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Title: Soil Conditions Along a Hydrologic Gradient and Successional Dynamics in a Grazed and Ungrazed Montane Riparian Ecosystem.

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Vegetation dynamics of eight riparian plant communities under livestock use or exclusion in northeastern Oregon was quantified for 10 years. In addition, belowground characteristics of five distinct riparian communities along a moisture gradient from continually anaerobic to continually aerobic conditions were characterized.

Vegetation parameters quantified include: species richness, species diversity, evenness, and aboveground biomass. In *Poa pratensis*-mixed dicot (dry meadow) and *Poa pratensis-Carex* spp. (moist meadow), the most heavily utilized communities, ruderal and competitive ruderal species were favored by grazing disturbance. In exclosures of the same communities, competitive or competitive stress tolerant species were favored. Mean height and density of woody species were significantly greater in exclosures of

Salix spp.-mixed dicot (gravel bar) communities. Disturbance associated with moderate stocking rates (1.3 to 1.8 ha/AUM over the study period) did not adversely affect plant community properties sampled.

The belowground soil parameters quantified include: depth to water table, redox potential, and soil temperature at 5, 10, 30, cm depths. In addition, total nitrogen (N), ammonium (NH_4^+), nitrate (NO_3^-), ferrous iron (Fe^{2+}), and free iron (Fe_2O_3) in soils at depths of 0 to 10 cm and 10 to 30 cm were sampled. During the June to September growing season, redox potential in *Glyceria grandis* communities, ranged from -19 to -226 mV. This was significantly ($P \leq 0.1$) lower than *Juncus balticus-Poa pratensis*, and *Poa pratensis-Carex* spp. communities over the growing season. At the dry end of the moisture gradient, *Poa pratensis-Carex* spp. communities had redox potential ranging from 460 to 634 mV. These riparian plant communities occurred in unique combinations of edaphic conditions which influence rhizosphere, vegetation, and aquatic systems.

Soil Conditions along a Hydrologic Gradient and Successional Dynamics in a Grazed and Ungrazed Montane Riparian Ecosystem.

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SOIL CONDITIONS ALONG A HYDROLOGIC GRADIENT AND SUCCESSIONAL DYNAMICS IN A GRAZED AND UNGRAZED RIPARIAN ECOSYSTEM

I. INTRODUCTION

In an ecological sense, riparian ecosystems are inextricably connected to instream communities and affect water quality (Swanson et al. 1982). Brinson et al. (1981) estimated that over 70% of riparian communities have been altered and less than 2% of the land area in the United States consists of intact natural riparian communities. Major losses of riparian bottom land forest have occurred as a result of lumbering, drainage for agriculture (Korte and Fredrickson 1977, McGill 1979), channelization (Funk and Robinson 1974, Braclay 1978, Triska et al. 1982), hydroelectric dams (Lagler 1969, Reily and Johnson 1982, Smith et al., 1991), or livestock grazing (Kauffman and Krueger 1984, Platts 1986, Clary and Webster 1989). It is probable that activities such as debris removal, beaver (*Castor candensis*) trapping, and grazing reduced the biological integrity of riparian zones before extensive research began (Harmon et al. 1986, Naiman et al. 1986). These changes have altered the ecosystem structure and function of riparian zones thereby changing biotic interrelationships with aquatic ecosystems.

Of particular interest to rangeland managers have been the impacts of livestock on riparian ecosystems. Livestock are attracted to riparian areas by the availability of water, shade, thermal cover, and quality and quantity of forage (Kauffman and Krueger 1984). Even though riparian meadows occupy only 1-2% of the interior northwest they may account for 81% of the forage removed by livestock (Roath and Krueger 1982). In reviewing livestock-riparian relationships, Kauffman (1988), separated the impacts of excessive grazing in the riparian zone into four components: 1) compaction of soils which increases runoff and decreases water availability to plants, 2) herbage removal which lowers plant vigor and changes competitive interactions among species, 3) physical damage to vegetation by rubbing, trampling, and browsing, and 4) changes in fluvial processes which may lower water tables and or cause a decline in invasion sites for woody species. In addition, there are increasing concerns about the impact of livestock on biological diversity, successional dynamics, and nutrient cycling.

Livestock have been shown to significantly impact the composition of riparian vegetation. Overgrazing by herbivores and subsequent site deterioration was attributed by Volland (1978) as the reason for the dominance of *Poa pratensis* on many dry riparian meadows. In northeastern Oregon, grasses such as *Poa pratensis* were being replaced by *Carex* spp. and forbs in the absence of grazing (Kauffman et al. 1983, 1988). Dobson (1973) found an increase in the zone. He concluded that grazing opened up the vegetation creating more niches for establishment of different plant species. Similar results have been found in Nevada (Clary and Medin 1990).

Livestock can have a significant impact on shrub and tree production in riparian systems. Woody vegetation can be eliminated if livestock grazing is severe enough to prevent establishment (Carothers 1977). Marcuson (1977) found shrub production to be 13 times greater in an ungrazed area than in a severely overgrazed area. Other studies have reported similar herbivore-woody vegetation interactions (Gunderson 1968, Leege et al. 1981, Davis 1982, Schultz and Leinginer 1990).

Many livestock grazing strategies have been discussed for riparian area rehabilitation or maintenance. These range from livestock exclusion to management of riparian areas as special use pastures (see review by Platts 1989).

Dahm et al. (1987) concluded that human influences (beaver trapping, channelization, and grazing) have acted to uncouple riparian and stream ecosystem interactions. This has important implications as riparian zones are physical, biological, and chemical links between terrestrial and aquatic environments. An important, yet little studied ecological process of riparian zones is the biogeochemical cycles that influence both riparian and aquatic systems. Riparian areas are unique in that they contain large areas of anaerobic (saturated) soils.

Reduction-oxidation (redox) potential is a measure of electron availability in chemical and biological systems (Mitsch and Gosselink 1986). Redox potential can provide a relative measure of the availability of certain nutrients and chemical conditions in saturated soils (Table I.1). The reduced form of many elements such as iron, manganese, and sulfide which are toxic to plants occur under conditions of low redox potential. Chemical reactions such as denitrification also occur under low redox potential and have a direct effect on water quality. Low redox potentials (+200 to -400 mV) are associated with reduced, submerged soils. Well oxidized soils have redox potentials of about 300 to 800 mV (Ponnamperuma 1972). Turner and Patrick (1968) found that when soil oxygen was at a level of 4%, redox potential began to decrease sharply. Much of this drop in redox potential results from increasing populations of anaerobic bacteria which use inorganic compounds such as nitrate-nitrogen as terminal electron acceptors (Brock et al. 1984).

Reduction of nutrients occurs in a predictable pattern as redox decreases (Table I.1). This process begins within a few hours to a few days after waterlogged conditions occur depending upon soil temperature and organic matter content (Glinski and Stepniewski 1985). Warm spring temperatures, high amounts of organic matter, water

Table I-1. Oxidized and reduced forms of several elements and approximate redox potentials for transformation. (Source: Mitsch and Gosselink 1986)

Element	Oxidized Form		Reduced Form		Redox potential (mV)
Nitrogen	NO_3^-	Nitrate	N_2O, N_2, NH_4^+		220
Manganese	Mn^{4+}	Managanic	Mn^{2+}	Manganous	200
Iron	Fe^{3+}	Ferric	Fe^{2+}	Ferrous	120
Sulfur	SO_4^{2-}	Sulfate	S^{2-}	Sulfide	-75 to -150
Carbon	CO_2	Carbon dioxide	CH_4	Methane	-250 to -350

saturation, and rapid microbial growth will result in rapid declines in redox potential (Meek et al. 1978). After waterlogged conditions occur in the spring or winter, oxygen is rapidly depleted by aerobic microorganisms. Oxygen is undetectable at a redox potential below the range of 300 to 340 mV (Gambrell and Patrick 1978).

Recent studies have reported that riparian zones are important sites for denitrification. Rhodes et al. (1985) found in an undisturbed watershed of the Sierra Nevada, California, over 99% of the incoming nitrate-nitrogen was denitrified. Vegetation uptake of nitrate-nitrogen was found to be insignificant in their study. In North Carolina, Jacobs and Gilliam (1985) found that 10 to 55 Kg hectare^{-1} yr^{-1} of nitrate-nitrogen was denitrified in the riparian zone of streams bordering agricultural fields. Gambrell et al. (1975) and Gilliam et al. (1978) also found significant losses of NO3-N in the riparian zone of North Carolina streams. Significant losses of nitrate in ground water passing through the riparian area adjacent agricultural fields was found in Georgia (Lowrance et al. 1984) and New Zealand (Cooper 1990).

Reduction of manganese from manganic (Mn^{4+}) to manganous (Mn^{2+}) form occurs at a redox potential of approximately 200 mV (Gambrell and Patrick 1978). Reduced Mn is mobile in the soil profile and can be toxic to plants at high concentrations Armstrong (1982). When redox decreases to around 120 mV, ferric iron (Fe^{3+}) is reduced to ferrous iron (Fe^{2+}) (Gambrell and Patrick 1978). The reduction of ferric iron to ferrous iron is most discernable since the brownish red color of ferric iron hydroxides change to the grey or bluish grey of ferrous iron hydroxides. In soils that are seasonally waterlogged, a mottled pattern of ferric iron and ferrous iron is apparent. A soil horizon with this mottled pattern or solid bluish grey matrix is referred to as a gleyed horizon (Buol et al. 1980). The red iron deposits often seen at the outflows of springs or seeps are an indication of reducing conditions in the soil profile behind the spring. Reduced iron (ferrous) is water soluble and can move with ground water until it reaches an aerobic environment where it is oxidized to ferric iron and precipitates out of solution.

Sulfur compounds are the next electron acceptors after iron as redox potential decreases. Sulfates are reduced to sulfides at a redox potential of about -150 mV (Gambrell and Patrick 1978). This is typified by a "rotten egg" smell characteristic of some marshes and riparian communities.

Conversion of carbon dioxide (CO_2) or methyl groups to methane occurs when they are utilized as electron acceptors by certain bacteria. This requires a low redox potential (-250 to 350 mV) and the absence of all other terminal acceptors (Mitsch and Gosselink 1986). This appears to be the final redox system in soils (Ponnamperuma et al. 1966). Although ferrous, manganous and sulfide ions can be toxic to plants at high concentrations (Armstrong 1982), low levels of these nutrients create habitat conditions which are suitable only for plant species that are adapted for growth in soils of low redox potential. This is reflected in the distribution of plant communities over landscapes influenced by shallow water tables (Misra 1938, Pierce 1953, Howes et al 1981).

Many riparian species are adapted to survive periods of low soil redox potential. These adaptations may be structural or physiological in nature. Structural adaptions may include aerenchyma in both the stem and roots (Armstrong 1972, Kawase and Whittmoyer 1980, Blom et al. 1990). Aerenchyma formulation is stimulated when roots submerged by water and subsequent anaerobic conditions (Kawase and Whittmoyer 1980). This tissue provides both support and a pathway for diffusion of oxygen to the root tip (Armstrong 1972, Beckett et al. 1988). Radial oxygen loss creates aerobic conditions in the environment immediately surrounding the plant roots (Teal and Kanwischer 1966, Armstrong 1970, Colin and Crowder 1989). This results in oxidation of the reduced iron, manganese, and organic soil toxins before they diffuse to plant tissues. Evidence of this can be seen through observation of a thin reddish coating (oxidized iron) on the root surface of many wetland species with roots in waterlogged soils (Mendelssohn and Postek 1982, Crowder and Macfie 1986).

Woody species such as *Salix* spp. and *Populus* spp. have numerous lenticles that are important in gas diffusion in and out of the stem. Lenticles are the primary entry points for oxygen diffused to the rhizosphere for *Salix* spp. and *Myrica gale* (bog myrtle) (Armstrong 1968, Hook et al. 1971). Acetaldehyde and ethylene were diffused out of lenticles on rooted cuttings *Salix* spp. and oxygen was diffused into the lenticles (Chirkova and Gutman 1972).

Other adaptions to waterlogging by wetland plants include the development of xeromorphic features such as thickened cuticles and single stem morphologies. It has been suggested that this would reduce the flow of water to the root surface allowing time for reduced phytotoxins to oxidize in the root zone (Armstrong 1982).

Flood tolerant species may produce fermentation end products less toxic than ethanol e.g. malate, for later use in aerobic respiration in roots or the shoot (McMannon and Crawford 1971, Crawford 1978). However Smith and ap Rees (1979) found no evidence of malate accumulation in three wetland species, in addition, this pathway generates less ATP than ethanol production and therefore may only be a short term solution to flooding stress (ap Rees and Wilson

1984, Smith and ap Rees 1979). In rice (*Oryza sativa*), ethanol diffuses from root tips to the surrounding soil and malate does not accumulate (Bertani et al. 1980). It is possible that other wetland species may release ethanol and so avoid the less efficient malate pathway.

Although much is known about nutrient cycling in wetland ecosystems, and grazing impacts in upland plant communities relatively little research has focused on these issues in the riparian ecosystem. Accordingly, this research addresses two significant gaps in our knowledge of riparian ecology; 1) a lack of quantitative data about vegetation response over time to grazing and; 2) lack of data about the dynamic belowground processes of riparian plant communities. Accordingly, the objective of the first paper was to quantify changes in species composition and productivity over 10 years of exclosure and late season grazing in eight riparian plant communities in north eastern Oregon. The objective of the second paper was to determine the unique physical and chemical, edaphic properties of five distinctive riparian plant communities along a hydric gradient.

II. LONGTERM SUCCESSIONAL DYNAMICS UNDER 10 YEARS OF LIVESTOCK GRAZING IN A NORTHEASTERN OREGON RIPARIAN ECOSYSTEM

Abstract

The vegetation dynamics of riparian plant communities under scenarios of annual livestock use and complete exclusion were quantified for 10 years. Vegetation parameters quantified include: species richness, species diversity, evenness, and aboveground biomass. Eight common plant communities representing an assemblage of over 250 species in a northeastern Oregon montane riparian zone were investigated. Stocking rate ranged from 1.3 to 1.8 ha/AUM over the study period. Exclosed (ungrazed) *Poa pratensis*-mixed dicot (dry meadow communities) and *Poa pratensis*-*Carex* spp. (moist meadow communities) communities had significantly lower ($P \leq 0.1$) species richness and total plant species diversity when compared to grazed counterparts. Exotic species such as *Bromus mollis* in the *Poa pratensis*-mixed dicot communities and *Phleum pratense* in the *Poa pratensis-Carex* spp. communities decreased significantly in the exclosures. Exclosed *Pinus ponderosa* (ponderosa pine) communities also had significantly lower species richness and species diversity. In the most heavily grazed communities i.e. sedge and grass dominated communities 48 to 73% utilization, ruderal and competitive ruderal species were favored by grazing disturbance. In exclosures of the same communities, competitive or competitive stress tolerant species were favored. Over the 10 year study period, grazed and exclosed cheatgrass

(*Bromus tectorum*) communities had lowest species richness and diversity of all 8 communities sampled. Mean height and density of woody species were significantly greater in exclosures of *Salix* spp.-mixed dicot (gravel bar) communities. Disturbance associated with moderate stocking rates did not adversely affect the plant community properties sampled. Results of this study indicate that the effects disturbance (livestock grazing) on species diversity and biomass varies from one community to another.

Key Words: riparian, livestock grazing, species diversity, disturbance

Introduction

Riparian ecosystems are important locations or sources of biological diversity. This high level of diversity is the result of hydrological disturbance, variable deposition of sediments and germplasm, as well as the presence of water. Natural disturbance processes such as periodic high flows create new sites for vegetation establishment (Swanson et al. 1982, Jensen and Platts 1987). The diverse nature of riparian ecosystems is also reflected by the disproportionately larger concentration of wildlife species compared to adjacent uplands (Brode and Bury 1984).

Riparian areas are critical linkages between instream and terrestrial ecosystems. Thus, the condition of riparian vegetation can influence: a) the structure and stability of stream banks (Platts 1979, Swanson et al. 1982, Harmon 1986, Robinson and Beschta 1990), b) solar energy input through shading that influences temperature changes (Meehan et al. 1977), and provides an important energy and nutrient source for instream ecosystems. This is especially important in low order stream systems (Cummins and Spengler 1978). In addition, vegetation associated with intact riparian areas decreases overland sediment inputs into the stream (Brown 1983, Cooper et al. 1987, Heede 1990). Riparian areas also influence nutrient dynamics of stream ecosystems (Triska et al. 1982, Peterjohn and Correll 1984, Hussey et al. 1985, Green and Kauffman 1989).

Livestock grazing is often selective in nature (Vallentine 1990). This selective defoliation causes shifts in species composition of plant communities (Harper 1977). Plant species that decrease under grazing tend to be: 1) relatively short lived colonizing perennials; 2) relatively palatable and nutritious to large grazers; 3) intermediate in growth rate and life history traits between weedy annuals (ruderals) and long lived competitively dominant perennials (Louda et al. 1990). The response of plant species is also dependent on timing, amount removed and availability of resources for regrowth (Coughenour et al. 1985, Polley and Detling 1989).

Many livestock grazing strategies have been discussed for riparian area rehabilitation or maintenance. These range from livestock exclusion to management of riparian areas as special use pastures (see review by Platts 1989). However, studies have shown little benefit to the riparian ecosystem from specific grazing strategies. Stream bank stability was not significantly different under four grazing strategies (deferred rotation, time controlled, season long and exclusion) during three years of study in southwestern Montana (Marlow et al. 1989). In reviewing 17 grazing strategies Platts (1989) stated that as use went from heavy to none the compatibility for fishery needs increased from poor to high. Results of other studies in both uplands and riparian indicate that in general, intensity of use is of greater importance than the specific grazing scheme utilized (Van Poolen and Lacy 1979, Skovlin 1984, Clary and Webster 1989).

Little information is available on the amount of livestock utilization that will not negatively influence maintain integrity of the riparian ecosystem. In wet meadows of the Sierra Nevada, 35 to 45 % utilization was found to maintain an "excellent" condition (76-100 % of climax species composition) (Ratliff et al. 1987). Riparian areas in southwestern Montana were classified as excellent, good, or improving condition if vigorous woody plant growth and at least 15 cm of stubble height remained at the end of the growing season (Meyers 1989).

Although cattle grazing impacts on riparian vegetation have been studied in some detail, few studies have actually quantified vegetation response over many years in a mix of communities of the same riparian system. This is of great importance as the net impact of grazing on individual species is expected to differ due to differential availability of resources, opportunities for regrowth, and pressure exerted by livestock on each species.

Without such information, it is difficult to predict longterm livestock impacts on plant community composition and succession. This leaves land managers without a sound basis for management decisions at a time when interest in riparian ecosystems is particularly high. The objective of this study were quantify changes in species composition and productivity over 10 years of exclosure and late season grazing in eight riparian plant communities.

Study Site

The study site is located in the Wallowa Mountains of northeastern Oregon on land administered by the Eastern Oregon Agricultural Research Center. The study site is approximately 100 ha in size, and extends for about 3 km along Catherine Creek. Catherine Creek is a third order tributary to the Grande Ronde River. Average discharge is 3.4 m^3/sec with peak flows occurring from April to early June (USGS 1987). During the spring runoff period, peak flows of over 14.3 m^3 sec^{-1} commonly occur. Elevation of the study site is approximately 1030 m. Mean annual precipitation for the study site is 600 mm, the majority of which falls as snow during the winter months. The closest weather station is located 19 km northwest of the study site in Union, Oregon (45°13'N and 117°53'W). Elevation of the Union weather station is 841 m. Mean annual precipitation at Union is 355 mm. Precipitation received at Union in 1980 and 1989 was 5.8 and 1.2 mm above average, respectively. Precipitation in 1979, 1987 and 1988 was 45, 102 and 57 mm below average.

On this study area, Kauffman (1982) subjectively segregated the study area into 256 stands of vegetation representing 60 plant communities in the Catherine Creek riparian area. Plant communities the current study were selected to provide a continuation of the study conducted by Kauffman (1982) and represent the 8 most widely occurring plant communities in the study area. The 8 plant communities were: *Poa pratensis* - *Phleum pratense* - *Carex* spp. - mixed dicot (moist meadows), *Poa pratensis* - mixed dicot (dry meadows), *Bromus tectorum* (cheatgrass), *Pinus ponderosa* / *Poa pratensis* (ponderosa pine / Kentucky bluegrass), *Populus trichocarpa* - mixed conifer (black cottonwood), *Alnus incana* / *Poa pratensis* (thinleaf alder / Kentucky bluegrass), (*Crataegus douglasii* / *Poa pratensis* (black hawthorn / Kentucky bluegrass), and *Salix* spp.-mixed dicot (gravel bars). The majority of stands sampled in 1979 and 1980 by Kauffman (1982) and Kauffman et al. (1983) were the same stands sampled in this study.

Plant community descriptions

Poa pratensis-Carex spp. communities

Poa pratensis-Carex spp. communities are dominated by *Poa pratensis* L. with *Phleum pratense* L. and various sedges occurring as codominants. The most abundant dicots include *Achillea millefolium* L., *Aster foliaceus* Lindl., *Collomia linearis* Nutt., *Collinsia parviflora* Lindl., *Epilobium paniculatum* Nutt. Ex T. & G., *Fragaria virginiana* Duchsne, *Geum macrophyllum* Willd., *Lathyrus polyphyllus* Nutt., *Potentilla gracilis* Dougl. Ex Hook., *Ranunculus acris* L., *Stellaria longipes* Goldie., *Veronica arvensis* L., *Viola adunca* Sm., and *Vicia americana* Mul. Ex Willd.. Common graminoid species include *Agrostis alba* L., *Phleum* *pratense*, *Poa pratensis*, *Carex nebraskensis* Dewey, *Carex rostrata* Allioni, and *Juncus balticus* Willd..

Poa pratensis-*Carex* spp. communities occur in areas of restricted drainage, generally where a clay to silt textured A horizon is underlain by a coarse sand or gravel layer. Mottling occurs at about 18 to 25 cm depth and standing water is common until June (personal observation).

Poa pratensis-mixed dicot communities

Based on examination of aerial photographs, *Poa pratensis*-mixed dicot communities are the most widespread communities in the study area. These communities are dominated by *Poa pratensis* with large a variety of perennial and annual dicots. *Achillea millefolium*, *Aster foliaceus*, *Epilobium paniculatum*, *Ranunculus acris*, *Lupinus leucophyllus* Dougl. Ex Lindl., *Trifolium repens* L., *Collinsia parviflora*, *Draba verna* L., and *Medicago lupulina* L., are the most commonly occurring dicot species. Graminoid species frequently encountered in *Poa pratensis*-mixed dicot communities are *Agrostis alba*, *Bromus mollis* L., *Phleum pratense*, and *Festuca elatior* L..

Soils of *Poa pratensis*-mixed dicot communities are among the deepest and most highly developed of the study site. Profile depths range from 60 to 170 cm with A horizon depths of 20 to 45 cm and loam to silt loam textures.

Bromus tectorum communities

These communities are dominated by *Bromus tectorum* L. and other annual species. Dicots with the highest frequencies include *Epilobium paniculatum*, *Erodium cicutarium* (L.) Loher., *Lepidium perfoliatum* L., *Polygonum douglasii* Greene, and *Rumex acetosella* L.. *Bromus mollis* is the only other graminoid species besides *Bromus tectorum* that regularly occurs within these communities.

Bromus tectorum communities are found in highly disturbed areas away from the stream channel. These sites are usually associated with old stream channels and ditch spoils. Soils are poorly developed with rocky surfaces and coarse textures.

Pinus ponderosa communities

Pinus ponderosa communities consist of an overstory layer dominated by *Pinus ponderosa* Dougl. Ex Loud. with a shrub layer of *Crataegus douglasii* Lindl. or *Symphoricarpos albus* (L.) Blake]. Common herb species are *Achillea millefolium*, *Collinsia parviflora*, *Montia perfoliata* (Donn) How., *Smilacina stellata* (L.) Desf., *Vicia americana*, *Viola adunca*, *Bromus tectorum*, *Elymus glaucus* Buckl., and *Poa pratensis*.

Pinus ponderosa communities occur on well drained sites in the study area with A horizons ranging from 15 to 50 cm thick over coarse textured, gravelly C horizons.

Populus trichocarpa communities

The *Populus trichocarpa* dominated communities consist of an overstory of *Populus trichocarpa* T. & E. Ex Hook. with an occasional *Pinus ponderosa*, *Abies grandis* (Doug.) Lindl., *Larix occidentalis* Nutt.. Dominant dicot species in the understory of these communities are *Achillea millefolium*, *Galium asperrimum* Gray, *Osmorhiza chilensis* H. & A., *Smilacina stellata*., *Ranunculus acris*, *Senecio pseudareus* Rydb.. *Elymus glaucus*, *Poa pratensis*, and *Carex* spp. are common graminoids.

Populus trichocarpa communities are found further from the stream than *Alnus incana* communities. Soils of *Populus trichocarpa* communities are slightly deeper and more well developed than those of *Alnus incana* communities.

Alnus incana communities

The *Alnus incana* dominated communities typically have an understory dominated by *Poa pratensis* and other perennial and annual dicot species. In the moister microsites within the understory of, *Poa pratensis* is often replaced by *Scirpus microcarpus* Presl. or *Carex* spp. Dominant dicot species of *Alnus incana* communities include *Achillea millefolium*, *Gallium asperrimum*, *Geum macrophyllum* Willd., *Montia perfoliata*, *Prunella vulgarus* L., *Ranunculus acris*, *Taraxacum officinale* Weber, and *Aster foliaceus*. Graminoid species most commonly found are *Poa pratensis*, *Glyceria striata* (Lam.) A. S. Hitcho., *Scirpus microcarpus* and many *Carex* spp..

Alnus incana communities are found parallel to Catherine Creek bordering the stream channel. This community also occurs in areas of high water table further away from the stream. Coarse sands and gravels overlain by a layer of fine silts up to 25 cm deep characterize the soils of *Alnus incana* communities.

Crataegus douglasii communities

Common dicots in *Crataegus douglasii* communities include *Achillea millefolium*, *Aster foliaceus*, *Collinsia parviflora*, *Fragaria virginiana*, *Galium asperrimum*, *Medicago lupulina*, *Microsteris gracilis* (Hook.) Greene, *Montia perfoliata*, *Ranunculus acris*, *Senecio pseudareus*, *Trifolium repens* L., *Taraxacum officinale*, *Trillium petiolatium* Pursh., *Viola adunca*. Common graminoid species are *Poa pratensis* and *Agrostis alba*. *Crataegus douglasii* communities vary from relatively open to almost total canopy cover.

Crataegus douglasii communities are found on loam to silt loam textured soils. Soil profiles range from 70 to 80 cm depth to a stone layer of fluvial nature.

Salix spp.-mixed dicot communities

Salix spp.-mixed dicots are early seral communities dominated by one or more species of the Salicaceae. These communities vary from ecology young gravel bars with little cover from either herbaceous or woody species to almost total canopy closure in exclosures. The most common woody species are seedlings of *Alnus incana*, *Populus trichocarpa*, *Salix exigua* Nutt., and *Salix ridgia* (Hook.) Cronq.. Common dicots include *Achillea millefolium*, *Cerastium viscosum* L., *Aster foliaceus*, *Equisetum arvense* L., *Heterocodon rariflorum* Nutt. Lax., *Medicago lupulina*, *Collomia linearis* Nutt., *Prunella vulgaris*, *Ranunculus acris*, *Taraxacum officinale*, *Trifolium repens*, *Trifolium pratense* L., and *Verbascum thapsus* L.. Common graminoid species include *Arostis alba*, *Agrostis exarata* Trin., *Bromus mollis*, *Phleum pratense*, *Poa compressa* L., *Poa pratensis*, *Vulpia myuros* L., *Juncus ensifolius* Wilsk., and numerous *Carex* spp.. *Salix* spp.-mixed dicot communities border the stream or occur as islands in the stream channel.

Soils are derived from unconsolidated alluvium ranging from silt sized particles to stone or cobble sized materials. *Salix* spp.-mixed dicot communities are often inundated with flowing water during peak flows in spring. Because of their proximity to the stream channel and inundation in spring these communities are often transitory in nature. For example, all sampled exclosed *Salix* spp.-mixed dicot communities were removed by channel changes the spring 1989, runoff period.

Methods

In 1978, five livestock exclosures were constructed alternating with grazed portions of the riparian area. The exclosures covered approximately one half of the riparian area within 50 meters of the stream. Since 1978, grazing has begun in late August and continued for 3 to 4 weeks. Stocking rates ranged from 1.3 to 1.8 ha/AUM.

To determine successional dynamics and species changes we quantified species frequency, diversity (H′), evenness (J′), and biomass in each community. In addition, we quantified mulch and root biomass of the *Poa pratensis*-mixed dicot and *Poa pratensis*-*Carex* spp. communities as well as shrub density and height of *Salix* spp.-mixed dicot communities.

Species changes over 10 years of grazing and nongrazing were quantified using species frequency. A 25X25 cm quadrat was used for frequency measurements. Thirty plots were measured in six stands of each community. One half of the replications were in the grazed areas and the other half of the replications were located in the exclosures. Frequency sampling was done from late June to early July when most perennial species were in a phenological stage that would facilitate identification.

Values for plant species diversity and evenness were calculated from frequency data using the AIDN program (Overton et al. 1987). The Shannon index (H′) (Shannon and

Weaver 1949) was selected to evaluate diversity as it provides an intermediate weighing of rare species compared to Simpson's index (λ) and Hill's first number (N1) (Peet 1974). The Shannon index (H') is calculated as follows: $H' = -\Sigma p_{ij} \log_e p_{ij}$ were p_{ij} is the frequency of the i^{th} species of the j^{th} sample unit and a sample unit is a replication of a plant community. Pielou's J' was selected to evaluate evenness where $J' = H'/H'|max$ (Pielou 1975). J' expresses species diversity relative to the maximum value of species diversity when all species in a community are equally common. H'|max is calculated as the $\log_e S$. S is species richness, the number of species in the community (Ludwig and Reynolds 1988). Minor differences in values of species richness, diversity, and evenness between this paper and earlier reported values (i.e. Kauffman 1982, Kauffman et al. 1984) reflect consolidation of certain species in the 1979 and 1980 data sets.

Aboveground biomass dynamics were also determined utilizing a 25X25 cm quadrat. The same six replications of each community were sampled. Ten 25X25 cm quadrats in each replicate were clipped to ground level and biomass was dried for 48 hours at 60°C. Dominant graminoid and dicot species were separated before drying. Mulch was collected at the same time as biomass and dried following the same procedure.

To determine successional dynamics of riparian woody species in *Salix* spp.-mixed dicot communities, shrub density, height, and composition was measured in 10 one X one meter plots in each community. Six replicate stands located on *Salix* spp.-mixed dicot communities were sampled with one half of the replications located in grazed areas and other half located in exclosures.

To examine grazing effects on belowground biomass of *Poa pratensis-Carex* spp. and *Poa pratensis*-mixed dicot communities was sampled to a depth of 10 cm using a soil augar with a seven cm diameter. Six replications of grazed and exclosed treatments were collected. Soil samples were carefully washed using a series of soil sieves down to a one mm mesh.

Analysis of each plant community also included selection of 4 to 5 key plant species in each community to provide comparison between exotic and native species. Species selected commonly occurred in each community over the study period. Changes both between years within treatments and within years between treatments were tested.

Changes in individual species frequency between years and treatments were tested using a 2X4 factorial design (Steele and Torrie 1980). Factors included treatments (grazed and exclosed) and years (1979, 1980, 1987 and 1998). Data were arcsine transformed where necessary to meet statistical assumptions (Ahrens et al. 1990). Changes in standing biomass were tested using Student's t-test (Steele and Torrie 1980).

Nonparametric analysis of variance (Kruskal-Wallis procedure) (Zar 1984) was used to detect changes in species richness, species diversity, and evenness between communities within years and treatments. When a significant change occurred in species richness, species diversity, or evenness, a nonparametric Tukey multiple comparison test were used to separate differences (Zar 1984). Significance limits for all tests were set at $P \leq 0.1$ due the highly heterogenous nature of riparian ecosystems.

Differences between years within treatments and between treatments within years for shrub densities, litter and root biomass were tested using Student's t test (Steele and Torrie 1980).

Results

Poa pratensis-Carex spp. communities

Utilization of *Poa pratensis-Carex* spp. communities ranged from 73 to 60 percent (Table II.1). Livestock use of these communities was second only to *Poa pratensis*-mixed dicot communities.

Total species richness in *Poa pratensis-Carex* spp. communities ranged from 29 to 66 over the study period (Table II.1). Exotic species accounted for 28 to 37% of total species richness in exclosures. Exotics ranged from 27 to 41% of total species richness in grazed communities. In the grazed communities the percentage of exotic species declined from 41% in 1979 to 27% in 1989. Significantly higher species richness occurred in the grazed than exclosed treatments of *Poa pratensis-Carex* spp. communities in 1989 (Table II.1). Values for species diversity ranged from 2.7485 to 3.5541 with no significant differences detected within treatments between years. Species diversity was significantly higher in grazed *Poa pratensis-Carex* spp. communities than ungrazed treatments in 1989. No significant differences were found for evenness between years within treatments. Within year treatment comparisons revealed higher evenness in the

Table II.1. Species richness (S), percent exotics, species diversity (H′), species evenness (J′), and percent utilization for all species in grazed and exclosed *Poa pratensis-Carex* spp. communities along the Catherine Creek study site.

	Year 1979	1980	1987	1989
	Exclosed			
S	29	49	53	55*
Percent Exotics	37	31	28	35
H′	2.7485	3.2041	3.4104	3.5026*
J	0.81624*	0.82330	0.8613	0.87404
Percent Utilization	2	T	1	--§
	Grazed			
S	48	52	46	66
Percent Exotics	41	27	33	27
H′	3.0552	3.3148	3.2554	3.5541
J	0.78921	0.83490	0.85519	0.84528
Percent Utilization	73	59	60	--

* Significant difference between treatments within year ($P \leq 0.1$).
§ Data not collected.

exclosed treatment (0.81624) than the grazed treatment (0.78921) in 1979; other comparisons were not significant.

Species chosen for analysis of frequency were *Achillea millefolium*, *Ranunculus acris*, *Taraxacum officinale*, *Phleum pratense*, and *Poa pratensis* (Table II.2). Frequencies of *Achillea millefolium*, *Taraxacum officinale*, and *Poa pratensis* were not significantly different between treatments within years or within treatments between years. The frequency of *Phleum pratense*, an exotic species, decreased significantly in the exclosed treatment from 1979 to 1989. *Ranunculus acris* also an exotic species declined in abundance for 1987 and 1989 in the exclosed treatment.

Partitioning of aboveground biomass between species revealed that exotic species had lower standingcrops in exclosures (Table II.3). Carex spp. appeared to be increasing in biomass within the exclosures. Standing biomass of grazed *Poa pratensis* and *Phleum pratense* was significantly less in the exclosed treatment than grazed areas in 1989 (Table II.3). Both *Phleum pratensis* and *Achillea millefolium* had higher biomass in grazed than exclosed areas in 1987. Total standing biomass of grasses was significantly greater in exclosed than grazed treatments in 1989. Other comparisons between treatments within years and within treatments between years were not significant.

Table II.2. Mean percent frequency for selected species in grazed and exclosed *Poa pratensis*-*Carex* spp. communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Achillea millefolium	33.3	52.2	37.8	44.4
Ranunculus acris	55.5	80.3	16.7*	12.2*
Taraxacum officinale	52.2	57.8	26.6	17.8
Phleum pratense	33.3*	40.0*	7.8*	3.3*
Poa pratensis	100.0	100.0	70.0	80.0
	Grazed			
Achillea millefolium	55.5	53.3	51.1	57.8
Ranunculus acris	52.2	58.9	58.9	71.1
Taraxacum officinale	48.9	54.4	35.6	36.7
Phleum pratense	70.0	85.6	74.4	76.7
Poa pratensis	100.0	100.0	100.0	100.0

* Significant difference between treatments within year ($P \leq 0.1$).

Table II.3. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Poa pratensis-Carex* spp. communities along the Catherine Creek study site.

	Year			
	1987	1989	1987	1989
Species	Exclosed		Grazed	
Achillea millefolium	14±14*	126±78	180±40	115±67
Carex spp.	574±874	641±451	264±205	275±204
Phleum pratense	24±14*	0±0*	758±86	414±146
Poa pratensis	817±488	831±327*	2026±832	1570±397
Ranunculus acris	12±6	9±9*	35±12	33±8
Taraxacum officinale	8±7	8±8	131±122	54±12
Grass	883±759	933±229*	2898±708	2449±432
Dicots	783±533	1556±543	573±99	899±273
Grasslikes	651±49	676±446	1052±836	693±442
Total	2317±613	3165±777	4513±1126	4031±746

* Significant difference between treatments within year ($P \leq 0.1$).

Belowground biomass of *Poa pratensis-Carex* spp. communities was almost twice that of the exclosed treatment, 4140 g/m^2 and 2542 g/m^2 respectively (Table II.4). Mulch biomass displayed the opposite relationship with significantly less mulch in the grazed treatment.

Poa pratensis-mixed dicot communities

Poa pratensis-mixed dicot communities were the most highly preferred communities. Utilization of *Poa pratensis*-mixed dicot communities ranged from 70 to 67 percent (Table II.5). Livestock utilization greatly affected measured parameters in this community.

Species richness in *Poa pratensis*-mixed dicot communities ranged from 23 to 38 in exclosures and from 44 to 60 in grazed areas (Table II.5) over the study period. The percentage of exotics in the exclosed areas declined form 57 to 47% from 1979 to 1989. Total species richness contributed by exotics in grazed areas remained relatively constant at 37%. In the exclosures, species richness was significantly higher in 1989 than in 1979. Species such as *Antennaria rosea*, *Montia perfoliata*, and *Lithophragma parviflora* were recorded for the first time in exclosures of *Poa pratensis*-mixed dicot communities. Significant differences within years and between treatments also occurred. For all years studied, species richness was

Table II.4. Mean mulch and belowground biomass (kg ± standard error) of exclosed and grazed *Poa pratensis-Carex* and *Poa pratensis*-mixed dicot communities along the Catherine Creek study site.

	Moist Meadows		Dry Meadows	
	Exclosed	Grazed	Exclosed	Grazed
Mulch	358±37*	151±46	444±35*	86±13
Belowground Biomass	2542±459*	4140±647	2805±451*	5054±405

* Significant difference between treatments ($P \leq 0.1$).

Table II.5. Species richness (S), percent exotics, species diversity (H′), species evenness (J′), and percent utilization for all species in grazed and exclosed *Poa pratensis*-mixed dicot communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
S	23a[1]*	33ab*	32ab*	38b*
Percent Exotics	57	45	71	47
H′	2.2122a*	2.7902ab*	2.6589ab*	2.8824b*
J	0.70554	0.80342	0.76719*	0.76791*
Percent Utilization	1	T	1	--§
	Grazed			
S	44	57	66	60
Percent Exotics	34	39	38	37
H′	2.7626a	3.2858ab	3.4986ab	3.5541b
J	0.75406a	0.81270ab	0.82916ab	0.86805b
Percent Utilization	70	67	48	--

[1] Data in the same row followed by a different letter are significantly different within treatment ($P \leq 0.1$).
* Significant difference between treatments within year ($P \leq 0.1$).
§ Data not collected.

significantly lower in the exclosed areas of *Poa pratensis*-mixed dicot communities.

During the course of the study, community species diversity increased significantly 2.2122 to 2.8824 and from 2.7626 to 3.5541 from 1979 to 1989 in exclosed and grazed areas, respectively. This may reflect the establishment of more native species in exclosures of this community as the percentage of exotics. (Table II.5). For all years, species richness and species diversity was significantly lower in the exclosed areas. Evenness showed no significant differences between years in the exclosed stands. However, in the grazed areas evenness increased significantly from 0.75406 to 0.86805 from 1979 to 1989. Between treatments, significant differences occurred for evenness in 1987 and 1989 where the grazed treatment had a higher evenness than the exclosed treatment (Table II.5). Indicating that in grazed areas, species were more equally abundant than in exclosures.

Species chosen for analysis of frequency were *Achillea millefolium*, *Aster foliaceus*, *Bromus mollis*, and *Poa pratensis* (Table II.6). No significant differences due to treatments within years or years within treatments were found for *Aster foliaceus* or *Poa pratensis* in *Poa pratensis*-mixed dicot communities. Other comparisons between years were not significant. *Achillea millefolium* and *Bromus mollis* showed significant differences due to

Table II.6. Mean percent frequency for selected species in grazed and exclosed *Poa pratensis*-mixed dicot communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Achillea millefolium	34.2*	27.5	27.5*	37.5*
Aster foliaceus	10.8	18.3	21.7	20.0
Bromus mollis	5.8	7.4	1.8*	0.8*
Poa pratensis	100.0	100.0	100.0	100.0
	Grazed			
Achillea millefolium	65.0	49.2	76.7	70.8
Aster foliaceus	18.3	17.5	35.8	24.2
Bromus mollis	1.7	11.7	40.8	47.5
Poa pratensis	100.0	100.0	100.0	100.0

* Significant difference between treatments within year ($P \leq 0.1$)

treatments. *Achillea millefolium* was significantly less frequent in the exclosed than the grazed treatment in 1979, 1987, and 1989. *Bromus mollis* was also less frequent in both the 1987 and 1989 exclosed treatment. The alien species, *Bromus mollis* increased dramatically, from 1.7% to 47.5%, in the grazed treatment from 1979 to 1989 while at the same it displayed a declining trend in the exclosures.

In addition to dramatic changes in species composition, differences in aboveground biomass were also striking. Aboveground biomass of the exotic species, *Poa pratensis* and *Bromus mollis* was significantly lower in exclosures in 1989 compared to 1987 (Table II.7). *Achillea millefolium* had significantly higher aboveground biomass in the grazed treatment in 1987 than 1989. In 1989, biomass estimates for *Bromus mollis* and total standing biomass were significantly higher in the grazed than the exclosed areas. In these communities it appears that livestock herbivory is modifying environmental conditions and thus may be maintaining a grazing adapted community. No significant differences were found for other comparisons between treatments within years and between years within treatments.

Belowground biomass and mulch relationships paralleled those of *Poa pratensis-Carex* spp. communities with significantly higher mulch and lower belowground biomass in exclosures (Table II.4).

Table II.7. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Poa pratensis*-mixed dicot communities along the Catherine Creek study site.

	Year			
	1987	1989	1987	1989
Species	Exclosed		Grazed	
Achillea millefolium	55±33	75±34	132±28+	44±10
Aster foliaceus	145±145	242±242	76±76	161±65
Bromus mollis	7±7+	0±0*	38±24	270±56
Poa pratensis	1840±775+	1028±383	1323±199	836±38
Grass	1907±716	1048±383	1689±298	1634±74
Dicots	247±193	438±250	1130±588	446±64
Total	2154±542	1485±217*	2819±768	2069±135

* Significant difference between treatments within year ($P \leq 0.1$).
\+ Significant difference between years within treatments ($P \leq 0.1$).

Bromus tectorum communities

Bromus tectorum communities were the least preferred of all communities sampled with utilization not exceeding 2% (Table II.8). This is most likely due to the unpalatable nature of forage found in this community when cattle were present. This low rate of utilization was one factor that contributed to few changes occurring over time in this community.

Abundance of exotic species in *Bromus tectorum* communities was higher than all other communities. Exotic species ranged from 50% of total species richness in 1979 to 57% in 1989 in exclosures. In grazed communities, exotics ranged from 46% in 1979 to 61% of total species richness in 1989 (Table II.8). Species diversity ranged from 2.2122 to 2.8540 in exclosures and from 2.3414 to 2.8511 in grazed areas. There were no significant effects for either species richness or species diversity when compared between treatments within years or between years within treatments. Evenness ranged from 0.7254 to 0.8496 in the exclosures. Evenness within the grazed *Bromus tectorum* communities was significantly higher in 1989 than 1979 (0.81307 vs 0.72551). No significant differences were found for species richness, species diversity, or evenness between treatments within years in *Bromus tectorum* communities.

Table II.8. Species richness (S), percent exotics, species diversity (H′), species evenness (J′), and percent utilization for all species in grazed and exclosed *Bromus tectorum* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
S	18	23	22	23
Percent Exotics	50	57	59	57
H′	2.2122	2.8540	2.5617	2.5867
J	0.72540	0.72889	0.83501	0.84963
Percent Utilization	T	T	T	--§
	Grazed			
S	26	26	26	23
Percent Exotics	46	50	58	61
H′	2.4394	2.3414	2.8511	2.5494
J	0.72551a[1]	0.71864ab	0.79223ab	0.81307b
Percent Utilization	2	1	2	--

[1] Data in the same row followed by a different letter are significantly different within treatment ($P \leq 0.1$).
§ Data not collected.

Species chosen for analysis of frequency were *Epilobium paniculatum*, *Erodium cicutarium*, and *Bromus tectorum* (Table II.9). In the exclosed treatment, *Bromus tectorum* declined while *Erodium cicutarium* increased in abundance. However, this may be the result of factors other than grazing. No significant differences were found between years within treatments or between treatments within years.

In *Bromus tectorum* communities, aboveground biomass of *Epilobium paniculatum* significantly increased in 1989 in both treatments (Table II.10). Within the grazed treatment biomass of *Erodium cicutarium* was significantly higher in 1989 than 1987. Dicot species had significantly higher above ground biomass in the exclosed treatment in 1989 than 1987. Total aboveground biomass was significantly higher in 1989 in the grazed treatment (878 kg ha^{-1}) compared to the exclosed treatment (318 kg ha^{-1}). Aboveground biomass also displayed the same trend in 1989. All other comparisons between treatments within years and between years within treatments were not significant.

Pinus ponderosa communities

Livestock utilization of *Pinus ponderosa* communities was low, reflecting their use primarily as shade and resting cover. Utilization of these communities ranged from 10 to 27 percent (Table II.11). Despite the

Table II.9. Mean percent frequency for selected species in grazed and exclosed *Bromus tectorum* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Epilobium paniculatum	21.1	38.9	18.9	23.2
Erodium cicutarium	18.9	41.1	47.8	38.9
Bromus tectorum	97.8	98.9	82.2	86.7
	Grazed			
Epilobium paniculatum	27.8	31.1	17.8	50.0
Erodium cicutarium	36.8	53.3	31.1	44.4
Bromus tectorum	97.8	96.7	96.8	93.8

Table II.10. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Bromus tectorum* communities along the Catherine Creek study site.

Species	Exclosed 1987	Exclosed 1989	Grazed 1987	Grazed 1989
Bromus tectorum	182±149	98±46	772±324	285±146
Epilobium paniculatum	7±3+	37±9	5±3+	58±24
Erodium cicutarium	11±9+	19±10*	7±3+	66±17
Grass	262±206	315±155	785±323	332±132
Dicots	56±18+	259±69	94±31	302±198
Total	318±196+	574±152	878±345	634±327

* Significant difference between treatments within year ($P \leq 0.1$).
[+] Significant difference between years within treatments ($P \leq 0.1$).

Table II.11. Species richness (S), percent exotics, species diversity (H′), species evenness (J′), and percent utilization for all species in grazed and exclosed *Pinus ponderosa* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
S	33	37	32	31*
Percent Exotics	42	35	34	35
H′	3.0031	2.6679*	2.8667	2.8038*
J	0.83804	0.73884*	0.82716	0.81648*
Percent Utilization	T	T	T	--§
	Grazed			
S	46	44	50	51
Percent Exotics	35	34	32	29
H′	3.0349	3.0077	3.36679	3.33944
J	0.79726	0.79482	0.85895	0.86331
Percent Utilization	17	10	27	--

* Significant difference between treatments within year ($P \leq 0.1$).
§ Data not collected.

relatively low level of utilization, significant changes did occur for some community parameters and species abundances.

Species richness for *Pinus ponderosa* communities ranged from a low of 32 in the 1987 exclosed treatment to a high of 51 in the 1989 grazed treatment (Table II.11). Species richness between years within treatment remained approximately constant from 1979 to 1989. The percentage of exotic species declined form 42 to 35% in exclosures and from 35 to 29% in grazed areas from 1979 to 1989. Significant differences occurred between treatments within years with lower species richness in the exclosed treatment in 1989. Total species diversity and evenness were significantly higher in the grazed treatment in 1980 and 1989, possibly reflecting the effects of livestock grazing. Even at the low levels of utilization livestock grazing may be maintaining niches for some species while altering the resource acquisition abilities of other species, thus increasing species diversity and evenness. Other comparisons in *Pinus ponderosa* communities were not significant.

Montia perfoliata, *Ranunculus acris*, *Elymus glaucus*, and *Poa pratensis* were selected for analysis of frequency (Table II.12). *Elymus glaucus*, a native graminoid increased significantly from 0 to 47.8% in the exclosures. Increases of *Elymus glaucus* in the grazed areas were not

Table II.12. Mean percent frequency for selected species in grazed and exclosed *Pinus ponderosa* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Montia perfoliata	0.0a[1]	47.8b	31.1b	46.6b
Ranunculus acris	6.7	7.8	0.0	0.0*
Elymus glaucus	0.0a	24.5a	44.5b	47.8b
Poa pratensis	98.9a	96.7a	74.4b	61.1b*
	Grazed			
Montia perfoliata	1.1a	20.0ab	32.2ab	34.5b
Ranunculus acris	3.3	20.0	10.0	9.6
Elymus glaucus	6.7	4.4	22.2	28.9
Poa pratensis	100.0	100.0	83.3	95.6

[1] Data in the same row followed by a different letter are significantly different within treatment ($P \leq 0.1$).
* Significant difference between treatments within year ($P \leq 0.1$).

significant. Frequencies of *Ranunculus acris* and *Poa pratensis*, both exotic species, were significantly higher in grazed than exclosed areas in 1989 (0.0 vs 19.6% and 61.6 vs 95.6%, respectively). Other treatment differences within years were not significant for these species. The exotic species *Poa pratensis*, had a significantly lower frequency in 1987 and 1989 than 1979 or 1980 in the exclosed treatment. *Montia perfoliata* showed significant increases in 1989 from 0.0 to 46.6% in exclosures and from 1.1 to 34.5% in grazed treatments.

Aboveground biomass of selected species in *Pinus ponderosa* communities was not significantly different when compared between treatments within years or between years within treatment (Table II.13). However total grass as well as total aboveground biomass in the grazed areas were significantly higher when compared to the exclosed treatment in 1987 possibly reflecting the less robust nature of species in exclosures or increasing canopy closure of overstory *Pinus ponderosa*. Significantly higher grass biomass was found in 1989 than 1987 within the exclosed treatment. All other comparisons were not significant.

Table II.13. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Pinus ponderosa* communities along the Catherine Creek study site.

	Year			
	1987	1989	1987	1989
Species	Exclosed		Grazed	
Elymus glaucus	74±29	75±65	155±149	136±107
Montia perfoliata	2±2	3±2	1±1	4±2
Poa pratensis	115±58	194±13	202±122	239±119
Ranunculus acris	0±0	2±2	4±3	6±1
Grass	271±34*+	365±28	393±66	386±62
Dicots	96±53	92±56	268±132	210±138
Total	367±163*	457±126	631±74	596±188

* Significant difference between treatments within year ($P \leq 0.1$).
+ Significant difference between years within treatments ($P \leq 0.1$).

Populus trichocarpa communities

Populus trichocarpa communities had relatively low livestock utilization ranging from 9 to 15 percent (Table II.14). Livestock typically utilized these communities asthermal cover to a greater degree than rather than as foraging sites. The low rate of utilization in these communities had little effect of measured community parameters.

Total species richness of exclosed *Populus trichocarpa* communities ranged from 35 to 44 of which up to 33% were exotic species. Grazed *Populus trichocarpa* communities had similar species richness and percent exotic species. Grazed *Populus trichocarpa* communities had species diversity values ranging from 2.8391 to 3.1614. Values of evenness ranged from 0.77833 to 0.86602 and from 0.79854 to 0.85702 for grazed and exclosed areas respectively. As in *Pinus ponderosa* communities, evenness values in 1987 were significantly higher in the grazed areas, indicating that species abundances were more even between species. There were no other significant differences in species richness, species diversity, or evenness due to treatment between years within treatments.

Osmorhiza chilensis, *Ranunculus acris*, *Taraxacum officinale* and *Poa pratensis* were chosen for analysis of frequency (Table II.15). Within years, the alien species *Ranunculus acris* had significantly lower frequency in

Table II.14. Species richness (S), percent exotics, species diversity (H'), species evenness (J'), and percent utilization for grazed and exclosed *Populus trichocarpa* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
S	35	41	44	40
Percent Exotics	26	27	30	33
H'	2.8391	2.9802	3.1356	3.1614
J	0.79854	0.80251	0.82862*	0.85702
Percent Utilization	1	T	1	--§
	Grazed			
S	37	43	43	33
Percent Exotics	22	35	37	30
H'	2.4430	2.9502	3.2563	3.0280
J	0.74833	0.81704	0.86577	0.86602
Percent Utilization	11	9	1	--

* Significant difference between treatments within year ($P \leq 0.1$).
§ Data not collected.

Table II.15. Mean percent frequency for selected species in grazed and exclosed *Populus trichocarpa* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Osmorhiza chilensis	7.8	16.7	23.3	22.2
Ranunculus acris	24.4	24.4	18.9*	7.8*
Taraxacum officinale	48.9	35.6	24.4	21.1
Poa pratensis	96.7	96.7	67.8	74.4
	Grazed			
Osmorhiza chilensis	46.7	38.9	10.0	26.7
Ranunculus acris	38.9	32.2	61.1	44.4
Taraxacum officinale	37.8	38.8	32.2	22.2
Poa pratensis	100.0	100.0	100.0	72.2

* Significant difference between treatments within year ($P \leq 0.1$).

exclosed than grazed treatments. No other significant differences were found between years within treatments or between treatments within years. *Osmorhiza chilensis* increased in the exclosures over the study period. Aboveground biomass of a native, *Osmorhiza chilensis* was significantly higher in the exclosed treatment in 1987 and 1989, 25 kg ha^{-1} and 24 kg ha^{-1}, respectively (Table II.16). *Poa pratensis* biomass was significantly higher in the grazed areas than in the exclosures in 1989. No significant differences were found for other comparisons between treatments within years and between years within treatments.

Alnus incana communities

Utilization of *Alnus incana* communities was slightly higher than *Populus trichocarpa* communities, ranging from 14 to 16 percent (Table II.17). These communities, like others with a dense canopy, are used be livestock primarily as shade and resting cover.

Alnus incana communities had the lowest percent exotic species all other communities. The percent exotic species were slightly higher on average in the grazed areas (30 vs 25%). Species richness ranged from 40 in 1979 to 56 in 1987 (Table II.17). Species evenness ranged from 0.79381 to 0.8811 and species diversity ranged from 2.7485 to 3.4074. Significantly lower species diversity was found in

Table II.16. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Populus trichocarpa* communities along the Catherine Creek study site.

Species	Exclosed 1987	Exclosed 1989	Grazed 1987	Grazed 1989
Osmorhiza chilensis	4±3*	5±2*	25±1	24±3
Poa pratensis	562±128	623±58*	230±97	340±24
Ranunculus acris	9±6	7±4	0±0	13±7
Taraxacum officinale	9±8	9±6	1±1	4±3
Grass	661±103	819±45	359±148	486±54
Dicots	199±108	241±156	271±137	216±72
Total	860±203	1060±201	630±264	702±125

* Significant difference between treatments within year ($P \leq 0.1$).

Table II.17. Species richness (S), percent exotics, species diversity (H′), species evenness (J′), and percent utilization for grazed and exclosed *Alnus incana* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
S	40	55	43	48
Percent Exotics	23	25	26	27
H′	2.7485	3.1285	2.9859*	3.2239
J	0.85384	0.82184	0.79387	0.83278
Percent Utilization	5	3	3	--§
	Grazed			
S	48	45	56	49
Percent Exotics	31	22	34	33
H′	3.2216	3.1285	3.4074	3.4291
J	0.83219	0.82184	0.84648	0.8811
Percent Utilization	16	14	16	--

* Significant difference between treatments within year ($P \leq 0.1$)

§ Data not collected.

exclosed areas compared to grazed treatment in 1987. There were no other significant differences between treatments within years or between years within treatments.

Changes in species frequency displayed no consistent pattern in *Alnus incana* communities with some exotic species increasing and others declining in both treatments. Individual species chosen for analysis of frequency were *Aster foliaceus*, *Montia perfoliata*, *Ranunculus acris*, *Taraxacum officinale* and *Poa pratensis* (Table II.18). *Taraxacum officinale* had significantly lower frequency in the exclosed treatments than grazed treatments in 1989 despite low utilization in these communities. Analysis revealed no additional significant differences between treatments within years or between years within treatments.

Significantly greater aboveground biomass was found for grasslike species (*Carex* spp. and *Juncus* spp.) in the exclosed treatments in both 1987 and 1989 (Table II.19). There were no other significant differences for aboveground biomass between treatments within year or between years within treatments.

Crataegus douglasii communities

Livestock utilization of *Crataegus douglasii* communities ranged from 47 to 35 percent (Table II.20). Use was highest in areas of lowest canopy cover.

Table II.18. Mean percent frequency for selected species in grazed and exclosed *Alnus incana* communities along Catherine Creek.

	Year			
	1979	1980	1987	1989
	Exclosed			
Aster foliaceus	23.3	6.6	55.5	28.9
Montia perfoliata	17.8	26.7	12.2	26.7
Ranunculus acris	21.1	23.3	31.1	35.6
Taraxacum officinale	41.1	40.0	12.2	10.0*
Poa pratensis	66.7	86.7	84.4	67.7
	Grazed			
Aster foliaceus	24.4	25.5	28.9	8.9
Montia perfoliata	27.8	38.9	32.2	37.8
Ranunculus acris	37.8	45.6	43.3	68.9
Taraxacum officinale	37.8	49.9	37.8	43.3
Poa pratensis	82.2	95.5	72.2	65.6

* Significant difference between treatments within year ($P \leq 0.1$).

Table II.19. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Alnus incana* communities along the Catherine Creek study site.

Species	Year			
	1987	1989	1987	1989
	Exclosed		Grazed	
Aster foliaceus	81±52	77±39	65±32	59±25
Montia perfoliata	15±11	9±5	9±4	6±9
Poa pratensis	293±42	343±22	204±137	321±152
Ranunculus acris	26±22	24±20	16±10	16±6
Taraxacum officinale	24±10	31±13	3±2	6±3
Grasses	375±9	367±43	436±244	555±301
Dicots	370±98	439±127	226±25	294±48
Grasslikes	118±59*	153±55*	0±0	0±0
Total	863±49	950±65	662±268	849±341

* Significant difference between treatments within year ($P \leq 0.1$).

Table II.20. Species richness (S), percent exotics, species diversity (H′), species evenness (J′), and percent utilization for all species in grazed and exclosed *Crataegus douglasii* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
S	47	49*	50	60
Percent Exotics	36	35	36	32
H′	2.9821	3.0209*	3.2915	3.4777
J	0.77453	0.78462	0.84139	0.82168
Percent Utilization	1	3	2	--§
	Grazed			
S	53	59	51	57
Percent Exotics	36	29	33	26
H′	3.2951	3.3251	3.2212	3.4707
J	0.77921	0.82604	0.81925	0.85844
Percent Utilization	47	37	35	--

* Significant difference between treatments within year ($P \leq 0.1$).
§ Data not collected.

Utilization was the highest of any community with a canopy and lower than the meadow communities.

The percent of total species richness contributed by exotics declined from 1979 to 1989 in both treatments (Table II.20). Total species richness ranged from 47 to 54 and from 51 to 59 in exclosed and grazed areas respectively. Species richness was significantly lower in the exclosed treatments in 1980. Diversity was not significantly different between years within treatments, however diversity was significantly lower in the exclosed treatment in 1980 compared to the grazed treatment (3.0209 vs 3.3251). No significant differences were detected for evenness in any comparison within the *Crataegus douglasii* community.

Despite levels of utilization lower than meadow communities, significant changes in species frequency occurred in *Crataegus douglasii* communities. Species chosen for analysis of frequency were *Achillea millefolium*, *Aster foliaceus*, *Medicago lupulina*, *Taraxacum officinale*, and *Poa pratensis* (Table II.21). The frequency of all of these species declined from 1979 to 1989 in the grazed treatment. The abundance of *Achillea millefolium* declined in 1987 and 1989 was significantly higher in exclosures than grazed areas. No other significant differences were found for this species. Similar to other communities, *Taraxacum officinale* displayed significantly lower

Table II.21. Mean percent frequency for selected species in grazed and exclosed *Crataegus douglasii* communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Achillea millefolium	50.8	49.7	58.4*	67.5*
Aster foliaceus	28.3	18.3	45.0	41.7
Medicago lupulina	25.8	6.7	13.4	21.7
Taraxacum officinale	53.4a[1]	54.2a	14.2b	10.0b
Poa pratensis	100.0	100.0	100.0*	99.2*
	Grazed			
Achillea millefolium	39.2	50.0	17.5	22.5
Aster foliaceus	25.0	39.2	26.7	17.5
Medicago lupulina	29.2	11.7	3.4	5.0
Taraxacum officinale	49.2	51.7	23.3	26.7
Poa pratensis	97.5	100.0	85.8	70.9

[1] Data in the same row followed by the different letter are significantly different within treatment ($P \leq 0.1$).
* Significant difference between treatments within year ($P \leq 0.1$).

frequencies within the exclosed treatment in 1987 and 1989 compared to 1979 and 1980. Unlike other communities, the frequency of *Taraxacum officinale* declined in the grazed treatment from 49.2 in 1979 to 26.7 in 1989. Incontrast to other communities, *Poa pratensis* had significantly lower frequencies in the 1987 and 1989 grazed treatment.

Aboveground biomass of *Poa pratensis* was significantly greater in both the 1987 and 1989 exclosed treatments when compared to the grazed treatment (Table II.22). Total grass biomass was significantly higher in the exclosed than the grazed treatment in 1987. Within treatments, significantly greater total grass and total aboveground biomass occurred in the grazed treatment in 1989 than in 1987. Other comparisons between treatments within years and between years within treatments were not significant.

Salix spp.-mixed dicot communities

Utilization of *Salix* spp.-mixed dicot communities ranged from 47 to 35 percent (Table II.23). However livestock browsing had significant effects on both the density and height of woody species. Lateral channel movement during the spring of 1989 removed all *Salix* spp.-mixed dicot community sampling sites located in exclosures.

Salix spp.-mixed dicot communities had values of species richness ranging from 53 to 71 during the years sampled (Table II.23). Percent exotic species ranged from 30 to 31% in exclosed areas and from 30 to 38%

Table II.22. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Crataegus douglasii* communities along the Catherine Creek study site.

Species	Exclosed 1987	Exclosed 1989	Grazed 1987	Grazed 1989
Achillea millefolium	51±19	49±14	31±15	24±21
Aster foliaceus	76±30	102±23	35±14	34±22
Medicago lupulina	0±0	3±3	1±1	3±3
Poa pratensis	592±130*	633±102*	112±61	261±61
Taraxacum officinale	2±1	5±4	3±1	9±4
Grass	611±133*	674±114	286±62+	522±18
Dicots	338±83	481±76	202±114	445±152
Total	946±213	1155±190	488±152+	968±130

* Significant difference between treatments within year ($P \leq 0.1$).
\+ Significant difference between years within treatments ($P \leq 0.1$).

Table II.23. Species richness (S), percent exotics, species diversity (H'), species evenness (J'), and percent utilization for all species in grazed and exclosed *Salix* spp.-mixed dicot communities along the Catherine Creek study site.

	Year 1979	1980	1987	1989
	Exclosed			
S	53	59	54	-[1]
Percent Exotics	30	34	31	--
H'	3.1497	3.4736	3.4893	--
J	0.81199	0.85188	0.87474	--
Percent Utilization	2	T	2	--
	Grazed			
S	48	62	63	71
Percent Exotics	38	37	30	31
H'	3.0561	3.4347	3.6739	3.7214
J	0.82994	0.83552	0.88674	0.87301
Percent Utilization	19	40	24	--§

[1] Not sampled due to destruction of sites by high spring runoff.

§ Data not collected.highest of any community in the study area.

in grazed areas. Species diversity ranged from 3.1497 to 3.7214 with no significant differences detected within treatments between years or within years between treatments. There were no significant differences for values of evenness for any comparison within the *Salix* spp.-mixed dicot community. Species chosen for frequency analysis were *Achillea millefolium*, *Epilobium paniculatum*, *Prunella vulgaris*, *Poa compressa*, and *Poa pratensis* (Table II.24). No significant differences between years within treatments or within years between treatments were found for *Achillea millefolium*, *Epilobium paniculatum*, or *Poa pratensis*. Both *Prunella vulgaris* and *Poa canadensis* had higher frequencies in grazed treatments in 1989 than in any other year. Other comparisons between treatments or years were not significant for *Prunella vulgaris* or *Poa compressa*.

No significant differences were found for aboveground biomass of herbaceous on *Salix* spp.-mixed dicot communities either between years within treatments or between treatments within years (Table II.25).

Utilization of *Salix* spp.-mixed dicot communities ranged from 47 to 35 percent (Table II.23). However livestock browsing had significant effects on both the density and height of woody species. A total of 16 woody species were identified in shrub density and height transects in *Salix* spp.-mixed dicot

Table II.24. Mean percent frequency for selected species in grazed and exclosed *Salix* spp.-mixed dicot communities along the Catherine Creek study site.

	Year			
	1979	1980	1987	1989
	Exclosed			
Achillea millefolium	21.1	21.3	43.4	--
Epilobium paniculatum	23.3	17.8	20.0	--
Prunella vulgaris	7.8	18.9	33.4	--
Poa canadensis	11.1	4.4	8.4	--
Poa pratensis	16.7	21.1	43.4	--
	Grazed			
Achillea millefolium	40.0	54.4	30.0	38.9
Epilobium paniculatum	45.7	43.3	13.3	11.1
Prunella vulgaris	4.5a[1]	28.9a	26.7a	56.7b
Poa canadensis	2.2a	2.2a	10.0a	34.5b
Poa pratensis	30.0	34.4	55.5	53.4

[1] Data in the same row followed by a different letter are significantly different within treatment ($P \leq 0.1$).
[2] Not sampled due to destruction of sites by high spring runoff.

Table II.25. Standing biomass (kg ha^{-1}, mean ± standard error) for selected species in grazed and ungrazed *Salix* spp-mixed dicot communities along the Catherine Creek study site.

Species	Exclosed 1987	Exclosed 1989	Grazed 1987	Grazed 1989
Achillea millefolium	8±6	-	9±1	5±2
Poa pratensis	157±8	-	89±40	96±35
Prunella vulgaris	6±1	-	2±0	4±2
Poa compressa	30±21	-	7±4	8±5
Grass	256±90	-	174±62	275±52
Dicots	348±25	-	430±286	662±260
Total	605±65	-	604±36	937±342

communities in 1978 and 1988. Five of the most commonly occurring species were selected for detailed analysis, these were *Alnus incana*, *Populus trichocarpa*, *Salix bebbiana*, *Salix exigua*, and *Salix rigida* (Table II.26 and II.27). In 1988, mean height of all species in exclosures ranged from 99 to 202 cm and from 4 to 138 cm in grazed areas (Table II.26). Heights of all selected species were significantly greater within the exclosures than the grazed areas in 1988. Comparisons between years indicated significant increases in height in exclosed *Salix* spp.-mixed dicot communities for all species. *Salix rigida* was the only species that significantly increased in the grazed treatment. However its mean height was less than 20% of those individuals in exclosures.

After 10 years of no grazing the density of woody species was significantly greater in exclosures (Table II.27). In 1978, *Salix rigida* and *Salix exigua* had 2.7 and 0.4 stems per m^2 respectively, significantly higher than stem densities in the grazed treatment in 1978. Within 1988, stem densities of *Alnus incana*, *Salix bebbiana*, and *Salix rigida* were significantly higher in the exclosures. Between years within the exclosed treatment, only *Populus trichocarpa* failed to show a significant increase in stem density. Significantly higher stem density was found for *Salix exigua* and *Salix rigida* within the grazed treatment between 1978 and 1988.

Table II.26. Mean height (cm ± standard error) for selected woody species on exclosed and grazed *Salix* spp.-mixed dicot communities along the Catherine Creek study site.

	Year			
	1978		1988	
Species	Exclosed	Grazed	Exclosed	Grazed
Alnus incana	0	12±6	202±48*	4±4
Populus trichocarpa	15±2+	12±8	101±20*	26±13
Salix bebbiana	2±1+	2±2	99±20*	4±3
Salix exigua	16±5+	8±8	118±9*	35±17
Salix rigida	29±4*+	18±9+	134±20*	138±21

* Significant difference between treatments within year ($P \leq 0.1$).
+ Significant difference between years within treatments ($P \leq 0.1$).

Table II.27. Mean density (stems m^2 ± standard error) for selected woody species on exclosed and grazed *Salix* spp.-mixed dicot communities along the Catherine Creek study site.

	Year			
	1978		1988	
Species	Exclosed	Grazed	Exclosed	Grazed
Alnus incana	0.5±0.1+	0.4±0.2	3.7±0.7*	0.3±0.2
Populus trichocarpa	10.8±3.7	13.7±6.2	14.4±2.3	5.9±3.3
Salix bebbiana	0+	0.3±0.1	2.3±0.5*	0.4±0.4
Salix exigua	0.4±0.2*+	0.3±0.1	17.6±1.3	7.9±4.6
Salix rigida	2.7±0.2*+	0.4±0.2+	9.4±2.1	4.5±2.4

* Significant difference between treatments within year ($P \leq 0.1$).
\+ Significant difference between years within treatments ($P \leq 0.1$).

Discussion

Analysis of data from the 10 year study period showed that not all communities responded to the grazing and exclosure treatments with changes in measured parameters or in a similar manner. This is not surprising however as the 8 communities studied represent a vast assemblage of over 250 species (Appendix A). Many of these species occurred in several communities. Some species such as *Poa pratensis* display different responses to treatments from one community to another. The impact of herbivory on plant species will also vary substantially between communities. Additionally, wide variation in species richness, species diversity, evenness and aboveground biomass between community replicates and variations in weather may have been responsible for few statistically significant differences over the study period. Random location of sample transects each year in the communities may have also added to variation in year to year samples. It should be noted that while frequency detects presence or absence of a plant species it does not contain information of the cover or size of individual species. Additionally the percent exotic species in each community is based on species richness which weighs all species equally, not on relative abundance of species.

However, this analysis of data encompassing a decade of vegetation change indicated that grazing influences riparian plant communities in several ways. Livestock influences are variable from one plant community to another. In the absence of livestock, species richness and diversity decreases in *Poa pratensis*-mixed dicot and *Poa pratensis*-*Carex* spp. communities. However, this may be due to declines in disturbance or grazing required by alien species. After 10 years of no domestic livestock grazing, *Poa pratensis* has dominated *Poa pratensis*-mixed dicot communities and the abundance of *Bromus mollis* and dicot species has declined (Tables II.6 and II.7). In ungrazed *Poa pratensis*-*Carex* spp. communities a native sedge, *Carex rostrata* was the dominant in 1989. Conversely, frequency and biomass of *Ranunculus acris* and *Phleum pratense*, both grazing-tolerant aliens, significantly decreased in the exclosures (Tables II.2 and II.3). *Taraxacum officinale*, another introduced grazing-tolerant species also had declined in abundance in exclosures (Tables II.2 and II.3).

The shift in species composition and dominance appear to follow a similar pattern to competition models presented by Grime (1979). These models indicated that competitive ruderal species, (i.e., those adapted to resource abundant habitats with moderate disturbance such as the grazing regime of this study) are displaced by competitive species with decreasing disturbance. For example, the alien annual *Bromus mollis* possesses ruderal characteristics such as vigorous production by seeds and establishment capabilities in open disturbed sites. In exclosures of *Poa pratensis*-mixed dicot communities, *Poa pratensis* would be considered the competitive species replacing *Bromus mollis* because of its ability to produce large amounts of persistent litter and vegetative reproduction by tillers and rhizomes. In the *Poa pratensis*-*Carex* spp. communities, *Phleum pratense* with a strategy intermediate between stress tolerant and competitive ruderal, and *Ranunculus acris*, a competitive-stress-tolerant strategist (Grime 1988) were maintained by grazing. In exclosures of the same community, these species were displaced by the more competitive *Carex rostrata*. Competitive characteristics of *Carex rostrata* include early and rapid growth, a tall, dense growth form, vegetative reproduction, and production of copious amounts of persistent litter (personal observation).

The competitive abilities of plant species is modified by various factors in its environment. The litter layer in ungrazed *Poa pratensis*-mixed dicot and *Poa pratensis*-*Carex* spp. communities was approximately twice that of their grazed counterparts in 1987 (Table II.4). Litter accumulation may have resulted in increased amounts of nutrients immobilized in the litter pool with concomitant reductions in plant available nutrients and therefore a more competitive environment. Biomass in exclosed *Poa pratensis*-mixed dicot and *Poa pratensis*-*Carex* spp. communities was lower than that in grazed areas.

In addition, litter accumulation may also change soil temperature and moisture regimes, and decrease light availability for seedlings and low growing species. Livestock grazing may be viewed as the disturbance factor that facilitated establishment of exotic species and hence resulted in a higher species richness and diversity. The absence of livestock related disturbance in *Poa pratensis*-mixed dicot communities would favor more species such as *Poa pratensis* at expense of species such as *Bromus mollis* and *Achillea millefolium*. Conversely in *Poa pratensis-Carex* spp., *Pinus ponderosa*, *Populus trichocarpa*, communities *Poa pratensis* declined.

Reduction of species richness in exclosures also occurred in riparian meadows in Idaho (Hayes 1978), New Zealand (Dobson 1973) and Nevada (Clary and Medin 1990). Increased quantities of litter in exclosures is consistent with studies of riparian meadow communities in the Rocky Mountains (Leege et al. 1981, Schultz and Leininger 1990).

Differences in grazing management among the *Poa pratensis*-mixed dicot and *Poa pratensis-Carex* spp. communities resulted in changes in edaphic properties, principally bulk density and structure (Kauffman et al. 1988). Soil surface layers in exclosed *Poa pratensis-Carex* spp. communities were characterized as a granular structure. Grazed treatments had consolidated structureless surface with a root bound surface layer.

However, due to significantly greater root biomass in the surface horizon of grazed *Poa pratensis-Carex* spp. communities (Table II.4), soil bulk density in grazed *Poa pratensis-Carex* spp. communities was lower than that of exclosed areas. These changes may in part be responsible for shifts in species richness and diversity.

Significantly greater below ground biomass in grazed compared exclosed meadow communities is contrary to many studies that show decreased below ground biomass with grazing or clipping (Robertson 1933, Crider 1955). Lower belowground biomass in exclosed meadow communities is probably due to changes in species composition and lowered species richness in the exclosures (Appendix B). In *Poa pratensis-Carex* spp. communities, species with fibrous root systems such as *Poa pratensis* and *Phleum pratense* were replaced by *Carex rostrata*, a species with a relatively coarse root system. In exclosed *Poa pratensis*-mixed dicot communities lower species richness may have led to the soil volume not being fully exploited by roots.

The impact of herbivory appears to differ in communities with tree and shrub overstories when compared to meadow communities. This may be due to differing competitive relationships between species, conditions for regrowth, or patterns of herbivory which are likely to differ between communities (Louda et al. 1990). For example, the abundance of *Poa pratensis* decreased in *Pinus* *ponderosa*, *Populus trichocarpa*, and *Alnus incana* communities despite relatively low levels utilization (Tables II.12, II.15, II.18). This contrasts with *Poa pratensis*-*Carex* spp. and *Poa pratensis*-mixed dicot communities where abundance of *Poa pratensis* did not change despite much higher levels of utilization (Tables II.1, II.5). Native species such *Montia perfoliata* and *Elymus glaucus* increased under grazing while others notably *Aster foliaceus* declined.

Density and height of the riparian tree species (i.e *Alnus incana*, *Populus trichocarpa*, and *Salix* spp.) dramatically increased in exclosures (Tables II.26 and II.27). Significant increases in species richness and diversity of woody species were found in *Salix* spp.-mixed dicot communities. Mean height of all woody species selected for analysis exceeded 1 meter in the exclosures while in the grazed *Salix* spp.-mixed dicot communities, mean height was less than 0.5 meter (Table II.26). Shorter heights of woody species were the result of livestock browsing. Densities of all woody species were greater after 10 years of no grazing for all species except for *Salix rigida* (Table II.27). Utilization of woody species by livestock did not occur until the latter part of the grazing season when herbaceous forage became less available (personal observation).

Increases in woody riparian species height have also been observed. In a rocky mountain riparian system, shrub production was 13 times greater in an exclosure than in a severely overgrazed area (Marcuson 1977). Other studies have reported similar herbivore-woody vegetation interactions (Gunderson 1968, Leege et al. 1981, Davis 1982, Schulz and Leininger (1990).

Riparian ecosystems play an important role in providing energy and nutrients to the stream. Up to 99% of the energy inputs in small streams may be from sources outside of the aquatic ecosystem (Cummins 1974). Although Catherine Creek is a 3rd order stream inputs from riparian species, particularly woody species are critical to the functioning of the aquatic ecosystem. Additionally mature *Alnus incana* and especially *Populus trichocarpa* and *Pinus ponderosa* provide woody debris to the stream. This is important in pool formation and channel complexity (Hogan 1985, Robison and Beschta 1990). All woody species provide shade to the channel which moderates stream temperatures (Meehan et al 1977, Swanson et al. 1982).

Conclusions

The late season grazing scheme employed in this study appears to have several advantages for riparian areas of this region compared to season long or other rotation systems. This grazing scheme has maintained species diversity in the plant communities studied. However, structural diversity, of woody plant communities has been affected through declines in the density and growth of riparian tree species. Although height of woody species is decreased in comparison to exclosed stands by livestock browsing, there was vigorous reproduction and establishment in grazed *Salix* spp.-mixed dicot communities. Disturbance from grazing and other livestock activities created conditions suitable for a number of species particularly exotic and or ruderal species. Grazing was conducted for a limited time period, (3 to 4 weeks in August and September) and throughout the 10 year study period, utilization ranged from a maximum value of 73% in *Poa pratensis-Carex* spp. communities to a minimum of 1% in *Bromus tectorum* communities.

This riparian ecosystem was extremely diverse. An earlier study recognized a complex array of 60 plant communities (Kauffman and Krueger 1985). Riparian areas are unique ecosystems in that they can be easily damaged by mismanagement, but in many instances show tremendous capacity to recover with proper management (Stuber 1985, Elmore and Beschta 1987, Grette 1990). This resilience of riparian ecosystems may be due to their development with a high frequency of natural disturbance as well as more available water and nutrients than upland sites.

Few changes in either measured community parameters were noted in grazed communities. However, the greatest changes in measured parameters occurred in exclosed treatments of communities with the highest livestock utilization. This may indicate that riparian meadow communities may have had, prior to livestock introduction, lower species richness and diversity than today. However it is not known how many native species have been extirpated from these communities by past management practices. While woody species associated with *Salix* spp.-mixed dicot communities may have been more diverse and of higher density and height than today. It should be noted that this does not consider the effects of altered fire regime or other human activities in riparian ecosystems. My results also indicate that to maintain a maximum species diversity, regardless of whether the species are of native or exotic origin, some degree of disturbance is necessary in this particular riparian ecosystem.

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III. REDOX POTENTIAL AND EDAPHIC CONDITIONS ALONG A HYDROLOGICAL GRADIENT IN A NORTHEASTERN OREGON RIPARIAN ECOSYSTEM

Abstract

Belowground characteristics of five distinct riparian plant communities along a moisture gradient ranging from continually anaerobic to continually aerobic were studied along Catherine in the Wallowa Mountains of northeastern Oregon. We quantified depth to water table, redox potential, and soil temperature at 5, 10, and 30, cm depths. In addition, total nitrogen (N), ammonium (NH_4^+), nitrate (NO_3^-), ferrous iron (Fe^{2+}), and free iron in soils at depths of 0 to 10 cm and 10 to 30 cm were sampled. Redox potential in *Glyceria grandis* communities ranged from -19 to -226 mV and was significantly ($P \leq 0.1$) lower than the more aerobic *Juncus balticus-Poa pratensis*, and *Poa pratensis-Carex* spp. communities over the growing season. Levels of ferrous iron in *Glyceria grandis* communities were higher than all other communities indicating the highly reduced nature of the soils in these communities. At the dry end of the moisture gradient, *Poa pratensis-Carex* spp. communities had redox potential ranging from 460 to 634 mV over the growing season. Significantly higher nitrate levels occurred here than other communities sampled throughout the sampling period. Four of these communities were anaerobic for much of the growing season, which can influence water quality through denitrification of ground water moving from uplands to the stream channel. Results indicate that riparian plant communities occur in unique

combinations of edaphic conditions which influences the rhizosphere, vegetation, and aquatic systems.

Key words: riparian; redox potential; anaerobic; nitrate; Oregon; riparian plant communities; ferrous iron; waterlogged soils.

Introduction

Riparian ecosystems possess a number of characteristics that contribute to their disproportionate importance to landscapes relative to their size. The heterogeneity of sites created by hydrological disturbances, transportation and deposition of sediments and germplasm, results in an unusually high level of diversity. Natural disturbance processes such as periodic flooding create numerous sites for vegetation establishment (Swanson et al. 1982, Jensen and Platts 1987). The diverse nature of riparian ecosystems is reflected by the disproportionately large concentration of wildlife species compared to adjacent uplands (Brode and Bury 1981).

Riparian areas provide critical linkages between terrestrial and aquatic systems that are of importance to instream processes and water quality. Riparian vegetation affects the structure and stability of stream banks (Platts 1979, Swanson et al. 1982, Harmon 1986, Robinson and Beschta 1990), provides shading that mitigates against adverse temperature changes (Meehan et al. 1977), and provides an important energy and nutrient source for instream ecosystems. Human influences such as beaver (*Castor canadensis*) trapping, channelization, and grazing have degraded riparian and stream ecosystems (Dahm et al. 1987).

Anaerobic soils arise from oxygen depletion by aerobic respiration where respiration rate exceeds diffusion rate of oxygen into the soil. Riparian areas are unique in that they contain large areas of anaerobic soils. Low redox potentials associated with water logged soil results from increasing populations of anaerobic bacteria which use inorganic compounds as terminal electron acceptors in the respiratory process (Brock et al. 1984). For example, nitrate is used as a terminal electron acceptor by certain bacteria. The process, which results in the reduction of nitrate, is termed denitrification.

Redox potential is a good indicator of the intensity of reduced conditions within a plant community. Low redox potentials (200 to -400 mV) are associated with reduced (submerged or waterlogged) soils. Well oxidized soils have redox potentials ranging from 300 to 800 mV (Ponnamperuma 1972, Gambrell and Patrick 1978, Gliniski and Stepniewski 1985). Under water logged conditions microbial reduction of nitrate to nitrous oxide, dinitrogen, or ammonium occurs at about 230 mV (Gambrell and Patrick 1978). Reduction of ferric iron to ferrous iron, and tetravalent to divalent manganese, both toxic to plants in high concentrations, occurs at 200 and 120 mV, respectively. Sulfur compounds, in particular sulfate, are reduced to sulfides at -75 to -150 mV (Gambrell and Patrick 1978). Sulfides are toxic to plant species in low concentrations (Howes et al. 1981).

Finally, carbon dioxide is reduced to methane by a specialized group of bacteria when redox potential declines to -250 to -350 mV (Mitsch and Gosselink 1986). This appears to be the final redox couple in natural soil systems (Ponnamperuma et at. 1966).

In addition to the inorganic toxins mentioned above, several organic phytotoxins are produced through anaerobic metabolism within plants or decomposition of organic matter. Some of these phytotoxins include ethylene, formic acid, butyric and valeric acids (Ponnamperuma 1984).

Many riparian plant species are adapted to unfavorable conditions associated with waterlogged soils of low redox potential. Adaptions may be structural or physiological in nature. Structural adaptions may include aerenchyma in both the stem and roots (Armstrong 1972, Kawase and Whittmoyer 1980, Blom et al. 1990). Aerenchyma tissue has low respiratory demands while providing structural support (Armstrong 1972). In addition, aerenchyma provides a pathway for diffusion of photosynthetic oxygen to root tips (Beckett et al 1988). Radial oxygen loss from the roots creates aerobic conditions in the rhizosphere, resulting in oxidation of reduced toxins before they can enter into plant tissue (Teal and Kanwischer 1966, Armstrong 1970, Colin and Crowder 1989). A thin coating of oxidized iron in the root surface in anaerobic soils is evidence of radial oxygen loss (Mendelssohn and Postek 1982, Crowder and Macfie 1986).

When flooded, flood tolerant species may produce fermentation end products less toxic than ethanol (e.g. malate) for later use in aerobic respiration in roots or the shoot (Crawford 1978). However, this pathway generates less ATP than ethanol production and therefore may only be a short term solution to flooding stress (ap Rees and Wilson 1984, Smith et al. 1984). In *Oryza sativa* L., ethanol diffuses from root tips to the surrounding soil and malate does not accumulate (Bertani et al. 1980). It is possible that other wetland species may release ethanol and so avoid the less efficient malate pathway.

Nutrient inputs into the stream as a result of chemical processes operating in riparian areas affects not only the aquatic community, but downstream users as well (Cooper et al. 1987, Rhodes et al. 1985). Intact riparian areas act as sites of denitrification, thereby enhancing water quality of the stream system (Coates et al 1976, Lowerance et al 1984, Jacobs and Gilliam 1985, Cooper 1990).

Although much is known about the value of riparian ecosystems little is known about the underlying mechanisms influencing plant community distribution. The objective of this study was to describe the physical, chemical, and edaphic character of distinctive riparian plant communities along a hydric gradient. Knowledge of these properties derived from this study can facilitate the formulation of management strategies that insure riparian ecosystems remain functioning in a dynamic equilibrium.

Methods

Study site

The study site is located in the Wallowa Mountains of northeastern Oregon on lands administered by the Eastern Oregon Agricultural Research Center (OSU Agriculture Research Station). The study site covered approximately 100 ha in area, and extended for approximately 3 km along Catherine Creek. Catherine Creek is a third order tributary to the Grande Ronde River. Average discharge is 3.4 m^3 s^{-1} with peak flows occurring from April to early June (USGS 1987). During this spring runoff period, peak flows of over 14.3 m^3 s^{-1} commonly occur. Elevation of the study site is approximately 1030 m. Mean annual precipitation for the study site is 600 mm, the majority of which falls as snow during the winter months (NOAA 1982). The closest weather station is located 19 km northwest of the study site in the town of Union, Oregon (45°13'N and 117°53'W). Elevation of the Union weather station is 841 m. Mean annual precipitation at Union is 355 mm. Precipitation received at Union in 1989 was 1.2 mm above average.

Within the study site five distinct plant communities representing a gradient from hydric to a mesic moisture regime were chosen for analysis. *Glyceria grandis* communities occur in the most waterlogged reduced habitats. The driest habitats along this gradient are occupied by *Juncus balticus*-*Poa pratensis* and *Poa pratensis*-*Carex* spp.

communities. *Carex rostrata* and *Carex nebraskensis* communities occupy intermediate positions along this moisture gradient.

With the exception of the *Poa pratensis-Carex* spp. communities, these communities were located in old meanders of the stream channel or in abandoned irrigation ditches utilized before 1930.

Aboveground properties

To characterize selected plant communities we measured species frequency, diversity (H′), and evenness (J′).

A 25X25 cm quadrat was used for frequency measurements. Thirty plots were measured in two replicates of each community. Vegetation measurements occurred from late June to early July when most of the perennial species were in a phenological stage that would facilitate identification.

Values for species diversity and evenness were calculated from frequency data using the AIDN program (Overton et al. 1987). The Shannon index (H′) (Shannon and Weaver 1949) was selected to calculate diversity. This measure provides an intermediate weighing of rare species compared to other indices (Peet 1974). Pielou's J′ was selected to evaluate evenness where species diversity is relative to the maximum value of species diversity when all species are equally common (Pielou 1975).

Belowground properties

To determine belowground chemical characteristics of the five communities we quantified reduction-oxidation (redox) potential, levels of nitrate, ammonium, total nitrogen, ferrous iron and free iron. In addition we measured soil temperatures and depth to water table in each community.

Redox potential was measured with platinum electrodes which were constructed according to the methods of Mueller et al. (1985) with slight modifications. The junction of each electrode was sealed with neoprene repair adhesive (Aquaseal) rather than the suggested epoxy as this was found to perform better under conditions at our study area.

All redox probes were tested in a ferrous-ferric ammonium sulfate solution (Light 1972). After the electrodes were inserted to the proper depths they were allowed to equilibrate for one week before readings were taken.

Measurements of redox potential were made in situ using as a reference electrode, a single junction Cole Parmer Ag/AgCl electrode (standard potential of +199 mV was added to each measured value). The electrodes were connected through a Beckman model PH1 11 pH/mV meter. To facilitate measurements when the upper soil layers were dry salt bridges (Veneman and Pickering 1983) were used in the

Poa pratensis-Carex spp. and *Juncus balticus-Poa pratensis* communities.

The pH of the soils varied from 6.3 to 6.8 for all communities and depths sampled. These differences would lead to a shift of less than 40 mV (Bohn 1971) and so are ignored here.

Within a community, we sampled at depths of 5, 10, and 30 cm. Three electrodes were placed at each depth in each community. Each community was replicated twice.

Soil temperature at depths of 5, 10, 30 cm was measured with an Omega HH-51 digital thermometer and teflon insulated Chromel/Alumel thermocouples.

Depth to water table in each community was measured with two 2.2 cm diameter perforated plastic (PVC) pipes. These were installed to a depth of at least 50 cm in the vicinity of the redox electrodes.

Measurements of redox potential were made in situ at approximately biweekly intervals. Data were collected from late June until mid-September of 1989. Both temperature and depth to water table were sampled when redox potential was measured.

At the same time as other measurements were made two soil cores from within each community were collected for nutrient analysis. All samples were immediately placed on ice and then frozen as soon as possible until laboratory analysis. Analysis for all nutrients were made on the 0-10 and 10-30 cm sections of each soil core.

Total nitrogen and two forms of nitrogen, nitrate and ammonium, were measured. These were selected as water logging and subsequent anaerobic conditions dramatically affect nitrogen cycling. Nitrate and ammonium were extracted from 5 g soil samples using 50 ml of 2M KCl (Keeney and Nelson 1982). The extract was analyzed with an Alpkem rapid flow analyzer. Total nitrogen was determined by the Kjeldahl method (Bremner and Mulvaney 1982) using a Büchi automatic nitrogen analyzer.

Ferrous (reduced) iron and free iron were measured because iron is a major redox couple in most soils, in addition ferrous iron is toxic to plants at high concentrations. Ferrous iron content of the soil was colormetrically determined using the a,a-dipyridyl method (Iri et al. 1957). The citrate dithionite extractable iron procedure was used to colormetrically determine free iron content in the soil (Holmgren 1967). All iron extracts were analyzed on a Shimizu spectrophotometer.

Data were analyzed as a completely random design with two replications (Steele and Torrie 1980). One way analysis of variance was used to detect differences between communities within sampling dates for each nutrient. When a significant value of F was obtained, communities were separated using the least significant difference procedure

(Petersen 1985). For all tests $P \leq 0.1$ was considered significant.

To better understand plant community distribution along the hydric gradient, the 23 June and 12 July sampling dates were combined into one class termed early season. The 1 August 12 August, 29 August, and 10 September sampling dates were combined into another grouped termed late season. These groupings reflect a break in conditions that occurred for many measured factors over the growing season.

Results and Discussion

Plant community descriptions

Glyceria grandis communities

Glyceria grandis communities can be characterized as an emergent wetland. These communities dominated by *Glyceria grandis* Wats. (Table III.1). Common associates include *Scirpus microcarpus* Presl. and *Alopecurus aequalis* Sobol.. Common dicots include *Alisma plantago-aquatica* Schul & Schul., *Lemna minor* L., *Mimulus guttatus* DC., and *Ranunculus aquatilis* L.. Species richness was 16, species diversity (H′) 2.3693, and evenness (J′) was 0.83818.

Soils of *Glyceria grandis* communities were mucky with a high organic matter content. These communities are underlain by an unconsolidated layer of cobbles and stones at 35 cm. The water table is at or above the soil surface for the majority of the year.

Carex rostrata communities

These communities are dominated by *Carex rostrata* Stokes. with *Scirpus microcarpus* occurring much less frequently (Table III.1). *Epilobium paniculatum* Nutt. Ex T. & G., *Ranunculus acris* L., and *Veronica scutellata* L. were the most commonly occurring dicot species. Species richness of *Carex rostrata* communities was 23, species diversity 2.4710, and evenness was 0.78807.

Table III.1. Mean percent frequency for selected species in *Glyceria grandis* (Glgr), *Carex rostata* (Caro), *Carex nebraskensis* (Cane), *Juncus baticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex) communities along Catherine Creek.

	Community				
Species	Glgr	Caro	Cane	Juba-Popr	Popr-Carex
Achillea millefolium	-	-	-	78.4	45.8
Carex nebraskensis	20.0	13.4	100.0	-	4.2
Carex rostrata	5.0	100.0	23.4	5.0	3.3
Glyceria grandis	78.4	13.4	6.7	-	-
Juncus balticus	-	8.4	30.0	100.0	35.8
Potentilla gracilis	-	-	-	21.7	30.0
Poa pratensis	-	1.7	-	100.0	85.0
Ranunculus acris	-	15.0	-	63.4	10.8
Ranunculus aquatilis	45.0	-	-	-	-
Scirpus microcarpus	33.3	16.7	30.0	-	-

Carex rostrata communities occur on soils that have a thin A horizon (15 cm) of clay texture. This is underlain with a AC horizon containing faint mottles and oxidized iron in the root channels. Below 32 cm is a layer of coarse sand and small cobbles. Water table is usually below 20 cm by mid-July.

Carex nebraskensis communities

Carex nebraskensis communities are dominated by *Carex nebraskensis* Dewey. (Table III.1). Other graminoids include *Carex rostrata*, *Glyceria elata* (Nash) Jones, *Juncus balticus* Willd., and *Scirpus microcarpus*. *Veronica scutellata* and *Ranunculus macounii* Britt. were the most commonly occurring dicot species. These communities were the least diverse with a species richness of 10, species diversity of 1.7087, and evenness of 0.74206.

Soils of *Carex nebraskensis* communities had a clay texture in the A horizon. The A horizon was underlain at 20 cm by a coarse sandy C horizon. This C horizon had visible mottling and oxidized root channels. The water table was usually below 20 cm by mid-July.

Poa pratensis-Carex spp. communities

Poa pratensis-Carex spp. communities are dominated by *Poa pratensis* L. with *Phleum pratense* L. and various *Carex* spp. occurring as codominants (Table III.1). These codominants include *C. rostrata* and *C. nebraskensis*. Most abundant dicots include *Achillea millefolium* L., *Aster foliaceus* Lindl., *Collomia linearis* Nutt., *Collinsia parviflora* Lindl., *Epilobium paniculatum* Nutt. Ex T. & G., *Fragaria virginiana* Duchsne, *Geum macrophyllum* Willd., *Lathyrus polyphyllus* Nutt., *Potentilla gracilis* Dougl. Ex Hook., *Ranunculus acris*, *Stellaria longipes* Goldie., *Veronica arvensis* L., *Viola adunca* Sm., and *Vicia americana* Mul. Ex Willd.. Common graminoid species include *Agrostis alba* L., *Phleum pratense*, *Poa pratensis*, *Carex nebraskensis*, *Carex rostrata*, and *Juncus balticus*. These communities were very diverse; 55 species were encountered during community sampling. Species diversity was 3.5026 and evenness was 0.87404.

Poa pratensis-Carex spp. communities occur in areas of restricted drainage, generally where a clay to silt textured A horizon is underlain by a coarse sand or gravel layer. Mottling occurs at about 18 to 25 cm depth and standing water is common until June.

Juncus balticus-Poa pratensis communities

These communities consist of *Juncus balticus* and *Poa pratensis* occurring as codominants (Table III.1). Common dicot species include *Achillea millefolium*, *Polemonium occidentale* Greene, *Ranunculus acris*, and *Senecio pseudareus* Rydb.. *Juncus balticus-Poa pratensis* communities had species richness of 30, diversity of 2.8508, and evenness of 0.83818.

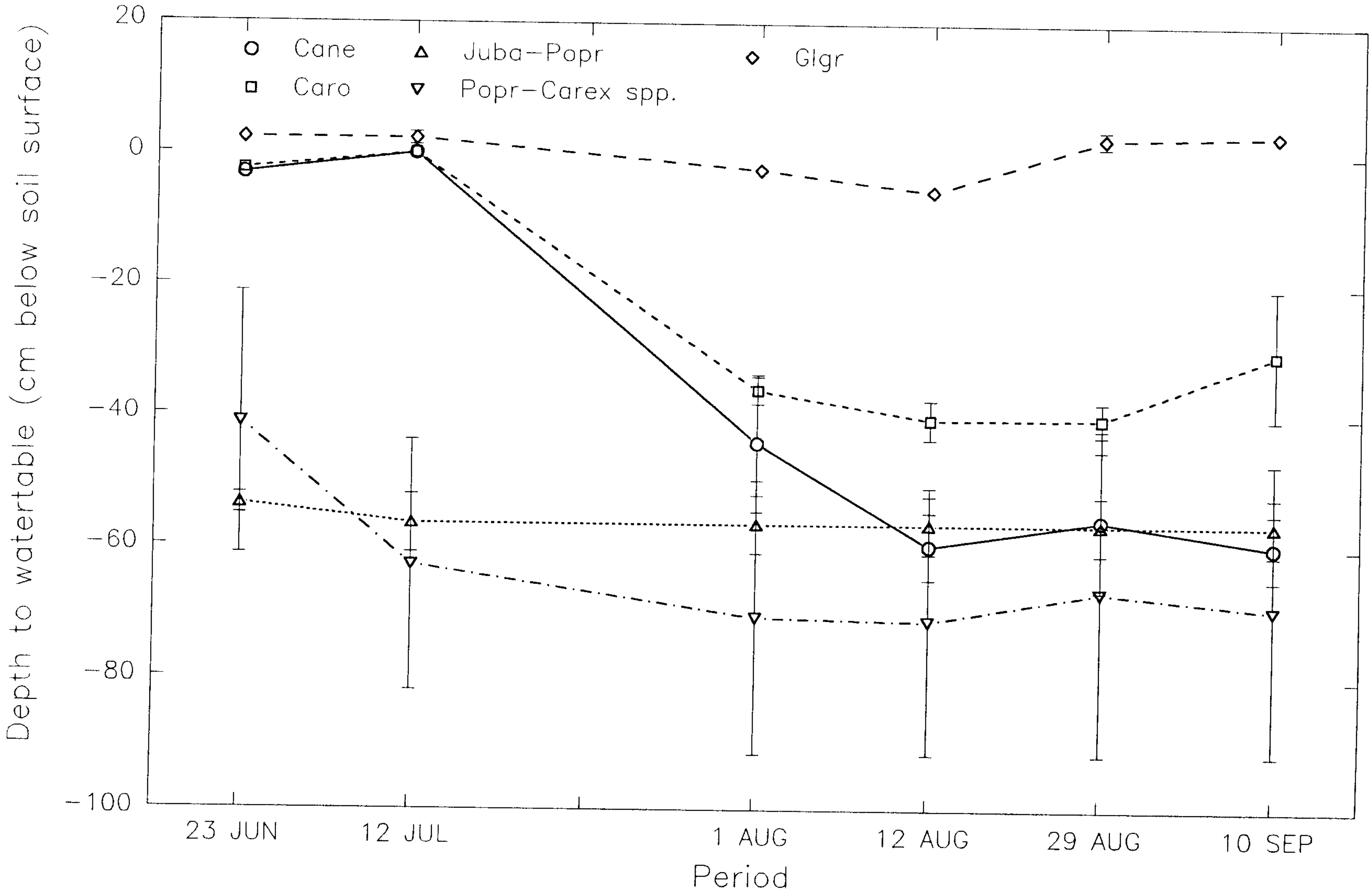
The soils of these communities had an A horizon 15 to 20 cm thick of clay to clay loam texture. Mottling was very faint and found only below 25 cm. This soil was underlain by a layer of cobbles and stones at 60 cm. The water table of *Juncus balticus-Poa pratensis* communities was below 50 cm throughout the growing season.

Belowground Properties

Water table depth

Water table depth declined in most communities during the course of the study (Fig. III.1). Water table levels of *Carex nebraskensis*, *Carex rostrata*, and *Glyceria grandis* communities were above or at the soil surface for the first two sampling periods. After 12 July, depth to water table in *Carex nebraskensis* and *Carex rostrata* communities dropped to levels only slightly higher than that in *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. communities. This would produce dramatic changes in soil chemical parameters as indicated by redox potential of the *Carex nebraskensis* communities (Fig. III.5). Water tables remained at or above the soil surface in the *Glyceria grandis* communities throughout the year. From the 1 August sampling period until the end of the study, water tables

Fig. III.1. Mean (± 1 SE) depth to water table in centimeters in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities over the study period in the Catherine Creek study area.



Cane
Caro
Juba−Popr
Popr−Carex spp.
Glgr
Depth to watertable (cm below soil surface)
20
0
−20
−40
−60
−80
−100
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

Figure III.1.

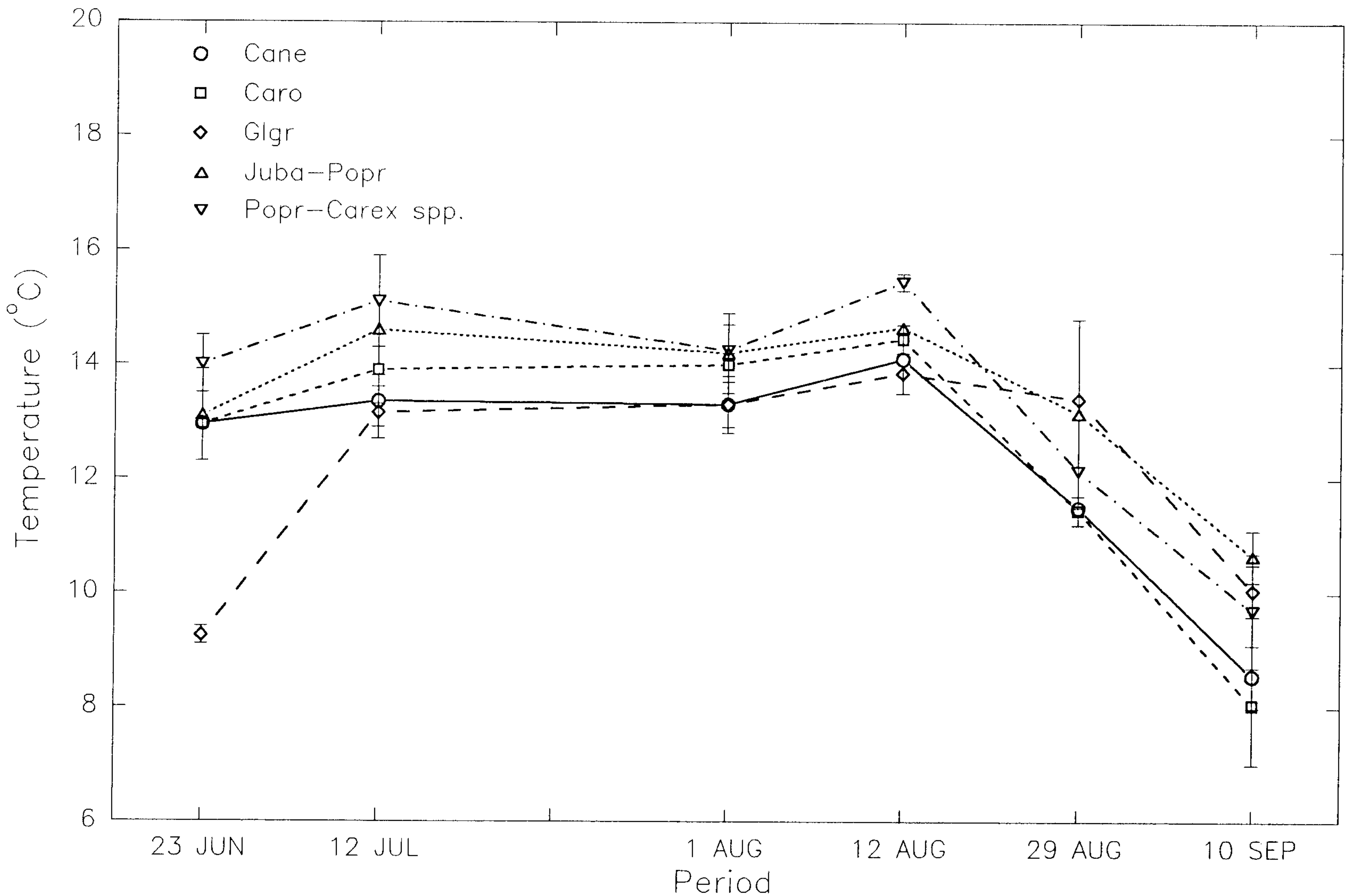
were significantly shallower in *Glyceria grandis* communities than other communities. During this same time period, *Carex rostrata* communities had significantly shallower water tables than *Poa pratensis-Carex* spp. communities. All other comparisons between communities were not significant.

Soil Temperature

For all sites, soil temperatures ranged from 8.5°C at 23 June to a peak of 15.5°C in 12 August. Soil temperatures declined to 8.3°C by 10 September. At the 5 cm depth the only significant differences were noted early in the growing season when soil temperatures in the *Glyceria grandis* communities were approximately 3°C lower than in the late season when the *Poa pratensis-Carex* spp. communities remained at a higher temperature than other communities (Fig. III.2). Other comparisons between communities within date were not significant.

Soil temperatures at the 10 cm depth followed the general pattern observed at 5 cm with low of 8°C early in the season, a 14°C peak in mid-August, and a decline in soil temperatures by the end of the growing season (Fig. III.3). Significant differences in soil temperatures between communities occurred both at the start and the end of the study period. *Juncus balticus-Poa pratensis* communities had significantly lower temperatures (8°C) than other

Fig. III.2. Mean (± 1 SE) soil temperature in degrees celsius for *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 5 cm depth over the study period in the Catherine Creek study area.



Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Temperature (°C)
20
18
16
14
12
10
8
6
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

Figure III.2.

Fig. III.3. Mean (± 1 SE) soil temperature in degrees celsius for *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus*-*Poa pratensis* (Juba-Popr), and *Poa pratensis*-*Carex* spp. (Popr-Carex spp.) communities at 10 cm depth over the study period in the Catherine Creek study area.

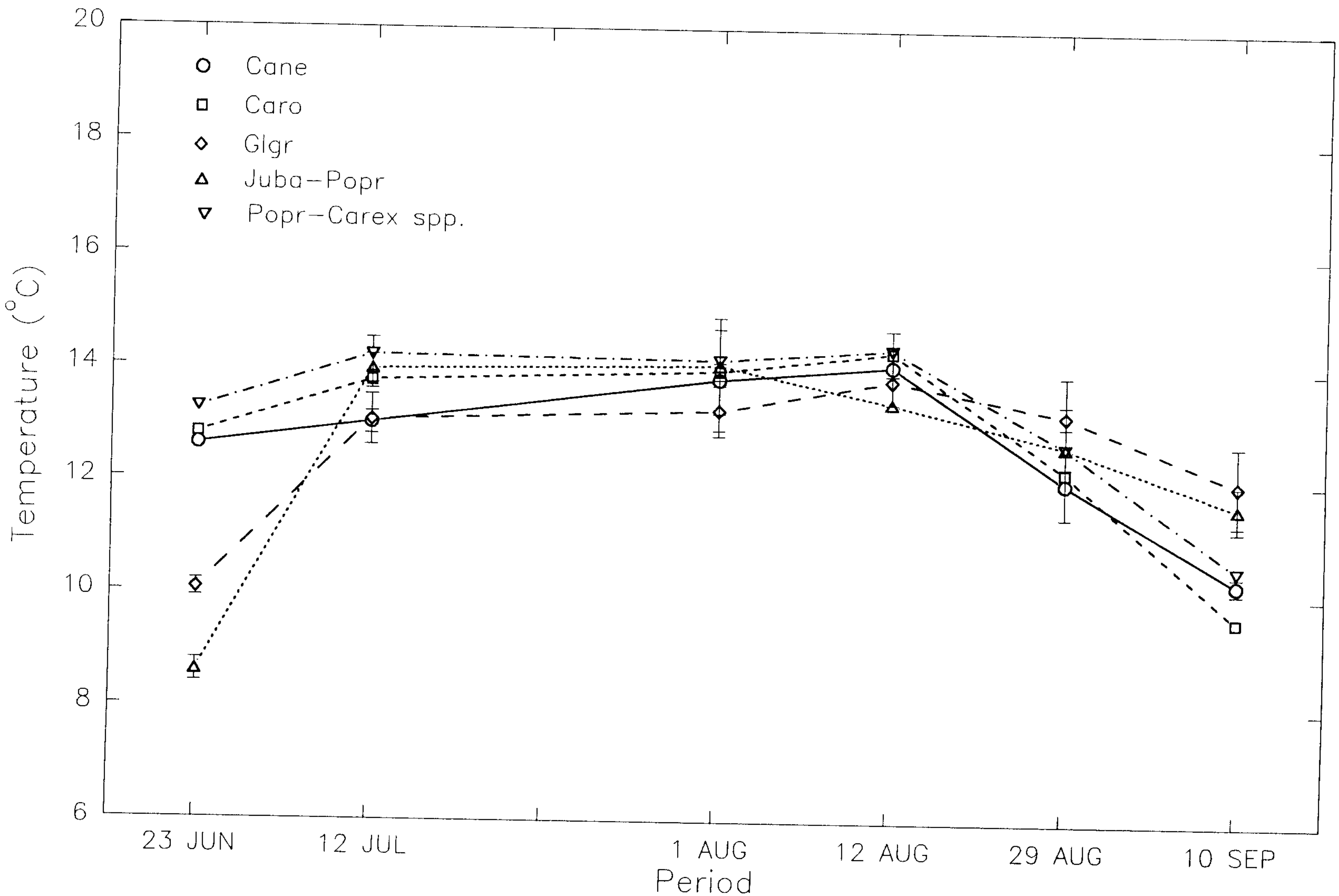

Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Temperature (°C)
20
18
16
14
12
10
8
6
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

Figure III.3.

communities at the 23 June sampling date. Temperatures in Glyceria grandis communities were significantly higher than *Juncus balticus-Poa pratensis*, but lower than other communities at the 23 June sampling date. *Poa pratensis-*Carex spp. communities had significantly higher temperatures (13.2°C) than all other communities at this same date. At the end of the study period, soil temperatures in *Glyceria grandis* and *Juncus balticus-Poa pratensis* communities were significantly higher than other communities. Comparisons of soil temperature between communities at other sampling periods were not significant.

Patterns of soil temperatures at 30 cm were similar to those at 10 cm (Fig. III.4). Soil temperatures of *Juncus balticus-Poa pratensis* (9.2°C) and *Glyceria grandis* communities (9.9°C) were significantly lower than other communities early in the growing season. Temperature at 30 cm in *Juncus balticus-Poa pratensis* was also significantly lower than in *Glyceria grandis* communities for the same period. Towards the end of season, *Juncus balticus-Poa pratensis* communities had significantly lower soil temperatures than *Glyceria grandis* or *Carex rostrata* communities. All other comparison between communities within date were not significant.

Fig. III.4. Mean (± 1 SE) soil temperature in degrees celsius for *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 30 cm depth over the study period in the Catherine Creek study area.

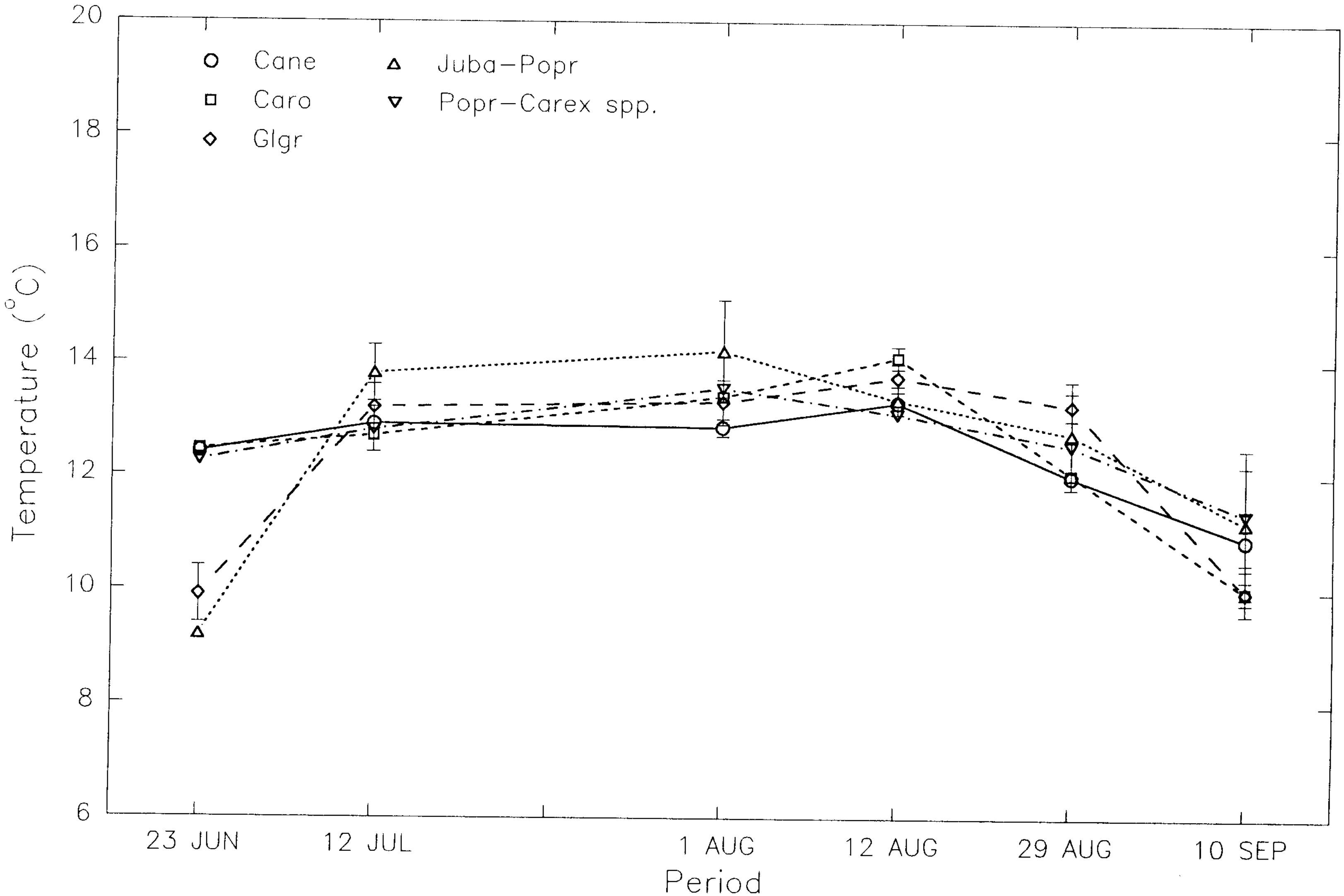

Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Temperature (°C)
20
18
16
14
12
10
8
6
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

Figure III.4.

Redox potential

Redox potential typically increased as the growing season progressed. At the 5 cm depth *Glyceria grandis* and *Carex rostrata* communities had lower redox potential throughout the year than the less hydric communities (Fig. III.5). Redox potential of *Carex nebraskensis* communities reflected that of the *Glyceria grandis* and *Carex rostrata* communities during the first two sampling dates ranging from -151 to -197 mV. However, by the mid August sampling period redox potential had risen to a level that was more reflective of the *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. communities (377 to 634 mV). No significant differences were found in the redox potential patterns between *Glyceria grandis* and *Carex rostrata* communities throughout the growing season. These two communities did have significantly lower redox potentials than either the *Juncus balticus-Poa pratensis* or the *Poa pratensis-Carex* spp. communities for the entire study period. For the first two sampling periods, redox potential was significantly higher in *Poa pratensis-Carex* spp. communities than the *Juncus balticus-Poa pratensis* communities. Redox potential of these communities was similar later in the growing season.

At the 10 cm depth, the three most mesic communities, *Glyceria grandis*, *Carex rostrata*, and *Carex nebraskensis*

Fig. III.5. Mean (± 1 SE) redox potentials in millivolts for Carex nebraskensis (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 5 cm depth over the study period in the Catherine Creek study area.

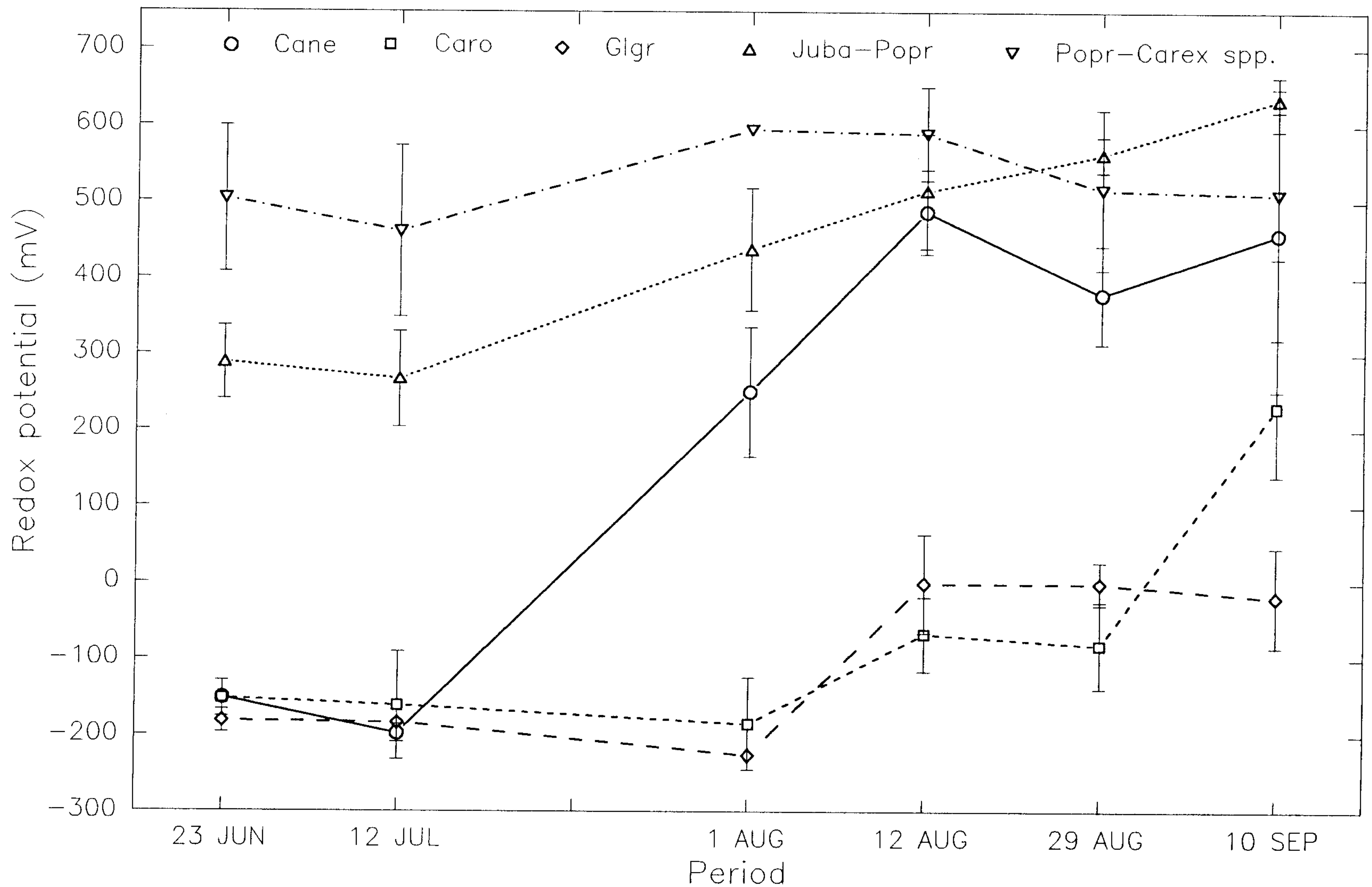

Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Redox potential (mV)
700
600
500
400
300
200
100
0
−100
−200
−300
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

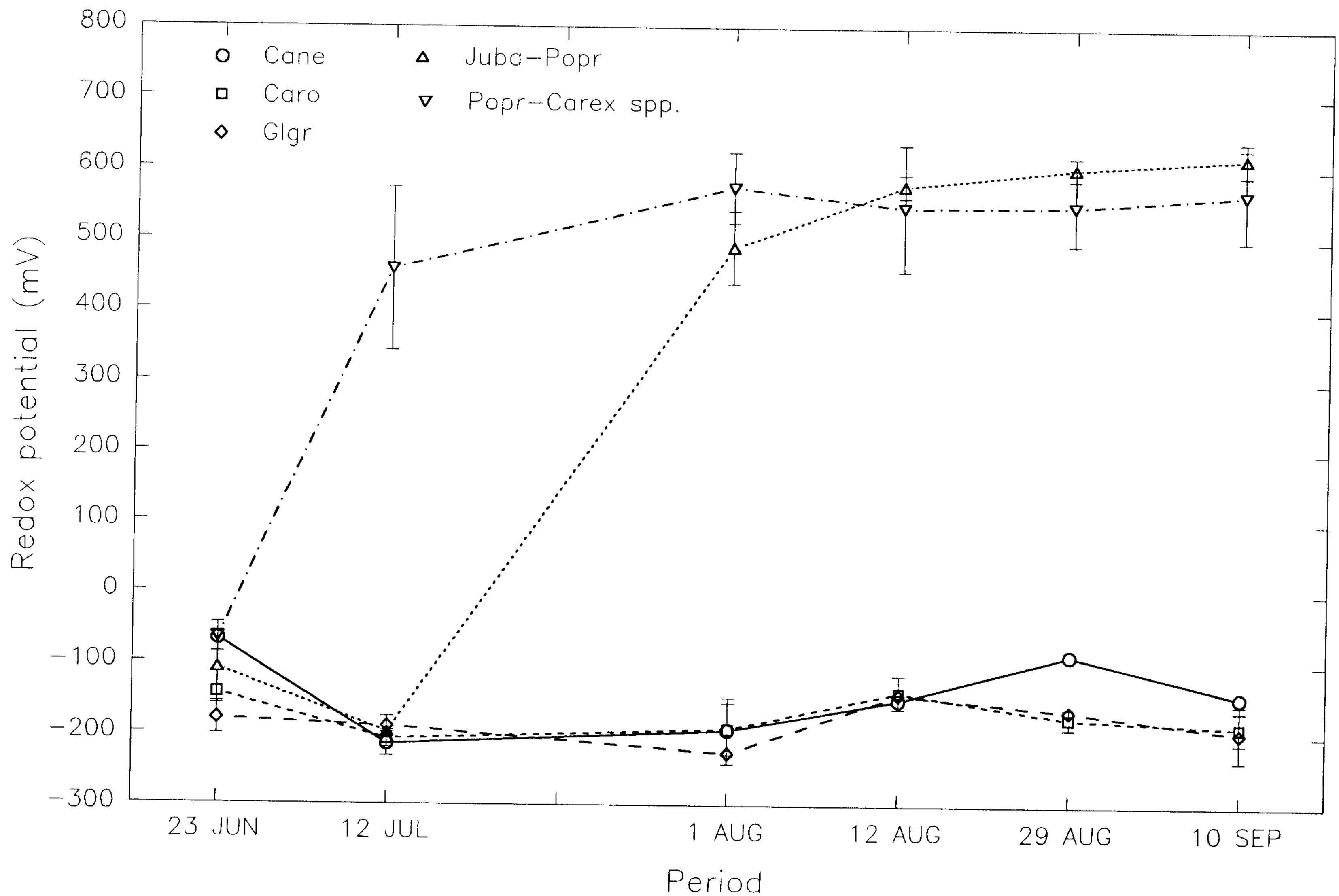
Figure III.5.

had consistently lower redox potentials than the drier *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. communities during the study period (Fig. III.6). No significant differences were found between any communities during the June sampling period. By mid July, the *Poa pratensis-Carex* spp. communities had significantly higher redox potential than other communities. From early August until the end of the study period, both *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. communities had significantly higher redox potential than other communities. Redox potential ranged from 488 to 617 mV in *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. after 1 August. No significant differences between these communities were found after 1 August. No significant differences occurred between the *Glyceria grandis*, *Carex rostrata*, or *Carex nebraskensis* communities over the study period with the exception of the 29 August sampling date when *Carex nebraskensis* had significantly higher redox potentials (-87 mV).

Redox potentials at 30 cm were less variable and more negative than at either the 5 or 10 cm depth (Fig. III.7). In addition, differences between communities were less evident. After the mid-July sampling, period redox potential increased from -17 mV to 578 mV in *Juncus balticus-Poa pratensis* communities and was significantly higher than in other communities studied. Redox potential

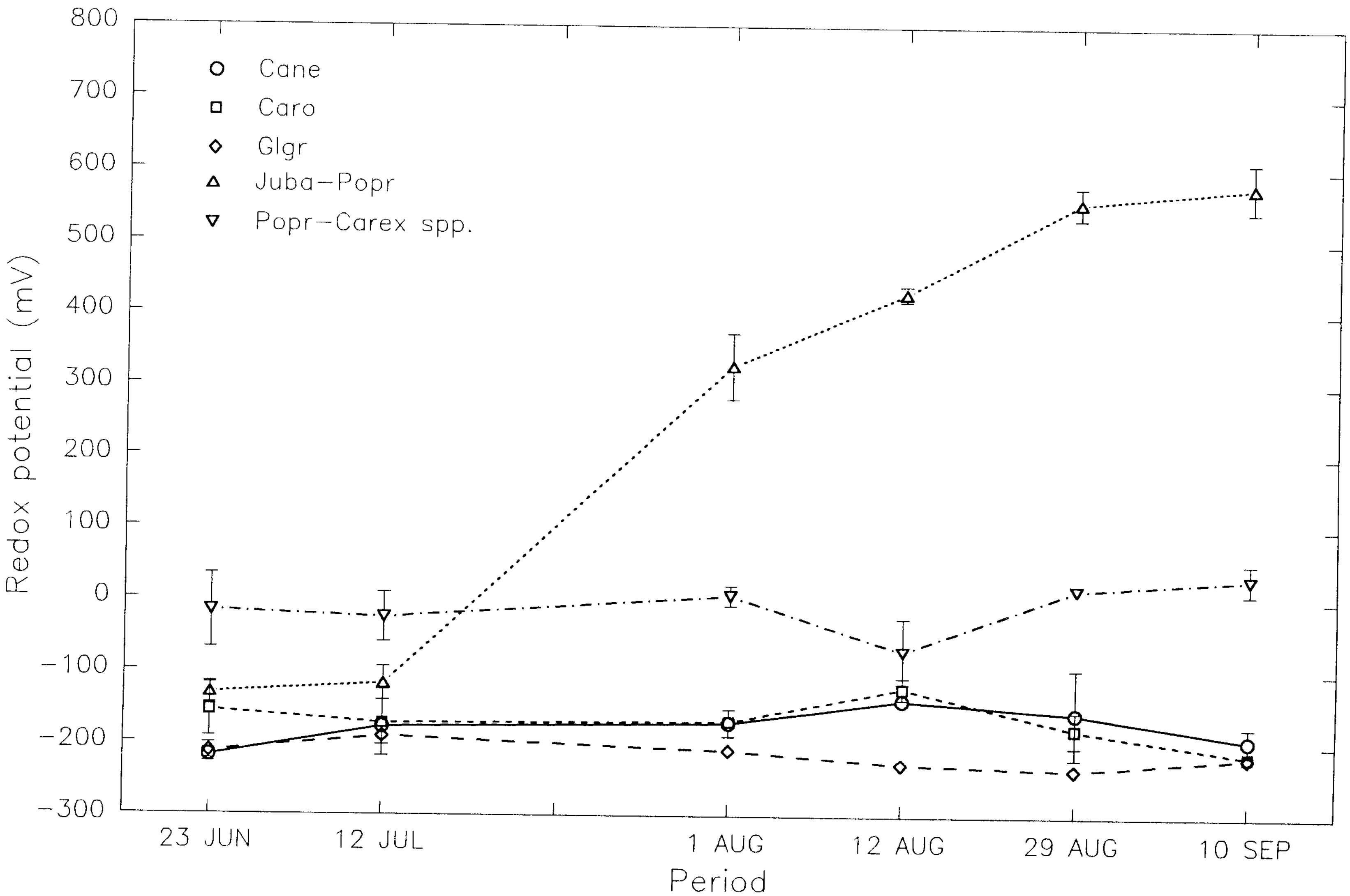
Fig. III.6. Mean (± 1 SE) redox potentials in millivolts for *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 10 cm depth over the study period in the Catherine Creek study area.

Figure III.6.



Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Redox potential (mV)
800
700
600
500
400
300
200
100
0
−100
−200
−300
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

Fig. III.7. Mean (± 1 SE) redox potentials in millivolts for *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 30 cm depth over the study period in the Catherine Creek study area.



Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
800
700
600
500
400
300
200
100
0
−100
−200
−300
Redox potential (mV)
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

Figure III.7.

of all other communities remained relatively constant over the growing season. Redox potential of *Poa pratensis-Carex* spp. communities was significantly higher than in *Carex rostrata* and *Carex nebraskensis* communities during the 1 August, 29 August, and 10 September sampling periods. Over the growing season, redox potential of *Glyceria grandis*, *Carex rostrata*, and *Carex nebraskensis* communities were not significantly different except during 12 August, when the *Glyceria grandis* communities had significantly lower redox potentials (-227 mV).

Ferrous Iron

Ferrous iron was significantly higher in *Glyceria grandis* communities, ranging from 541 to 902 mg kg^{-1}, than all other communities at the 0 to 10 cm depth (Fig. III.8, III.18). Ferrous iron in other communities ranged from 8 to 177 mg kg^{-1} at the same depth. Throughout the growing season, *Glyceria grandis* communities had significantly higher amounts of ferrous iron than all other communities. Comparisons between other communities were significant only at the 1 August sampling date. At that date, ferrous iron levels in the soils of *Carex nebraskensis* communities were significantly higher than levels in either *Juncus balticus-Poa pratensis* or *Poa pratensis-Carex* spp. communities. Levels of ferrous iron reflected the overall trend in redox

Fig. III.8. Mean (± 1 SE) ferrous iron concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 0 to 10 cm depth over the study period in the Catherine Creek study area.

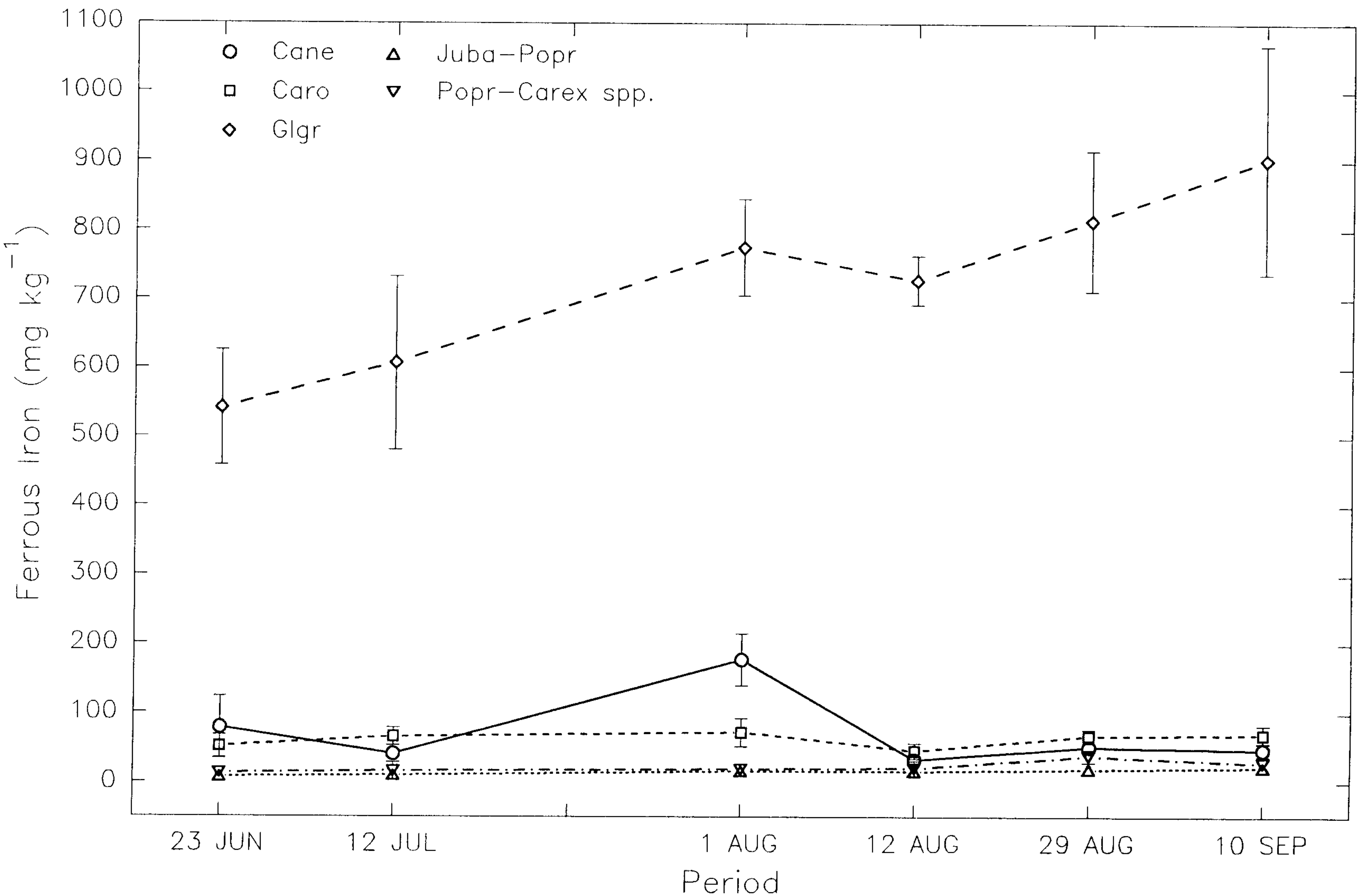

Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Ferrous Iron (mg kg^{-1})
1100
1000
900
800
700
600
500
400
300
200
100
0
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

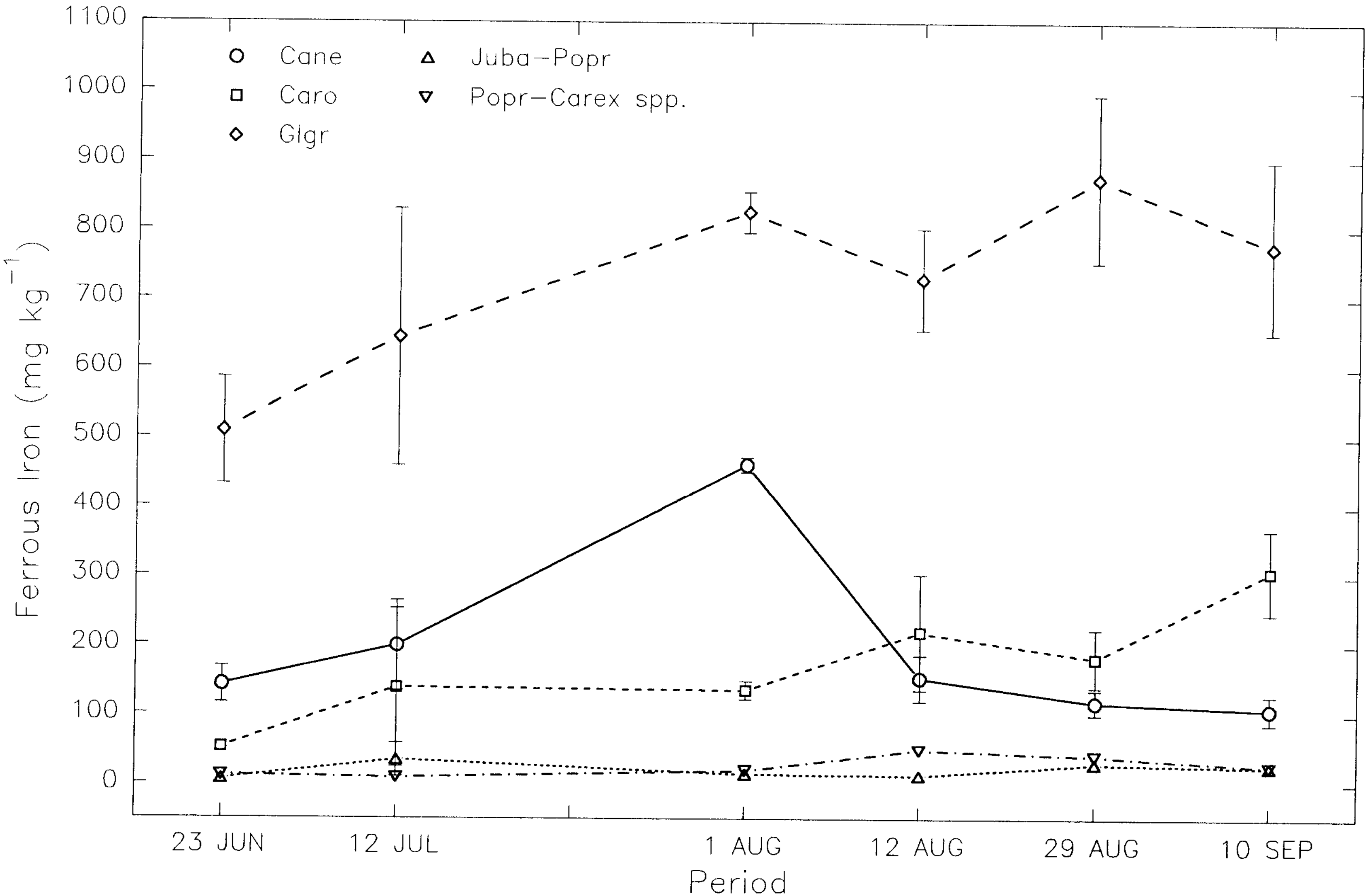
Figure III.8.

potential, higher in communities of low redox potential and lowest in communities of high redox potential (Fig. III.18). However, late season levels of ferrous iron were higher despite higher redox potential in most communities. Other comparisons between communities within dates were not significant.

At the 10 to 30 cm depth, ferrous iron was more variable between communities (Fig. III.9). *Glyceria grandis* communities had significantly higher levels of ferrous iron, ranging from 509 to 874 mg kg^{-1}, throughout the study period than other communities. At the start of the study *Carex nebraskensis* communities had significantly higher soil ferrous iron concentrations than either *Juncus balticus-Poa pratensis* or *Poa pratensis-Carex* spp. communities. Levels of ferrous iron peaked at 460 mg kg^{-1} at 1 August for the *Carex nebraskensis* communities and were significantly higher than all other communities except *Glyceria grandis*. Ferrous iron in *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. communities remained relatively constant varying between 6 and 49 mg kg^{-1}. *Carex rostrata* communities displayed a trend of slowly increasing ferrous iron concentration as the growing season progressed. By the end of the growing season levels of ferrous iron in *Carex rostrata* communities had risen to 306 mg kg^{-1}, significantly higher than all other communities except *Glyceria grandis*. As in the 0 to 10 cm depth,

Fig. III.9. Mean (± 1 SE) ferrous iron concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 10 to 30 cm depth over the study period in the Catherine Creek study area.

Figure III.9.



Cane
Caro
Glgr
Juba–Popr
Popr–Carex spp.
Ferrous Iron (mg kg^{-1})
1100
1000
900
800
700
600
500
400
300
200
100
0
23 JUN
12 JUL
1 AUG
12 AUG
29 AUG
10 SEP
Period

communities with low redox potentials had high levels of ferrous iron at the 10 to 30 cm depth (Fig. III.18). Levels of free iron increased at the 10 to 30 cm depth in the late season despite higher redox potentials at this depth. Free Iron

In the five communities studied soil concentrations of free iron at the 0 to 10 cm depth were extremely variable and ranged from 4 to 14.1 mg kg^{-1} (Fig. III.10). No one community had consistently significant high or low levels of free iron. *Carex nebraskensis* communities had significantly higher free iron levels (13.4 mg kg^{-1}) than other communities at the first sampling period. By mid-July, levels of free iron in *Poa pratensis-Carex* spp. communities were 14 mg kg^{-1}, significantly higher than other communities. Levels of free iron in *Carex nebraskensis* and *Carex rostrata* communities were significantly higher (12.1 and 14.1 mg kg^{-1}, respectively) at the 29 August sampling period when compared to other communities. All other comparisons over season were not significant. *Glyceria grandis* communities had the lowest levels of free iron over the season, but this was not significant. Over the growing season, *Glyceria grandis* and *Juncus balticus-Poa pratensis* communities had relatively stable levels of free iron when compared to other communities.

Fig. III.10. Mean (± 1 SE) free iron concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 0 to 10 cm depth over the study period in the Catherine Creek study area.

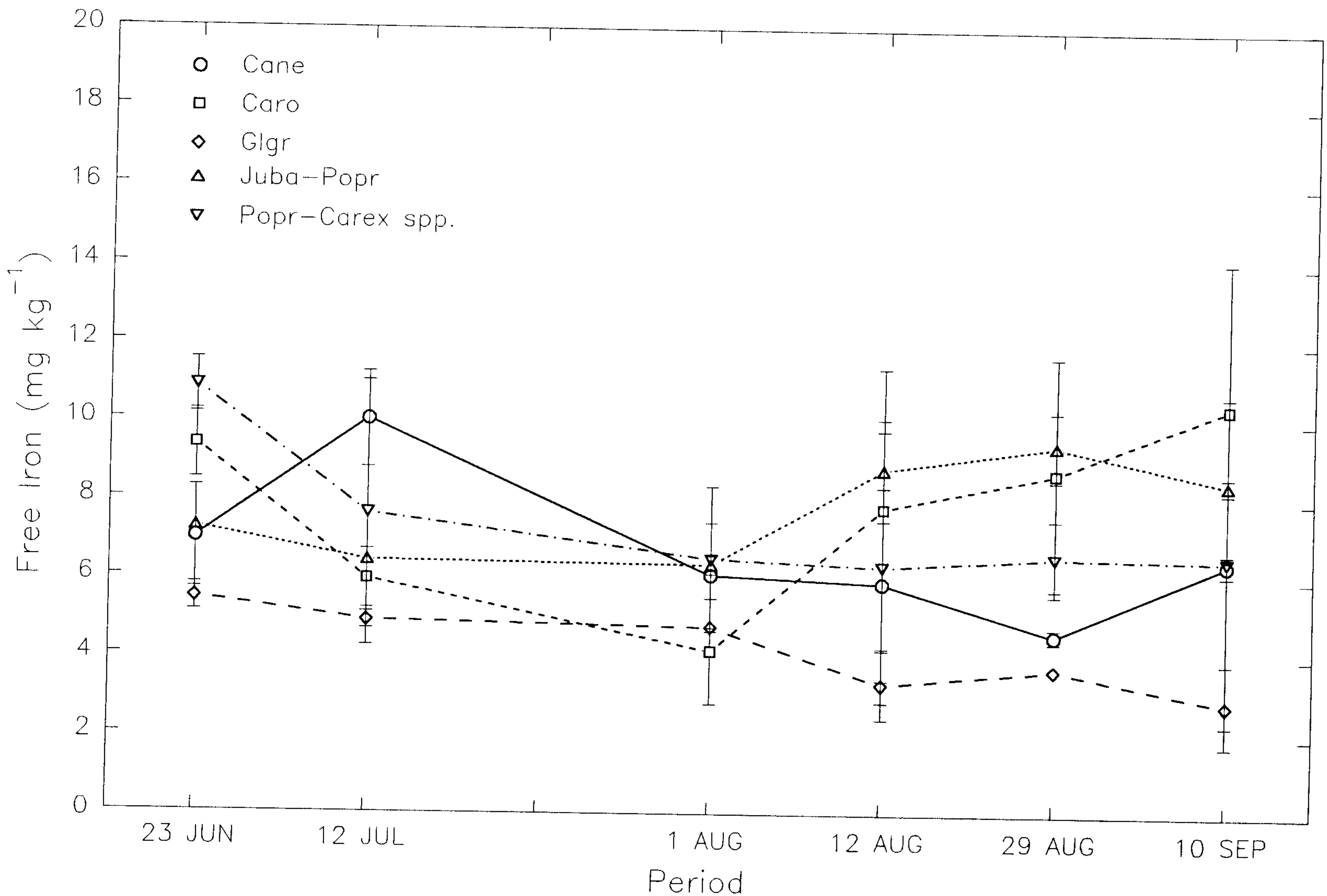


Figure III.10.

Free iron concentrations at the 10 to 30 cm depth were less variable than those at the 0 to 10 cm depth ranging from 2.8 to 10.9 mg kg^{-1} (Fig. III.11). This probably reflects more stable soil temperatures and less biological activity the 10 to 30 cm depth. Significant differences between communities occurred only at the first sampling date. At this sampling period, concentration of ferrous iron was significantly higher in *Poa pratensis-Carex* spp. communities than in the *Glyceria grandis*, *Carex nebraskensis* or *Juncus balticus-Poa pratensis* communities. Free iron levels of *Carex rostrata* communities was significantly higher at 9 mg kg^{-1} than *Glyceria grandis* or *Carex nebraskensis* communities at the first sampling date. All other comparisons were not significant. As in the 0-10 cm depth, soils in the *Glyceria grandis* communities had consistently lower concentrations of free iron over the growing season.

Total Nitrogen

Total soil nitrogen in the communities varied greatly (Fig. III.12). No significant differences in total nitrogen between communities were found for any sampling date at the 0 to 10 cm depth. The concentration of nitrogen in *Poa pratensis-Carex* spp. communities was greater than all other communities throughout the growing season. In general the concentration of soil nitrogen in

Fig. III.11. Mean (± 1 SE) free iron concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 10 to 30 cm depth over the study period in the Catherine Creek study area.

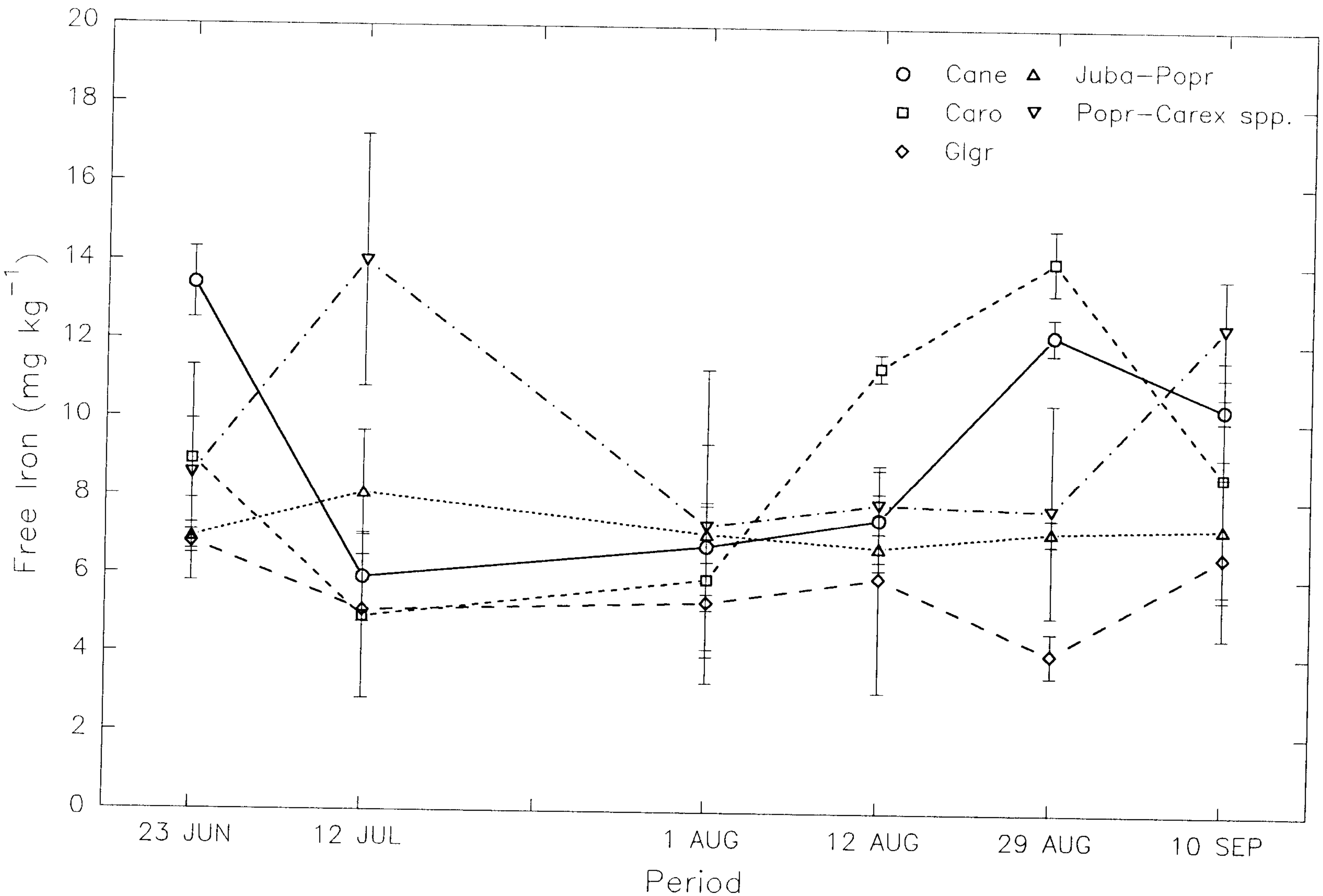


Figure III.11.

Fig. III.12. Mean (± 1 SE) total nitrogen concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 0 to 10 cm depth over the study period in the Catherine Creek study area.

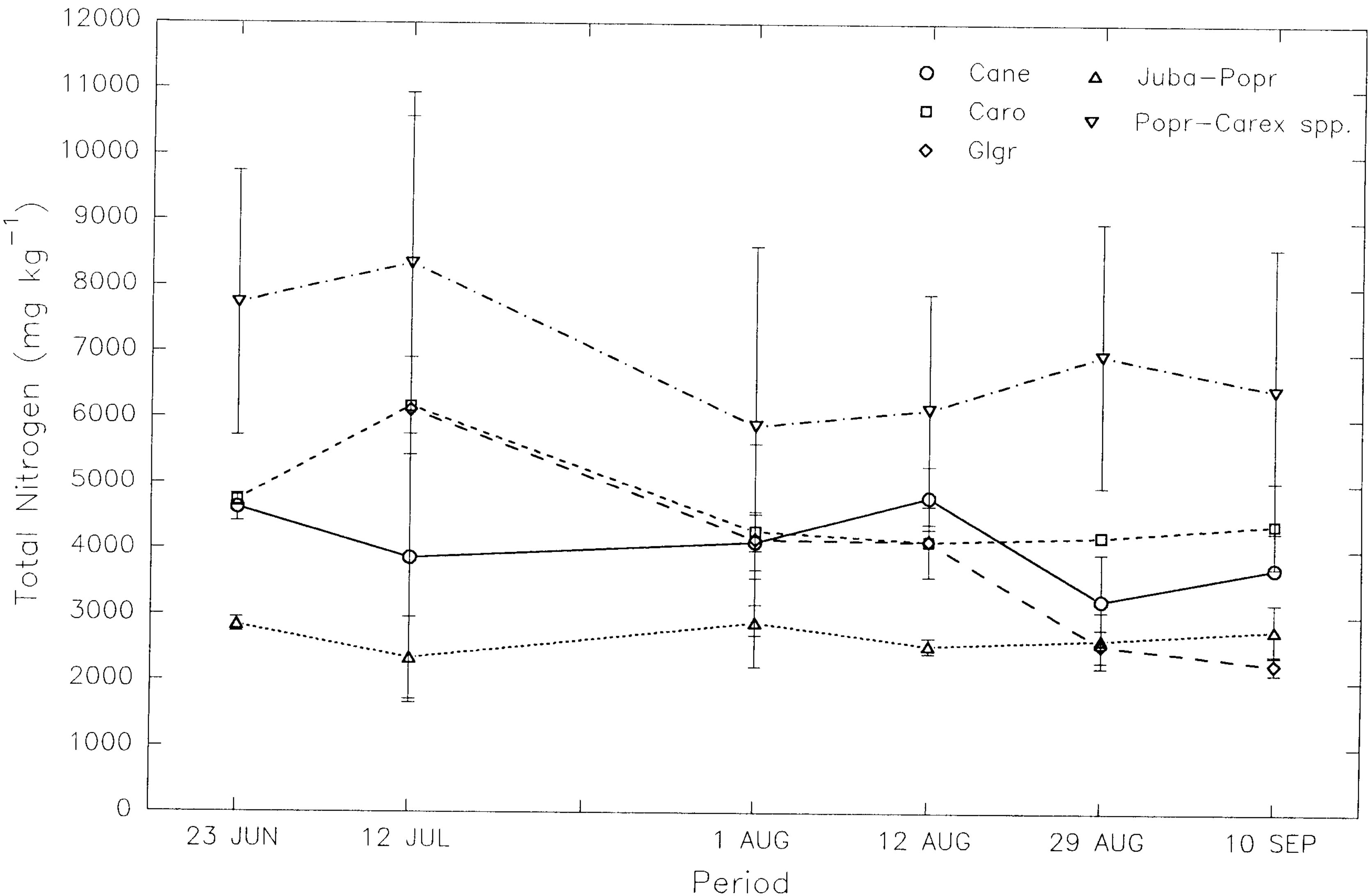


Figure III.12.

Juncus balticus-Poa pratensis communities was lowest over the growing season.

At the 10 to 30 cm depth, there was much less variability in total nitrogen (Fig. III.13). However, trends noted for the 0 to 10 cm depth were similar. Significant differences did occur at the start of the growing season. *Carex rostrata* communities had significantly higher (3400 mg kg^{-1}) total nitrogen than *Poa pratensis-Carex* spp. (1250 mg kg^{-1}) or *Juncus balticus-Poa pratensis* (1795 mg kg^{-1}) communities. There were no significant differences between *Carex rostrata* or *Carex nebraskensis* communities. At the 12 August sampling date, *Poa pratensis-Carex* spp. communities had higher total N than *Juncus balticus-Poa pratensis* or *Glyceria grandis* communities. Levels of total nitrogen were not significantly different between *Carex rostrata* or *Carex nebraskensis* communities at this time. All other comparisons between communities within sampling dates were not significant.

Ammonium nitrogen

Concentrations of ammonium nitrogen in the five communities sampled were highly variable at the 0 to 10 cm depth ranging from 2.1 to 51.0 mg kg^{-1} (Fig. III.14). No significant differences in ammonium concentrations were

Fig. III.13. Mean (± 1 SE) total nitrogen concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 10 to 30 cm depth over the study period in the Catherine Creek study area.

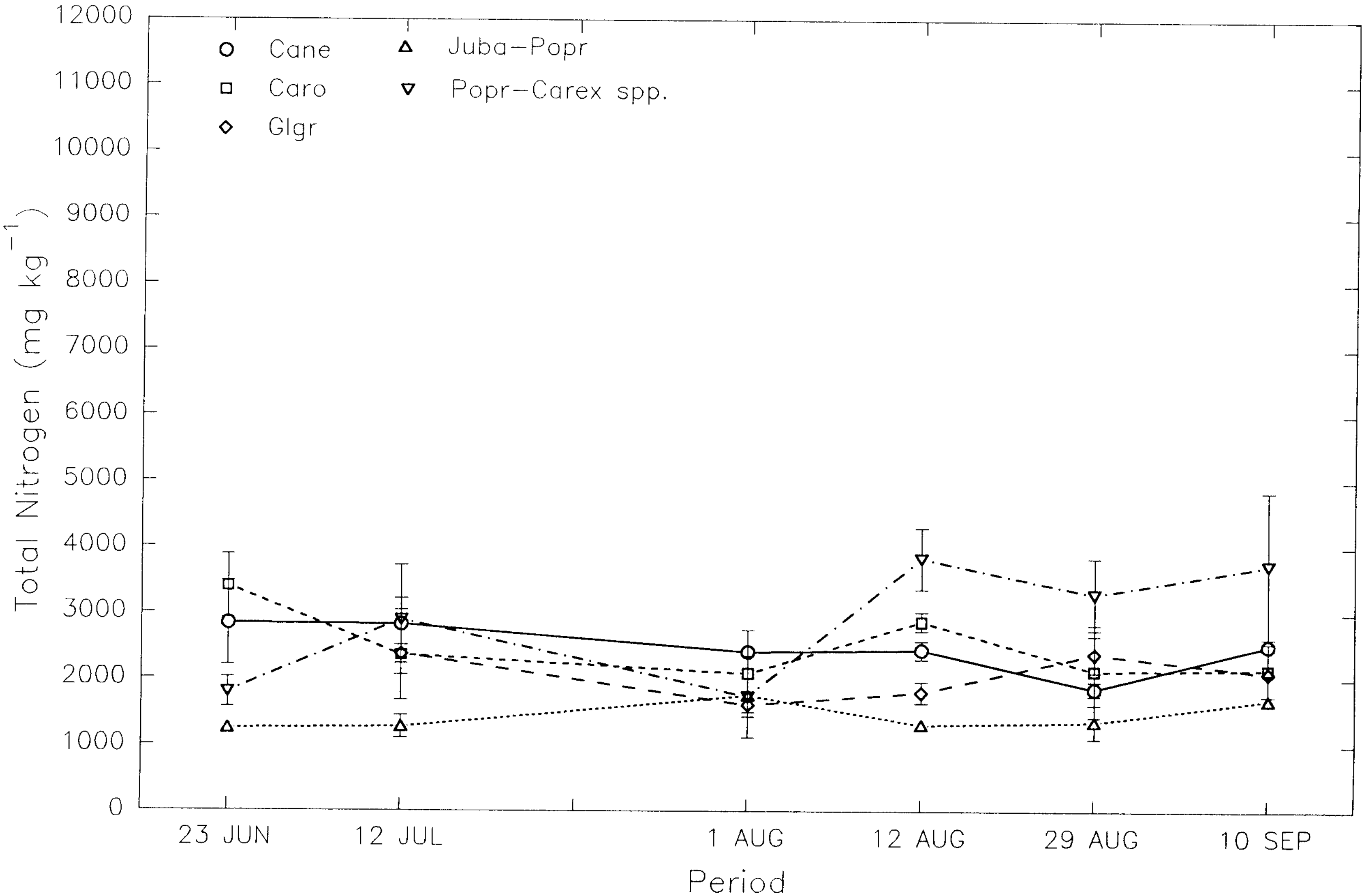


Figure III.13.

Fig. III.14. Mean (± 1 SE) ammonium nitrogen concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 0 to 10 cm depth over the study period in the Catherine Creek study area.

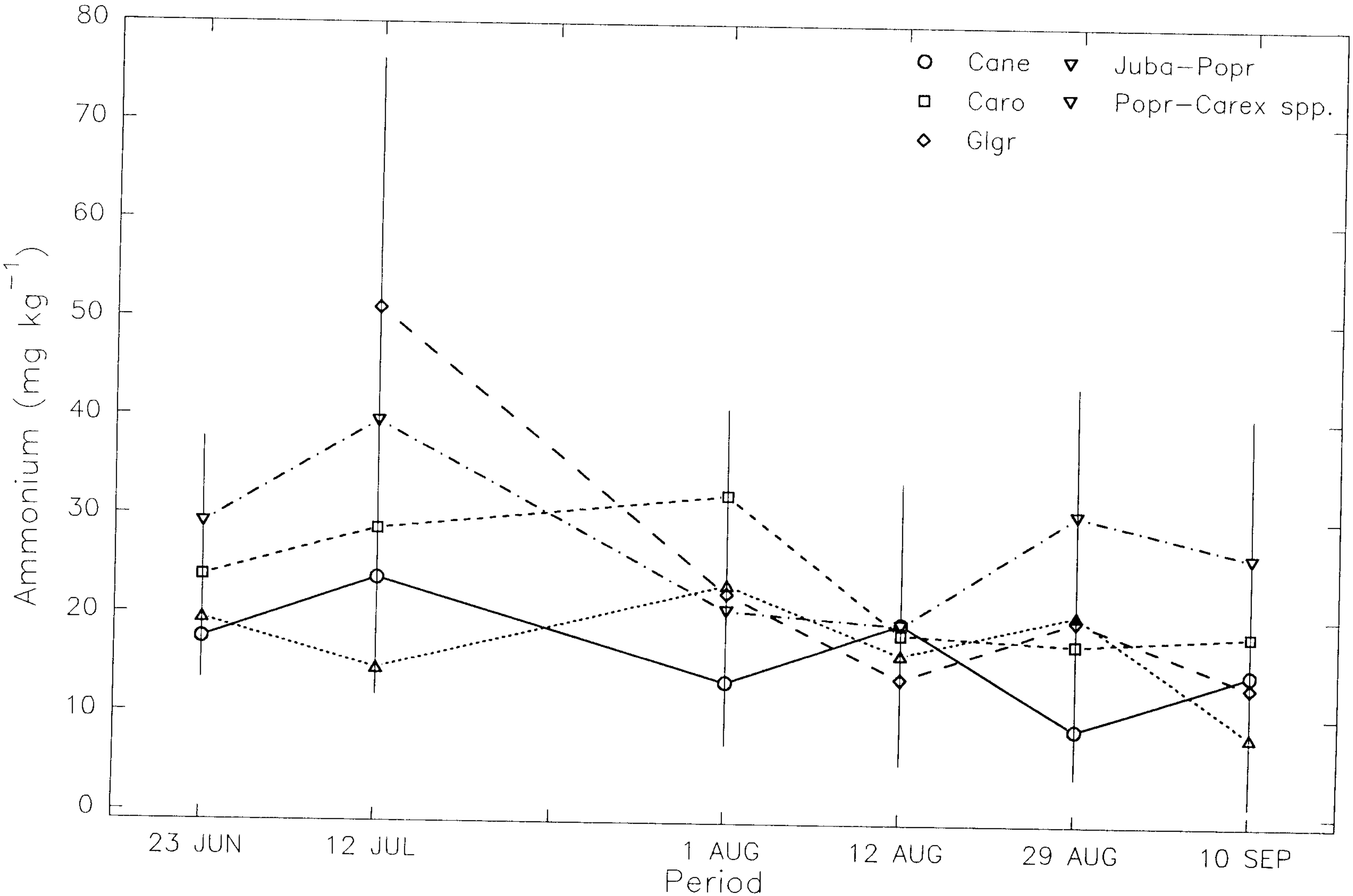


Figure III.14.

found between communities during the growing season. No overall trends between communities were apparent.

Except for the *Glyceria grandis* communities, variability in ammonium concentrations at the 10 to 30 cm depth was much less than at the 0 to 10 cm depth (Fig. III.15). The higher variability of ammonium in the 0 to 10 cm depth may be due to greater biological activity in this layer. Levels of ammonium ranged from 5 to 70.5 mg kg^{-1} in *Glyceria grandis* communities. *Poa pratensis-Carex* spp. communities had significantly higher levels of ammonium (10.5 mg kg^{-1}) at the 12 August sampling date than all other communities sampled. At the last sampling period, *Glyceria grandis* a dramatic increase in the ammonium concentration was observed. Soil ammonium increased from 16 mg kg^{-1} at 29 August to 70.5 mg kg^{-1} by 10 September. The sharp rise of ammonium levels in these communities may be due to dynamics of fine root biomass. Root elongation and biomass are known to decline in the fall as perennial plant species prepare for dormancy (Fernandez and Caldwell 1975, Edwards and Harris 1977). Decomposition (ammonification) of these fine roots may produce ammonium that due to low redox potentials cannot undergo nitrification and so accumulates in the soil profile. No additional significant differences were found between communities within dates.

Fig. III.15. Mean (± 1 SE) ammonium nitrogen concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 10 to 30 cm depth over the study period in the Catherine Creek study area.

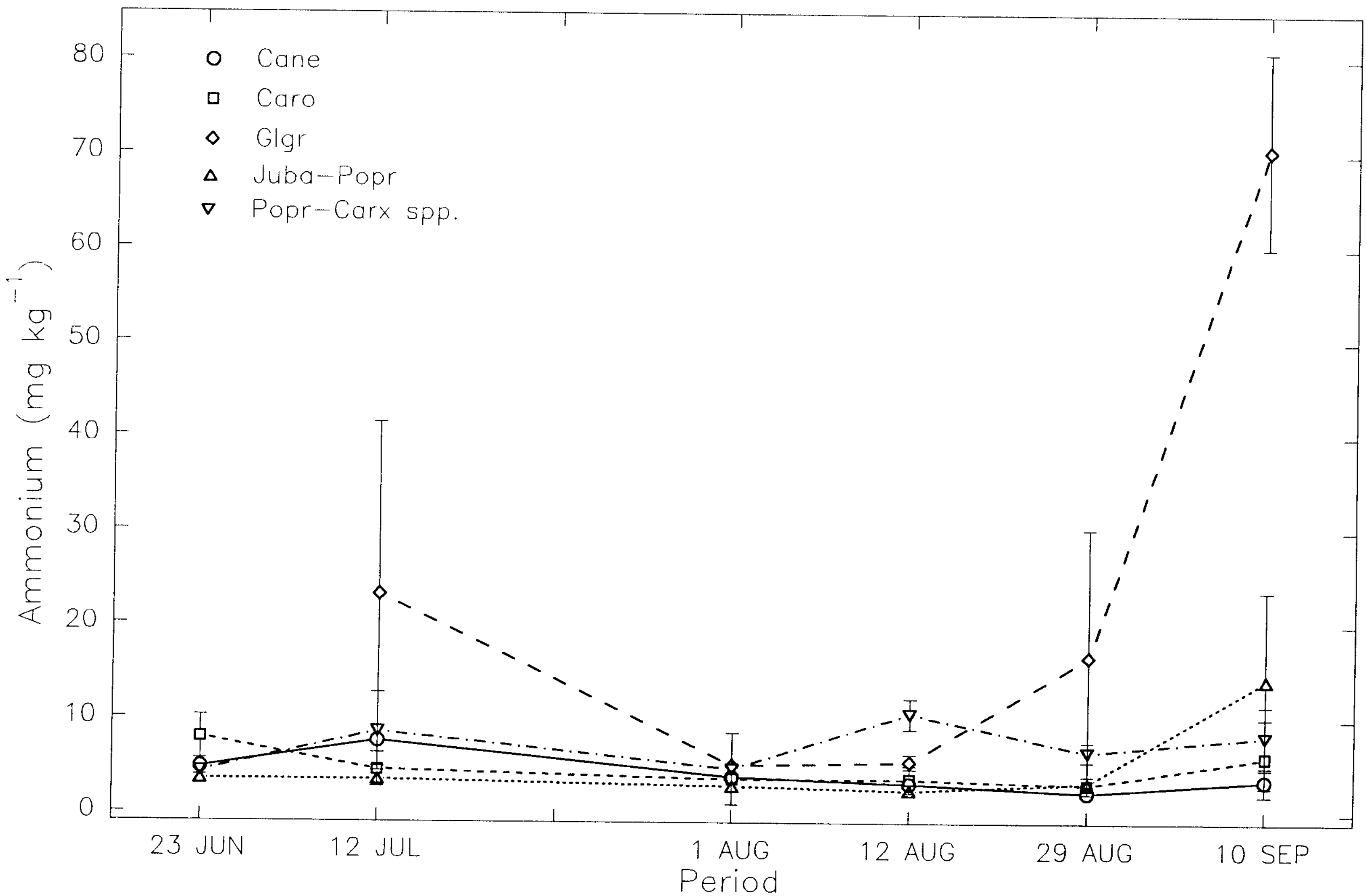


Figure III.15.

Nitrate nitrogen

Based on soil nitrate concentrations at the 0 to 10 cm depth, the five communities can be placed into two groups (Fig 16). Concentration of soil nitrate tended to remain higher in the drier *Poa pratensis-Carex* spp. communities throughout the sampling period. Conversely, low nitrate concentrations were found in *Juncus balticus-Poa pratensis* and the highly reduced *Carex rostrata*, *Carex nebraskensis* and *Glyceria grandis* communities. At 29 August, nitrate levels in *Poa pratensis-Carex* spp. and *Carex nebraskensis* communities were significantly higher than in *Juncus balticus-Poa pratensis* or *Glyceria grandis* communities. No other significant differences were found between communities within sampling dates.

Late season nitrate concentrations were higher than early season at the 0 to 10 cm depth in *Carex rostrata* and *Carex nebraskensis* communities, possibly reflecting increased nitrification with increased redox potentials (Fig. III.18). Despite late season increased in redox potential in *Juncus balticus-Poa pratensis* and *Poa pratensis-Carex* spp. communities, nitrate levels decreased at the 0 to 10 cm depth. This may be a result of increased plant uptake of nitrate.

At the 10 to 30 cm depth, the same general patterns occurred as at the 0 to 10 cm depth (Fig. III.17). Nitrate

Fig. III.16. Mean (± 1 SE) nitrate nitrogen concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 0 to 10 cm depth over the study period in the Catherine Creek study area.

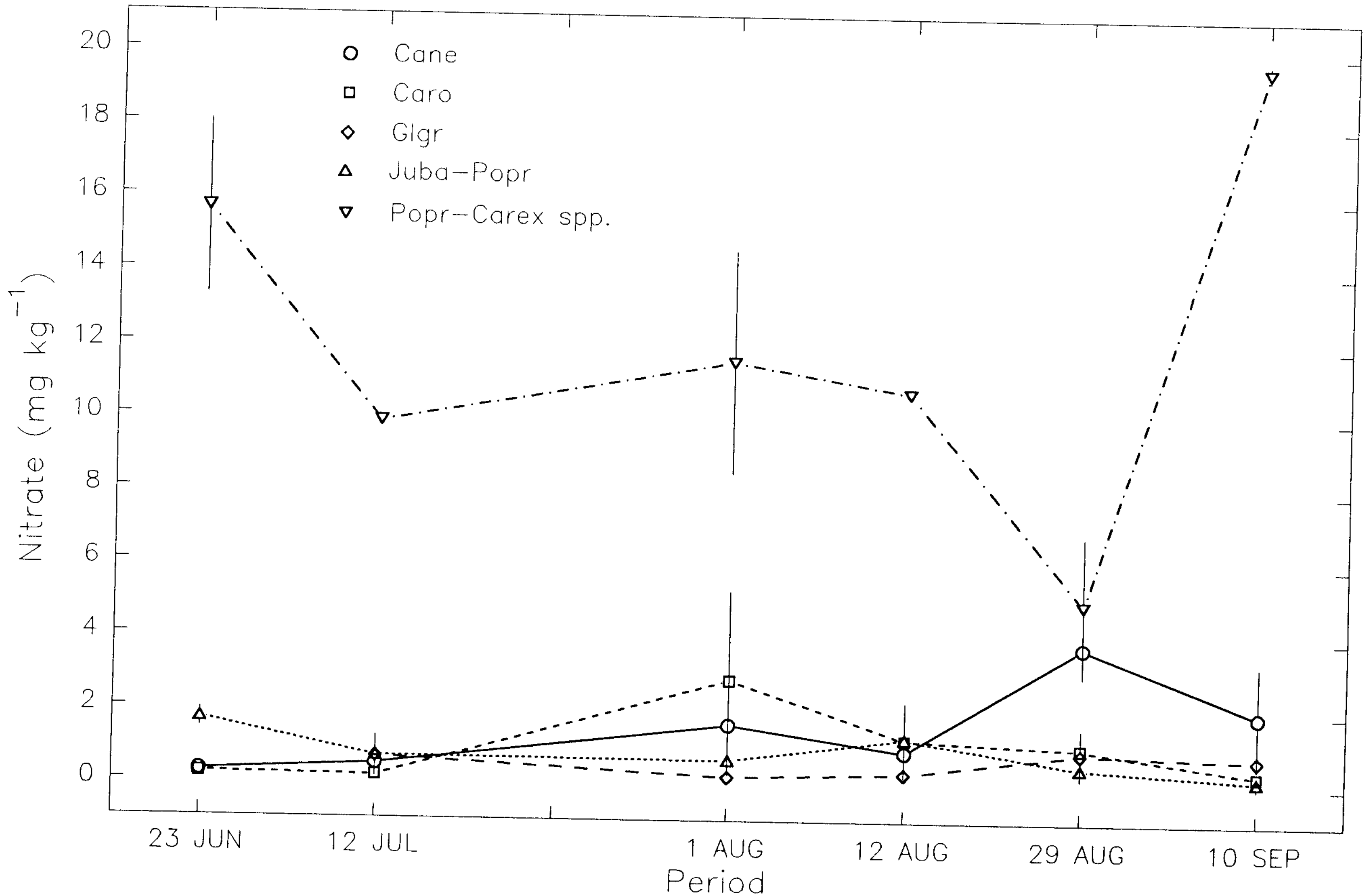


Figure III.16.

Fig. III.17. Mean (± 1 SE) nitrate nitrogen concentration in milligrams per kilogram in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex spp.) communities at 10 to 30 cm depth over the study period in the Catherine Creek study area.

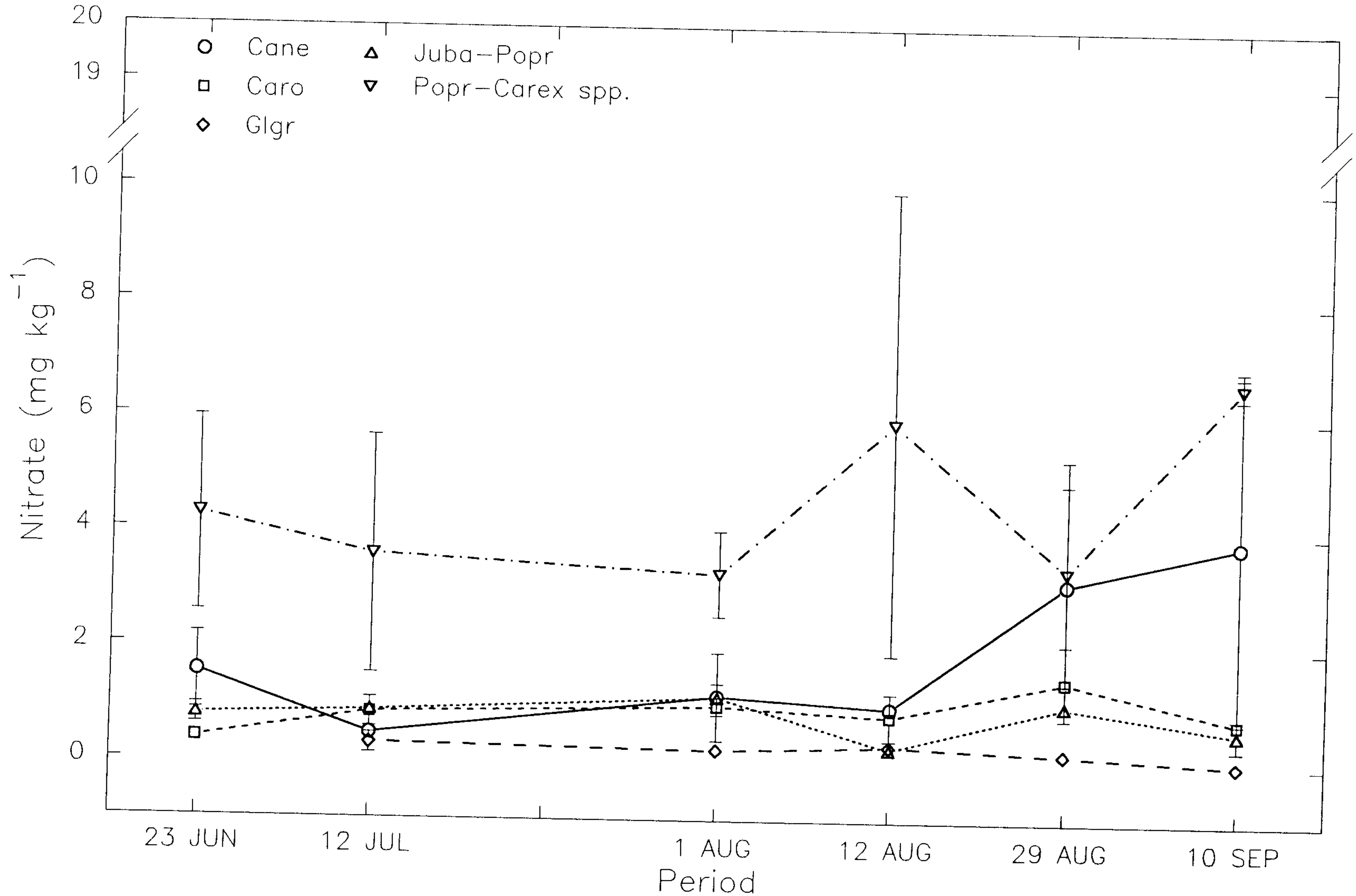


Figure III.17.

Fig. III.18. Conceptual diagram of the hydric gradient showing depth to water table, temperature, redox potential, nitrate concentration and levels of ferrous iron in *Carex nebraskensis* (Cane), *Carex rostrata* (Caro), *Glyceria grandis* (Glgr), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex) communities. Temperature and redox potential are shown for 5 and 30 cm depths. Ferrous iron and nitrate are shown for 0 to 10 and 10 to 30 cm depths.

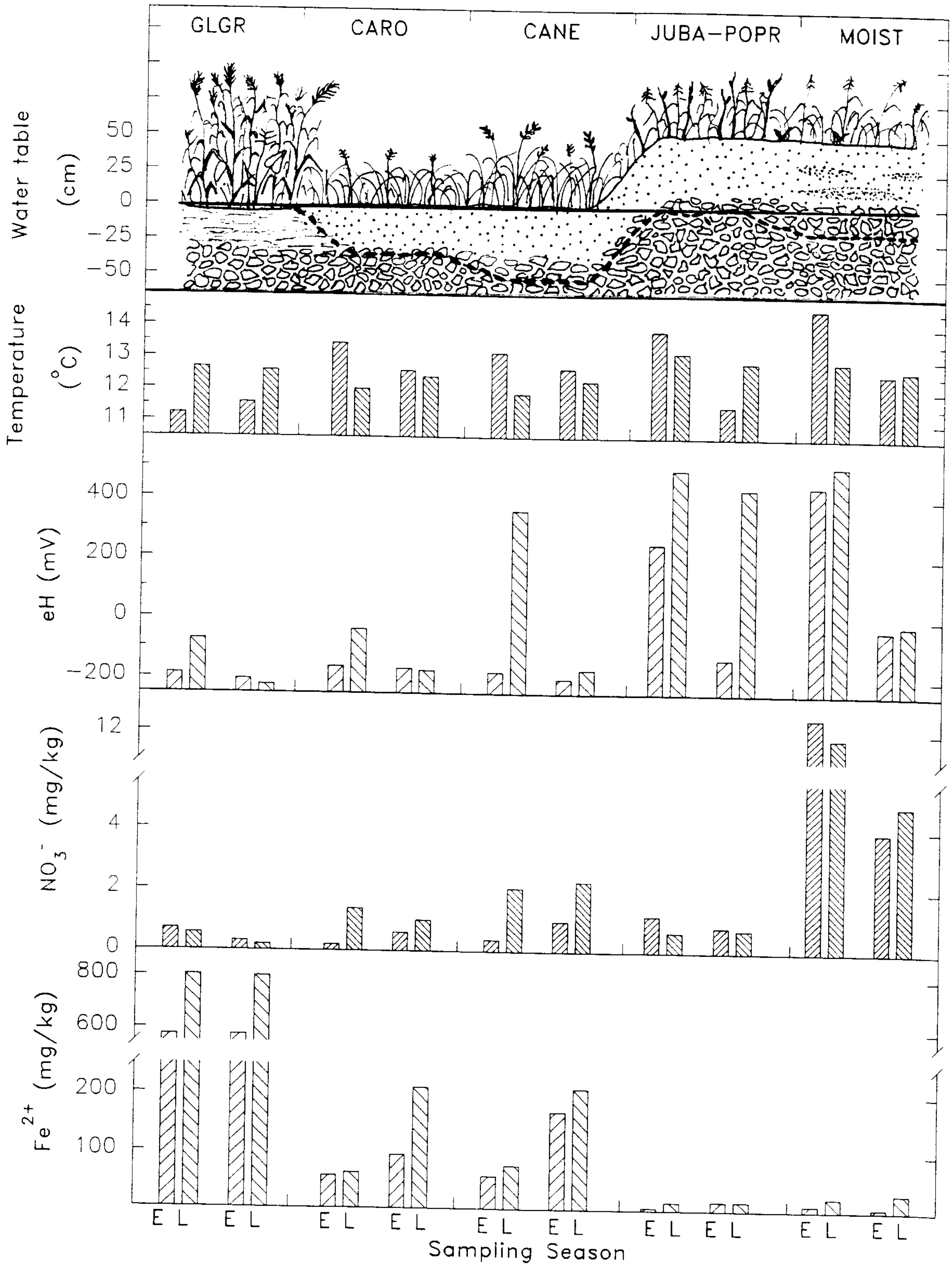


Figure III.18.

concentrations tended to remain higher in the *Poa pratensis-Carex* spp. throughout the growing season. Nitrate levels were significantly higher than other communities at the 1 August sampling date. By 10 September nitrate concentration in *Poa pratensis-Carex* spp. communities were significantly higher than in *Glyceria grandis*, *Juncus balticus-Poa pratensis*, and *Carex rostrata*, but were not significantly differently from *Carex nebraskensis* communities. No significant differences in nitrate levels occurred between communities at any other sampling date.

Levels of nitrate increased by late season in all communities except *Glyceria grandis* and *Juncus balticus-Poa pratensis*. In the *Juncus balticus-Poa pratensis* communities nitrate concentrations did not increase despite a dramatic rise in redox potential (Fig. III.18).

Glyceria grandis communities occurred in the most saturated and reduced habitats sampled. This is suggested by low redox potential, nitrate and high concentrations of ferrous iron when compared to other communities (Fig. III.18). Redox potentials of -19 to -226 mV and as a result relatively large amounts of ferrous iron (509 to 902 mg kg^{-1}) were present (Fig. III.8 & III.9). Redox potential of *Glyceria grandis* communities were comparable to those found in *Spartina alterniflora* marshes (-170 to 190 mV) (Delaune et al. 1983). Studies of saturated rice paddy soils report ferrous iron levels from 3,000 to 27,800 mg kg^{-1} (Ponnamperuma 1984). Seasonally flooded soils in the Willamette Valley of Oregon ranged from 0 to 341 mg kg^{-1} ferrous iron during a November to May sampling period (Somera 1967). Nitrate levels in *Glyceria grandis* communities generally were the lowest of any sampled community, possibly reflecting active nitrate reduction. Ammonium concentrations in this community did not differ greatly from the more mesic communities as would have been expected under anaerobic conditions (Mitsch and Gosselink 1986). Ammonium can diffuse to the thin, oxidized surface layer present near the surface of many reduced soils where it can be nitrified or ammonium may escape directly into the atmosphere (Mitsch and Gosselink 1986). It is also likely that rapid conversion of ammonium to dinitrogen or nitrous oxide under low redox potentials would keep ammonium levels low. (Patrick and Delaune 1972, Ponnamperuma 1972).

Unlike other communities sampled, *Glyceria grandis* and associated species communities must be adapted to constant soil saturation and the attendant chemical status of such soils. Roots of *Glyceria maxima*, a closely related species to *Glyceria grandis* are highly aerenchymatous, containing about 53% air space (Crawford 1982). In addition, it was observed that many roots of *Glyceria grandis* had thin coatings of oxidized iron. Many of the common species associated with *Glyceria grandis* communities also appear to be adapted to waterlogged conditions.

Based on water table depth, redox potential, nitrate, and ferrous iron levels, *Carex rostrata* and *Carex nebraskensis* communities occur approximately midway along the stress gradient associated with reduced or waterlogged conditions (Fig. III.18). Overall redox potential, nitrate, and ferrous iron concentrations of *Carex rostrata* and *Carex nebraskensis* communities were significantly different from the hydric *Glyceria grandis* communities. However, depth to water table and low concentration of ferrous iron was more related to communities at the drier end of the gradient. Consistent with the lower redox potentials of *Carex nebraskensis* and *Carex rostrata* communities at the 10 and 30 cm depth, levels of ferrous iron were higher than those found in *Poa pratensis-Carex* spp. and *Juncus balticus-Poa pratensis* communities at the both early and late season. However, at the 0 to 10 cm depth levels of ferrous iron in *Carex rostrata, Carex nebraskensis,* were only slightly higher than *Poa pratensis-Carex* spp., and *Juncus balticus-Poa pratensis* communities despite the low redox potentials of the carex dominated communities. It may be possible that submergence of *Carex nebraskensis* communities was too short and during too low soil temperatures to allow for iron reduction at the 0 to 10 cm depth. Unlike the *Carex rostrata* communities, *Carex* *nebraskensis* communities exhibited a rapid rise of redox potential in early July at the 5 cm depth. Low redox potentials in *Carex rostrata* communities may have been maintained by capillary rise of water from the water table. Low levels of nitrate in *Carex rostrata* and *Carex nebraskensis* communities may reflect denitrification processes which are favored by redox potentials lower than 230 mV (Gambrell and Patrick 1978).

Plant species in the *Carex rostrata* and *Carex nebraskensis* communities appear to have several adaptions to anaerobic conditions. Adaptions include thickened leaf epidermis and in the case of *Carex nebraskensis* a glaucous coating on the leaf (pers. observation). These adaptions may decrease water loss and hence uptake of reduced soil toxins from the soil solution. *Carex nebraskensis* communities had the lowest species richness and diversity, an indication that few species in this particular riparian system may be able to cope successfully with the large shifts in redox potential and other chemical factors over the growing season. It is also possible that few species are able to compete with *Carex nebraskensis* under these dynamic conditions. In addition to a thickened epidermis, radial oxygen loss has been shown to occur in *Carex rostrata* Conlin and Crowder (1989). This could possibly the explain occurrence of *Carex rostrata* communities in areas of lower surface redox potential than *Carex nebraskensis* communities.

Juncus balticus-Poa pratensis and *Poa pratensis-Carex* spp. communities were at the driest position of this moisture gradient. High redox potentials, low levels of ferrous iron, and low water tables characterized edaphic conditions of these communities (Fig. III.18). With exception of the early growing season, redox potentials of both communities were generally high enough to indicate aerobic conditions in the 0 to 10 cm depth. However based upon the redox potential at the 30 cm depth it is probable that after 1 August, *Juncus balticus-Poa pratensis* communities were aerobic while *Poa pratensis-Carex* spp. communities remained anaerobic.

Levels of nitrate in *Juncus balticus-Poa pratensis* communities were very close to those found in *Glyceria grandis*, *Carex rostrata*, and *Carex nebraskensis* communities. Low redox potentials at 10 cm depth and the probability of local anaerobic mircrosites at the 5 cm depth in *Juncus balticus-Poa pratensis* communities coupled with warmer temperatures in these communities, may have permitted significant denitrification early in the growing season. Levels of nitrate may remain low in *Juncus balticus-Poa pratensis* communities over the growing season despite aerobic conditions because, in many communities nitrifying bacteria are outcompeted for ammonium by the root-mycorrhizal complex and other soil biota and hence little nitrification occurs (Huntjens, 1971, Robertson and Vitousek 1981, Vitousek et al. 1982). The effect of these factors would be to produce a community with low levels of nitrate. Few species of *Juncus balticus* and *Carex rostrata* communities have adaptions to survive saturated soils and low redox potentials.

Just as communities are distributed along gradients of edaphic conditions, individual species also respond to edaphic conditions. When plotted against redox potential, nitrate, and ferrous iron concentrations, plant species displayed varying degrees of abundance (Figs. III.19, III.20, III.21). *Glyceria grandis* and *Ranunculus aquatilis* are most abundant under conditions of low redox potential (-220 to -0.8 mV), low nitrate (1 to 9 mg kg^{-1}), and high levels of ferrous iron (570 to 890 mg kg^{-1}). Both of these species were restricted to the most anaerobic community sampled (Table III.1, Fig. III.18).

Species common to the more aerobic *Poa pratensis-Carex* spp. communities and *Juncus balticus-Poa pratensis* communities show a limited tolerance to edaphic conditions associated with water logging (Table III.1). *Achillea millefolium* and *Potentilla gracilis* were restricted to redox potentials of 275 to 630 mV, and low levels of ferrous iron (0 to 20 mg kg^{-1}) (Figs. III.19, III.21). These species appeared to be tolerant of a wide range of

Fig. III.19. Frequency of selected species along a gradient of redox potential at 5 cm in the Catherine Creek study area.

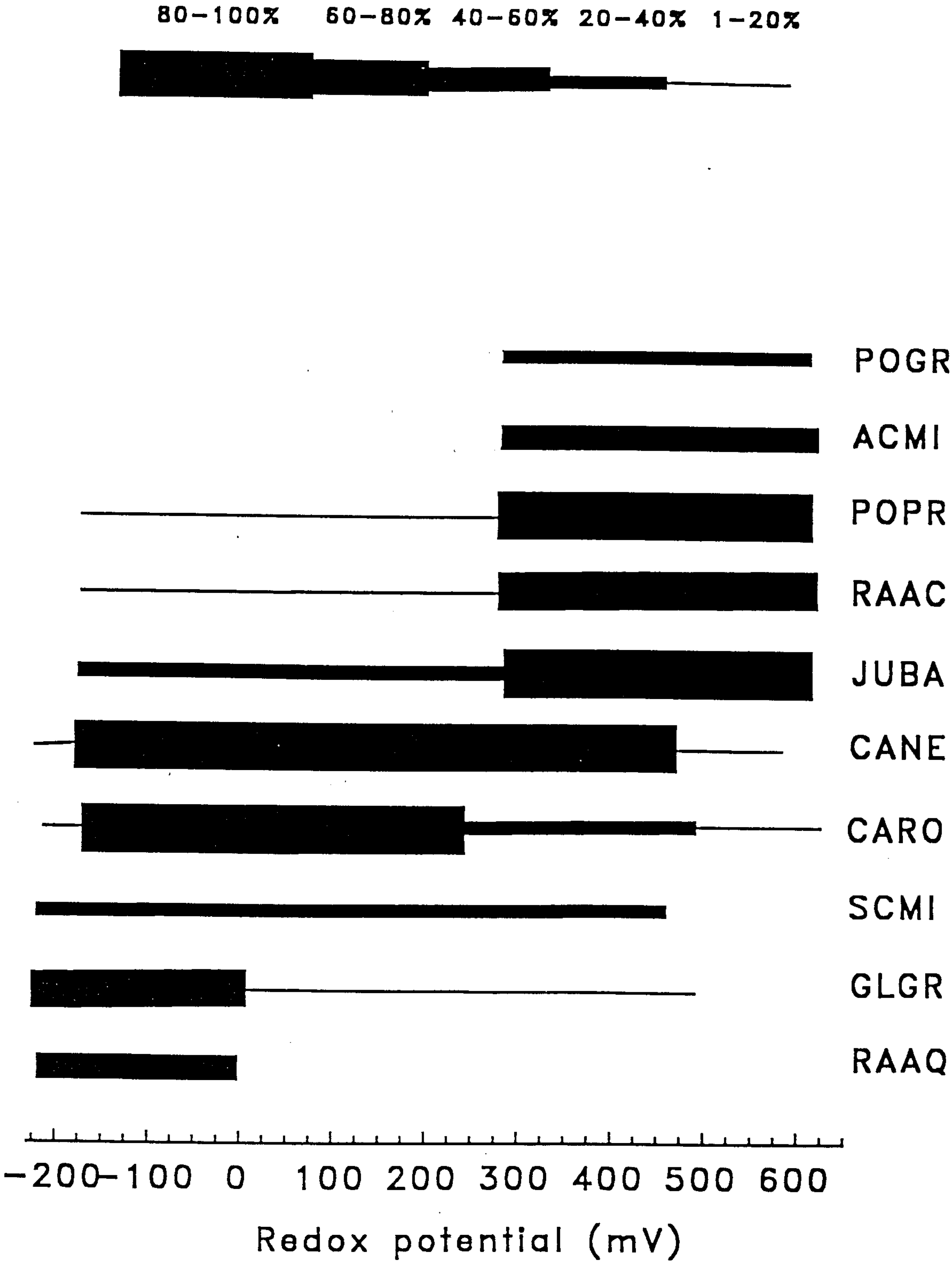


Figure III.19.

Fig. III.20. Frequency of selected species along a gradient of nitrate concentration (mg kg^{-1}) at the 0 to 10 cm depth in the Catherine Creek study area.

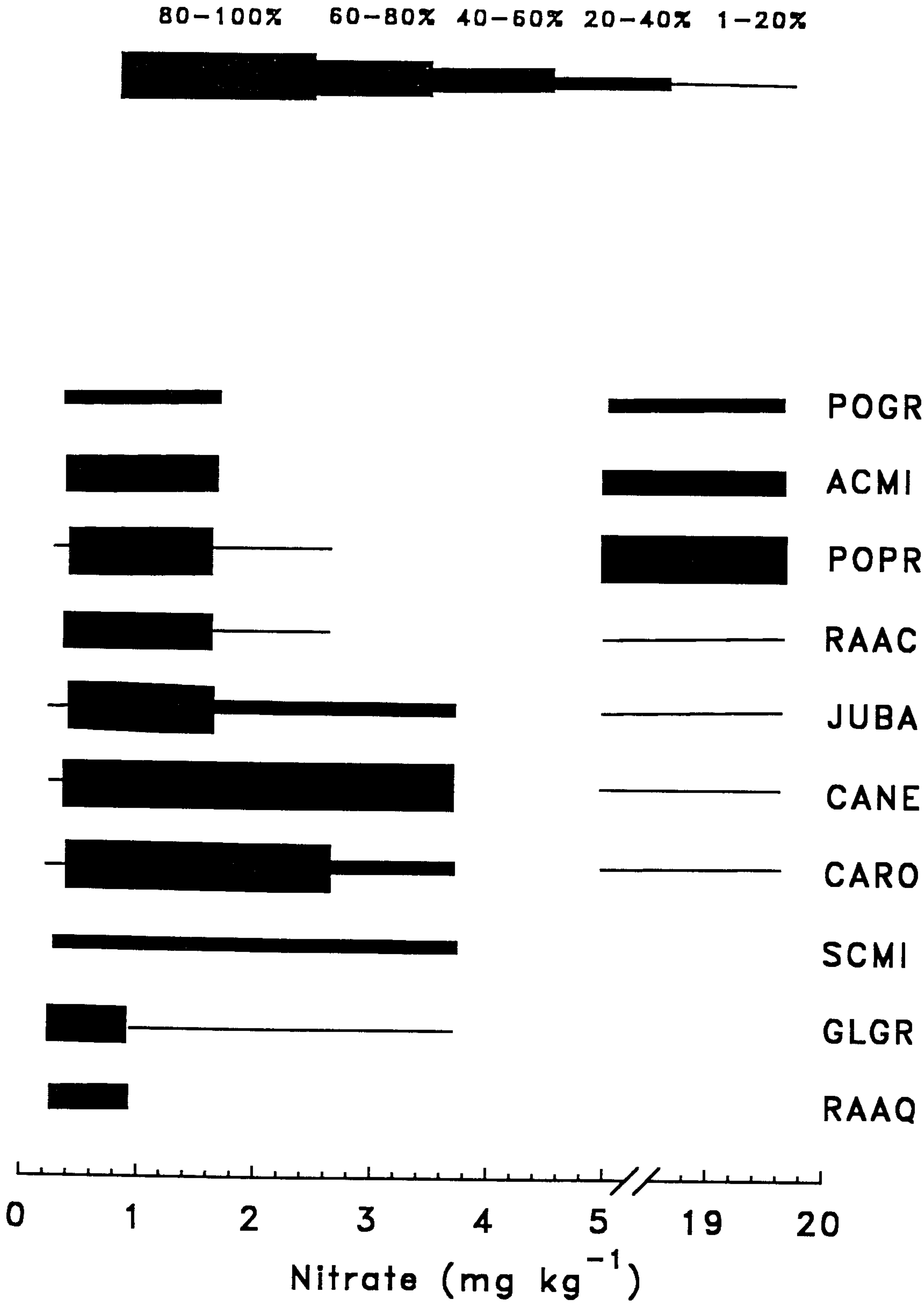


Figure III.20.

Fig. III.21. Frequency of selected species along a gradient of ferrous iron concentration (mg kg^{-1}) at the 0 to 10 cm depth in the Catherine Creek study area.

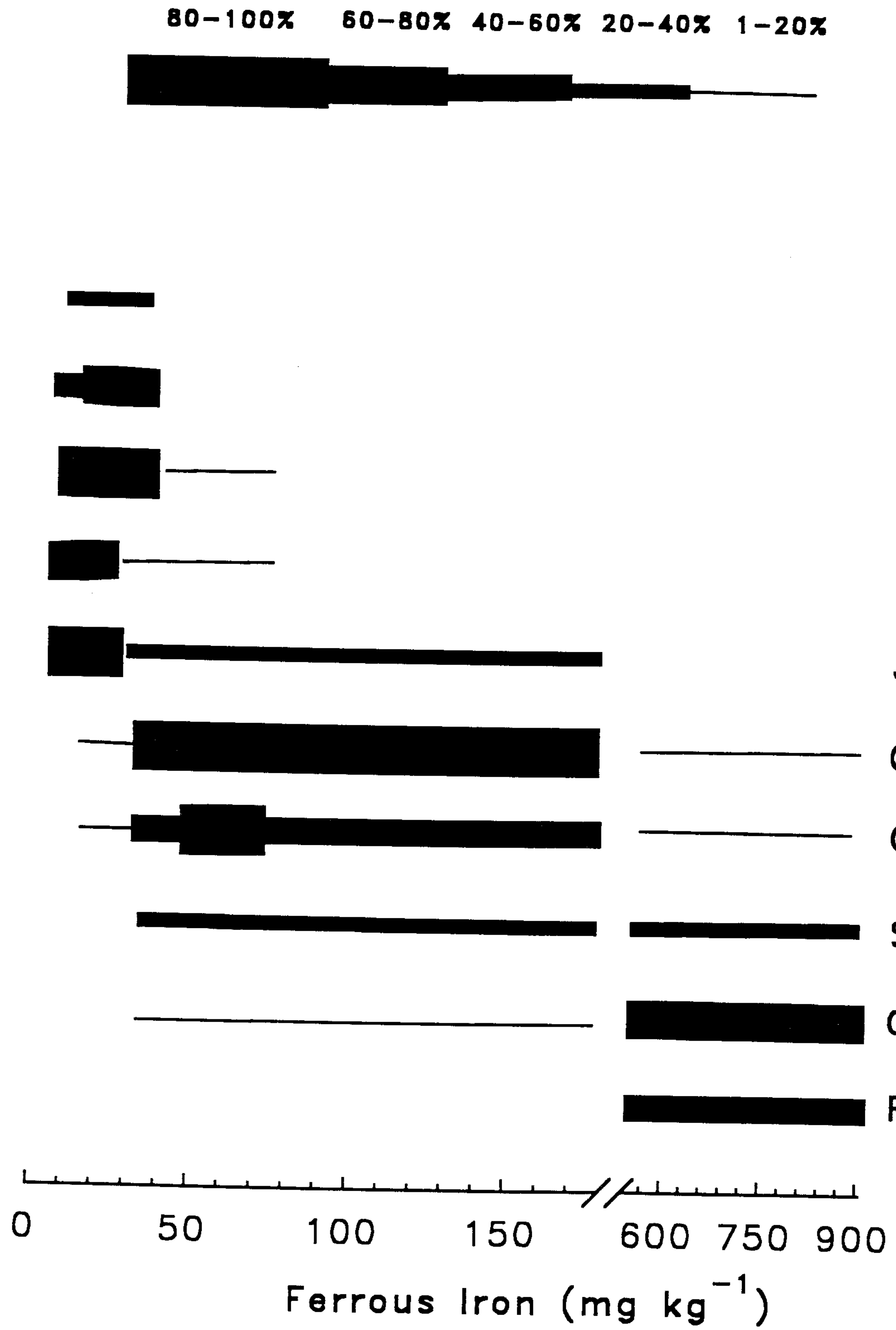


Figure III.21.

nitrate (Fig. III.20). This is due to low of levels of nitrate in *Juncus balticus-Poa pratensis* communities and high levels in *Poa pratensis-Carex* spp. communities (Fig. III.18). Both *Poa pratensis* and *Ranunculus acris* were most abundant under the same conditions as *Achillea millefolium* and *Potentilla gracilis*, but these species also displayed a much broader tolerance of redox potential, nitrate and ferrous iron. Although maximum abundances of *Juncus balticus* occurs under the same edaphic conditions as the species mentioned above it is more tolerant of low redox potentials, nitrate and high levels of ferrous iron.

Carex rostrata and *Carex nebraskensis* were abundant over a broad range of redox potentials, nitrate and ferrous iron (Figs. III.19, III.20, III.21). These species were most abundant in communities situated midway along the moisture gradient (Table III.1). This would indicate that *Carex rostrata* and *Carex nebraskensis* are well adapted to fluctuations in redox potential nitrate and ferrous iron. While *Carex nebraskensis* is broadly tolerant to wide range of measured edaphic conditions, *Carex rostrata* has a much lower degree of tolerance, especially for ferrous iron.

The range of tolerance displayed by these species contributes, in part, to the number of communities they were occurred in. Species such as *Carex nebraskensis*, *Carex rostrata*, and *Juncus balticus*, that are relatively tolerant to a variety of edaphic conditions were found in most of the communities sampled (Table III.1). Species with a narrow tolerance of edaphic conditions such as *Ranunculus aquatilis* were restricted to only a few communities.

Conclusions

A common characteristic of many undisturbed, montane, low gradient, riparian areas of the western United States is a water table at or above the soil surface throughout the year. Results of our study indicate that anaerobic layers are close to the soil surface and that levels of nitrate in these layers tend to be low. Conditions favoring denitrification (i.e. saturated soils, low redox potentials) in these communities will disappear if the riparian ecosystem is modified as a result of channel downcutting. Downcutting can be initiated by beaver dam removal, removal of coarse woody debris, road construction, and overgrazing. Channel downcutting increases the depth at which anaerobic conditions occur. Organic matter available for possible microbial use as an energy source will be lower at these greater depths (Brady 1990) and it would be expected that microbial processes would slow. In addition, total area available for denitrification in riparian areas can be decreased through management practices such as channelization, or road building. Due to such anthropogenic disturbances the function of riparian areas as nitrate sinks may be reversed to nitrate source areas. Nitrate from riparian areas entering streams can cause eutrophication of an originally nitrogen limited ecosystem.

In this study we have utilized soil chemical characteristics, especially redox potential to characterize a riparian plant community gradient from continually anaerobic to aerobic conditions. Our results indicated that communities are products of unique combinations of soil chemical and physical conditions. These conditions influence critical processes at the rhizosphere, whole plant, community, ecosystem, and landscape level. Future research should focus on further quantifying soil chemical processes in relation to plant communities and investigate landscape level relationships between the terrestrial, riparian, and aquatic ecosystems. Without increased understanding of the functions of riparian systems at different scales, we can expect continuing deterioration in aesthetics, quality, and productivity of our riparian ecosystems.

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IV. SUMMARY

High diversity is common to many riparian ecosystems and the Catherine Creek study site was no exception. In the eight communities studied, over 250 species were encountered in sampling (Appendix A). Many of these species occurred in several communities. Some species such as *Poa pratensis* show a unique response to grazing from one community to another as competitive relationships were altered. It is not surprising then that analysis of data from the 10 year study period shows not all communities responded to grazing and exclosure in the same manner.

The late grazing scheme employed in this study appears to have several advantages for riparian areas of this region. Since its initiation in 1978, this grazing scheme has maintained species diversity in the plant communities studied. However, woody riparian species were negatively affected through declines in diversity and height. Disturbance from grazing and other livestock activities created conditions suitable for a number of species particularly exotic or ruderal species. Grazing was also limited to 3 to 4 weeks during a period when many herbaceous species were close to dormancy.

Although late season grazing did have some advantages, livestock influence was variable from one plant community to another. For example, *Poa pratensis*-mixed dicot and *Poa pratensis-Carex* spp. communities had significantly lower species richness and diversity when compared to grazed counterparts (Tables 1, 5). Exotic species such as *Bromus mollis* in the *Poa pratensis*-mixed dicot communities and *Phleum pratense* in the *Poa pratensis-Carex* spp. communities decreased significantly in the exclosures (Table 2). In the most heavily utilized communities ruderal and competitive ruderal species were favored by grazing disturbance. In exclosures of the same communities, competitive or competitive stress tolerant species were favored. Other plant communities with relatively low rates of utilization, such as *Pinus ponderosa* communities also significant declines in species richness and abundance of exotic species in exclosures.

This may indicate some riparian plant communities may have had, prior to livestock introduction, lower species richness and diversity than today. We must temper this statement by the fact that it is not known if any native species were extirpated from the site prior to initiation of research activities. It should be noted that species richness weighs exotic and native species equally without consideration of abundance.

Woody species associated with grazed *Salix* spp.-mixed dicot communities had significantly lower heights and densities than ungrazed treatments (Tables 26 and 27). This indicates that grazing is slowing growth of woody species in these communities. *Salix* spp.-mixed dicot communities may have been more diverse and of higher density and height than today. Because of this the instream system may been more detrital based and had much higher loadings of coarse woody debris, and higher frequency of pools than today. To promote maximum growth, and density of riparian woody species, livestock exclusion from *Salix* spp.-mixed dicot communities may be necessary.

A lowered species richness and species diversity in exclosures of riparian meadow communities has important implications for those interested in preserving biodiversity and threatened and endangered species. Reduced species diversity in exclosures should not be equated with impoverishment of the biological community, particularly if decreases of exotic species are contributing to our diversity numbers. However it is possible that certain native species may require disturbance for populations to successfully maintain themselves. This is a subject that urgently requires study as many preserves exclude most common types of disturbance such as fire, or grazing.

The role of livestock grazing in individual riparian communities needs to be carefully evaluated particularly in regards to how it impacts the functioning of the particular riparian community in question. This information is critical if grazing impacts on riparian ecosystem structure and function are to be assessed.

At Catherine Creek the high aboveground diversity was also reflected by high belowground diversity. This diversity was determined by sampling five plant communities *Glyceria grandis*, *Carex rostrata*, *Carex nebraskensis*, *Juncus balticus-Poa pratensis*, and *Poa pratensis-Carex* spp.. Belowground physical and chemical differences indicated these communities occur relative to unique combinations of soil chemical conditions. For example, in *Glyceria grandis* communities, redox potential was significantly lower than *Juncus balticus-Poa pratensis*, and *Poa pratensis-Carex* spp. communities (Fig. 1). Levels of ferrous iron in *Glyceria grandis* communities were higher than all other communities (Figs. 7 and 8). The *Poa pratensis-Carex* spp. communities at the driest part of the moisture gradient with high redox potential and significantly higher nitrate levels than other communities sampled (Fig. 15). Values for Carex dominated communities varied between the anaerobic *Glyceria grandis* communities and the more aerobic *Juncus balticus-Poa pratensis* communities (Fig. 1).

Water logging and associated soil chemical conditions of riparian soils have important implications for water quality of stream ecosystems. Recent research has shown that riparian areas are important sites for denitrification (Gilliam et al. 1978, Jacobs and Gilliam 1985, Cooper 1990). In addition, riparian areas are also important sinks for many other nutrients (Lowrance et al. 1984).

Conditions favoring denitrification (i.e. saturated soils, low redox potentials) in these communities will disappear if the riparian ecosystem is modified as a result of channel downcutting. Downcutting can be initiated by beaver dam removal, removal of coarse woody debris, road construction, and overgrazing. Channel downcutting increases the depth at which anaerobic conditions occur. Organic matter available for possible microbial use as an energy source will be less at these greater depths and it would be expected that microbial processes would slow. In addition, total area available for denitrification in riparian areas can be decreased by management practices such as channelization, or road building. Due to such anthropogenic disturbances the function of riparian areas as nitrate sinks may be reversed to nitrate source areas. Nitrate from riparian areas entering streams will cause eutrophication of a originally nitrogen limited ecosystem.

In addition to reducing the areal extent of anaerobic conditions, the previously mentioned activities will structurally alter riparian vegetation as well as the ecosystem. A decline in aboveground biomass of vegetation will result in reduced amounts of sediment trapping in the riparian zone. Many nutrients, especially phosphorus, are deposited in the riparian zone during high flows (Yarbro 1979). these nutrients would be lost to down stream systems in degraded situations. Other important functions of the riparian ecosystems such as woody debris input (Robinson and Bestcha 1990), temperature moderation (Swanson et al 1982), are also affected to varying degrees by management activities.

The two studies of this thesis taken together indicate that riparian ecosystems are extremely complex both above and belowground. The condition of the riparian zone is a reflection of many complex and biogeochemical processes with linkages to both aquatic and terrestrial communities. Chemical status of riparian soils greatly influence water quality, the aquatic ecosystem, and the pattern and productivity of the riparian vegetation. Currently, little quantitative data exists on the long term effects of grazing, logging, channelization, recreation or other anthropogenic activities on either above or belowground processes in western riparian ecosystems. We do know that isolating the stream from its riparian zone either by channel downcutting or by channelization seriously impairs the functional integrity of the riparian zone. Source-sink relationships between riparian and stream ecosystems are severed. This ultimately will result in declines in those resource values associated with water quality, livestock grazing, fisheries, and wildlife diversity and productivity. Research should focus on quantifying the landscape-level relationships between the terrestrial, riparian, and aquatic ecosystems.

Developing land management systems that allow ecosystem processes to function as close to a natural equilibrium as possible will insure a stable output of resource values for all interested users. Without an increased understanding on how riparian ecosystems function and the development of management strategies that reflect this knowledge, we can expect further declines in the quality and productivity of our riparian ecosystems.

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APPENDICES

Appendix A

Orgin, scientific and common names of plant species idenitified on the Catherine Creek study site. Nomenclature follows Hitchcock and Cronquist (1973).

Appendix A.

Origin	Scientific Name Grasses	Common Name
E	Agropyron cristatum (L.) Gagrth.	fairway crested wheatgrass
E	Agropyron repens (L.) Beauv.	quackgrass
N	Agropyron spicatum (Pursh) Scribn. and Smith	bluebunch wheatgrass
E	Agrostis alba L.	redtop
N	Agrostis diegoensis Vasey	thin bentgrass
N	Agrostis exarata Trin.	spike bentgrass
N	Agrostis scabra Willd.	winter bentgrass
E	Aira elegans Willd	diffuse hairgrass
N	Alopecurus aequalis sobol.	shortawn foxtail
E	Alopecurus pratensis L.	meadow foxtail
E	Anthoxanthum odoratum L.	sweet vernalgrass
E	Arrhenatherum elatus (L.) Presl.	tall oatgrass
E	Bromus brizaeformis Fisch. and Mey.	rattle brome
N	Bromus marginatus Ness	mountain brome
E	Bromus mollis L.	soft brome
E	Bromus racemosus L.	bald brome
E	Bromus tectorum L.	cheatgrass
N	Calamagrostis rubescens Buckl.	Pinegrass
E	Dactylis glomerata L.	orchardgrass
N	Deschampsia caespitosa (L.) Beauv.	tufted hairgrass
N	Deschampsia danthonoides (Trin.) Munro Ex Benth.	Annual hairgrass
N	Deschampsia elongata (Hook.) Munro ex Benth.	Slender hairgrass
N	Elymus glaucus Buckl.	blue wildrye
N	Festuca elatior L.	meadow fescue
N	Festuca idahoensis Elmer	idaho fescue
N	Festuca occidentalis Walt.	western fescue
N	Festuca ovina L.	sheep fescue
N	Glyceria elata (Nash) M. E. Jones	tall mannagrass
N	Glyceria grandis Wats.	tall mannagrass
N	Glyceria striata (Lam.) A. S. Hitcho.	fowl mannagrass
E	Holcus lanatus L.	common velvetgrass
E	Hordeum jubatum L.	foxtail barley
N	Koeleria cristata	prairie junegrass
N	Melica bulbosa Geyer Ex Porter and Coult.	oniongrass
N	Muhlenbergia filiformis (Thurb.) Rydb.	pullup muhly
N	Phleum alpinum L.	alpine timothy
E	Phleum pratense L.	timothy
N	Poa ampla Merrill	big bluegrass
E	Poa bulbosa L.	bulbous bluegrass
N	Poa compressa L.	Canada bluegrass
N	Poa nevadensis Vasey Ex Scribn.	Nevada bluegrass
E	Poa pratensis L.	Kentucky bluegrass
N	Poa sandbergii Vasey	Sandberg bluegrass
N	Sitanion hystrix (Nutt.) J. G. SM.	bottlebrush squirreltail
N	Stipa occidentalis Thurb. Ex. Wats.	western needlegrass
N	Trisetum canescens Buckl.	tall trisetum
E	Vulpia myuros L.	rat-tail fescue

	Grasslikes	Common Name
N	Carex aurea Nutt.	golden sedge
N	Carex aquatilis Wahl.	water sedge
N	Carex atrostachya Olney.	slenderbeak sedge
N	Carex comosa Boott.	bristly sedge
N	Carex flava L.	yellow sedge
N	Carex geyeri Holm.	elk sedge
N	Carex hoodii Boott	Hood's sedge
N	Carex laeviculmis Meinsh.	smooth-stem sedge
N	Carex langinosa Michx.	wooly sedge
N	Carex lenticularis Michx.	sedge
N	Carex microptera Mark.	smallwing sedge
N	Carex nebraskensis	Nebraska sedge
N	Carex praegracilis W. Boott	clustered sedge
N	Carex rostrata Stokes	beaked sedge
N	Carex stiptata Muhl.	sawbeak sedge
N	Carex straminiformis L. H. Bailey	Mount Shasta sedge

Appendix A. Continued.

Origin	Forbs and Allies	Common Name
N	Eleocharis acicularis (L.) R.&S.	needle spike-rush
N	Elocharis palustris (L.) R.&S.	common spike-rush
N	Juncus balticus var. balticus Willd.	baltic rush
N	Juncus balticus var. montanus Englem	baltic rush
N	Juncus bufonius L.	toad rush
N	Juncus ensifolius Wilsk.	swordleaf rush
N	Juncus nodosus L.	tuberous rush
N	Luzula campestris var. multiflora (Ehrh.) Celak.	common woodrush
N	Scirpus microcarpus Presl.	panicled bulrush
N	Achillea millefolium L.	western yarrow
N	Acontium columbianum Nutt.	Columbia monkshood
N	Agoseris glauca (Pursh) Raf.	pale agoseris
N	Alisma plantago-aquatica var. americanum Schul. & Schul.	waterplantain
N	Allium acuminatum Hook.	tapertip onion
N	Alyssum alyssoides L.	pale allysum
N	Amsinckia retorsa Suksd.	ridgid fiddleneck
N	Anaphalis margaritacea (L.) B. & H.	common pearleverlasting
N	Anemone piperi Britt.	piper anemone
N	Antennaria rosea Greene	rose pussytoes
N	Aquilegia formosa Fisch.	Sitka columbine
E	Arabis drummondii Gray	Drummond rockcress
E	Arenaria macrophylla Hook.	sandwort
E	Arenaria serpyllifolia L.	sandwort
N	Arnica chamissonis Less.	chamisso arnica
N	Artemisia ludoviciana Nutt.	Louisiana wormwood
E	Asperugo procumbens L.	madwort
N	Aster campestris Nutt.	aster
N	Aster foliaceus Lindl.	ridgid fiddleneck
N	Astragalus canadensis L.	Canada milkvetch
N	Babarea orthoceras Ledeb.	wintercress
N	Besseya rubra (Dougl.) Ryab.	besseya
N	Brodiaea douglasii Wats.	Douglas brodiea
N	Camassia quamash (Pursh) Greene	common camas
E	Capsella bursa-pastoris (L.) Medik.	shepards purse
E	Cardaria draba (L.) Desv.	whitetop
N	Castilleja cusickii Greenm.	cusick paintbrush
E	Cerastium viscosum L.	sticky cerastium
N	Chaenactis douglasii (Hook.) H. & A.	hoary chaenactis
N	Cicuta douglasii (DC.) Coult. & Rose	western waterhemlock
N	Circaea alpina L.	circaea
E	Cirsium vulgare (Savi) Airy-shew	bull thistle
N	Collinsia parviflora Lindl.	littleflower collinsia
N	Collomia grandiflora Hook.	collomia
N	Collomia linearis Nutt.	narrowleaf collomia
N	Conyza canadensis (L.) Cronq.	horseweed
N	Daucus carota L.	wild carrot
N	Delphinium bicolor Nutt.	little larkspur
N	Descurania pinnata (Walt.) Britt.	pinnate tansymustard
N	Dicentra cucullaria (L.) Bernh.	Dutchman's breeches
N	Dipsacus sylvestris Huds.	teasel
E	Draba nemorosa L.	woods draba
E	Draba verna L.	spring draba
N	Epilobium glabberimum Barbcy	smooth willoweed
N	Epilobium paniculatum Nutt. Ex T. & G.	autumn willoweed
N	Equisetum arvense L.	field horsetail
N	Equisetum variegatum schleich.	variegated horsetail
N	Erigeron philadelphicus L.	Philadelphia fleabane
N	Erigeron pumilus Nutt.	low fleabane
N	Eriogonum heracleoides Nutt.	wyeth Eriogonum
E	Erodium cicutarium (L.) Loher.	stork's bill
N	Fragaria vesca L.	Wood's strawberry
N	Fragaria virginiana Duchsne	blueleaf strawberry
N	Galium aparine L.	bed straw
N	Galium asperrimum Gray	rough bedstraw
N	Galium boreale L.	northern bedstraw
N	Geranium bicknellii	bicknell geranium
N	Geranium viscosissimum F. & M.	stick geranium
N	Geum macrophyllum Willd.	largeleaf averis

Appendix A. Continued.

Origin	Forbs and Allies	Common Name
N	Geum triflorum Pursh.	prairiesmoke avens
N	Gnaphalium palustre Nutt.	cudweed
N	Habenaria dilatata (Pursh) Hook.	white bogorchid
N	Heracleum lanatum Michx.	common cowparsnip
N	Heterocodon rariflorum L.	hetercodon
E	Holosteum umbellatum L.	jagged chickweed
N	Hydrophyllum capitatum Dougl. Ex Benth	ballhead waterleaf
N	Hypericum anagalloides C. & S.	trailing St. Johnswort
E	Hypericum perforatum L.	common St. Johnswort
N	Iris missouriensis Nutt.	rocky mountain iris
E	Lactuca serriola L.	prickly lettuce
E	Lamium purpureum L.	deadnettle
N	Lathyrus polyphyllus Nutt.	leafy peavine
N	Lemna minor L.	common duckweed
E	Lepidium perfoliatum L.	clasping pepperweed
N	Lepidium virginicum L.	tall pepperweed
N	Lithophragma bulbifera Rydb.	bulbous woodlandstar
N	Lithophragma parviflora (Hook). Nutt. Ex T. & G.	smallflower woodlandstar
N	Lomatium triternatum (Pursh) Coult. & Rose	nineleaf lomatium
N	Lupinus leucophyllus Dougl. Ex Lindl.	velvet lupine
E	Medicago lupulina L.	black medic
N	Mentha arvensis L.	field mint
N	Mertensia campanulata A. Nels.	bluebells
E	Microsteris gracilis (Hook.) Greene	microsteris
N	Mimulus guttatus var. depauperatus (Gray) Grant	common monkeyflower
N	Mimulus guttatus var. guttatus DC.	common monkeyflower
N	Mimulus lewisii Pursh.	lewis monkeyflower
N	Mimulus lewisii var. alba Henry	white lewis monkeyflower
N	Mimulus moschatus Dougl.	muskplant monkeyflower
N	Mitella stauropetala Hook.	cross-shaped mitella
N	Montia linearis (Dougl.) Greene	lineleaf indianlettuce
N	Montia perfoliata (Donn) How.	minerslettuce
N	Nemophila breviflora Gray	great basin nemophila
N	Nemophila pedunculata Dougl. Ex Benth.	nemophila
E	Onopordium acanthium L.	scotch thistle
N	Osmorhiza chilensis H. & A.	wild sweetanise
N	Penstemon rydbergii A. Nels.	rydberg penstemon
E	Plantago lanceolata L.	buckhorn plantain
N	Plantago major L.	rippleseed plantain
N	Polemonium occidentale Greene	western polemonium
N	Ploygonum aviculare L.	prostate knotweed
N	Polygonum douglasii Greene	douglas knotweed
N	Potentilla arguta Rydb.	baker cinquefoil
N	Potentilla glandulosa Lindl.	gland cinquefoil
N	Potentilla gracilis Dougl. Ex Hook.	northwest cinquefoil
E	Prunella vulgaris L.	common selfheal
E	Ranunculus acris L.	tall buttercup
N	Ranunculus aquatilis L.	water crowfoot
N	Ranunculus macounii Britt.	buttercup
N	Ranunculus sceleratus L.	buttercup
E	Ranunculus testiculatus Crantz	buttercup
N	Ranunculus uncinatus D. Don	buttercup
E	Rorippa natsrutium-aquaticum (L.) Schinz & Thell	water-cress
N	Rudbeckia occidentalis Nutt.	blackhead
E	Rumex acetosella L.	sheep sorrel
E	Rumex crispus L.	curly dock
N	Rumex occidentalis Watts.	western dock
N	Scrophularia lanceolata Pursh	lance-leaf figwort
N	Sedum stenopetalum Pursh	wamrleaf stonecrop
N	Senecio integerrimus Nutt.	lambstongue groundsel
N	Senecio pseudareus Rydb.	golden ragwort
N	Senecio serra Hook.	butterweed groundsel
N	Sidalecea oregana (Nutt.) Gray	Oregon checkermallow
N	Silene menziesii Hook.	Menzies' silene
E	Sisymbrium altissimum L.	tumblemustard
N	Smilacina stellata (L.) Desf.	starry solomon plume
N	Solidago missouriensis Nutt.	Missouri goldenrod
N	Stellaria longifolia Muhl.	longleaved stellaria
N	Stellaria longipes Goldie	longstalk stellaria
N	Stellaria nitins Nutt.	chickweed

Appendix A. Continued.

Origin	Forbs and Allies	Common Name
E	Taraxacum officinale Weber	common dandelion
N	Thalictrum occidentale Gray	western meadowrue
E	Thlaspi arvense L.	field pennycress
E	Tragopogon dubius Scop.	salsify
N	Trifolium agrarium L.	yellow clover
E	Trifolium pratense L.	red clover
E	Trifolium repens L.	white clover
N	Trillium petiolatum Pursh	Idaho trillium
E	Urtica gracilis Ait.	slim nettle
E	Valerianella locusta (L.) Betcke	lamb's lettuce
N	Veratrum californicum Durand	California falsehellbore
E	Verbascum thapsus L.	flannel mullien
N	Veronica americana Schewin. Ex Benth.	American speedwell
E	Veronica arvensis L.	common speedwell
N	Veronica scutellata L.	marsh speedwell
E	Veronica peregrina L.	purslane speedwell
E	Veronica serpyllifolia L.	thymeleaf speedwell
N	Vicia americana Muhl. Ex Willd.	American vetch
N	Viola adunca Sm.	hook violet
N	Viola nuttallii var. major Hook.	nuttal violet

Origin	Shrubs	Common Name
N	Amelanchier alnifolia Nutt.	Saskatoon serviceberry
N	Berberis repens Lindl.	creeping hollygrape
N	Chrysothamnus nauseosus (Pall.) Brit.	gray rabbitbrush
N	Cornus stolonifera Michv.	red oshier dogwood
N	Crataegus douglasii Lindl.	black hawthorne
N	Holodiscus discolor (Pursh) Maxim	creambush rock spirea
N	Lonicera involucrata (Rich.) Banks Ex Spreng.	bearberry honysuckle
N	Philadelphicus lewisii Pursh	Lewis mockorange
N	Ribes aureum Pursh	golden currant
N	Ribes cereum Dougl.	wax currant
N	Ribes hudsonianum Richards.	Hudsonbay currant
N	Ribes lacustre (Pursh) Poir.	prickly currant
N	Rosa woodsii Lindl.	Woods rose
N	Rubus idaeus L.	red raspberry
N	Salix amygoeloides Anderss.	peachleaf willow
N	Salix bebbiana var. perrustrata (Rydb.) Schneid.	bebb willow
N	Salix drummondiana Barratt	Drummond willow
N	Salix exigua var. exigua	coyote willow
N	Salix lasiandra Benth.	willow
N	Salix rigida var. mackenzieana (Hook.) Cronq.	Mackenzie willow
N	Salix rigida var. watsonii (Bebb.) Cronq.	Mackenzie willow
N	Sambucus cerula Raf.	blue elderberry
N	Symphoricarpos albus (L.) Blake	common snowberry
N	Symphoricarpos oreophilus Gray	mountain snowberry

Origin	Trees	Common Name
N	Abies grandis (Dougl.) Lindl.	grand fir
N	Alnus incana (L.) Moench.	thin leaf alder
N	Betula occidentalis Hook.	water birch
N	Larix occidentalis Nutt.	westernlarch
N	Picea englemannii Parry Ex Englem.	Englemann spruce
N	Pinus contorta Dougl. Ex Loud.	lodgepole pine
N	Pinus ponderosa Dougl. Ex Loud.	ponderosa pine
N	Populus trichocarpa T. & E. Ex Hook.	black cottonwood
N	Prunus virginiana L.	common chokecherry
N	Pseudotsuga menziesii (Mirbel) Franco	Douglas fir

Appendix B.

Average percent frequency of species in grazed and exclosed communities along the Catherine Creek study site, 1987-1989.

Table B-1. Average percent frequency for species in grazed and exclosed (excl.) *Alnus incana* communities along the Catherine Creek study site 1987-1989.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Agropyron repens	-	-			2.2	1.1
Agrosits alba	6.6	-			28.9	1.1
Agrostis exarata	-	-			-	-
Agrostis scabra	-	-			-	-
Alopecurus aequalis	-	-			-	-
Aria elegans	-	-			-	-
Arrhenatherum elatus	5.6	-			-	-
Bromus marginatus	-	-			-	-
Bromus mollis	-	-			5.6	-
Bromus racemosus	1.1	-			-	-
Bromus tectorum	-	-			1.1	-
Dactylis glomerata	-	4.4			-	2.2
Dechampsia caespitosa	-	-			-	-
Elymus glaucus	12.2	23.3			4.4	12.2
Festuca elatior	1.1	-			-	-
Festuca idahoensis	-	-			-	-
Festuca occidentalis	-	-			-	-
Glyceria grandis	12.2	4.4			-	-
Glyceria striata	-	-			32.2	4.4
Holcus lanatus	-	1.1			-	1.1
Melica bulbosa	-	-			2.2	-
Phleum alpinum	-	-			-	-
Phleum pratense	14.4	6.7			18.9	8.9
Poa ampla	-	-			-	-
Poa bulbosa	-	-			-	-
Poa compressa	6.7	-			8.9	-
Poa pratensis	72.2	84.4			65.6	67.7
Poa sandbergii	-	-			-	-
Stipa occidentalis	-	-			-	-
Trisetum canescens	2.2	-			11.1	5.6
Vulpia myuros	-	-			-	-
Carex aquatilis	-	-			-	-
Carex aurea	-	-			-	-
Carex geyri	-	-			-	-
Carex hoodii	-	-			-	2.2
Carex laeviculmis	-	-			5.6	10.0
Carex microptera	-	-			15.6	-
Carex nebraskensis	1.1	-			-	-
Carex praegracilis	-	-			-	-
Carex rostrata	-	-			5.6	-
Carex spp.	15.6	-			-	4.4
Carex stiptata	10.0	-			-	-
Juncus balticus	-	-			-	-
Juncus bufonius	-	-			-	-
Juncus ensifolius	-	-			-	-
Juncus nodosus	-	-			-	-

Table B-1. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus spp	-	-			-	-
Luzula campestris	-	-			-	-
Scirpus microcarpus	1.1	-			-	-
Achillea millefolium	13.3	5.6			24.4	10.0
Agoseris glauca	-	-			-	-
Alisma plantago	-	-			2.2	-
Amsinckia retorsa	-	-			-	-
Anaphalis margaritacea	-	-			-	1.1
Antennaria rosea	-	-			-	-
Aquilegia formosa	-	-			-	-
Arabis drummondii	-	-			-	-
Arenaria macrophylla	-	3.3			-	-
Arenaria serpyllifolia	5.6	-			-	-
Arnica chamissonis	1.1	-			-	-
Artemisia ludoviciana	-	-			-	-
Asperugo procumbens	-	-			-	-
Aster campestris	-	-			21.1	12.2
Aster foliaceus	28.9	55.5			8.9	28.9
Astragalus canadensis	-	-			-	-
Cerastium siculum	-	-			-	-
Cerastium viscosum	30.0	2.2			10.0	2.2
Circea alpina	-	-			-	-
Circea alpina	1.1	-			7.8	-
Cirsium vulgare	1.1	1.1			3.3	4.4
Collinsia parviflora	13.3	1.1			42.2	1.1
Collomia grandiflora	-	-			-	2.2
Collomia linearis	10.0	4.4			6.7	-
Cornus stolonifera	-	-			-	-
Dipsacus sylvestris	1.1	10.0			-	10.0
Draba verna	-	-			-	-
Epilobium glabberimum	1.1	1.1			4.4	-
Epilobium paniculatum	-	1.1			-	2.2
Equisetum arvense	1.1	4.5			4.5	2.2
Erigeron philadelphicum	-	2.2			-	-
Erigeron pumilus	-	-			-	-
Erigonum heracleoides	-	-			-	-
Erodium cicutarium	-	-			-	-
Fragaria vesca	-	-			-	-
Fragaria virginiana	7.8	3.3			3.3	2.2
Galium aparine	-	-			-	-
Galium asperrimum	42.2	36.7			38.9	21.1
Galium boreale	-	-			-	13.3
Geranium bicknellii	-	-			-	-
Geranium viscosissumum	-	-			-	-
Geum macrophyllum	30.0	32.2			34.4	42.2
Gnaphalium palustre	-	-			-	-
Habenaria dilatata	-	-			2.2	-
Heracleum lanatum	4.4	1.1			2.2	2.2

Table B-1. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heterocodon rariflorum	-	-			-	-
Holosteum umbellatum	16.7	1.1			-	1.1
Hypericum anagalloides	-	-			-	-
Hydrophyllum capitatum	-	-			-	-
Hypericum perforatum	-	-			-	-
Iris missouriensis	-	-			-	-
Lactuca serriola	-	-			-	-
Lathyrus polyphyllous	-	-			-	-
Lepidium perfoliatum	-	-			-	-
Lithophragma parviflora	-	-			-	-
Lomatium triternatum	-	-			-	-
Lupinus leucophyllus	-	-			-	-
Medicago lupulina	2.2	-			-	-
Mentha arvensis	2.2	14.5			3.3	3.3
Microsteris gracilis	-	-			-	-
Mimulus guttatus	8.9	1.1			8.9	-
Mitella stauropetala	-	-			-	-
Montia linearis	5.5	1.1			15.5	-
Montia perfoliata	32.2	12.2			37.8	26.7
Nemophila pedunculata	-	-			-	-
Nemophila pedunculata	7.8	1.1			-	-
Osmorhiza chilensis	25.5	11.1			24.4	8.9
Penstemon rydbergii	-	-			-	-
Plantago lanceolata	-	-			-	-
Plantago major	2.2	-			-	-
Polimonium occidentale	-	-			-	-
Polygonum douglasii	-	-			-	-
Potentilla arguta	-	-			-	-
Potentilla gracilis	-	-			-	-
Prunella vulgaris	5.6	-			22.2	6.7
Ranunculus arcis	43.3	31.1			68.9	35.6
Rorippa natsrutium	-	-			3.3	2.2
Rumex crispus	1.1	-			-	-
Rumex acetosella	5.6	-			-	-
Rumex occidentalis	-	-			-	-
Senecio pseudareus	2.2	10.0			12.2	11.1
Sidalecea oregana	-	-			-	-
Silene menziesii	-	-			20.0	3.3
Sisymbrium altissimum	-	-			-	-
Smilacina stellata	-	1.1			-	1.1
Solidago missouriensis	-	-			-	-
Stellaria longifolia	-	-			-	-
Stellaria longipes	-	-			-	-
Stellaria nitins	8.9	5.6			6.7	2.2
Taraxacum officinale	37.8	12.2			43.3	10.0
Thalictrum occidentale	-	-			-	1.1
Thlaspe arvense	-	-			-	-
Tragopogon dubius	1.1	-			-	-

Table B-1. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Trifolium pratense	-	1.1			8.9	2.2
Trifolium repens	1.1	1.1			7.8	-
Trillium petiolatum	-	1.1			-	-
Urtica gracilis	1.1	-			3.3	-
Veratrum californicum	-	-			-	-
Verbascum thapsus	1.1	-			-	-
Veronica americana	5.6	-			-	-
Veronica arvensis	-	-			-	-
Veronica peregrina	-	-			-	-
Veronica serpyllifolia	-	-			-	-
Vicia americana	-	4.5			-	-
Viola adunca	1.1	-			10.0	-
Viola nuttallii	-	-			-	-
Amelanchier alinfolia	-	-			-	-
Crataegus douglasii	12.2	8.9			6.7	2.2
Rosa woodsii	-	9.2			3.3	7.8
Rubus idaeus	5.6	15.6			-	10.0
Salix bebbiana	-	-			-	-
Salix exigua	-	-			-	-
Salix lasiandra	-	-			-	-
Salix rigida	-	-			-	-
Symphoricarpos albus	-	1.1			-	2.2
Abis grandis	2.2	-			-	-
Alnus incana	6.7	5.5			7.8	3.3
Pinus ponderosa	-	-			-	-
Populus trichocarpa	-	-			-	-
Prunus virginana	-	-			-	-
unkown	-	-			-	3.3

Table B-2. Average percent frequency for species in grazed and exclosed (excl.) *Bromus tectorum* communities along the Catherine Creek study site 1987-1989.

	Year					
	1987		1988		1989	
Species	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Agropyron repens	-	-			-	-
Agrosits alba	-	-			-	-
Agrostis exarata	-	-			-	-
Agrostis scabra	-	-			-	-
Alopecurus aequalis	-	-			-	-
Aria elegans	-	-			-	-
Arrhenatherum elatus	-	-			-	-
Bromus marginatus	-	-			-	-
Bromus mollis	17.5	12.2			20.0	17.8
Bromus racemosus	-	-			-	-
Bromus tectorum	96.8	82.2			93.8	86.7
Dactylis glomerata	-	-			-	-
Dechampsia caespitosa	-	-			-	-
Elymus glaucus	-	-			-	-
Festuca elatior	-	-			-	-
Festuca idahoensis	-	-			-	-
Festuca occidentalis	-	-			-	-
Glyceria grandis	-	-			-	-
Glyceria striata	-	-			-	-
Holcus lanatus	-	-			-	-
Melica bulbosa	-	-			-	-
Phleum alpinum	-	-			-	-
Phleum pratense	-	-			-	-
Poa ampla	-	-			-	-
Poa bulbosa	2.5	-			2.1	-
Poa compressa	-	-			-	-
Poa pratensis	22.5	14.4			4.2	12.2
Poa sandbergii	-	7.8			4.2	4.4
Stipa occidentalis	-	-			-	-
Trisetum canescens	-	-			-	-
Vulpia myuros	1.7	-			-	-
Carex aquatilis	-	-			-	-
Carex aurea	-	-			-	-
Carex geyri	-	-			-	-
Carex hoodii	-	-			-	-
Carex laeviculmis	-	-			-	-
Carex microptera	-	-			-	-
Carex nebraskensis	-	-			-	-
Carex praegracilis	-	-			-	-
Carex rostrata	-	-			-	-
Carex spp.	0.8	-			-	-
Carex stiptata	-	-			-	-
Juncus balticus	-	-			-	-
Juncus bufonius	-	-			-	-
Juncus ensifolius	-	-			-	-

Table B-2. Continued.

Species	Year 1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus nodosus	-	-			-	-
Juncus spp	-	-			-	-
Luzula campestris	-	-			-	-
Scirpus microcarpus	-	-			-	-
Achillea millefolium	2.5	7.8			0.8	16.7
Agoseris glauca	-	2.2			-	3.3
Alisma plantago	-	-			-	-
Amsinckia retorsa	-	-			-	-
Anaphalis margaritacea	-	-			-	-
Antennaria rosea	-	-			-	-
Aquilegia formosa	-	-			-	-
Arabis drummondii	-	3.3			6.7	-
Arenaria macrophylla	-	-			-	-
Arenaria serpyllifolia	14.2	37.8			13.3	30.0
Arnica chamissonis	-	-			-	-
Artemisia ludoviciana	-	-			0.8	-
Asperugo procumbens	-	-			-	-
Aster campestris	-	-			-	-
Aster foliaceus	-	-			-	-
Astragalus canadensis	-	-			-	-
Cerastium siculum	-	-			-	-
Cerastium viscosum	3.3	-			0.8	-
Circea alpina	10.0	3.3			-	-
Circea alpina	-	-			-	-
Cirsium vulgare	-	-			-	-
Collinsia parviflora	-	-			14.2	-
Collomia grandiflora	-	-			-	-
Collomia linearis	6.7	10.0			37.5	12.2
Cornus stolonifera	-	-			-	-
Dipsacus sylvestris	0.8	11.0			-	7.8
Draba verna	5.9	1.1			-	2.2
Epilobium glabberimum	-	-			-	-
Epilobium paniculatum	21.7	18.9			46.7	23.2
Equisetum arvense	-	-			-	-
Erigeron philadelphicu	-	-			-	-
Erigeron pumilus	-	-			-	-
Erigonum heracleoides	-	13.3			-	8.9
Erodium cicutarium	40.9	47.8			48.3	38.9
Fragaria vesca	-	-			-	-
Fragaria virginiana	-	-			-	-
Galium aparine	-	-			-	-
Galium asperrimum	-	-			-	-
Galium boreale	-	-			-	-
Geranium bicknellii	-	-			-	-
Geranium viscosissumum	-	-			-	-
Geum macrophyllum	-	-			-	-
Gnaphalium palustre	-	-			-	-
Habenaria dilatata	-	-			-	-

Table B-2. Continued.

Species	Year 1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heracleum lanatum	-	-			-	-
Heterocodon rariflorum	-	-			-	-
Holosteum umbellatum	24.2	-			-	-
Hydrophyllum capitatum	-	-			-	-
Hypericum anagalloides	-	-			-	-
Hypericum perforatum	-	-			-	-
Iris missouriensis	-	-			-	-
Lactuca serriola	-	10.0			5.0	7.8
Lathyrus polyphyllous	0.8	-			-	-
Lepidium perfoliatum	24.2	41.1			34.2	36.7
Lithophragma parviflor	-	-			-	-
Lomatium triternatum	-	-			-	-
Lupinus leucophyllus	-	-			-	-
Medicago lupulina	-	-			-	-
Mentha arvensis	-	-			-	-
Microsteris gracilis	-	-			-	-
Mimulus guttatus	-	-			-	-
Mitella stauropetala	-	-			-	-
Montia linearis	-	-			-	-
Montia perfoliata	-	-			-	-
Nemophila pedunculata	-	-			-	-
Nemophila pedunculata	-	-			-	-
Osmorhiza chilensis	-	-			-	-
Penstemon rydbergii	-	-			-	-
Plantago lanceolata	-	-			-	-
Plantago major	-	-			-	-
Polimonium occidentale	-	-			-	-
Polygonum douglasii	-	-			24.2	10.0
Potentilla arguta	-	-			-	-
Potentilla gracilis	-	-			-	-
Prunella vulgaris	-	-			-	-
Ranunculus arcis	-	-			-	-
Rorippa natsrutium	-	-			-	-
Rumex crispus	-	-			-	-
Rumes occidentalis	-	-			-	-
Rumex acetosella	7.5	25.6			30.0	23.3
Senecio pseudareus	-	-			-	-
Sidalecea oregana	-	-			-	-
Silene menziesii	-	-			-	-
Sisymbrium altissimum	-	-			5.8	6.7
Smilacina stellata	-	-			-	-
Solidago missouriensis	-	-			-	-
Stellaria longifolia	-	-			-	-
Stellaria longipes	-	-			-	-
Stellaria nitins	-	-			-	-
Taraxacum officinale	3.3	1.1			-	1.1
Thalictrum occidentale	-	-			-	-
Thlaspe arvense	-	-			-	-

Table B-2. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Tragopogon dubius	2.5	3.3			5.0	4.4
Trifolium pratense	-	-			-	-
Trifolium repens	-	-			-	-
Trillium petiolatum	-	-			-	-
Urtica gracilis	-	-			-	-
Veratrum californicum	-	-			-	-
Verbascum thapsus	3.4	1.1			5.0	1.1
Veronica americana	-	-			-	-
Veronica arvensis	26.7	27.8			40.0	27.8
Veronica peregrina	-	-			-	-
Veronica serpyllifolia	-	-			-	-
Vicia americana	-	-			-	-
Viola adunca	-	-			-	-
Viola nuttallii	-	-			-	-
Amelanchier alinfolia	-	-			-	-
Crataegus douglasii	-	-			-	-
Rosa woodsii	1.7	-			0.8	0.8
Rubus idaeus	0.8	-			-	-
Salix bebbiana	-	-			-	-
Salix exigua	-	-			-	-
Salix lasiandra	-	-			-	-
Salix rigida	-	-			-	-
Symphoricarpos albus	-	-			-	-
Abis grandis	-	-			-	-
Alnus incana	-	-			-	-
Pinus ponderosa	-	-			-	-
Populus trichocarpa	-	-			-	-
Prunus virginana	-	-			-	-
unkown	23.3	-			-	-

Table B-3. Average percent frequency for species in grazed and exclosed (excl.) *Populus trichocarpa* communities along the Catherine Creek study site 1987-1989.

	Year					
	1987		1988		1989	
Species	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Agropyron repens	-	2.2			4.4	-
Agrosits alba	11.1	5.6			-	4.4
Agrostis exarata	-	-			-	-
Agrostis scabra	-	-			-	-
Alopecurus aequalis	-	-			-	-
Aria elegans	-	-			-	-
Arrhenatherum elatus	-	-			-	-
Arrhenatherum elatus	-	4.4			-	-
Bromus marginatus	-	-			3.3	-
Bromus mollis	5.6	-			4.4	-
Bromus racemosus	-	-			-	-
Bromus tectorum	1.1	2.2			-	1.1
Dactylis glomerata	-	-			-	-
Dechampsia caespitosa	-	-			-	-
Elymus glaucus	4.4	13.3			33.3	23.3
Festuca elatior	5.6	-			6.7	4.4
Festuca idahoensis	-	-			-	-
Festuca occidentalis	-	-			-	-
Glyceria grandis	-	-			-	-
Glyceria striata	-	-			-	-
Holcus lanatus	-	-			-	-
Melica bulbosa	-	-			-	-
Phleum alpinum	-	-			-	-
Phleum pratense	2.2	3.3			-	3.3
Poa ampla	-	-			-	-
Poa bulbosa	-	-			-	-
Poa compressa	-	-			-	-
Poa pratensis	100.0	67.8			72.2	74.4
Poa sandbergii	-	-			-	-
Stipa occidentalis	-	-			-	-
Trisetum canescens	-	3.3			4.4	10.0
Vulpia myuros	-	-			-	-
Carex aquatilis	-	-			-	-
Carex aurea	-	-			-	-
Carex geyri	-	-			-	-
Carex hoodii	-	1.1			-	-
Carex laeviculmis	-	-			-	-
Carex microptera	-	-			-	-
Carex nebraskensis	-	-			-	-
Carex praegracilis	-	-			-	-
Carex rostrata	-	-			-	-
Carex spp.	2.2	3.3			-	10.0
Carex stiptata	-	-			-	-
Juncus balticus	-	1.1			-	-
Juncus bufonius	-	-			-	-

Table B-3. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus ensifolius	-	-			-	-
Juncus nodosus	-	-			-	-
Juncus spp	-	-			-	-
Luzula campestris	-	1.1			-	2.2
Scirpus microcarpus	-	-			-	-
Achillea millefolium	31.1	8.9			18.9	14.5
Agoseris glauca	-	-			-	4.4
Alisma plantago	-	-			-	-
Amsinckia retorsa	-	-			-	-
Anaphalis margaritacea	-	-			-	-
Antennaria rosea	-	-			-	-
Aquilegia formosa	6.7	-			-	-
Arabis drummondii	-	-			-	-
Arenaria macrophylla	15.6	-			-	-
Arenaria serpyllifolia	-	-			-	-
Arnica chamissonis	-	-			-	-
Artemisia ludoviciana	-	-			-	-
Asperugo procumbens	-	-			-	-
Aster campestris	-	-			-	-
Aster foliaceus	8.9	20.0			5.6	17.8
Astragalus canadensis	-	-			-	-
Cerastium siculum	-	-			-	-
Cerastium viscosum	14.4	2.2			5.6	1.1
Circea alpina	-	-			-	-
Circea alpina	-	-			-	-
Cirsium vulgare	-	-			-	2.2
Collinsia parviflora	-	-			8.9	-
Collomia grandiflora	-	-			-	-
Collomia linearis	4.4	1.1			7.8	2.2
Cornus stolonifera	-	-			-	-
Dipsacus sylvestris	-	-			-	-
Draba verna	-	-			-	-
Epilobium glabberimum	-	-			-	-
Epilobium paniculatum	17.8	1.1			16.7	-
Equisetum arvense	-	-			-	-
Erigeron philadelphicu	-	-			-	-
Erigeron pumilus	-	-			-	-
Erigonum heracleoides	-	-			-	-
Erodium cicutarium	-	-			-	-
Fragaria vesca	-	-			-	-
Fragaria virginiana	2.2	7.8			-	10.0
Galium aparine	21.1	20.0			-	-
Galium asperrimum	-	-			35.6	28.9
Galium boreale	2.2	3.3			-	3.3
Geranium bicknellii	15.6	-			-	-
Geranium viscosissumum	-	-			-	-
Geum macrophyllum	5.6	3.3			-	8.9
Gnaphalium palustre	-	-			-	-

Table B-3. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Habenaria dilatata	2.2	-			-	-
Heracleum lanatum	-	-			-	-
Heterocodon rariflorum	-	-			-	-
Holosteum umbellatum	5.6	-			-	-
Hydrophyllum capitatum	-	-			-	-
Hypericum anagalloides	-	-			-	-
Hypericum perforatum	-	-			-	-
Iris missouriensis	-	-			-	-
Lactuca serriola	-	-			-	-
Lathyrus polyphyllous	6.7	-			5.6	-
Lepidium perfoliatum	-	-			-	-
Lithophragma parviflor	-	-			-	-
Lomatium triternatum	-	1.1			-	-
Lupinus leucophyllus	-	-			-	-
Medicago lupulina	12.2	-			6.7	8.9
Mentha arvensis	-	-			-	-
Microsteris gracilis	-	-			-	-
Mimulus guttatus	-	-			-	-
Mitella stauropetala	-	-			-	-
Montia linearis	-	-			-	-
Montia perfoliata	4.5	4.4			7.8	1.1
Nemophila pedunculata	-	-			-	-
Nemophila pedunculata	-	-			-	-
Osmorhiza chilensis	10.0	23.3			26.7	22.2
Penstemon rydbergii	-	-			-	-
Plantago lanceolata	-	-			-	1.1
Plantago major	-	-			-	-
Polimonium occidentale	-	-			-	-
Polygonum douglasii	-	-			-	-
Potentilla arguta	-	-			-	-
Potentilla gracilis	5.6	-			-	-
Prunella vulgaris	-	2.2			-	2.2
Ranunculus arcis	61.1	18.9			44.4	7.8
Rorippa natsrutium	-	-			-	-
Rumex crispus	-	-			-	-
Rumex occidentalis	-	-			-	-
Rumex acetosella	12.2	1.1			-	-
Senecio pseudareus	6.7	21.1			-	15.6
Sidalecea oregana	-	-			-	-
Silene menziesii	-	-			2.2	8.9
Sisymbrium altissimum	-	-			-	-
Smilacina stellata	10.0	31.1			17.8	31.1
Solidago missouriensis	-	-			-	-
Stellaria longifolia	-	-			-	-
Stellaria longipes	-	-			-	8.9
Stellaria nitins	5.6	1.1			-	-
Taraxacum officinale	32.2	24.4			22.2	21.1
Thalictrum occidentale	-	-			-	-

Table B-3. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Thlaspe arvense	-	-			-	-
Tragopogon dubius	5.6	-			6.7	-
Trifolium pratense	14.5	4.5			5.6	-
Trifolium repens	13.3	3.3			5.6	1.1
Trillium petiolatum	-	-			1.1	4.4
Urtica gracilis	-	3.3			-	5.6
Veratrum californicum	-	-			-	-
Verbascum thapsus	1.1	-			-	-
Veronica americana	-	-			-	-
Veronica arvensis	25.6	1.1			3.3	-
Veronica peregrina	-	-			-	-
Veronica serpyllifolia	-	-			-	-
Vicia americana	14.5	15.5			1.1	4.5
Viola adunca	18.9	1.1			3.3	-
Viola nuttallii	-	-			5.6	-
Amelanchier alinfolia	-	-			-	-
Crataegus douglasii	15.6	12.2			8.9	3.3
Rosa woodsii	4.4	7.8			10.0	8.9
Rubus idaeus	-	-			-	-
Salix bebbiana	-	-			-	-
Salix exigua	-	-			-	-
Salix lasiandra	-	-			-	-
Salix rigida	-	-			-	-
Symphoricarpos albus	31.1	12.2			18.9	10.0
Abis grandis	-	-			-	-
Alnus incana	-	1.1			-	2.2
Pinus ponderosa	-	1.1			-	-
Populus trichocarpa	-	3.3			-	3.3
Prunus virginana	-	-			-	-
unkown	-	3.3			-	4.4

Table B-4. Average percent frequency for species in grazed and exclosed (excl.) *Poa pratensis*-mixed dicot communities along the Catherine Creek study site 1987-1989.

	Year					
	1987		1988		1989	
Species	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Agropyron repens	8.3	-	8.1	-	6.1	-
Agrosits alba	9.5	-	8.6	-	12.8	-
Agrostis exarata	-	-	-	-	-	-
Agrostis scabra	-	-	-	-	-	-
Alopecurus aequalis	-	-	-	-	-	-
Aria elegans	-	-	-	-	1.1	-
Arrhenatherum elatus	-	-	-	-	-	-
Bromus marginatus	-	-	18.1	-	18.9	6.7
Bromus mollis	35.8	1.8	39.5	-	43.3	0.8
Bromus racemosus	19.4	7.5	-	-	-	-
Bromus tectorum	2.2	-	7.6	-	6.1	-
Dactylis glomerata	-	-	-	-	-	-
Dechampsia caespitosa	-	-	-	-	-	-
Elymus glaucus	-	-	-	-	-	0.8
Festuca elatior	8.3	-	5.2	-	10.0	-
Festuca idahoensis	-	-	-	-	-	-
Festuca occidentalis	1.7	-	-	-	-	-
Glyceria grandis	-	-	-	-	-	-
Glyceria striata	-	-	-	-	-	-
Holcus lanatus	-	-	-	-	-	-
Melica bulbosa	10.0	-	17.6	-	17.8	-
Phleum alpinum	-	-	-	-	1.1	-
Phleum pratense	11.7	3.3	7.6	-	15.0	3.3
Poa ampla	1.1	-	-	-	-	-
Poa bulbosa	-	-	-	-	-	-
Poa compressa	-	-	3.3	-	-	-
Poa pratensis	100.0	100.0	92.4	100.0	100.0	100.0
Poa sandbergii	-	-	-	-	-	-
Stipa occidentalis	-	-	-	-	0.6	-
Trisetum canescens	-	-	-	-	-	-
Vulpia myuros	-	-	9.0	-	-	-
Carex aquatilis	-	-	-	-	-	-
Carex aurea	-	-	-	-	-	-
Carex geyri	-	-	-	-	-	-
Carex hoodii	1.1	-	1.0	-	0.6	0.8
Carex laeviculmis	-	-	-	-	-	-
Carex microptera	4.5	-	-	-	-	-
Carex nebraskensis	1.1	-	0.5	-	-	-
Carex praegracilis	-	-	-	-	-	-
Carex rostrata	-	-	-	-	-	-
Carex spp.	1.7	-	5.7	-	3.3	1.7
Carex stiptata	-	-	-	-	-	-
Juncus balticus	13.3	-	3.3	-	11.1	-
Juncus bufonius	-	-	-	-	-	-
Juncus ensifolius	-	-	2.9	-	-	-

Table B-4. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus nodosus	-	-	-	-	-	-
Juncus spp	-	-	-	-	-	-
Luzula campestris	1.1	-	1.9	-	-	-
Scirpus microcarpus	-	-	-	-	-	-
Achillea millefolium	76.7	27.5	67.6	33.4	70.8	37.5
Agoseris glauca	3.9	0.8	0.5	-	3.9	-
Alisma plantago	-	-	-	-	-	-
Amsinckia retorsa	-	-	-	-	2.8	-
Anaphalis margaritacea	-	-	0.5	-	-	-
Antennaria rosea	1.1	-	2.4	0.8	2.8	0.8
Aquilegia formosa	-	-	1.9	-	-	-
Arabis drummondii	-	-	-	-	-	-
Arenaria macrophylla	-	-	-	-	-	-
Arenaria serpyllifolia	-	-	-	-	-	-
Arnica chamissonis	-	1.7	0.5	-	-	-
Artemisia ludoviciana	-	-	0.5	-	-	-
Asperugo procumbens	-	-	-	-	-	-
Aster campestris	-	-	-	-	-	-
Aster foliaceus	35.0	21.7	39.5	21.7	24.2	20.0
Astragalus canadensis	-	-	-	-	-	-
Cerastium siculum	33.0	34.2	-	-	-	-
Cerastium viscosum	17.8	4.2	26.7	6.7	29.5	3.3
Circea alpina	-	-	-	-	-	-
Circea alpina	-	-	-	-	-	-
Cirsium vulgare	18.9	2.5	16.2	-	21.1	-
Collinsia parviflora	1.7	15.0	15.2	47.5	22.8	72.5
Collomia grandiflora	-	-	1.4	-	-	-
Collomia linearis	4.4	1.7	25.2	41.7	-	0.8
Cornus stolonifera	-	-	-	-	-	-
Dipsacus sylvestris	12.2	-	20.5	-	9.5	-
Draba verna	10.0	5.8	21.0	30.9	17.8	36.7
Epilobium glabberimum	0.6	-	1.0	-	-	-
Epilobium paniculatum	6.1	19.2	17.6	31.7	37.8	49.2
Equisetum arvense	2.8	-	10.0	-	2.8	-
Erigeron philadelphicu	-	-	-	-	-	-
Erigeron pumilus	-	-	0.5	0.8	-	-
Erigonum heracleoides	-	-	-	-	-	-
Erodium cicutarium	17.2	15.8	11.0	5.8	5.6	10.0
Fragaria vesca	-	-	-	-	-	-
Fragaria virginiana	27.8	2.5	34.8	0.8	30.0	-
Galium aparine	-	-	-	-	-	-
Galium asperrimum	3.9	-	6.7	-	5.6	-
Galium boreale	-	-	-	-	-	-
Geranium bicknellii	-	-	3.8	-	2.8	-
Geranium viscosissumum	-	-	1.4	-	-	-
Geum macrophyllum	8.3	-	8.1	-	6.1	0.8
Gnaphalium palustre	-	-	-	-	-	-
Habenaria dilatata	-	-	-	-	-	-

Table B-4. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heracleum lanatum	-	-	-	-	-	-
Heterocodon rariflorum	-	-	1.0	-	5.6	-
Holosteum umbellatum	0.6	5.8	9.5	20.9	-	1.7
Hydrophyllum capitatum	-	-	0.5	-	-	-
Hypericum anagalloides	-	-	0.5	-	-	-
Hypericum perforatum	-	-	1.0	-	-	-
Iris missouriensis	-	-	-	-	-	-
Lactuca serriola	2.2	-	1.9	0.8	1.7	2.5
Lathyrus polyphyllous	1.7	1.7	12.4	20.0	5.6	-
Lepidium perfoliatum	-	-	-	-	3.9	0.8
Lithophragma parviflor	-	-	-	-	-	1.7
Lomatium triternatum	-	-	-	-	-	-
Lupinus leucophyllus	11.1	-	8.6	1.7	20.2	4.2
Medicago lupulina	21.1	-	30.0	3.3	31.7	9.2
Mentha arvensis	-	-	-	-	-	-
Microsteris gracilis	0.6	-	-	-	9.5	49.2
Mimulus guttatus	-	-	-	-	-	-
Mitella stauropetala	-	-	-	-	-	-
Montia linearis	0.6	-	1.4	-	-	-
Montia perfoliata	-	3.3	2.9	21.7	5.0	11.7
Nemophila pedunculata	-	-	-	-	-	-
Nemophila pedunculata	-	-	-	-	-	-
Osmorhiza chilensis	1.1	-	0.9	-	2.8	-
Penstemon rydbergii	-	-	-	1.7	-	-
Plantago lanceolata	-	-	-	-	-	-
Plantago major	0.6	-	1.4	-	-	-
Polimonium occidentale	-	-	-	-	-	-
Polygonum douglasii	-	-	-	-	-	-
Potentilla arguta	-	-	-	-	-	-
Potentilla gracilis	6.1	1.7	5.2	-	6.1	-
Prunella vulgaris	0.6	-	11.4	4.2	7.2	-
Ranunculus arcis	33.3	2.5	35.7	2.5	34.4	4.2
Rorippa natsrutium	-	-	-	-	-	-
Rumex crispus	-	-	-	-	-	-
Rumex occidentalis	-	-	-	-	-	-
Rumex acetosella	24.5	5.8	13.3	3.3	17.3	5.8
Senecio pseudareus	15.0	-	15.7	-	19.4	-
Sidalecea oregana	-	-	-	-	-	-
Silene menziesii	-	-	-	-	-	-
Sisymbrium altissimum	1.7	-	-	-	-	-
Smilacina stellata	-	-	-	-	-	-
Solidago missouriensis	-	-	-	-	-	-
Stellaria longifolia	-	-	-	-	-	-
Stellaria longipes	-	-	-	3.3	-	-
Stellaria nitins	-	-	-	-	-	-
Taraxacum officinale	28.9	3.3	24.8	5.9	23.9	5.8
Thalictrum occidentale	-	-	-	-	-	-
Thlaspe arvense	-	-	1.0	-	-	0.8

Table B-4. Continued.

Species	Year					
	1987		1988		1989	
	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Tragopogon dubius	8.3	-	15.2	4.2	8.9	3.4
Trifolium pratense	19.5	-	23.8	1.7	28.3	-
Trifolium repens	16.7	2.5	13.3	4.2	14.5	1.7
Trillium petiolatum	1.7	0.8	1.4	-	1.1	1.7
Urtica gracilis	0.6	-	-	-	-	-
Veratrum californicum	-	-	-	-	-	-
Verbascum thapsus	2.8	1.7	-	-	1.7	0.8
Veronica americana	-	-	-	-	-	-
Veronica arvensis	12.8	23.4	27.1	14.2	28.9	38.3
Veronica peregrina	-	-	-	-	-	-
Veronica serpyllifolia	-	-	-	-	-	-
Vicia americana	11.1	28.4	1.9	15.8	16.1	40.0
Viola adunca	11.1	10.0	11.9	11.7	11.7	17.5
Viola nuttallii	-	-	-	-	-	-
Amelanchier alinfolia	0.6	-	-	-	-	-
Crataegus douglasii	2.2	-	1.9	-	3.3	-
Rosa woodsii	-	-	0.5	-	0.6	-
Rubus idaeus	-	-	-	-	-	-
Salix bebbiana	-	-	1.4	-	-	-
Salix exigua	0.6	-	1.4	-	0.6	-
Salix lasiandra	-	-	-	-	-	-
Salix rigida	-	-	-	-	-	-
Symphoricarpos albus	1.7	0.8	4.3	5.8	0.6	5.0
Abis grandis	-	-	-	-	-	-
Alnus incana	-	-	0.5	-	-	-
Pinus ponderosa	-	-	-	-	-	-
Populus trichocarpa	-	-	1.4	-	-	-
Prunus virginana	-	-	-	-	-	-
unkown	10.6	5.0	5.8	10.0	2.8	5.0

Table B-5. Average percent frequency for species in grazed and exclosed (excl.) *Salix spp.*-mixed dicot communities along the Catherine Creek study site 1987-1989.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Agropyron repens	2.2	6.7	4.0	1.7	1.1	
Agrosits alba	-	25.0	60.0	61.7	22.2	
Agrostis exarata	47.8	40.0	-	-	35.5	
Agrostis scabra	6.7	-	-	-	13.3	
Alopecurus aequalis	1.1	1.7	0.7	-	2.2	
Aria elegans	-	-	-	-	-	
Arrhenatherum elatus	-	-	-	-	-	
Bromus marginatus	4.4	-	-	1.7	-	
Bromus mollis	25.6	5.0	34.0	2.5	30.0	
Bromus racemosus	-	-	-	-	-	
Bromus tectorum	3.3	-	4.0	0.8	3.3	
Dactylis glomerata	-	-	-	-	-	
Dechampsia caespitosa	5.6	3.4	-	-	-	
Elymus glaucus	1.1	5.0	-	9.2	2.2	
Festuca elatior	20.0	1.7	12.7	-	26.7	
Festuca idahoensis	-	-	-	-	-	
Festuca occidentalis	-	-	-	-	-	
Glyceria grandis	-	-	-	-	-	
Glyceria striata	-	-	-	-	-	
Holcus lanatus	2.2	-	-	-	1.1	
Melica bulbosa	-	-	6.7	-	-	
Phleum alpinum	-	-	-	-	-	
Phleum pratense	36.7	13.4	56.0	0.8	35.6	
Poa ampla	-	-	-	-	-	
Poa bulbosa	3.3	-	-	-	4.5	
Poa compressa	10.0	8.4	21.3	2.5	34.5	
Poa pratensis	55.5	43.4	76.0	60.0	53.4	
Poa sandbergii	-	-	-	-	2.2	
Stipa occidentalis	-	-	-	-	-	
Trisetum canescens	-	-	-	-	-	
Vulpia myuros	27.8	-	4.0	0.8	20.0	
Carex aquatilis	7.8	10.0	4.0	1.7	-	
Carex aurea	2.2	-	-	-	-	
Carex geyri	-	-	-	-	-	
Carex hoodii	24.4	1.7	-	1.7	-	
Carex laeviculmis	-	-	2.0	10.0	-	
Carex microptera	-	-	8.0	0.8	-	
Carex nebraskensis	-	-	6.0	-	-	
Carex praegracilis	-	-	-	-	-	
Carex rostrata	-	-	-	-	4.4	
Carex spp.	6.7	30.0	14.0	10.9	18.9	
Carex stiptata	-	-	-	-	-	
Juncus balticus	4.4	-	2.0	-	3.3	
Juncus bufonius	-	-	-	-	-	
Juncus ensifolius	4.4	-	8.0	5.0	20.0	

Table B-5. Continued.

Species	Year 1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus nodosus	-	-	-	-	1.1	
Juncus spp	11.1	5.0	2.7	-	1.1	
Luzula campestris	5.6	13.4	0.7	-	3.3	
Scirpus microcarpus	-	-	-	-	1.1	
Achillea millefolium	30.0	43.4	26.7	20.8	38.9	
Agoseris glauca	1.1	-	1.3	-	-	
Alisma plantago	-	-	-	-	-	
Amsinckia retorsa	-	-	-	-	-	
Anaphalis margaritacea	2.2	8.3	-	2.5	-	
Antennaria rosea	-	-	-	-	1.1	
Aquilegia formosa	-	-	-	-	-	
Arabis drummondii	-	-	-	-	-	
Arenaria macrophylla	-	-	-	-	-	
Arenaria serpyllifolia	-	-	-	-	2.2	
Arnica chamissonis	-	-	-	-	-	
Artemisia ludoviciana	-	-	-	-	-	
Asperugo procumbens	-	-	-	-	-	
Aster campestris	-	-	6.7	25.9	3.3	
Aster foliaceus	26.7	41.7	34.7	30.0	17.8	
Astragalus canadensis	-	-	-	-	-	
Cerastium siculum	-	-	-	-	-	
Cerastium viscosum	17.8	40.0	22.0	10.9	14.4	
Circea alpina	-	-	-	-	-	
Circea alpina	1.1	1.7	-	1.7	-	
Cirsium vulgare	6.7	-	9.3	7.5	5.6	
Collinsia parviflora	-	-	3.3	-	8.9	
Collomia grandiflora	-	-	2.0	-	-	
Collomia linearis	22.2	6.7	32.0	2.5	34.5	
Cornus stolonifera	-	-	-	1.6	-	
Dipsacus sylvestris	-	1.7	2.0	0.8	2.2	
Draba verna	6.6	5.0	7.3	0.8	13.3	
Epilobium glabberimum	1.1	10.0	0.7	-	10.0	
Epilobium paniculatum	13.3	20.0	27.3	14.2	11.1	
Equisetum arvense	26.7	3.4	25.3	7.5	37.8	
Erigeron philadelphicu	4.4	-	0.7	0.8	1.1	
Erigeron pumilus	-	-	5.3	4.2	5.6	
Erigonum heracleoides	-	-	-	-	-	
Erodium cicutarium	-	-	-	-	-	
Fragaria vesca	-	-	1.3	0.8	-	
Fragaria virginiana	21.1	8.3	3.3	15.0	13.3	
Galium aparine	-	-	1.3	6.7	-	
Galium asperrimum	-	-	-	-	-	
Galium boreale	-	-	-	-	-	
Geranium bicknellii	-	-	-	-	-	
Geranium viscosissumum	-	-	-	-	-	
Geum macrophyllum	1.1	26.7	18.7	22.5	7.8	
Gnaphalium palustre	-	-	-	1.7	-	
Habenaria dilatata	-	1.7	-	-	-	

Table B-5. Continued.

Species	Year 1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heracleum lanatum	-	-	-	-	-	
Heterocodon rariflorum	-	-	-	-	13.3	
Holosteum umbellatum	1.1	-	1.3	-	-	
Hydrophyllum capitatum	-	-	-	-	-	
Hypericum anagalloides	3.3	1.7	2.0	-	6.7	
Hypericum perforatum	-	-	0.7	0.8	2.2	
Iris missouriensis	-	-	-	-	-	
Lactuca serriola	0.8	1.7	1.3	-	-	
Lathyrus polyphyllous	-	3.4	-	-	-	
Lepidium perfoliatum	-	-	-	-	-	
Lithophragma parviflora	-	-	-	-	-	
Lomatium triternatum	-	-	-	-	-	
Lupinus leucophyllus	-	-	-	-	-	
Medicago lupulina	28.9	20.0	10.0	3.3	33.3	
Mentha arvensis	-	1.7	-	0.8	-	
Microsteris gracilis	-	-	-	-	-	
Mimulus guttatus	2.2	-	-	-	1.1	
Mitella stauropetala	-	-	-	-	-	
Montia linearis	1.1	3.3	8.7	3.3	4.4	
Montia perfoliata	-	-	-	2.5	2.2	
Nemophila pedunculata	-	-	-	-	-	
Nemophila pedunculata	-	-	-	-	-	
Osmorhiza chilensis	-	1.7	0.7	-	-	
Penstemon rydbergii	-	-	-	-	1.1	
Plantago lanceolata	-	-	-	-	-	
Plantago major	13.3	10.0	9.3	0.8	3.3	
Polimonium occidentale	-	-	-	-	-	
Polygonum douglasii	-	-	-	-	-	
Potentilla arguta	-	-	-	0.8	-	
Potentilla gracilis	-	5.0	2.0	-	2.2	
Prunella vulgaris	26.7	33.4	44.7	54.2	56.7	
Ranunculus arcis	26.7	13.4	18.7	8.3	27.8	
Rorippa natsrutium	-	-	-	-	-	
Rumex crispus	-	1.7	-	-	-	
Rumex occidentalis	-	-	-	-	13.3	
Rumex acetosella	12.2	25.0	17.3	10.0	6.7	
Senecio pseudareus	-	-	2.0	8.3	3.3	
Sidalecea oregana	-	-	-	-	-	
Silene menziesii	-	-	-	-	-	
Sisymbrium altissimum	-	-	-	-	-	
Smilacina stellata	-	-	-	-	-	
Solidago missouriensis	-	1.7	-	-	1.1	
Stellaria longifolia	-	-	0.7	-	-	
Stellaria longipes	-	-	8.0	1.7	6.7	
Stellaria nitins	1.1	-	2.0	-	-	
Taraxacum officinale	28.9	46.7	38.0	32.5	32.2	
Thalictrum occidentale	-	-	1.3	-	-	
Thlaspe arvense	-	-	14.0	-	-	

Table B-5. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Tragopogon dubius	-	-	-	-	-	
Trifolium pratense	36.7	-	16.7	0.0	53.3	
Trifolium repens	26.7	51.7	48.7	5.0	31.1	
Trillium petiolatum	-	-	-	-	-	
Urtica gracilis	-	-	-	-	-	
Veratrum californicum	-	-	-	-	-	
Verbascum thapsus	7.8	5.0	6.0	9.2	10.0	
Veronica americana	-	-	-	-	2.2	
Veronica arvensis	2.2	1.7	3.3	-	2.2	
Veronica peregrina	-	-	-	-	-	
Veronica serpyllifolia	-	3.4	-	-	-	
Vicia americana	1.1	-	2.7	-	-	
Viola adunca	4.4	-	2.0	-	1.1	
Viola nuttallii	-	-	-	0.8	-	
Amelanchier alinfolia	-	-	-	-	-	
Crataegus douglasii	2.2	-	5.3	5.8	2.2	
Rosa woodsii	-	-	-	-	-	
Rubus idaeus	-	-	-	1.7	-	
Salix bebbiana	-	-	2.0	5.0	-	
Salix exigua	10.0	11.7	12.7	5.0	1.1	
Salix lasiandra	-	-	-	0.8	-	
Salix rigida	12.2	20.0	10.0	22.5	-	
Symphoricarpos albus	-	-	0.7	-	-	
Abis grandis	-	-	-	-	-	
Alnus incana	8.9	1.7	1.3	8.4	1.1	
Pinus ponderosa	-	-	1.3	-	-	
Populus trichocarpa	13.3	8.4	6.0	19.2	12.2	
Prunus virginana	-	-	-	-	-	
unkown	8.9	18.2	2.0	8.4	1.1	

Table B-6. Average percent frequency for species in grazed and exclosed (excl.) *Crataegus douglasii* communities along the Catherine Creek study site 1987-1989.

Species	Year					
	1987		1988		1989	
	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Agropyron repens	1.7	12.7			4.2	4.7
Agrosits alba	0.8	2.0			0.8	-
Agrostis exarata	-	-			-	-
Agrostis scabra	-	-			-	-
Alopecurus aequalis	-	-			-	-
Aria elegans	-	-			-	-
Arrhenatherum elatus	-	-			-	-
Bromus marginatus	0.8	6.0			4.2	5.3
Bromus mollis	5.0	6.7			0.8	7.3
Bromus racemosus	-	-			-	-
Bromus tectorum	-	-			-	2.7
Dactylis glomerata	0.8	-			1.7	-
Dechampsia caespitosa	-	-			-	-
Elymus glaucus	30.0	-			34.2	1.3
Festuca elatior	-	-			1.7	4.7
Festuca idahoensis	-	-			-	-
Festuca occidentalis	-	-			-	-
Glyceria grandis	-	-			-	-
Glyceria striata	-	-			-	-
Holcus lanatus	-	-			-	-
Melica bulbosa	-	-			-	-
Phleum alpinum	-	-			-	-
Phleum pratense	3.3	6.7			4.2	9.3
Poa ampla	-	-			-	-
Poa bulbosa	-	-			-	-
Poa compressa	-	-			-	-
Poa pratensis	85.8	100.0			70.9	99.2
Poa sandbergii	-	-			-	-
Stipa occidentalis	-	-			-	-
Trisetum canescens	8.3	-			15.8	-
Vulpia myuros	-	-			-	-
Carex aquatilis	-	-			-	-
Carex aurea	-	-			-	-
Carex geyri	-	-			-	-
Carex hoodii	2.5	4.7			1.7	6.7
Carex laeviculmis	-	-			-	-
Carex microptera	-	-			-	-
Carex nebraskensis	-	-			-	-
Carex praegracilis	-	-			-	-
Carex rostrata	-	-			-	-
Carex spp.	2.5	0.7			9.2	3.3
Carex stiptata	-	-			-	-
Juncus balticus	-	-			-	-
Juncus bufonius	-	-			-	-
Juncus ensifolius	-	-			-	-

Table B-6. Continued.

Species	Year					
	1987		1988		1989	
	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Juncus nodosus	-	-			-	-
Juncus spp	-	-			-	-
Luzula campestris	1.7	0.7			3.3	2.0
Scirpus microcarpus	-	-			-	-
Achillea millefolium	17.5	58.4			22.5	67.4
Agoseris glauca	-	6.0			-	7.3
Alisma plantago	-	-			-	-
Amsinckia retorsa	-	-			-	-
Anaphalis margaritacea	-	-			-	-
Antennaria rosea	-	3.3			-	0.7
Aquilegia formosa	6.7	1.3			4.2	-
Arabis drummondii	-	-			-	-
Arenaria macrophylla	-	6.0			-	1.7
Arenaria serpyllifolia	-	-			-	-
Arnica chamissonis	-	-			-	-
Artemisia ludoviciana	-	-			-	-
Asperugo procumbens	-	-			-	-
Aster campestris	-	-			-	6.0
Aster foliaceus	26.7	45.0			17.5	41.7
Astragalus canadensis	-	-			-	-
Cerastium siculum	-	-			-	-
Cerastium viscosum	17.5	4.0			4.2	2.7
Circea alpina	-	-			-	-
Circea alpina	0.8	-			5.1	-
Cirsium vulgare	3.3	2.0			8.3	2.0
Collinsia parviflora	-	2.7			4.2	37.3
Collomia grandiflora	-	-			-	-
Collomia linearis	3.4	33.3			0.8	2.7
Cornus stolonifera	-	-			-	-
Dipsacus sylvestris	-	-			-	-
Draba verna	0.8	2.0			-	4.7
Epilobium glabberimum	-	-			-	-
Epilobium paniculatum	0.8	9.3			0.8	12.0
Equisetum arvense	5.8	4.0			10.8	4.0
Erigeron philadelphicus	3.3	-			-	-
Erigeron pumilus	-	-			-	0.8
Erigonum heracleoides	-	-			-	-
Erodium cicutarium	-	-			-	1.3
Fragaria vesca	-	-			6.7	-
Fragaria virginiana	23.3	26.7			28.3	24.0
Galium aparine	-	-			-	-
Galium asperrimum	53.4	2.7			44.2	0.7
Galium boreale	-	1.3			6.7	9.3
Geranium bicknellii	-	-			-	-
Geranium viscosissumum	-	-			-	-
Geum macrophyllum	18.4	6.7			11.7	-
Gnaphalium palustre	-	-			-	-
Habenaria dilatata	-	-			-	-

Table B-6. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heracleum lanatum	-	-			-	-
Heterocodon rariflorum	-	-			-	2.7
Holosteum umbellatum	1.7	4.7			-	-
Hydrophyllum capitatum	-	-			-	-
Hypericum anagalloides	-	-			-	-
Hypericum perforatum	-	-			-	-
Iris missouriensis	-	-			-	-
Lactuca serriola	-	1.3			-	1.3
Lathyrus polyphyllous	-	16.7			5.0	20.0
Lepidium perfoliatum	-	-			-	-
Lithophragma parviflora	-	-			-	-
Lomatium triternatum	-	-			-	-
Lupinus leucophyllus	-	0.7			-	-
Medicago lupulina	3.4	13.4			5.0	21.7
Mentha arvensis	-	-			-	-
Microsteris gracilis	-	-			-	38.7
Mimulus guttatus	-	-			-	-
Mitella stauropetala	-	-			4.2	-
Montia linearis	-	-			-	-
Montia perfoliata	28.4	8.7			19.2	18.0
Nemophila pedunculata	-	2.0			-	-
Nemophila pedunculata	-	-			-	-
Osmorhiza chilensis	18.4	0.7			16.7	4.0
Penstemon rydbergii	-	-			-	-
Plantago lanceolata	-	-			-	-
Plantago major	2.5	1.3			-	2.2
Polimonium occidentale	-	-			-	-
Polygonum douglasii	-	-			-	0.7
Potentilla arguta	-	-			-	-
Potentilla gracilis	-	-			-	-
Prunella vulgaris	-	2.7			9.2	6.7
Ranunculus arcis	37.5	22.0			53.3	32.7
Rorippa natsrutium	-	-			-	-
Rumex crispus	-	-			-	-
Rumex occidentalis	-	-			-	-
Rumex acetosella	7.5	1.3			-	0.7
Senecio pseudareus	37.5	23.3			16.7	27.3
Sidalecea oregana	-	-			-	-
Silene menziesii	-	-			2.5	-
Sisymbrium altissimum	-	-			-	-
Smilacina stellata	1.7	-			2.5	1.3
Solidago missouriensis	-	-			-	-
Stellaria longifolia	-	-			-	-
Stellaria longipes	0.8	-			3.3	-
Stellaria nitins	-	-			-	-
Taraxacum officinale	23.3	14.2			26.7	10.0
Thalictrum occidentale	-	-			1.7	0.7
Thlaspe arvense	-	-			-	-

Table B-6. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Tragopogon dubius	-	4.7			4.2	8.7
Trifolium pratense	2.5	4.7			4.2	10.7
Trifolium repens	3.3	-			0.8	6.0
Trillium petiolatum	14.2	2.0			16.7	4.0
Urtica gracilis	3.3	-			6.7	-
Veratrum californicum	-	1.3			-	4.0
Verbascum thapsus	0.8	1.3			8.3	2.7
Veronica americana	-	-			-	-
Veronica arvensis	1.7	9.3			-	8.0
Veronica peregrina	-	-			-	-
Veronica serpyllifolia	-	-			-	-
Vicia americana	8.3	4.0			2.5	13.3
Viola adunca	12.5	18.7			7.5	22.0
Viola nuttallii	-	-			5.0	-
Amelanchier alinfolia	-	-			6.7	-
Crataegus douglasii	50.0	7.3			20.0	4.0
Rosa woodsii	5.0	-			0.8	0.8
Rubus idaeus	-	-			-	-
Salix bebbiana	-	-			-	-
Salix exigua	-	-			-	-
Salix lasiandra	-	-			-	-
Salix rigida	-	-			-	-
Symphoricarpos albus	13.4	0.7			10.0	16.7
Abis grandis	-	-			-	-
Alnus incana	-	-			-	-
Pinus ponderosa	0.8	-			-	-
Populus trichocarpa	1.7	-			1.7	-
Prunus virginana	2.5	-			1.7	-
unkown	-	-			3.3	2.7

Table B-7. Average percent frequency for species in grazed and exclosed (excl.) *Pinus ponderosa* communities along the Catherine Creek study site 1987-1989.

Species	Year					
	1987		1988		1989	
	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Agropyron repens	-	4.4			-	-
Agrosits alba	1.1	-			-	-
Agrostis exarata	-	-			-	-
Agrostis scabra	-	-			-	-
Alopecurus aequalis	-	-			-	-
Aria elegans	-	-			-	-
Arrhenatherum elatus	-	-			-	4.4
Bromus marginatus	3.3	2.2			13.3	3.3
Bromus mollis	7.8	14.5			3.3	18.9
Bromus racemosus	-	-			-	-
Bromus tectorum	7.8	6.7			11.1	27.8
Dactylis glomerata	-	-			-	-
Dechampsia caespitosa	-	-			-	-
Elymus glaucus	22.2	44.5			28.9	47.8
Festuca elatior	-	-			-	-
Festuca idahoensis	-	-			-	-
Festuca occidentalis	-	-			-	-
Glyceria grandis	-	-			-	-
Glyceria striata	-	-			-	-
Holcus lanatus	-	-			-	-
Melica bulbosa	4.4	-			7.8	-
Phleum alpinum	-	-			-	-
Phleum pratense	-	-			3.3	-
Poa ampla	-	-			-	-
Poa bulbosa	-	-			-	-
Poa compressa	10.0	-			2.2	-
Poa pratensis	83.3	74.4			95.6	61.1
Poa sandbergii	-	-			-	-
Stipa occidentalis	1.1	-			-	-
Trisetum canescens	-	-			13.3	-
Vulpia myuros	-	-			-	-
Carex aquatilis	-	-			-	-
Carex aurea	-	-			-	-
Carex geyri	-	-			7.8	-
Carex hoodii	2.2	-			-	-
Carex laeviculmis	-	-			-	-
Carex microptera	-	-			-	-
Carex nebraskensis	-	-			-	-
Carex praegracilis	-	-			-	-
Carex rostrata	-	-			-	-
Carex spp.	3.3	5.5			11.1	2.2
Carex stiptata	-	-			-	-
Juncus balticus	-	-			-	-
Juncus bufonius	-	-			-	-
Juncus ensifolius	-	-			-	-

Table B-7. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus nodosus	-	-			-	-
Juncus spp.	-	-			-	-
Luzula campestris	6.7	-			6.7	-
Scirpus microcarpus	-	-			-	-
Achillea millefolium	41.1	7.8			26.7	10.1
Agoseris glauca	5.5	2.2			-	4.4
Alisma plantago	-	-			-	-
Amsinckia retorsa	-	-			-	-
Anaphalis margaritacea	-	-			-	-
Antennaria rosea	-	-			-	-
Aquilegia formosa	5.6	1.1			3.3	-
Arabis drummondii	-	-			-	-
Arenaria macrophylla	-	5.6			-	-
Arenaria serpyllifolia	-	-			-	-
Arnica chamissonis	-	-			-	-
Artemisia ludoviciana	-	-			-	-
Asperugo procumbens	-	1.1			-	7.8
Aster campestris	-	-			-	-
Aster foliaceus	12.2	3.3			10.0	-
Astragalus canadensis	-	-			-	-
Cerastium siculum	-	-			-	-
Cerastium viscosum	51.1	5.5			10.0	2.2
Circea alpina	-	-			-	-
Circea alpina	-	-			1.1	-
Cirsium vulgare	2.2	-			3.3	-
Collinsia parviflora	2.2	5.6			14.4	37.8
Collomia grandiflora	-	-			-	-
Collomia linearis	13.3	11.1			4.4	14.5
Cornus stolonifera	-	-			-	-
Dipsacus sylvestris	-	-			-	-
Draba verna	-	-			-	1.1
Epilobium glabberimum	-	-			-	-
Epilobium paniculatum	-	6.7			-	21.1
Equisetum arvense	-	-			-	-
Erigeron philadelphicus	-	-			-	-
Erigeron pumilus	-	-			-	-
Erigonum heracleoides	-	-			-	-
Erodium cicutarium	-	-			-	-
Fragaria vesca	-	-			-	-
Fragaria virginiana	17.8	-			7.8	-
Galium aparine	-	-			-	-
Galium asperrimum	21.1	12.2			14.4	44.4
Galium boreale	4.4	14.4			20.0	1.1
Geranium bicknellii	22.2	5.6			1.1	10.0
Geranium viscosissumum	-	-			-	-
Geum macrophyllum	2.2	-			1.1	-
Gnaphalium palustre	-	-			-	-
Habenaria dilatata	1.1	-			-	-

Table B-7. Continued.

Species	Year 1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heracleum lanatum	-	-			-	-
Heterocodon rariflorum	-	-			-	-
Holosteum umbellatum	6.7	5.6			-	-
Hydrophyllum capitatum	-	-			-	-
Hypericum anagalloides	-	-			-	-
Hypericum perforatum	-	-			-	-
Iris missouriensis	-	-			-	-
Lactuca serriola	1.1	1.1			-	7.8
Lathyrus polyphyllous	20.0	-			-	-
Lepidium perfoliatum	-	-			-	-
Lithophragma parviflor	-	-			-	-
Lomatium triternatum	-	-			-	-
Lupinus leucophyllus	6.7	-			5.6	-
Medicago lupulina	4.4	-			-	-
Mentha arvensis	-	-			-	-
Microsteris gracilis	-	-			-	-
Mimulus guttatus	-	-			-	-
Mitella stauropetala	-	-			4.4	-
Montia linearis	-	1.1			-	-
Montia perfoliata	32.2	31.1			34.5	46.6
Nemophila pedunculata	-	-			-	-
Nemophila pedunculata	-	-			-	-
Osmorhiza chilensis	3.3	-			27.8	-
Penstemon rydbergii	-	-			-	-
Plantago lanceolata	-	-			2.2	-
Plantago major	-	-			-	-
Polimonium occidentale	-	-			-	-
Polygonum douglasii	-	-			-	-
Potentilla arguta	-	-			-	-
Potentilla gracilis	-	-			1.1	-
Prunella vulgaris	2.2	-			4.4	-
Ranunculus arcis	10.0	-			19.6	-
Rorippa natsrutium	-	-			-	-
Rumex crispus	-	-			-	-
Rumex occidentalis	-	-			-	-
Rumex acetosella	12.2	-			14.4	-
Senecio pseudareus	11.1	-			-	-
Sidalecea oregana	-	-			-	-
Silene menziesii	-	-			32.2	2.2
Sisymbrium altissimum	-	-			-	-
Smilacina stellata	2.2	1.1			7.8	2.2
Solidago missouriensis	-	-			-	-
Stellaria longifolia	-	-			-	-
Stellaria longipes	-	-			-	-
Stellaria nitins	5.6	1.1			-	-
Taraxacum officinale	11.1	-			21.1	3.3
Thalictrum occidentale	-	-			-	-
Thlaspe arvense	-	-			-	-

Table B-7. Continued.

Species	Year 1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Tragopogon dubius	4.4	-			7.8	-
Trifolium pratense	4.4	4.4			-	-
Trifolium repens	5.6	-			12.2	-
Trillium petiolatum	-	-			1.1	5.6
Urtica gracilis	-	14.4			-	4.4
Veratrum californicum	-	-			-	-
Verbascum thapsus	1.1	-			1.1	-
Veronica americana	-	-			-	-
Veronica arvensis	4.5	7.8			1.1	1.1
Veronica peregrina	-	-			1.1	-
Veronica serpyllifolia	-	-			-	-
Vicia americana	8.9	-			24.4	2.2
Viola adunca	10.0	-			1.1	-
Viola nuttallii	-	-			12.2	-
Amelanchier alinfolia	-	-			3.3	-
Crataegus douglasii	11.1	4.4			4.4	1.1
Rosa woodsii	1.1	14.5			1.1	8.9
Rubus idaeus	-	-			-	-
Salix bebbiana	-	-			-	-
Salix exigua	-	-			-	-
Salix lasiandra	-	-			-	-
Salix rigida	-	-			-	-
Symphoricarpos albus	14.4	24.5			13.3	5.5
Abis grandis	-	-			-	-
Alnus incana	-	-			-	-
Pinus ponderosa	-	-			-	-
Populus trichocarpa	-	-			-	-
Prunus virginana	-	-			-	-
unkown	-	-			5.6	1.1

Table B-8. Average percent frequency for species in grazed and exclosed (excl.) *Poa pratensis-Carex* spp. communities along the Catherine Creek study site 1987-1989.

	Year					
	1987		1988		1989	
Species	Grazed	Excl.	Grazed	Excl.	Grazed	Excl.
Agropyron repens	-	-	5.9	0.8	8.3	1.7
Agrosits alba	5.6	4.2	14.2	8.3	10.0	12.5
Agrostis exarata	-	-	-	-	-	-
Agrostis scabra	-	-	-	-	-	-
Alopecurus aequalis	-	-	-	-	-	-
Aria elegans	-	-	-	-	-	-
Arrhenatherum elatus	-	-	-	-	-	-
Bromus marginatus	5.6	15.0	12.5	-	10.8	-
Bromus mollis	1.1	-	2.5	-	20.8	-
Bromus racemosus	-	-	-	-	-	-
Bromus tectorum	-	-	-	-	0.8	1.7
Dactylis glomerata	-	-	-	-	-	-
Dechampsia caespitosa	-	-	-	-	-	-
Elymus glaucus	-	-	-	-	-	-
Festuca elatior	6.7	-	10.8	-	15.9	-
Festuca idahoensis	1.1	0.8	-	-	-	-
Festuca occidentalis	-	-	-	-	-	-
Glyceria grandis	-	-	-	-	-	-
Glyceria striata	-	-	-	-	-	-
Holcus lanatus	-	-	-	-	-	-
Melica bulbosa	-	-	0.8	-	-	-
Phleum alpinum	-	-	-	-	-	-
Phleum pratense	74.4	7.8	69.2	0.8	76.7	3.3
Poa ampla	-	-	-	-	-	-
Poa bulbosa	-	-	-	-	-	-
Poa compressa	-	-	-	-	-	-
Poa pratensis	100.0	70.0	99.2	83.3	100.0	80.0
Poa sandbergii	-	-	-	-	-	-
Stipa occidentalis	-	5.0	7.5	13.3	3.3	7.5
Trisetum canescens	-	-	-	-	-	-
Vulpia myuros	-	-	-	-	-	-
Carex aquatilis	-	-	6.7	2.5	-	-
Carex aurea	-	-	-	-	-	-
Carex geyri	-	-	-	-	-	-
Carex hoodii	10.0	37.6	3.4	5.8	3.3	7.5
Carex laeviculmis	-	-	18.3	-	-	-
Carex microptera	-	-	0.8	-	2.5	-
Carex nebraskensis	25.6	8.3	16.7	-	16.7	4.2
Carex praegracilis	3.3	1.7	-	-	-	-
Carex rostrata	-	-	5.8	25.0	14.2	3.3
Carex spp.	-	1.7	20.8	15.0	11.7	6.7
Carex stiptata	-	-	-	-	-	-
Juncus balticus	21.1	36.7	35.0	29.2	19.2	35.8
Juncus bufonius	-	-	-	-	-	2.5
Juncus ensifolius	-	-	-	-	-	-

Table B-8. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Juncus nodosus	-	-	-	-	-	-
Juncus spp.	-	-	-	-	-	-
Luzula campestris	2.2	0.8	0.8	-	0.8	-
Scirpus microcarpus	-	-	-	-	-	-
Achillea millefolium	51.1	37.8	71.7	42.5	57.8	44.4
Agoseris glauca	-	-	1.7	-	2.5	-
Alisma plantago	-	-	-	-	-	-
Amsinckia retorsa	-	-	-	-	-	-
Anaphalis margaritacea	-	-	-	-	-	-
Antennaria rosea	-	-	0.8	-	0.8	-
Aquilegia formosa	-	-	-	-	-	-
Arabis drummondii	-	-	-	-	-	-
Arenaria macrophylla	-	-	-	-	-	-
Arenaria serpyllifolia	-	-	-	-	-	-
Arnica chamissonis	6.7	3.3	1.7	-	-	-
Artemisia ludoviciana	-	-	-	-	-	-
Asperugo procumbens	-	-	-	-	-	-
Aster campestris	-	-	-	-	-	-
Aster foliaceus	44.5	26.7	54.2	30.8	45.0	23.3
Astragalus canadensis	-	-	-	-	-	-
Cerastium siculum	3.3	-	-	-	-	-
Cerastium viscosum	27.8	5.8	20.9	2.5	9.2	10.8
Circea alpina	-	-	-	-	-	-
Circea alpina	-	-	-	-	-	-
Cirsium vulgare	1.1	4.2	0.8	7.5	1.7	19.2
Collinsia parviflora	3.3	5.0	39.2	18.3	32.5	28.4
Collomia grandiflora	-	-	1.7	-	-	-
Collomia linearis	16.7	20.0	38.4	27.5	29.2	34.2
Cornus stolonifera	-	-	-	-	-	-
Dipsacus sylvestris	-	-	-	3.3	9.2	2.5
Draba verna	11.1	2.5	14.2	1.7	3.4	1.7
Epilobium glabberimum	-	14.2	-	12.5	-	18.3
Epilobium paniculatum	2.2	15.0	3.3	5.9	17.5	6.7
Equisetum arvense	-	-	-	-	1.7	-
Erigeron philadelphicus	-	-	-	-	-	-
Erigeron pumilus	-	-	-	-	-	-
Erigonum heracleoides	-	-	-	-	-	-
Erodium cicutarium	1.1	3.3	-	-	2.5	0.8
Fragaria vesca	-	-	-	-	-	-
Fragaria virginiana	11.1	8.3	15.0	12.5	12.5	12.5
Galium aparine	-	-	-	-	-	-
Galium asperrimum	-	-	0.8	-	-	-
Galium boreale	-	5.8	-	-	2.5	-
Geranium bicknellii	-	1.7	-	0.8	-	-
Geranium viscosissumum	1.1	-	-	-	-	-
Geum macrophyllum	18.9	19.2	19.2	14.2	10.9	23.4
Gnaphalium palustre	-	-	-	-	-	-
Habenaria dilatata	1.1	-	-	-	0.8	-

Table B-8. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Heracleum lanatum	-	-	-	-	-	-
Heterocodon rariflorum	-	-	-	-	1.7	-
Holosteum umbellatum	-	8.3	0.8	-	-	-
Hydrophyllum capitatum	-	-	-	-	-	-
Hypericum anagalloides	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-
Iris missouriensis	-	-	-	-	0.8	-
Lactuca serriola	-	-	-	0.8	-	0.8
Lathyrus polyphyllous	-	11.7	30.0	18.4	15.0	10.0
Lepidium perfoliatum	-	-	-	-	-	-
Lithophragma parviflora	-	-	-	-	-	-
Lomatium triternatum	-	-	1.7	-	0.8	-
Lupinus leucophyllus	8.9	0.8	1.7	-	13.3	-
Medicago lupulina	17.9	3.4	24.2	2.5	20.8	9.2
Mentha arvensis	-	-	-	5.0	-	-
Microsteris gracilis	-	-	-	-	-	-
Mimulus guttatus	-	-	-	0.8	1.7	3.3
Mitella stauropetala	-	-	-	-	-	-
Montia linearis	3.3	12.5	13.4	15.8	8.3	16.7
Montia perfoliata	-	0.8	-	4.2	-	2.5
Nemophila pedunculata	-	-	-	-	-	-
Nemophila pedunculata	-	-	-	-	-	-
Osmorhiza chilensis	-	-	-	-	-	-
Penstemon rydbergii	-	-	0.8	10.0	5.8	17.5
Plantago lanceolata	-	-	-	-	-	-
Plantago major	-	-	6.7	-	0.8	-
Polimonium occidentale	-	-	-	-	1.7	5.0
Polygonum douglasii	-	-	-	6.7	-	5.8
Potentilla arguta	-	-	-	-	-	-
Potentilla gracilis	32.2	32.5	29.2	32.5	39.2	30.0
Prunella vulgaris	-	-	-	-	3.3	-
Ranunculus arcis	58.9	16.7	50.0	2.5	71.1	12.2
Rorippa natsrutium	-	-	-	10.8	-	2.5
Rumex crispus	-	0.8	-	-	-	4.2
Rumex occidentalis	-	-	-	1.7	-	-
Rumex acetosella	24.4	9.2	5.0	2.5	12.5	9.2
Senecio pseudareus	-	13.3	7.5	29.2	0.8	19.2
Sidalecea oregana	20.0	3.3	-	-	3.3	0.8
Silene menziesii	-	-	-	-	-	-
Sisymbrium altissimum	-	-	-	-	-	-
Smilacina stellata	-	-	1.7	-	3.3	-
Solidago missouriensis	-	1.7	-	-	0.8	-
Stellaria longifolia	-	-	-	-	-	-
Stellaria longipes	21.1	5.8	31.7	15.0	14.2	11.7
Stellaria nitins	-	6.7	-	5.8	-	-
Taraxacum officinale	35.6	26.6	42.5	14.2	36.7	17.8
Thalictrum occidentale	-	-	-	-	-	-
Thlaspe arvense	-	-	-	2.5	-	-

Table B-8. Continued.

Species	1987 Grazed	1987 Excl.	1988 Grazed	1988 Excl.	1989 Grazed	1989 Excl.
Tragopogon dubius	1.1	0.8	6.7	-	5.0	0.8
Trifolium pratense	31.1	0.8	16.7	1.7	16.7	0.8
Trifolium repens	6.7	2.5	14.2	2.5	11.7	10.0
Trillium petiolatum	-	-	-	-	3.4	0.8
Urtica gracilis	-	-	-	-	-	-
Veratrum californicum	8.9	3.3	8.3	8.3	1.7	7.5
Verbascum thapsus	-	-	0.8	-	3.3	-
Veronica americana	-	-	-	-	-	-
Veronica arvensis	23.3	11.7	30.0	3.3	15.8	11.7
Veronica peregrina	-	-	-	-	-	2.5
Veronica serpyllifolia	-	-	-	-	-	-
Vicia americana	10.0	21.7	22.5	16.7	20.0	12.5
Viola adunca	22.2	18.4	41.7	15.0	40.0	19.2
Viola nuttallii	-	-	3.3	-	-	-
Amelanchier alinfolia	-	-	-	-	-	-
Crataegus douglasii	1.1	0.8	0.8	0.8	0.8	2.5
Rosa woodsii	-	1.7	-	-	-	-
Rubus idaeus	-	-	-	-	-	-
Salix bebbiana	-	-	-	-	-	-
Salix exigua	-	-	-	-	-	-
Salix lasiandra	-	-	-	-	-	-
Salix rigida	-	-	-	-	-	-
Symphoricarpos albus	5.6	-	2.5	-	5.0	17.5
Abis grandis	-	-	-	-	-	-
Alnus incana	-	-	-	-	-	-
Pinus ponderosa	-	-	-	-	-	-
Populus trichocarpa	-	-	-	-	-	-
Prunus virginana	-	-	-	-	-	-
unkown	1.1	22.2	-	16.7	0.8	2.5

Appendix C.

Mean percent frequency of species along a hydric gradient at the Catherine Creek study area.

Appendix C. Mean percent frequency for *Glyceria grandis* (Glgr), *Carex rostrata* (Caro), *Carex nebraskensis* (Cane), *Juncus balticus-Poa pratensis* (Juba-Popr), and *Poa pratensis-Carex* spp. (Popr-Carex) communities along a hydric gradient at the Catherine Creek study area.

Species	Community				
	Glgr	Caro	Cane	Juba-Popr	Popr-Carex
Agropyron repens	–	–	–	–	1.7
Agrostis alba	–	8.4	–	6.7	12.5
Alopecurus aequalis	23.4	–	–	–	–
Bromus tectorum	–	–	–	–	1.7
Glyceria elata	25.0	–	–	–	–
Glyceria grandis	78.4	13.4	6.7	–	–
Glyceria striata	–	3.4	15.0	–	–
Holcus lanata	–	5.0	–	3.4	–
Phleum pratense	–	1.7	–	20.0	2.5
Poa pratensis	–	1.7	–	100.0	85.0
Stipa occidentalis	–	–	–	–	7.5
Carex hoodii	–	–	–	3.4	7.5
Carex langinosa	3.4	–	1.7	–	–
Carex microptera	–	1.7	–	–	–
Carex nebraskensis	20.0	13.4	100.0	–	4.2
Carex rostrata	5.0	–	23.4	5.0	3.3
Carex spp.	–	100.0	–	–	6.7
Juncus balticus	–	8.4	30.0	100.0	35.8
Juncus bufonius	–	–	–	–	2.5
Juncus ensifolius	–	5.0	–	–	–
Juncus spp.	1.7	–	–	–	–
Scirpus microcarpus	33.3	16.7	30.0	–	–
Achillea millefolium	–	–	–	78.4	45.8
Alisma plantago	5.0	–	–	–	–
Aster foliaceus	–	–	–	43.3	23.3
Cerastium viscosum	–	5.0	–	11.7	10.8
Cirsium vulgare	–	–	–	3.4	19.2
Collinsia parviflora	–	–	–	3.4	28.4
Collomia linearis	–	–	–	–	34.2
Dipsacus sylvestris	–	–	–	–	2.5
Draba verna	–	–	–	–	1.7
Epilobium glabberimum	1.7	–	–	–	18.3
Epilobium paniculatum	15.0	23.4	–	–	6.7
Equisetum arvense	–	10.0	–	–	–
Erodium cicutarium	–	–	–	–	0.8
Fragaria virginiana	–	–	–	–	12.5
Galium asperrimum	–	–	–	11.7	–
Geum macrophyllum	–	–	–	23.4	23.4
Holosteum umbellatum	–	–	–	5.0	–
Lactuca serriola	–	–	–	–	0.8
Lathyrus polyphyllus	–	–	–	–	10.0
Lemna minor	40.0	–	–	–	–
Medicago lupulina	–	–	–	–	9.2
Mimulus guttatus	28.4	6.7	–	–	3.3
Montia linearis	–	1.7	–	–	16.7

Appendix C. Continued.

Species	Community				
	Glgr	Caro	Cane	Juba-Popr	Popr-Carex
Montia perfoliata	-	-	-	-	2.5
Penstemon rydbergii	-	-	-	-	17.5
Polygonum douglasii	-	-	-	5.0	5.0
Polygonum douglasii	-	-	-	-	5.8
Potentilla gracilis	-	-	-	21.7	30.0
Prunella vulgaris	-	-	-	10.0	-
Ranunculus acris	-	15.0	-	63.4	10.8
Ranunculus aquatilis	45.0	-	-	-	-
Ranunculus macounii	6.7	11.7	5.0	-	-
Rorippa natsrutium	-	1.7	-	-	2.5
Rumex acetosella	-	-	-	-	9.2
Rumex crispus	-	-	-	-	4.2
Rumex occidentalis	-	-	-	1.7	-
Senecio pseudareus	-	3.4	-	83.3	19.2
Sidalecea oregana	-	-	-	-	0.8
Smilacina stellata	-	-	-	23.4	-
Stellaria longipes	-	-	-	20.0	11.7
Taraxacum officinale	-	-	-	20.0	13.3
Tragopogon dubius	-	-	-	-	0.8
Trifolium pratense	-	-	-	1.7	0.8
Trifolium repens	-	6.7	-	6.7	10.0
Trillium petiolatum	-	-	-	-	0.8
Veonica scutellata	10.0	15.0	13.4	-	-
Veratrium californicum	-	-	-	-	7.5
Veronica americana	-	-	-	8.4	-
Veronica arvensis	-	-	1.7	25.0	11.7
Veronica serpyllifolia	-	-	-	-	2.5
Vicia americana	-	-	-	-	12.5
Viola adunca	-	-	-	-	19.2
Crataegus douglasii	-	-	-	-	2.5
Rosa woodsii	-	-	-	18.4	-
Symphoricarpos albus	-	-	-	-	17.5
unknown	-	-	-	-	2.5