	42.57	29.25	0.446	61.98	9.23	**0.039**
APEINT	0	0	40.17	24.23	0.352	17.47	4.45	**0.087**	7.22	0.95	0.297
ARTLUD	0	1	13.33	8.73	0.740	11.90	3.20	0.504	0.00	7.18	0.281
ARTTRI	0	1	0.00	0.00	--	0.00	0.00	--	0.00	0.00	--
BOIGLA	0	0	0.00	3.17	0.363	5.55	26.00	0.181	12.90	37.08	0.172
BROJAP	1	0	0.40	0.00	0.363	0.00	0.00	--	0.00	0.00	--
BROMOL	1	0	11.03	24.67	0.287	0.00	5.00	0.178	0.00	1.40	0.391
BROTEC	1	0	2.28	12.90	**0.030**	2.73	4.62	0.544	0.00	6.95	0.391
CARDOU	0	1	0.00	3.47	0.363	0.00	0.00	--	0.00	2.78	0.391
CASTEN	0	0	4.63	0.38	0.221	1.65	0.00	0.184	0.00	0.00	--
CIRARV	1	1	0.00	0.38	0.363	0.00	0.00	--	0.00	0.95	0.391
COLPAR	0	0	3.27	0.50	0.123	0.00	0.00	--	0.00	0.00	--
CONCAN	1	0	5.62	4.10	0.611	0.00	3.18	0.213	0.00	0.00	--
CUSCAN	0	1	0.00	0.00	--	0.00	0.63	0.363	0.00	6.83	0.391
DANUNI	0	1	6.08	2.17	0.413	0.00	0.00	--	0.00	0.00	--
DESDAN	0	0	94.80	83.93	0.427	72.78	76.22	0.854	41.68	53.43	0.661
DOWYIN	0	0	0.33	3.42	0.410	4.02	0.63	0.304	8.12	0.00	0.374
DRAVER	0	0	34.23	26.18	0.622	0.62	6.45	**0.075**	0.00	5.55	0.391
ELEMAC	0	1	2.15	12.70	0.408	32.12	25.83	0.752	89.54	40.80	**0.100**
ELYELY	0	1	8.15	0.00	**0.069**	2.38	0.00	0.363	0.00	0.00	--
EPIPAN	1	0	48.10	42.83	0.608	32.83	16.75	0.321	8.12	25.00	0.559
ERIPER	0	1	0.00	0.72	0.363	0.00	0.00	--	0.00	0.00	--
ERIPUM	0	1	0.00	4.37	0.242	0.00	0.00	--	0.00	0.00	--
FESIDA	0	1	0.00	0.70	0.363	0.00	0.55	0.363	0.00	0.00	--
GNAPAL	1	0	0.35	6.90	0.170	0.98	21.25	0.155	0.62	21.48	0.293
GRINAN	0	1	47.13	24.30	0.178	37.08	22.05	0.384	6.00	12.40	0.568
HOLUMB	1	0	2.73	8.95	0.125	0.00	1.90	**0.083**	0.00	0.00	--

Species	Weed - N-0, Y-1	Annual(0)/ Perennial(1)	Ungrazed Mean, Zone 1	Grazed Mean, Zone 1	P	Ungrazed Mean, Zone 2	Grazed Mean, Zone 2	P	Ungrazed Mean, Zone 3	Grazed Mean, Zone 3	P
IDASCA	0	0	0.00	0.00	--	0.00	0.00	--	0.00	0.00	--
JUNBUF	1	0	2.37	20.72	**0.092**	6.30	28.85	0.171	0.00	15.38	0.391
LACSER	1	0	65.52	41.78	**0.052**	32.72	17.90	0.276	9.20	21.60	0.475
LEPPER	1	0	0.00	17.37	**0.035**	0.98	7.82	0.184	0.00	5.55	0.391
LIMAQU	0	0	0.00	1.38	0.363	9.88	2.22	0.480	17.60	17.05	0.980
LOMGRA	0	1	17.02	16.27	0.951	7.05	2.93	0.483	0.00	0.00	--
LOTPUR	1	0	0.00	13.75	0.272	0.00	8.33	0.363	0.00	2.08	0.184
MADEXI	1	0	1.92	23.17	**0.034**	2.50	5.80	0.449	0.00	1.40	0.391
MONDIC	0	0	5.00	0.00	**0.026**	2.92	0.00	0.267	0.00	0.00	--
MONLIN	0	0	9.98	0.00	**0.058**	20.35	0.00	0.196	1.88	1.40	0.851
MUHRIC	0	1	2.73	0.75	0.438	0.00	0.00	--	0.00	0.00	--
MYOAPE	0	0	0.00	2.92	0.198	0.00	5.00	0.363	0.00	0.00	--
MYOMIC	1	0	6.72	0.00	0.158	1.97	2.22	0.924	0.00	2.78	0.391
MYOMINA	0	0	0.00	0.00	--	0.00	0.00	--	0.00	0.00	--
MYOMINM	0	0	45.53	38.60	0.677	40.00	51.68	0.511	21.68	32.40	0.662
NAVINT	0	0	3.97	14.07	0.387	1.97	4.48	0.567	0.00	0.00	--
NAVLEU	0	0	38.17	45.22	0.680	28.85	47.03	0.297	18.22	26.18	0.635
PHLGRA	0	0	0.00	0.00	--	0.00	0.00	--	0.00	0.00	--
PLALEP	0	0	17.45	66.65	**0.001**	28.05	69.03	**0.004**	42.84	49.43	0.733
PLAPAT	1	0	0.00	0.00	--	0.00	0.32	0.363	0.00	0.00	--
POASCA	0	1	4.83	3.32	0.564	0.00	0.55	0.363	0.00	0.00	--
POLAVI	1	0	9.35	28.83	**0.080**	25.45	39.37	0.330	11.46	43.60	**0.050**
POLPOL	0	0	44.58	19.55	0.160	36.80	34.90	0.911	15.50	19.58	0.820
PSIBRE	0	0	4.03	5.88	0.750	20.80	34.35	0.315	59.04	50.50	0.686
RUMSAL	0	1	1.02	2.78	0.552	0.00	1.12	0.363	0.00	1.40	0.391
SISALT	1	0	3.47	0.00	**0.039**	1.97	1.67	0.910	0.00	1.40	0.391
SPEDIA	1	0	0.00	0.40	0.363	0.00	0.00	--	2.66	2.88	0.958
TAROFF	1	1	0.33	2.52	0.112	0.00	0.00	--	0.00	0.00	--
VERPER	0	0	22.77	14.98	0.503	27.77	27.30	0.975	11.96	33.93	0.343

1999 Data

[Significant differences (p<0.10) in bold.]

Species	Weed - N-0, Y-1	Annual(0)/ Perennial(1)	Ungrazed Mean, Zone 1	Grazed Mean, Zone 1	P	Ungrazed Mean, Zone 2	Grazed Mean, Zone 2	P	Ungrazed Mean, Zone 3	Grazed Mean, Zone 3	P
ACHMIL	0	1	14.10	12.17	0.846	2.45	3.03	0.826	0.00	0.00	--
AGOHET	0	0	11.90	18.45	0.392	1.17	4.77	0.220	0.00	0.00	--
ALLGEY	0	1	21.53	22.12	0.959	9.47	21.72	0.193	7.80	20.93	0.578
ALOSAC	0	0	8.73	0.53	0.108	30.73	2.93	**0.081**	23.76	0.45	0.220
APEINT	1	0	22.73	26.35	0.687	11.52	7.50	0.900	1.74	0.00	0.374
ARTLUD	0	1	6.58	7.40	0.919	9.60	4.70	0.639	0.00	0.00	--
ARTTRI	0	1	0.38	0.00	0.187	0.00	0.00	--	0.00	0.00	--
BOIDEN	0	0	3.63	1.67	0.472	7.37	0.43	0.108	0.22	0.00	0.374
BOIGLA	0	0	0.33	0.42	0.835	9.98	18.57	0.216	6.04	22.68	0.152
BROMOL	1	0	8.85	18.05	0.251	3.77	6.13	0.651	0.00	0.00	--
BROTEC	1	0	7.35	11.88	0.482	0.25	2.70	0.297	0.00	0.00	--
CARDOU	0	0	0.00	1.08	0.274	0.00	2.78	0.363	0.00	0.00	--
CASTEN	0	0	1.25	0.23	0.318	3.78	0.00	0.363	0.44	0.00	0.374
CLAPUL	0	0	0.13	0.00	0.363	0.25	0.00	0.363	0.00	0.00	--
COLLIN	0	0	1.23	0.00	0.284	0.00	0.00	--	0.00	0.00	--
COLPAR	0	0	23.63	8.37	0.221	5.28	0.42	0.376	0.00	0.00	--
CONCAN	1	0	0.15	0.00	0.363	0.00	0.00	--	0.00	0.00	--
CUSCAL	0	0	0.18	0.00	0.363	0.58	1.70	0.488	9.10	2.43	0.402
DANUNI	0	1	4.17	0.00	0.187	0.23	0.00	0.363	0.00	0.00	--
DESDAN	0	0	59.23	41.25	**0.051**	43.65	35.38	0.307	13.18	8.93	0.699
DOWYIN	0	0	0.18	0.00	0.363	2.07	0.00	0.101	5.88	0.00	0.324
DRAVER	0	0	71.28	54.60	0.261	15.25	15.58	0.974	0.00	0.85	0.183
ECHCRU	1	1	1.37	4.50	0.520	0.00	0.85	0.363	0.00	1.20	0.391
ELEACI	0	1	0.00	0.45	0.360	0.00	0.90	0.363	14.00	2.48	0.173
ELEMAC	0	1	0.68	11.82	0.340	26.90	25.25	0.920	67.60	40.55	0.339
ELYELY	0	1	4.48	0.08	0.150	1.77	0.00	0.363	0.00	0.00	--
EPIPAN	1	0	40.57	40.58	0.990	16.07	19.85	0.764	0.22	2.68	0.427
ERIPUM	0	1	0.00	1.42	0.360	0.00	1.35	0.363	0.00	0.00	--
FESSP	0	1	0.00	0.55	0.360	0.00	0.00	--	0.00	0.00	--
GNAPAL	0	0	0.00	0.08	0.360	17.48	21.72	0.588	33.64	38.43	0.668
GRINAN	0	1	30.03	10.23	0.140	23.30	4.13	**0.033**	10.56	15.63	0.769

Species	Weed - N-0, Y-1	Annual(0)/ Perennial(1)	Ungrazed Mean, Zone 1	Grazed Mean, Zone 1	P	Ungrazed Mean, Zone 2	Grazed Mean, Zone 2	P	Ungrazed Mean, Zone 3	Grazed Mean, Zone 3	P
GRISP	0	1	0.20	0.83	0.490	1.67	1.35	0.879	0.58	2.68	0.495
HESPUM	0	1	0.00	0.83	0.310	0.00	0.00	--	0.00	0.00	--
HOLUMB	1	0	14.55	28.20	0.199	2.78	7.27	0.454	0.00	0.85	0.183
JUNBUF	1	0	0.78	6.48	0.110	1.13	23.90	**0.010**	0.00	22.93	**0.087**
LACSER	1	0	27.40	44.68	**0.090**	13.88	21.60	0.564	3.48	5.98	0.539
LAGRAM	0	0	2.28	16.52	**0.069**	0.93	3.92	0.203	0.22	0.90	0.511
LEPPER	1	0	0.57	21.88	**0.023**	0.00	2.83	0.176	0.00	0.40	0.391
LIMAQU	0	0	0.00	0.00	--	2.47	0.58	0.442	5.04	5.20	0.970
LOMGRA	0	1	18.28	24.88	0.612	5.20	5.65	0.918	3.58	0.80	0.521
LOMMAC	0	1	1.52	0.18	0.422	0.20	0.00	0.363	0.00	0.00	--
LOMTRI	0	1	0.47	0.72	0.695	0.00	0.00	--	0.00	0.00	--
LOTPUR	1	0	0.00	14.40	0.363	0.00	8.35	0.351	0.00	2.68	0.391
MADEXI	0	0	5.28	11.28	0.224	0.30	3.42	0.206	0.00	0.45	0.391
MONDIC	0	0	47.35	11.78	**0.012**	18.95	2.60	**0.082**	0.00	0.00	--
MONLIN	0	0	34.33	9.70	**0.083**	32.62	5.92	**0.081**	4.14	0.00	0.374
MUHRIC	0	1	4.53	2.75	0.488	0.18	0.00	0.363	0.00	0.00	--
MYOAPE	0	0	7.03	3.67	0.457	3.27	0.10	0.187	2.66	0.00	0.374
MYOMIC	1	0	17.63	3.40	0.125	10.05	2.83	0.280	0.00	0.00	--
MYOMINA	0	0	1.13	0.00	0.363	3.68	0.00	0.363	4.00	0.00	0.374
MYOMINM	0	0	65.92	60.13	0.703	72.02	40.23	**0.094**	36.82	21.80	0.552
NAVLEU	0	0	25.52	33.88	0.637	23.32	20.60	0.773	14.44	9.68	0.678
PHLGRA	0	0	9.12	0.45	**0.057**	1.02	0.00	0.363	0.00	0.00	--
PLALEP	0	0	31.80	59.17	**0.077**	50.87	55.48	0.675	32.30	32.95	0.970
PLAPAT	1	0	0.00	1.17	0.163	0.00	0.00	--	0.00	0.00	--
POASCA	0	1	4.37	4.30	0.980	1.07	0.48	0.499	0.00	0.00	--
POLAVI	1	0	3.00	17.55	**0.041**	16.38	40.02	0.115	2.22	51.35	**0.055**
POLPOL	0	0	21.70	1.30	**0.051**	28.93	1.07	**0.019**	3.20	0.40	0.150
PSISP	0	0	1.82	1.02	0.519	7.78	6.55	0.760	10.60	12.05	0.799
RANTES	1	0	0.00	0.53	0.281	0.00	0.22	0.363	0.00	0.00	--
RUMSAL	0	1	0.00	0.00	--	0.75	0.43	0.722	0.00	0.00	--
SISALT	1	0	0.15	0.08	0.706	0.00	0.00	--	0.00	0.00	--
SONASP	1	0	0.00	1.60	0.336	0.00	2.42	**0.083**	0.00	0.45	0.391
SPEDIA	1	0	0.00	0.00	--	2.15	0.20	0.407	12.64	2.43	0.190
TAROFF	1	1	0.00	1.52	**0.045**	0.00	0.22	0.363	0.00	0.00	--

Species	Weed - N-0, Y-1	Annual(0)/ Perennial(1)	Ungrazed Mean, Zone 1	Grazed Mean, Zone 1	P	Ungrazed Mean, Zone 2	Grazed Mean, Zone 2	P	Ungrazed Mean, Zone 3	Grazed Mean, Zone 3	P
TRADUB	1	0	0.68	1.48	0.390	0.00	1.47	**0.069**	0.00	0.00	--
VERPER	0	0	20.83	6.43	0.107	19.45	8.52	**0.036**	7.50	1.20	0.212

APPENDIX F. Mean Percent Cover Values.

Pool	Zone	ACHMIL	AGOHET	ALLGEY	ALOSAC	APEINT	ARTLUD	BOIDEN	BOIGLA	BROMOI	BROTEC	COLLIN	COLPAR	CUSCAL
M1	1	0	0	0	0.25	19	0	0	0	9.5	0	9.5	0	0
M1	2	0	0	0	0	0	0	0	19.5	0	0	0	0	0
M1	3	0	0	0	0	0	0	0	10	0	0	0	0	0
M6	1	13.625	0	0	0	28.75	9.5	0	0	9.5	9.75	0	22.875	0
M6	2	0	0	0	0	9.5	9.5	0	0	0	0	0	0	0
M7	1	0	0.25	9.5	9.5	0	0	0	0	0	0	0	0	0
M7	2	0	0	3.875	0	0	0	0	0.25	0	0	0	0	0
M7	3	0	9.5	0	28.5	0	0	0	9.5	0	0	0	0	0.5
M11	1	0	0	0	0	38	0	15.5	0	0	0	0	0	0
M11	2	0	0	0	0	9.5	0	0	0	0	0	0	0	0
M11	3	0	0	0	13.625	0	0	0	0	0	0	0	0	0
M17	1	0.25	0.25	17.25	0.25	0.25	0	9.75	0	0	0	0	0	0
M17	2	0	0	0	9.5	0	0	0	19.25	0	0	0	0	0
M17	3	0	0	9.5	38	0	0	0	0	0	0	0	0	0
M18	1	13.375	32.375	0	0	19.25	0	3.875	0	13.375	0.25	0	0	0
M18	2	0	0	0	0	0	0	0	19	0	0	0	0	0.25
M18	3	0	0	0	0	0	0	0	0.5	0	0	0	0	0.25
D1a	1	0	9.5	0	0	0	0	0	0	25.25	0	0	0	0
D1a	2	0	0	28.5	0	0	0	0	10	0.25	0	0	0	0
D1a	3	0	0	63	0	0	0	0	19.5	0	0	0	0	0
D1b	1	0	28.5	0	0.25	15.5	0	0	0	0	19	0	0	0
D1b	2	0	0	13.375	0	0	0	0	28.75	0	0	0	0	0
D2	1	0	0	9.5	0	0	13.375	0	0	0	0	0	0	0
D2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
D2	3	0	0	9.5	0	0	0	0	10	0	0	0	0	0
D3	1	0	19	7.75	0	26.75	0	9.5	0	0	0	0	0	0
D3	2	0	0	28.5	0	3.875	0	0	28.5	0	0	0	0	0
D3	3	0	0	0	0	0	0	0	38	0	0	0	0	0
D25	1	0	0	0	0	31.5	0	0	0	9.75	13.625	0	0	0
D25	2	0	0	0	0	9.5	0	0	0	0	0	0	0	0
D25	3	0	0	0	0	0	0	0	0	0	0	0	0	0
D26	1	9.5	19	22.875	0	3.875	3.875	0	0	9.5	0	0	0	0
D26	2	0	0	0	0	0	0	0	28.5	0	0	0	0	0

Pool	Zone	DANUNI	DESDAN	DOWYIN	DRAVER	ECHCRU	ELEACI	ELEMAC	ELYELY	EPIPAN	GNAPAL	GRINAN	GRISP	HOLUMP
M1	1	0	44.25	0	13.375	0	0	0	0	0	0	19	0	0
M1	2	0	0	0	0	0	0	0	0	0	22.875	0	0	0
M1	3	0	0	0	0	0	0	32.375	0	0	9.5	0	0	0
M6	1	0	29.375	0	28.5	0	0	0	9.5	26.75	0	0	0	0
M6	2	0	11.625	0	3.875	0	0	19	0	38	0	17.25	0	0
M7	1	13.375	38.625	9.5	9.5	0	0	0	9.5	19.25	0	17.25	0	0
M7	2	0	0.25	0	0	0	0	0	0	0	22.875	3.875	0	0
M7	3	0	9.5	9.5	0	0	19	26.75	0	0	21.125	7.75	0	0
M11	1	0	26.75	0	0	0	0	19	0	8.25	0	38	0	0
M11	2	0	13.375	0	0	0	0	26.75	0	0	28.5	9.5	0	0
M11	3	0	9.5	0	0	0	0	69.25	0	0	9.5	9.5	0	0
M17	1	0	32.375	0	9.5	9.5	0	0	0	28.5	0	9.5	0	0
M17	2	0	0	0	0	0	0	9.5	0	0	26.75	3.875	0	0
M17	3	0	0.25	0	0	0	0	63	0	0	9.5	3.875	0	0
M18	1	0	21.125	0	22.875	0	0	0	4.125	19.25	0	3.875	0	0
M18	2	0	0.25	0	0	0	0	0	0	0	32.375	0	0	0
M18	3	0	0	0	0	0	28.75	22.875	0	0	19.5	0	0	0
D1a	1	0	29.375	0	3.875	0	0	0	0	19	0	0	0	19.25
D1a	2	0	26.75	0	0	0	0	0	0	9.5	10	0	0	0
D1a	3	0	9.5	0	0	0	0	0	0	0	28.5	0	0	0
D1b	1	0	44.875	0	28.5	0	0	0	0	19	0	0	0	28.5
D1b	2	0	22.875	0	0	0	0	0	0	0	9.75	0	0	0
D2	1	0	21.125	0	0	0	0	0	0	9.5	0	0	0	0
D2	2	0	19.25	0	0	0	0	0	0	0	19	0	0	0
D2	3	0	0	0	0	0	0	15.75	0	0	9.75	0	0	0
D3	1	0	21.125	0	0	0	0	0	0	19	0	9.5	9.5	0
D3	2	0	38	0	0	0	0	13.375	0	0	21.125	9.5	19	0
D3	3	0	0	0	0	0	0	19	0	0	15.5	0	0	0
D25	1	0	0	0	0	0	0	21.125	0	28.5	0	7.75	0	9.5
D25	2	0	0	0	0	0	0	50.5	0	0	9.5	13.375	0	0
D25	3	0	0	0	0	0	0	19	0	0	22.875	22.875	0	0
D26	1	0	26.75	0	0	0	0	0	0	19	0	0	0	0
D26	2	0	22.875	0	0	0	0	9.5	0	0	9.75	9.5	0	0

Pool	Zone	JUNBUF	LACSER	LAGRAM	LEPPER	LIMAQU	LOMGRA	LOMTRI	LOTPUR	MADEXI	MONDIC	MONLIN	MONPER	MUHRIC
M1	1	0	0	0	0	0	0	0	0	0	0	9.5	0	9.5
M1	2	0	0	0	0	19	0	0	0	0	0	0	0	0
M1	3	0	0	0	0	19	0	0	0	0	0	0	0	0
M6	1	0	9.5	0	0.5	0	0	0	0	0	9.5	9.5	0	0
M6	2	0	38	0	0	0	0	0	0	0	17.25	21.125	0	0
M7	1	0	0.25	0	0	0	32.375	0	0	0	0	0	0	0
M7	2	0	0	0	0	0.5	0	0	0	0	0	0	0	0
M7	3	0	0	0	0	0	0	0	0	0	0	0	0	0
M11	1	0	19	38	0	0	0	0	0	0	0	15.5	19	0
M11	2	0	28.5	0	0	0	0	0	0	0	0	13.375	0	0
M11	3	0	17.25	0	0	0	0	0	0	0	0	32.375	0	0
M17	1	0	9.5	0	0	0	17.25	9.5	0	0.25	0	26.75	0	0
M17	2	0	0	0	0	0	0	0	0	0	0	0	0	0
M17	3	0	0	0	0	0	0	0	0	0	0	0	0	0
M18	1	0	9.75	0	0	0	0	0	0	0	0	0	0	0
M18	2	0	0	0	0	0	0	0	0	9.75	13.375	0	0	0
M18	3	0	0	0	0	0	0	0	0	0	0	0	0	0
D1a	1	9.5	0	28.5	9.75	0	4.125	0	0	0	0	0	0	0
D1a	2	19	0.25	0.25	0	0	0	0	0	0	0	0	0	0
D1a	3	0	0	0	0	0	0	0	0	0	0	0	0	0
D1b	1	0.25	9.75	0	15.5	0	0	0	0	0	0	0	0	0
D1b	2	0	0	0	0	0	0	0	0	28.5	0	3.875	0	0
D2	1	0	0	3.875	0	0	22.875	0	13.375	0	0	0	0	0
D2	2	9.5	3.875	0	0	0	9.5	0	28.5	0	0	0	0	0
D2	3	0	0	0	0	0.25	0.25	0	0	0	0	0	0	0
D3	1	22.875	0	0	0	0	13.375	0	0	9.5	0	0	0	0
D3	2	38.625	0	0	0	0	0	0	0	0	0	0	0	0
D3	3	32.375	0	0	0	0	0	0	0	0	0	0	0	0
D25	1	0.5	17.25	0	0	0	0	0	0	0.25	0	0	0	0
D25	2	9.5	11.875	0	0	0	0	0	0	0	0	0	0	0
D25	3	9.5	3.875	0	0	9.5	0	0	0	0	0	0	0	0
D26	1	3.875	22.875	19	0	0	9.5	0	0	0	0	0	0	9.5
D26	2	0.25	0	0	0	0	9.5	0	0	0	0	0	0	0

Pool	Zone	MYOMIC	MYOMINA	MYOMINM	NAVLEU	PHLGRA	PLALEP	POASCA	POLAVI	POLPOL	PSISP	RUMEX	SISALT	SONASP
M1	1	0	0	26.75	19.5	0	13.375	0	9.5	0	0	0	0	0
M1	2	0	0	0	9.5	0	0	0	13.875	9.5	0	0	0	0
M1	3	0	0	0	0	0	9.5	0	9.5	0	0	0	0	0
M6	1	9.75	0	9.5	0	3.875	0	9.5	0	0	0	0	0	0
M6	2	3.875	0	38	0	0	0	0	0	19	0	9.5	0	0
M7	1	0	0	19.5	0	0	0.25	0	0	26.75	0	0	0	0
M7	2	0	28.5	19	17.5	0	3.875	0	9.5	3.875	0.25	0	0	0
M7	3	0	0	28.5	21.125	0	19	0	0	0	10	0	0	0
M11	1	26.75	0	38	7.75	0	19.5	0	0	0	0	0	0	0
M11	2	0	0	26.75	9.5	0	19	0	9.75	0.25	9.5	0	19	0
M11	3	0	0	0	0	0	28.5	0	0	0	0	0	0	0
M17	1	0	0	0	9.5	0	0.25	0	0	0	0	0	0	0
M17	2	0	0	32.375	21.125	0	7.75	0	0	0	0	0	0	0
M17	3	0	0	21.125	9.5	0	13.375	0	0	0	0	0	0	0
M18	1	0	0	13.375	19	3.875	0	0	0	22.875	0	0	0	0
M18	2	0	0	9.5	0	0	9.5	0	0	0	0.25	0	0	0
M18	3	0	0	0	0	0	0	0	0	0	0	0	0	0
D1a	1	0	0	17.5	22.875	0	22.875	0	3.875	0	0	0	0	0
D1a	2	0	0	17.25	22.875	0	19	0	26.75	0	0	0	0	0
D1a	3	0	0	28.75	38	0	28.5	0	26.75	0	0.5	0	0	0
D1b	1	0	0	38	0	0	19	0	19	0	0	0	0	0
D1b	2	0	0	19	9.75	0	19	0	26.75	0	0	0	0	0
D2	1	0	0	9.5	13.375	0	17.25	0	9.5	0	0	0	0	19
D2	2	0	0	0	22.875	0	26.75	0	13.375	0	0	0	0	19
D2	3	0	0	0	0	0	9.5	0	22.875	0	0.25	0	0	0
D3	1	0	0	9.75	9.5	0	13.375	0	0	0	0	0	0	0
D3	2	0	0	0	13.375	0	13.375	0	9.75	0	0	0	0	0
D3	3	0	0	0	0	0	19	0	0	0	0	0	0	0
D25	1	0.25	0	19	0	0	19	0	0	0	0	0	0	0
D25	2	0	0	0	0	0	26.75	0	19	0	0	0	0	0
D25	3	0	0	0	0	0	13.375	0	32.375	0	0	9.5	0	9.5
D26	1	0	0	3.875	26.75	0	7.75	0	0	0	0	0	0	0
D26	2	0	0	9.5	9.75	0	13.375	0	19	9.5	0.5	0	0	9.75

Pool	Zone	SPEDIA	VERPER
M1	1	0	9.5
M1	2	9.5	0
M1	3	0	9.75
M6	1	0	0
M6	2	0	28.5
M7	1	0	0
M7	2	0	0.5
M7	3	9.5	0.25
M11	1	0	0
M11	2	0	21.125
M11	3	0	28.5
M17	1	0	10
M17	2	0	0
M17	3	0	0
M18	1	0	0
M18	2	17.5	0.5
M18	3	22.875	0
D1a	1	0	0
D1a	2	0	0
D1a	3	0	0
D1b	1	0	0
D1b	2	0	0
D2	1	0	0.25
D2	2	0	19
D2	3	0	0.25
D3	1	0	0
D3	2	0	38
D3	3	0	0
D25	1	0	0
D25	2	0	0
D25	3	0	0
D26	1	0	0
D26	2	0	0.25

APPENDIX G. Plant Inventory of Marcellus Pools, 1998 and 1999.

05-24-98
Pool 2
Note: Grasses dominant, *Artemisia ludoviciana* at outside edge.

Deschampsia danthonioides
Lactuca serriola
Allium geyeri
Epilobium paniculatum
Conyza canadensis
Bromus tectorum
Artemesia ludoviciana
Holosteum umbellatum
some *Achillea millefolium*
Castilleja tenuis
Apera interrupta (highly abundant)
Veronica peregrina
Plagiobothrys leptocladus
Myosurus minimus ssp *minimus*
Draba verna
Juncus bufonius
Alopecurus saccatus
Madia exigua
Cirsium arvense
Sisymbrium altissimum
Myosotis micrantha
Taraxacum officinale
Tragopogon dubius

05-23-98
Pool 3a and b
Note: Entire pool covered in *Deschampsia danthonioides.*

<u>Outer Zone</u>
Deschampsia danthonioides (abundant)
Achillea millefolium (abundant)
Lactuca serriola (abundant)
Muhlenbergia richardsonis (abundant)
Poa scabrella
Allium geyeri
Epilobium paniculatum
Sisymbrium altissimum
Bromus mollis
Artemesia ludoviciana
Verbascum thapsus
Plagiobothrys leptocladus
Navarretia leucocephala
Taraxacum officinale
Myosotis micrantha
Veronica peregrina
Conyza canadensis
Draba verna
Collinsia parvifolium
Lomatium sp.
Montia dichotoma
Cirsium arvense

<u>Inner Zone</u>
Deschampsia danthonioides
Muhlenbergia richardsonis
Allium geyeri
Lactuca serriola
Epilobium paniculatum
Taraxacum officinale
Plagiobothrys leptocladus
Veronica peregrina
Montia dichotoma
Navarretia leucocephala
Alopecurus saccatus
Polygonum aviculare
Psilocarphus brevissimus
Myosurus minimus ssp *minimus*
Polygonum polygaloides

05-23-98
Pool 4
Note: One zone, sage-dominated, also abundant *Achillea millefolium, Bromus mollis*

Artemesia ludoviciana
Achillea millefolium
Poa scabrella
Draba verna
Deschampsia danthonioides
Muhlenbergia richardsonis
Taraxacum officinale
Epilobium paniculatum
Lactuca serriola
Conyza canadensis
Erigeron pumilus
Allium geyeri
Lomatium grayi

05-23-98
Pool 5
Note: No zonation, vegetation relatively uniform, patch of cobbles off-center.

Cirsium arvense
Achillea millefolium (abundant)
Artemesia ludoviciana (abundant)
Lactuca serriola
Epilobium paniculatum
Madia exigua
Deschampsia danthonioides
Myosotis micrantha
Bromus mollis
Muhlenbergia richardsonis
Artemesia tridentata
Allium geyeri
Sisymbrium altissumum
Conyza canadensis
Lomatium sp.
Grindelia nana
Verbascum thapsus
Poa scabrella
Lomatium grayi
Taraxacum officinale

07-11-98
Pool 8
Note: Uniform coverage, mostly grasses and Achillea

Achillea millefolium
Elymus elymoides
Deschampsia danthonioides
Allium geyeri
Lactuca serriola
Madia exigua
Conyza canadensis
Navarretia leucocephala
Apera interrupta
Bromus mollis
Erigeron pumilus
Cirsium arvense
Gnapthalium palustre
Grindelia nana

05-23-98
Pool 9a and b

Outer Zone
Epilobium paniculatum (abundant)
Deschampsia danthonioides (abundant)
Lactuca serriola (abundant)
Veronica peregrina (abundant)
Grindelia nana (abundant)
Rumex salicifolius
Myosotis micrantha
Castilleja tenuis
Montia linearis
Plagiobothrys leptocladus
Lepidium perfoliatum
Draba verna
Montia perfoliata
Psilocarphus brevissimus
Sisymbrium altissimum
Bromus mollis
Polygonum polygaloides
Vulpia octoflora
Alopecurus saccatus
Oenothera tanacetifolia
Allium geyeri
some *Artemesia ludoviciana*

Intermediate Zone
Psilocarphus brevissimus
Plagiobothrys leptocladus
Polygonum aviculare
Alopecurus saccatus
Myosurus minimus spp *minimus*
Veronica peregrina
Grindelia nana
Polygonum polygaloides
Boisduvalia glabella
Myosurus minimus ssp *apus*
Downingia yina
Allium geyeri
Lactuca serriola
Myosurus aristatus

Center Zone
Eleocharis macrostachya (most abundant, in large patches)
Grindelia nana (abundant)
Polygonum aviculare (abundant)
Plagiobothrys leptocladus (abundant)
Psilocarphus brevissimus (abundant)
Veronica peregrina
Myosurus minimus ssp *minimus*
Navarretia leucocephala
Polygonum polygaloides
Lactuca serriola
some *Deschampsia danthonioides*
Alopecurus saccatus
*no *Limosella aquatica*

05-23-98
Pool 10
Note: unclear zones.

<u>Outer Zone</u>
Deschampsia danthonioides (abundant)
Epilobium paniculatum (abundant)
Grindelia nana (abundant)
Lactuca serriola (abundant)
Muhlenbergia richardsonis (abundant)
Bromus mollis
Allium geyeri
some *Holosteum umbellatum*
Myosotis micrantha
Lomatium grayi
some *Lepidium perfoliatum*
some *Sisymbrium altissimum*
Juncus bufonius
Castilleja tenuis
Montia linearis
Navarretia leucocephala
Draba verna

<u>Center Zone</u>
Eleocharis macrostachya
Lactuca serriola
Bromus mollis
Deschampsia danthonioides
Epilobium paniculatum
some *Allium geyeri*
Grindelia nana
some *Sisymbrium altissimum*
Myosurus minimus ssp *minimus*
Juncus bufonius
some *Myosotis micrantha*
Psilocarphus brevissimus
some *Castilleja tenuis* (mostly in outer zone)
Alopecurus saccatus
some *Holosteum umbellatum*
Montia linearis

06-05-98
Pool M12

<u>Outer Zone</u>
Apera interrupta (thick, dominant)
Poa scabrella
Artemesia ludoviciana (large, crescent-shaped patch)
Conyza canadensis
Epilobium paniculatum
Montia linearis
Grindelia nana
Potentilla
Achillea millefolium
Myosotis micrantha
some *Deschampsia danthonioides*
some *Plagiobothrys leptocladus*
some *Psilocarphus brevissimus*
Draba verna
Bromus tectorum
Lactuca serriola
Polygonum polgaloides
some *Sisymbrium altissimum*
Gnapthalium palustre
Veronica peregrina

<u>Intermediate/Center Zone</u>
Eleocharis macrostachya (dense)
Montia linearis (scattered in small, dense patches)
Veronica peregrina
Unknown composite
Epilobium paniculatum
Plagiobothrys leptocladus
Polgonum polyaloides
Grindelia nana
Sisymbrium altissimum
Lactuca serriola

05-24-98
Pool 13a and b
Note: Remnants of large *Navarretia leucocephala*; *Deschampsia danthonioides* dominant with many patches of *Grindelia nana*, *Allium geyer* abundant, small cobble patch on NE side that is covered in moss.

Deschampsia danthonioides
Grindelia nana
Allium geyeri
Lactuca serriola
Epilobium paniculatum
Plagiobothrys leptocladus
Veronica peregrina
Oenothera tanacetifolia
Navarretia leucocephala
Castilleja tenuis (much around outer edge)
Lomatium sp.
Achillea millefolium
Bromus tectorum
Bromus mollis
Artemesia tridentata
Trogopogon dubius

Carex douglasii
Sisymbrium altissimum
Muhlenbergia richardsonis
Poa scabrella
Cirsium arvense
Apera interrupta
Festuca idahoensis
Conyza canadensis

05-24-98
Pool 14
Note: Densely carpeted with *Artemesia ludoviciana*, scattered *Poa scabrella*, dead *Artemesia tridentata* in pool center and scattered along outside.

Artemesia ludoviciana
Poa scabrella
Deschampsia danthonioides
Epilobium paniculatum
Apera interrupta
Achillea millefolium
Conyza canadensis
Lactuca serriola
Draba verna
Collinsia parviflora
Myosotis micrantha
Phlox gracilis
Montia linearis
Potentilla biennis
Muhlenbergia richardsonis
Taraxacum officinale
Festuca idahoensis
Montia dichotoma

05-24-98
Pool 15
Note: One zone, *Artemesia ludoviciana*, *Achillea millefolium*, and *Poa scabrella* are dominant.

Poa scabrella
Artemesia ludoviciana
Achillea millefolium
Phlox gracilis
Draba verna
Holosteum umbellatum
Epilobium paniculatum
Conyza canadensis
Vulpia octoflora
Apera interrupta
Deschampsia danthonioides
Bromus tectorum
Sisymbrium altissimum
Bromus mollis
some *Lactuca serriola*
Verbascum thapsus
Clarki puchellum
Taraxacum officinale
Artemesia tridentata
Cirsium arvense
Collinsia parviflorum

05-23-98
Pool 16
Note: No distinct zones. Pool vegetation comprised mostly of *Artemesia ludoviciana* and *Achillea millefolium*.

Artemesia ludoviciana
Achillea millefolium
Muhlenbergia richardsonis
Navarretia leucocephala
Lactuca serriola
some *Deschampsia danthonioides*
Epiolobium paniculatum
Draba verna
Poa scabrella
Conyza canadensis
Lomatium grayi
Taraxacum officinale
Cirsium arvense
Sisymbrium altissimum
Montia linearis
Allium geyeri
Bromus mollis
some *Eleocharis macrostachya*
Verbascum thapsus

1999 Marcellus Pool Inventory

06-07-99
Pool M2

Outer portion
Bromus mollis
Deschampsia danthonioides
Montia linearis
Allium geyeri
Epilobium paniculatum
Artemisia ludoviciana
Bromus tectorum
Sisymbrium altissimum
Lagophylla ramosissima
Poa scabrella
Lactuca serriola
Myosotis micrantha
Poa pratensis
Navarretia sp.
Plagiobothrys leptocladus
Veronica peregrina
Myosurus minimus ssp. *minimus*
Tragopogon dubius
Achillea millefolium
Lepidium perfoliatum
Sonchus asper
Apera interrupta

Inner portion
Deschampsia danthonioides
Poa pratensis
Myosurus minimus ssp. *minimus*
Plagiobothrys leptocladus
Veronica peregrina
Gnaphalium palustre
Epilobium paniculatum
Lactuca serriola
Artemisia ludoviciana
Allium geyeri
Boisduvalia densiflora
Apera interrupta
Senecio integerrimus

06-02-99
Pool M3a
Good quality pool, homogenous.

Artemisia ludoviciana (along pool margin only)
Allium geyeri
Lomatium grayi
small patches of *Eleocharis macrostachya*
Deschampsia danthonioides
Elymus elymoides
Alopecurus saccatus
Epilobium paniculatum
Achillea millefolium
Lactuca serriola
Veronica peregrina
Myosurus minimus ssp. *minimus*
Plagiobothrys leptocladus
Navarretia leucocephala
Polygonum polygaloides
Lagophyllum ramosissima
Polygonum aviculare
Agoseris heterophylla
Gnaphalium palustre
Boisduvalia glabella
Montia linearis
Bromus tectorum (along margin only)
Grindelia nana
Boisduvalia densiflora
Draba verna
Collinsia parviflora
Tragopogon dubius
Poa pratensis
Apera interrupta

06-02-99
Pool M3b

Along margin
Achillea millefolium
Allium geyeri
Lomatium grayi
Artemisia ludoviciana
Bromus mollis
Lagophylla ramosissima
Lactuca serriola
Elymus elymoides
Bromus tectorum
Lepidium perfoliatum

In pool basin
Allium geyeri
Deschampsia danthonioides
Draba verna
Elymus elymoides
Epilobium paniculatum
Lactuca serriola
Agoseris heterophylla
Lagophylla ramosissima
Plagiobothrys leptocladus
Myosurus minimus ssp. *minimus*

Veronica peregrina
Montia linearis
Alopecurus saccatus
Sonchus asper
Montia dichotoma
Eleocharis macrostachya
Polygonum aviculare
Poa scabrella

06-02-99
Pool M4

Achillea millefolium
Artemisia ludoviciana
Bromus tectorum
Myosotis micrantha
Montia linearis
Collinsia parviflora
Epilobium paniculatum
Lomatium grayi
Poa scabrella
Lactuca serriola
Draba verna
Myosurus apetalus
Allium geyeri
Elymus elymoides
Agoseris heterophylla
Holosteum umbellatum
Deschampsia danthonioides
Erigeron pumilus
Taraxacum officinale
Montia dichotoma
Bromus mollis

06-02-99
Pool M5

Poa pratensis
Achillea millefolium
Bromus tectorum
Epilobium paniculatum
Myosotis micrantha
Phlox gracilis
Artemisia tridentata
Tragopogon dubius
Poa scabrella
Collinsia parviflora
Veronica peregrina
Agoseris heterophylla
Lactuca serriola
Grindelia nana
Elymus elymoides
Deschampsia danthonioides
Holosteum umbellatum
Lagophylla ramosissima
Artemisia ludoviciana
Lomatium grayi
Draba verna
Taraxacum officinale
Rumex sp.
Myosurus minimus ssp. *minimus*
Allium geyeri
Bromus mollis

06-02-99
Pool M6a

Bromus tectorum (dominant)
Artemisia ludoviciana
Elymus eleymoides
Poa scabrella
Epilobium paniculatum
Allium geyeri
Taraxacum officinale
Achillea millefolium
Holosteum officinale
Collinsia parviflora
Tragopogon dubius
Bromus mollis
Erigeron pumilus
Lactuca serriola
Draba verna
Apera interrupta
Myosotis micrantha
Agoseris heterophylla
Montia linearis
Montia perfoliata

In small, deep portion of pool
Oenothera tanacetifolia
Myosurus minimus ssp. *minimus*
Deschampsia danthonioides
Plagiobothrys leptocladus

06-15-99
Pool M8

Elymus elymoides (dominant)
Deschampsia danthonioides
Bromus mollis
Bromus tectorum
Achillea millefolium

Collinsia parviflora
Draba verna
Sisymbrium altissimum
Epilobium paniculatum
Lactuca serriola
Lomatium grayi
Agoseris heterophylla
Allium geyeri
Poa scabrella
Gnaphalium palustre
Lagophylla ramosissima
Myosurus minimus ssp. *miminus*
Veronica peregrina
Madia exigua
Montia dichotoma
Erigeron pumilus
Holosteum umbellatum
Apera interrupta
Myosotis micrantha
Sonchus asper
Tragopogon dubius

06-07-99
Pool M9a,b

Zone 1
Deschampsia danthonioides
Grindelia nana
Epilobium paniculatum
Navarretia leucocephala
Myosurus minimus ssp. *minimus*
Boisduvalia densiflora
Apera interrupta
Bromus tectorum
Allium geyeri
Polygonum polygaloides
Lactuca serriola
Bromus mollis
Sisymbrium altissimum
Tragopogon dubius
Achillea milllefolium
Alopecurus saccatus
Veronica peregrina
Montia linearis
Artemisia ludoviciana
Elymus elymoides
Lagophylla ramosissima
Madia exigua

Zone 2
Polygonum polygaloides
Gnaphalium palustre
Deschampsia danthonioides
Veronica peregrina
Plagiobothrys leptocladus
Navarretia leucocephala
Myosurus minimus ssp. *minimus*
Boisduvalia glabella
Alopecurus saccatus
Spergularia diandra
Grindelia sp.
Polygonum aviculare
Psilocarphus sp.
Grindelia nana
Limosella aquatica
Eleocharis macrostachya
Allium geyeri
Castilleja tenuis

Zone 3
Eleocharis macrostachya
Gnaphalium palustre
Boisduvalia glabella
Veronica peregrina
Grindelia nana
Myosurus minimus ssp. *minimus*
Lactuca serriola
Oenothera tanacetifolia
Plagiobothrys leptocladus
Alopecurus saccatus
Montia linearis
Psilocarphus sp.
Navarretia leucocephala
Eleocharis acicularis
Deschampsia danthonioides
Downingia yina
Montia dichotoma

06-07-99
Pool M10

Bromus mollis (approximately 60% cover)
Grindelia nana
Deschampsia danthonioides
Allium geyeri
Grindelia sp.
Castilleja tenuis
Navarretia leucocephala
Gnaphalium palustre
Eleocharis macrostachya
Lactuca serriola
Apera interrupta
Juncus bufonius
Montia linearis

Epilobium paniculatum
Boisduvalia densiflora
Myosotis micrantha
Holosteum umbellatum
Clarkia pulchella
Madia exigua
Montia dichotoma
Bromus tectorum
Alopecurus saccatus
Veronica peregrina
Poa pratensis

06-02-99
Pool M12

Outer zone
Deschampsia danthonioides
Epilobium paniculatum
Montia linearis
Artemisia ludoviciana
Elymus elymoides
Bromus tectorum
Draba verna
Achillea millefolium
Holosteum umbellatum
Apera interrupta
Veronica peregrina
Sonchus asper
Plagiobothrys leptocladus
Grindelia nana
Myosotis micrantha
Poa pratensis
Lactuca serriola
Myosurus minimus ssp. *minimus*
Sisymbrium altissimum
Montia dichotoma
Montia perfoliata
Clarkia pulchella

Inner zone
Eleocharis macrostachya (dense stand)
Montia linearis
Alopecurus saccatus
Deschampsia danthonioides
Myosurus minimus ssp. *minimus*
Epilobium paniculatum
Sonchus asper
Boisduvalia glabella
Plagiobothrys leptocladus
Veronica peregrina
Epilobium paniculatum
Grindelia nana

Navarretia leucocephala

06-07-99
Pool M13

Artemisia ludoviciana
Bromus tectorum
Lomatium grayi
Madia exigua
Collomia linearis
Allium geyeri
Holosteum umbellatum
Deschampsia danthonioides
Myosotis micrantha
Epilobium paniculatum
Poa scabrella
Achillea millefolium
Elymus elymoides
Danthonia unispicata
Erigeron pumilus
Bromus tectorum
Sisymbrium altissimum
Lactuca serriola
Tragopogon dubius
Grindelia nana
Montia dichotoma
Lagphylla ramosissima
Draba verna
Agoseris heterophylla
Clarkia pulchella
Deschampsia danthonioides

06-07-99
Pool M14

Poa pratensis
Poa scabrella
Lomatium grayi
Allium geyeri
Bromus mollis
Madia exigua
Elymus elymoides
Achillea millefolium
Epilobium paniculatum
Senecio integerrimus
Collomia linearis
Castilleja tenuis
Apera interrupta
Draba verna
Grindelia nana
Holosteum umbellatum

Lactuca serriola
Sisymbrium altissimum
Clarkia pulchella
Veronica peregrina
Boisduvalia densiflora
Myosurus minimus ssp. *minimus*
Plagiobothrys leptocladus
Navarretia leucocephala
Alopecurus saccatus
Boisduvalia glabella
Grindelia sp.
Artemisia ludoviciana
Myosotis micrantha
Juncus bufonius
Gnaphalium palustre
Sonchus asper
Deschampsia danthonioides
Oenothera tanacetifolia
Psilocarphus sp.
Eleocharis macrostachya
Montia linerais
Lagophylla ramosissima
Bromus tectorum

06-07-99
Pool M15

Bromus tectorum
Sisymbrium altissimum
Collomia linearis
Allium geyeri
Epilobium paniculatum
Madia exigua
Achillea millefolium
Poa pratensis
Plantago patagonica
Myosotis micrantha
Artemisia ludoviciana
Tragopogon dubius
Lactuca serriola
Montia linearis
Holosteum umbellatum
Bromus mollis
Collinsia parviflora
Erigeron pumilus
Apera interrupta
Rumex sp.
Galium aparine
Mimulus suskdorfii
Amsinkia sp.
Clarkia pulchella
Oenothera tanacetifolia
Apera interrupta
Montia perfoliata
Plectritis macrocera

06-15-99
Pool M16

Poa scabrella
Artemisia ludoviciana
Elymus elymoides
Achillea millefolium
Collomia linearis
Clarkia pulchella
Epilobium paniculatum
Agoseris heterophylla
Draba verna
Bromus mollis
Collinsia parviflora
Phlox gracilis
Montia linearis
Mimulus suskdorfii
Myosotis micrantha
Montia dichotoma
Rumex sp.