MONTANA STATE UNIVERSITY

Effects of land use on vegetation in glaciated depressional wetlands in western Montana
by Cynthia S Borth

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University
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Abstract:
Human influence and biological condition in streams are commonly assessed with multimetric indices, which combine measurements at several ecological levels into an overall rating of biological integrity. Efforts to develop such biological assessment methods for wetlands are relatively recent. This study examined effects of grazing and cultivation on vegetation in 24 depressional wetlands in western Montana. The two primary objectives of this research were to (1) evaluate differences in vegetation among wetlands with different land uses and (2) identify vegetation characteristics that vary predictably with land use, and, therefore, may be useful in a multimetric index of human influence on wetlands. I examined plant community composition and vertical distribution of species in wetlands surrounded by land uses ranging from relatively undisturbed to currently grazed or cultivated. Sites were selected using physical and chemical criteria to limit natural variability among sites. Environmental data showed that wetlands differed between the two study areas selected to investigate effects of cultivation and grazing but were similar within each study area. I found limited evidence for elevated nutrient concentrations, which might alter vegetation indirectly, in areas of increased disturbance but considerable evidence of direct, physical impacts such as tillage and trampling. Patterns of differences in wetland vegetation among land uses were also consistent with direct, physical impacts of cultivation and grazing and indicated that cultivation caused greater changes in plant communities than grazing. In cultivated areas, the clearest differences were observed in groups and species related to life history, successional role or native origin: annuals, perennials, native perennials, moss, Agropyron species, Eleocharis species, and Juncus balticus. In grazed areas, dominance, Eleocharis species, and Juncus balticus differed among land uses. Vertical distributions of many species shifted to lower elevations at disturbed sites. Because land use appears to affect vascular plant communities in a measurable and ecologically rational way, vascular plants show good potential for use as metrics to assess wetland condition and human influence on wetlands. Because changes in vegetation were greater for cultivation than grazing, plant-based metrics are more likely to succeed in assessing impacts of cultivation.

EFFECTS OF LAND USE ON VEGETATION IN GLACIATED DEPRESSIONAL WETLANDS IN WESTERN MONTANA

by

Cynthia S. Borth

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Human influence and biological condition in streams are commonly assessed with multimetric indices, which combine measurements at several ecological levels into an overall rating of biological integrity. Efforts to develop such biological assessment methods for wetlands are relatively recent. This study examined effects of grazing and cultivation on vegetation in 24 depressional wetlands in western Montana. The two primary objectives of this research were to (1) evaluate differences in vegetation among wetlands with different land uses and (2) identify vegetation characteristics that vary predictably with land use, and, therefore, may be useful in a multimetric index of human influence on wetlands. I examined plant community composition and vertical distribution of species in wetlands surrounded by land uses ranging from relatively undisturbed to currently grazed or cultivated. Sites were selected using physical and chemical criteria to limit natural variability among sites. Environmental data showed that wetlands differed between the two study areas selected to investigate effects of cultivation and grazing but were similar within each study area. I found limited evidence for elevated nutrient concentrations, which might alter vegetation indirectly, in areas of increased disturbance but considerable evidence of direct, physical impacts such as tillage and trampling. Patterns of differences in wetland vegetation among land uses were also consistent with direct, physical impacts of cultivation and grazing and indicated that cultivation caused greater changes in plant communities than grazing. In cultivated areas, the clearest differences were observed in groups and species related to life history, successional role or native origin: annuals, perennials, native perennials, moss, *Agropyron* species, *Eleocharis* species, and *Juncus balticus*. In grazed areas, dominance, *Eleocharis* species, and *Juncus balticus* differed among land uses. Vertical distributions of many species shifted to lower elevations at disturbed sites. Because land use appears to affect vascular plant communities in a measurable and ecologically rational way, vascular plants show good potential for use as metrics to assess wetland condition and human influence on wetlands. Because changes in vegetation were greater for cultivation than grazing, plant-based metrics are more likely to succeed in assessing impacts of cultivation.

INTRODUCTION

Wetlands are transitional environments between uplands and aquatic environments. In wetlands, biological, chemical, and physical components interact in distinctive ways that generate basic ecological attributes and functions that influence adjacent ecosystems. For example, biogeochemical changes affecting chemical constituents in the water column and substratum, removal of sediment, reduction in water velocity, water storage, and provision of unique habitat needed by many different lifeforms are all influenced by the wetland ecosystem (Mitsch and Gosselink 1993). These wetland functions are increasingly recognized as valuable to human society, yet wetland habitat continues to be threatened by land use either directly or in the surrounding watershed.

In Montana, two of the most extensive uses of land affecting wetlands are livestock grazing and cultivation (Montana Agricultural Statistics Service 1990). These land uses are recognized as strongly impacting wetland vegetation in the northern prairie region (Kantrud et al. 1989, Millar 1973, Stewart and Kantrud 1972, Walker and Coupland 1970, Dix and Smeins 1967). However, Kantrud et al. (1989) state that information on the impacts of different kinds of agricultural activities on wetland vegetation is not extensive and for the most part consists of incidental observations recorded as part of vegetation surveys or waterfowl studies.

Changes in vegetation are among the most conspicuous and ecologically significant consequences of human activity in and around wetlands. The flora of depressional wetlands in glaciated landscapes is influenced by the water regime, salinity,

and disturbance by humans, but direct and indirect disturbances are so widespread that they are often the most important factors controlling the distribution and composition of contemporary wetland vegetation (Kantrud et al. 1989). Direct physical disruption of sites by land use can alter plant community composition by removal of vegetation, introduction of species, or physical alteration of the soil. Indirect effects of land use on vegetation may result from changes in water and sediment chemistry in wetlands due to changes in surface runoff or groundwater quality, which may alter plant growth or competition between species. Either direct or indirect impacts to wetlands can result in broad changes in vegetation.

The primary legal protections for wetlands from human impacts are contained in the Clean Water Act. Section 101(a) states that the objective of the Clean Water Act is to "maintain and restore the chemical, physical, and biological integrity of our Nation's waters." The jurisdiction of this Act includes wetlands (Danielson 1998). Unfortunately, although this federal mandate as well as state and local regulations are in place to protect wetlands, wetlands are still altered or lost at high rates (Karr and Chu 1997). Impacts in and around wetlands continue, due in part to a limited understanding of how land use affects wetlands and how to assess the condition of wetlands prior to, during, and after human activity. In addition, while some land uses clearly alter wetlands, the long-term effects of moderate land use in wetlands, or land use in the surrounding watersheds, are less obvious, less well understood, and more difficult to quantify.

Following passage of the Clean Water Act, emphasis was placed on development of chemical criteria to maintain and restore the Nation's waters. However, it has become increasingly clear that aquatic systems continue to deteriorate as a result of human

actions (Karr and Chu 1997). Nonpoint source pollution, habitat alteration and fragmentation, and land use within a watershed can all alter the biological components of aquatic ecosystems, yet the resulting impacts may not be detected using chemical criteria (Danielson 1998). Because chemical criteria alone are unable to measure the impacts caused by these kinds of stressors, the U.S. EPA has begun to focus on direct assessment and protection of biological condition of aquatic systems (Danielson 1998).

One common approach to direct assessment of biological condition in aquatic systems is the use of multimetric indices (Karr and Chu 1997). A multimetric index combines quantitative measurements at several ecological levels into an overall rating of biological integrity. While multimetric indices have been developed for stream ecosystems in many states (Karr and Chu 1997), efforts to develop biological assessment methods for wetlands are relatively recent (Danielson 1998). Further, multimetric indices for streams have primarily used fish and macroinvertebrates, while in wetlands, vascular plants may be useful for biological assessment (Adamus and Kentula 1996).

As of 1996, no state agencies in the prairie region were monitoring biological integrity of wetlands using vascular plants (Adamus and Kentula 1996), although research is now underway in some states. Researchers have documented that vascular plant community composition in wetlands changes with land use, although detailed information that could be used for quantitative monitoring is limited. Vascular plants may be especially useful for biological assessment of wetlands because water is not always present in wetlands to support other assemblages such as aquatic macroinvertebrates or fish. Furthermore, because plant populations are persistent, sessile,

and respond to the soil environment, they may integrate effects of impacts over longer periods than either invertebrates or fish.

Research Objectives and Approach

This study examined effects of grazing and cultivation on vegetation in depressional wetlands in western Montana. The two primary objectives were to (1) evaluate differences in vegetation among wetlands with different land use and (2) identify vegetation characteristics that vary predictably in relation to land uses and, therefore, may be useful in a multimetric index of human influence on wetlands. This work was undertaken partially in response to the state of Montana's need to develop methods for wetland assessment in compliance with the Clean Water Act.

I studied effects of land use on plant community composition and species distribution relative to surface elevation in 24 depressional wetlands in western Montana. Twelve sites located in the Mission Valley were used to investigate the effects of cultivation; these sites were all within a 3-km range. Another twelve sites located in the Ovando Valley were used to investigate the effects of grazing; these sites were within a 30-km range. Each study area of 12 sites was evenly subdivided into three groups: a reference group representing least human impact, a group currently grazed or cultivated, and a group retired from grazing or cultivation for several years.

I hypothesized that wetland vegetation is impacted directly or indirectly by cultivation and grazing and, therefore, differs among sites with different land uses. Tillage can uproot plants, change soil structure and cause erosion and sedimentation.

Grazing can stress plants by removing leaves and reducing photosynthesis and carbon reserves; defoliation may also allow other species to compete more successfully. Trampling by hooves can damage roots and shoots and compact soil, restricting plant growth. Trampling can also alter surface microtopography, and resultant microsite changes in hydrology may cause changes in species composition.

Cultivation and grazing can also affect wetland vegetation indirectly by altering water and sediment chemistry in wetlands. I hypothesized that the most likely indirect effects of these land uses would be changes in nutrient concentrations in the water column and sediment. Possible avenues for changes in nutrient concentrations in cultivated areas included increased runoff due to soil and vegetation disturbance, transport of fertilizer nutrients from surrounding cropland by runoff, and direct application of fertilizer in wetlands during drawdown periods. In grazed areas, changes in nutrient concentrations may occur due to animal defecation or urination in wetland margins, where livestock spend disproportionate amounts of time (Nader et al. 1998).

The study design focused on limiting natural variation among sites in order to detect differences in land uses. All sites were depressional wetlands as defined within a hydrogeomorphic classification (Brinson 1993). Depressional wetlands occur in low areas in the landscape and receive water from surface precipitation and runoff, groundwater, or both. Based on Omernik's (1987) ecoregion map, the two study areas were in the same ecoregion. However, the two areas were in different ecological units, according to the ecological units map developed by Nesser et al. (1997). The selected sites met criteria for hydrologic regime, salinity, and landscape setting. The study sites were as similar as possible except for the differing land uses around individual sites.

Environmental data were collected to verify that sites were similar and to evaluate whether land use effects on the vegetation were most likely direct, via physical disturbance to the wetland, or indirect, via water or sediment chemistry.

I compared plant community composition among land uses. Because relatively little research has been done on the use of vegetation to assess biological integrity of wetlands (Adamus and Kentula 1996), I examined several groups of plant species, as well as genera and individual species. These groupings primarily were based on ecological factors such as life history, lifeform, and whether species were native or exotic. Other groups were based on results of relevant research and examination of the data.

I also investigated whether disturbance related to land use altered the spatial distribution of plant species with respect to elevation, and whether species distribution with respect to elevation or water depth could be incorporated as a metric. Physical disturbance or changes in resources might affect mortality, reproduction, or competition, resulting in changes in abundance. If these effects varied along the hydrologic gradient, species distributions could shift to higher or lower elevation ranges. I compared whether the distribution of each species with respect to water surface elevation differed among reference, retired, and currently impacted wetlands, and tested whether change in elevational distribution was consistent among species.

Finally, data were used to identify potential variables for use in a multimetric index for depressional wetlands in western Montana. In addition to examining land use impacts generally, sampling two different land uses allowed me to examine patterns in vegetation composition and distribution specific to grazing or cultivation. Understanding

distinctive effects of these land uses may lead to useful diagnostic tools for assessing wetlands with unknown land use histories to determine past impacts.

LITERATURE REVIEW

Hydrologic regime and salinity are two of the most important natural controls of plant distribution in depressional prairie wetlands (Kantrud et al. 1989, Millar 1973, Stewart and Kantrud 1972, Walker and Coupland 1970, Walker and Coupland 1968). These factors in turn are influenced by geomorphic characteristics and subsurface geology. Human disturbance also plays an important role in plant distribution (Kantrud et al. 1989).

Below, I first discuss geomorphic characteristics, hydrologic regime, and salinity and how they interact in depressional wetlands formed by glaciation. Next, I describe the state of knowledge regarding the response of vegetation to these environmental factors. Third, I discuss vegetation response to land use impacts. Wetlands examined in this study are hydrogeomorphically similar to the prairie potholes of the Dakotas, where much research has been completed on depressional wetlands in response to conflicts between waterfowl habitat preservation and agriculture. Therefore, much of the literature cited comes from this region. Finally, I outline the scientific basis for multimetric indices and how vascular plants may be useful in a multimetric index.

Geomorphology, Hydrology, and Water Chemistry

Hydrology is the driving force behind the existence of wetlands. "A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or

near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation." (National Research Council 1995). Wetland hydrology is the most important determinant of a wetland's structure and function (Mitsch and Gosselink 1993). Geomorphic characteristics and subsurface geology influence hydrologic regime, water source, and water and sediment chemistry in wetlands, all of which influence the biological attributes of wetlands.

Depressional wetlands are common in the glaciated northern plains of North America; they are referred to as prairie potholes in the United States and as sloughs in Canada (Kantrud et al. 1989). These wetlands are formed in glacial deposits: till, glaciolacustrine sediments, and outwash. All these types of glacial deposition result in generally similar surface topography: a relatively young landscape of gently rolling to hummocky topography with very little drainage development, pockmarked with small, shallow, and often temporary bodies of water in slight depressions in the landscape. The shallow depressional topography and physical characteristics of the glacial material influence water source, hydrologic regime, and water and sediment chemistry. The physical and chemical composition of the parent material of the glacial deposits also play a role in characteristics of these wetlands (Fetter 1994, Van Voast and Novitzki 1968).

Glacial till is deposited directly by glacial ice without significant sorting by running water. Generally, till has a low hydraulic conductivity, especially if it is clay-rich (Fetter 1994). Permeability of till depends upon the clay content, mode of deposition and degree of weathering (Fetter 1994). Hydraulic conductivity of the unfractured till

matrix is 10^{-9} cm/s for in the prairies of Canada and North Dakota (Winter and Rosenberry 1995). Other researchers report hydraulic conductivity of till ranging from 10^{-5} to 10^{-9} cm/s (Fetter 1994). Fracturing affects hydraulic conductivity. The unfractured till matrix generally has low hydraulic conductivity, but the presence of fractures due to desiccation, particularly near the surface, gives a secondary permeability, which may increase the hydraulic conductivity of the overall matrix by orders of magnitude (Woo and Rowsell 1993).

Fetter (1994) states that glaciolacustrine sediments have hydraulic conductivity values similar to those of tills, ranging from 10^{-6} to 10^{-8} cm/s. Glacial outwash sediment is deposited by meltwater from the glacier, and therefore is well-sorted, giving it a higher hydraulic conductivity. Fetter (1994) gives a general range for outwash of 10^{-3} to 1 cm/s, but states that some silty outwash materials have hydraulic conductivities as low as 10^{-5} cm/s.

Low hydraulic conductivity slows the downward movement of water, causing ponding in wetlands for extended periods. According to Stewart and Kantrud (1971), permanence of surface water in prairie potholes is modified by permeability of bottom soils. Shjeflo (1968) reports that average outflow seepage ranged from $3x10^{-7}$ cm/s to $3x10^{-6}$ cm/s in 10 semi-permanent and seasonal potholes. Sloan (1970) observed changes in pothole water levels indicating that outflow seepage rates are much higher from ephemeral and temporary potholes. Rates of outflow influence hydrologic regime, as discussed below.

Due to low hydraulic conductivity, which prevents rapid equilibration of groundwater levels, transpiration by phreatophytic vegetation can cause pronounced

diurnal depressions in groundwater directly surrounding a pothole. Water levels in the zone of phreatophytic vegetation adjacent to potholes rise and fall in response to variations in climate and groundwater flow in much the same way as the pothole water surfaces do, but with much greater amplitude, resulting in groundwater levels that are often significantly above or below the pothole water surface (Sloan 1970).

Low hydraulic conductivity causes water to follow the surface topography of glacial deposits closely. Sloan (1970) notes that closely spaced potholes are often separated by a large vertical distance and a steep water-table gradient, which result from the low permeability conditions characteristic of the glacial till surrounding the potholes. The relation of the water table to the wetland position in the landscape influences groundwater flow direction. This relationship causes wetlands to vary in water source.

Water source is one of the most important factors controlling wetland hydrologic regimes. Hydrologic regime refers to the depth and duration of inundation during the growing season (Kantrud et al. 1989). Stewart and Kantrud (1971) state that water permanence is influenced by permeability of bottom soils, as explained above, and by groundwater. Groundwater can be an important contributor to a wetland's surface water. Wetlands typically fall into three categories according to water source: (i) "recharge wetlands" recharge groundwater with water derived primarily from overland flow and snow-catch, (ii) "throughflow wetlands" receive both water from and yield water to the groundwater system, and (iii) "discharge wetlands" obtain some water from overland flow but receive the majority as groundwater discharge (Arndt and Richardson 1989).

Stewart and Kantrud (1971) developed a wetland classification system for natural ponds and lakes (prairie potholes) in the glaciated prairie region. The hydrologic regime

of the vegetation zone in the central or deeper part of a wetland is used to distinguish several classes. Major classes of hydrologic regime are ephemeral ponds, temporary ponds, seasonal ponds and lakes, semi-permanent ponds and lakes, permanent ponds and lakes, alkali ponds and lakes, and fens.

In the prairie pothole region, recharge wetlands tend to have ephemeral or seasonal hydrologic regimes because the main water source is from precipitation, largely as spring runoff, and water is lost by percolation as well as evapotranspiration. Duration of ponding can be modified by the hydraulic conductivity of bottom soils. Flow-through wetlands tend to be semi-permanent because their water source is shallow groundwater discharge. Discharge wetlands tend to be semi-permanent or permanent because their water source, groundwater, is more constant than seasonal runoff.

Water chemistry is related to hydrologic regime, water source, and underlying substrate, which is derived from the geologic source material of glacial deposits. Water chemistry is largely influenced by the configuration of the water table surrounding the wetland (Sloan 1970) and subsurface geology (Van Voast and Novitzki 1968).

Salinity is the concentration of total dissolved solids in the soil or water column (Kantrud et al. 1989). Total salinity of water in a pothole is largely controlled by the rate of groundwater flow and the relationship of seepage inflow to outflow: generally, potholes with water relatively low in dissolved solids have net seepage outflow, and potholes with high concentration of dissolved solids have net seepage inflow (Eisenlohr and Sloan 1968). Total dissolved solids are low in rainfall, but high in discharging groundwater. Few dissolved solids are removed from potholes, other than by seepage outflow or infrequent pothole overflow. Evapotranspiration further concentrates

dissolved solids (Eisenlohr 1972). Electrical conductivity is often measured to estimate salinity (Cowardin et al. 1979, Stewart and Kantrud 1972).

The chemical composition of freshwater in recharge wetlands can vary due to subsurface geology. Richardson et al. (1994) state that several chemical processes other than mineralogical controls explain subtle variations in the dilute solutions characteristic of recharge wetlands. These controls include weathering and lithological differences, differences in ionic mobility, exchange relationships between the aquifer media and solute, and biological cycling.

Natural Controls on Plant Distribution

Water depth and duration largely determine distribution of plant species (Kantrud et al. 1989). In the prairie potholes, the gradient of depth and duration of water in each pothole creates visually conspicuous zonation, with each zone dominated by a single plant species (Kantrud et al. 1989). The Stewart and Kantrud (1972) classification uses the central vegetation zone of each wetland to identify hydrologic regime. Zones corresponding to less permanent wetlands may also occur as peripheral bands around more permanent wetlands. These zones and corresponding hydrologic regime are as follows: a wetland-low-prairie zone associated with ephemeral ponds; a wet-meadow zone associated with temporary ponds; a shallow marsh associated with seasonal ponds and lakes; a deep marsh associated with semipermanent ponds and lakes; and permanent open water associated with permanent ponds and lakes (Stewart and Kantrud 1972). As long-term hydrologic cycles occur, peripheral vegetation zones may shift in elevation or

the central vegetation zone may change altogether as the hydrologic regime of a wetland is altered. Consequently, classification of a wetland may change.

Plant species have differing tolerances for salinity. Researchers in the prairie pothole region have found that salinity has a profound effect on the plant community composition and the distribution of species (Kantrud et al. 1989). Stewart and Kantrud (1971) used salinity to define subclasses of vegetation types in prairie potholes. Within any hydrologic regime, the dominant and subdominant species may vary with salinity. As salinity increases, the number of species diminishes considerably (Kantrud et al. 1989). Walker and Coupland (1968) report most of the species in sloughs to be strongly affected by the hydrologic regime and somewhat less affected by salinity.

Long-term climatic changes can alter the wetland hydrologic regime and vegetation zonation. It may take a year or more for species composition within a zone to adjust to environmental change. These lags sometimes result in abnormal zonation patterns, particularly after a change in water level (Kantrud et al. 1989). Kantrud et al. (1989) caution that because hydrologic regime is a principal factor in controlling distribution and composition of vegetation, it follows that hydrologic fluctuation will induce changes in the composition and structure of wetland vegetation. Consequently, any attempt to study the composition, classification, or dynamics of the region's wetland vegetation must recognize the impact of long-term climatic fluctuation.

Human Influence on Vegetation

Direct and indirect disturbances by human activity are so widespread that they are often the most important factors controlling the distribution and composition of contemporary wetland vegetation (Kantrud et al. 1989). Cultivation, grazing, mowing, and burning have altered the composition of pothole vegetation (Kantrud et al. 1989, Millar 1973, Stewart and Kantrud 1972, Walker and Coupland 1968). Kantrud et al. (1989) and Stewart and Kantrud (1972) documented differences in species found in wetlands of the same hydrologic and salinity regime but surrounded by contrasting land uses of grazing, haying, and cultivation or idle land. Walker and Coupland (1968) rated the intensity of disturbance by mowing, grazing, and cultivation and were able to distinguish dominant species associated with varying intensities of these land uses. They concluded that cultivation is by far the most drastic type of disturbance, completely overriding the effects of natural gradients. The Stewart and Kantrud (1971) classification recognizes a completely separate vegetation phase for tilled wetlands.

Land use impacts vary with hydrology and climate. Relatively permanent wetlands are exploited for native hay and as pastures, and less permanent wetlands are used extensively for crop production during dry years (Kantrud et al. 1989). Wetland-low-prairie, wet-meadow, and shallow-marsh zones are frequently cultivated when they become dry, which creates early successional plant communities that differ markedly from those of undisturbed sites (Millar 1973). Following cultivation, such communities often retain early seral characteristics for a few years. Subsequently, the number of

species decreases progressively as small, rapidly growing annuals are excluded by competition; succession plays a significant role during extended periods without disturbance (Walker and Coupland 1970).

Although farmers often cultivate as far into depressions as possible, or even across them when they are dry, these sites are usually too wet to seed crops (Dix and Smeins 1967). Whether seeded to a crop or not, species may be introduced by tillage. Cultivated depressions typically become mudflats after disturbance, providing excellent seedbeds for weedy species, both native and introduced (Dix and Smeins 1967). Mudflat communities often develop on such sites after disturbance. During dry years, however, some shallow wetlands are planted to crops. Small grain or row crops are often present in the cropland tillage phase of prairie potholes (Stewart and Kantrud 1972).

Agriculture may result in indirect impacts to vegetation. Agricultural activities have affected many wetlands through runoff that contains large quantities of sediment, nutrients, and pesticides (Kantrud et al.1989). Writing in 1989, Kantrud et al. reported that indirect effects of runoff water quality on vegetation had not been studied in prairie potholes. However, impacts of nutrients on wetland vegetation have been investigated in other parts of the United States. For example, increased agricultural runoff, laden with phosphorus, is believed to have promoted the spread of *Typha* spp. in conservation areas the Everglades in Florida (Gunderson and Loftis 1993, Koch and Reddy 1992).

There is conflicting information on the relative importance of water and sediment nutrient levels to wetland vegetation change. Numerous experimental studies have shown that submerged plants take up nutrients both from the water through the leaves and from the substrate via roots (Bristow 1975, Carignan 1982). In contrast, Anderson and

Kalff (1988) state that it is now generally agreed that rooted aquatic plants derive almost all their nutrients from sediments. Because surface water and sediment chemistry are related through sedimentation and solute exchange, this distinction may be more important to water quality monitoring than vegetation change.

Grazing has effects similar to cultivation. Dominance types in wetlands that are grazed are often very different from nongrazed wetlands (Kantrud et al. 1989). Marshes often show greater vegetation response to grazing than upland communities (Bassett 1980). Species composition changes in grazed areas because soil is physically disturbed, plants are stressed by defoliation, and light competition is reduced (Archer and Smeins 1991). Changes in vegetation composition are likely related to the exposure of soil that can result from grazing (Millar 1973). Effects of defoliation on species dominance may be related to differences in the palatability of emergent species, which results in preferential grazing, and to opening of the otherwise dense canopy, which allows establishment or increase of species that are not abundant under closed canopies (Kantrud 1986). Research in riparian wetlands shows a wide range of plant community responses to grazing (Kauffman and Krueger 1984). Hansen et al. (1995) interpret several Montana riparian community types as resulting from excessive grazing.

Effects of grazing may not all be negative; prairie wetlands probably were grazed frequently by native herbivores before European settlement, and had grazing-tolerant species. Moderate grazing may promote greater species diversity, complex spatial patterns, and sharp boundaries between vegetation zones in prairie wetlands (Bakker and Ruyter 1981). However, overgrazing can reduce primary production, increase water turbidity and even eliminate vegetation (Kantrud et al. 1989).

Grazing may affect wetland water and sediment chemistry, though probably less severely than cultivation. Runoff can be increased by trampling, soil compaction, and reduced vegetative cover, which may accelerate sediment and nutrient delivery to wetlands (Spaeth et al. 1996). Churning of water and sediment by trampling and defecation and urination may also affect water quality (Nader et al. 1998).

Assessment of Biological Integrity

The U.S. Environmental Protection Agency (EPA) has adopted the policy that measures of biological condition are necessary to maintain biological integrity as mandated by the Clean Water Act (Danielson 1998). Biological integrity is "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr 1987). Continuing degradation of aquatic systems suggests that chemical measures of water quality are not sufficient to reflect all impacts that can occur to aquatic systems (Karr and Chu 1997). Simple biological measurements such as toxicity bioassays and diversity indices do not provide integrated assessments of biological condition and, therefore, have not adequately protected aquatic resources (Karr and Chu 1997).

"Multimetric" indices attempt to provide more integrative ratings of biological integrity by including measurements at several ecological levels. A "metric" is a measurable biological attribute that reflects specific and predictable responses of organisms to changes in landscape condition, is sensitive to a range of factors that stress

biological systems, and is relatively easy to measure and interpret (Karr and Chu 1997). A multimetric index combines metrics of different attributes of an assemblage (e.g. aquatic invertebrates, fish, or vascular plants) into an overall score of integrity, or condition, of an aquatic ecosystem.

Development of a multimetric index for wetlands starts with classification of wetland types and regional environments (Danielson 1998). Systems for wetland classification include the Army Corps of Engineers' hydrogeomorphic classification (Brinson 1993) and the Fish and Wildlife Service's Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979). Stewart and Kantrud's classification of natural ponds and lakes in the glaciated prairie region (1971) is a regional classification of depressional wetlands. Classifications of regional environments include the EPA's Ecoregions (Omernik 1987), and the U.S. Forest Service's Ecological Units (Nesser et al. 1997).

Within each wetland class, biological attributes of one or more assemblages are measured over the range of human influence, from "reference," or relatively unimpacted, to severely impacted sites. The biological measurements that show a clear response to this gradient of impact are identified as potential metrics. Ideally, several metrics reflecting different ecological levels of the assemblage will be identified. Each metric is scored individually, and all metric scores are combined into a final index score. The index is then tested and validated on new wetlands.

Adamus and Kentula (1996) recommended analysis of a broad array of community level and individual species measurements during initial phases of bioindicator development; subsequently, the most useful measurements should be refined

and combined. Barbour et al. (1995) also advocated combining several biological measurements to arrive at an overall score for environmental health. A multimetric index should be composed of measurements from the individual, population, community, and ecosystem levels into a multimetric index (Karr and Chu, 1997). Danielson (1998) suggests that within a multimetric index, some metrics should be more sensitive to chemical alteration, others to physical alteration, and still others to biological alterations in order to discern many types of human influence.

Multimetric indices have been developed primarily for stream systems and have been based on fish or macroinvertebrates. Forty-two states now use multimetric assessments of biological condition of streams (Karr and Chu 1997), but efforts to develop multimetric indices for wetlands are relatively recent. Several states, including Florida, Maine, Minnesota, Montana, North Dakota, and Ohio, are currently developing biological assessment methods for monitoring wetlands (Danielson 1998). In Montana, development of wetland multimetric indices utilizing macroinvertebrates and diatoms has been initiated (R. Apfelbeck, 1997, personal communication).

Indices based on vegetation may be useful to assess wetland biological condition, either alone or in conjunction with another assemblage. Plants may be easier for non-specialist field personnel to quantify, may integrate water quality over longer time scales, and may respond somewhat differently to water quality and disturbance, thus providing additional information about water quality and biological integrity. Chemicals from high-intensity, occasional events or low-level but chronic impacts may be transient in the water column, but remain and accumulate in wetland substrates. Because plants take up chemicals primarily from sediment, they may show the effects of these types of impacts

more effectively than aquatic organisms. Perhaps most importantly, vegetation can be sampled when no water is present, which is not possible with most other biological assemblages used in wetland bioassessment.

Adamus and Kentula (1996) suggested that vascular plants may be the best biological indicators of ongoing or recent changes in water regime or salinity, good indicators of excessive nutrients and anoxia, and fair to poor for monitoring herbicides, insecticides, and heavy metals. Small et al. (1996) sampled many riparian wetlands in the Chesapeake Bay watershed and found that differences in stream water quality could be identified by analyzing vascular plant communities. Small et al. (1996) noted that vegetation is ideal for an initial biosurvey because plants are easier to identify and quantify than other organisms used in biomonitoring of stream impairment. The Minnesota Pollution Control Agency is developing a multimetric index for biological assessment for depressional wetlands using emergent and submerged vascular plants, mosses, and liverworts. Initial development has shown effective identification of impaired and unimpaired sites (M. Gernes, 1997, personal communication). Because the use of vascular plants for assessment of biological condition of wetlands is not yet well established, particularly for glaciated depressional wetlands (Adamus and Kentula 1996), there are no clear conventions in the selection and use of vegetation groups for quantitative monitoring.

METHODS

Study Areas

Study Design

I studied effects of land use on plant community composition and species distribution relative to elevation in 24 depressional wetlands in western Montana. The study design included two major land uses, three levels of impact within each land use, and four replicate sites for each level of impact. Twelve sites located in the Mission Valley, at the Ninepipe Wildlife Management Area, were sampled to investigate the effects of cultivation and 12 sites located in the Ovando Valley were sampled to investigate the effects of grazing. The 12 wetlands in each of these valleys will each be referred to as the " Ninepipe area" or "Ovando area." Each area contained three land use groups with four replicates: a reference group representing least human impact, a group currently grazed or cultivated, and a group retired from grazing or cultivation for several years. These three land use groups will be referred to as "reference," "retired," and "current" or "currently impacted" sites. Because land use impacts were not interspersed or randomly assigned among wetlands, there is potential to confound land use effects and inherent site differences; thus caution is required when extrapolating results.

Site Selection

The study was limited to depressional wetlands, as defined by a hydrogeomorphic classification system (Brinson 1993). Study site selection took place in May 1997, when over 50 candidate sites were surveyed over a 240 km range in western Montana to determine the general study location. Two study areas were selected based upon public access and the range of land use impacts present.

After screening to select general study areas, an additional 50 sites were sampled within those areas during the final site selection process in June 1997. Study sites were selected using physical and chemical criteria to limit natural variability among sites. Two primary selection criteria related to hydrology and salinity. All sites had semi-permanent or extended seasonal inundation, based on information from land managers, past research data, presence on topographic maps, and presence of vegetation known to be tolerant of these hydrologic regimes. Surface water at all sites had conductivity under 800 µmhos/cm during site selection in June.

Secondary site selection criteria included absence of surface water connections with other wetlands, moderate slopes around wetlands, similar depths among reference and impacted sites, size between 0.1 and 1.2 hectares, similar topographic settings, and isolation from other human influences. Overall, the emphasis in applying secondary criteria was to keep hydrogeomorphic characteristics similar among sites.

Description of Study Sites

The study of cultivation impacts took place in the Mission Valley of Montana, approximately 30 km south of Flathead Lake (Figure 1). Environmental characteristics and land use are summarized in Table 1. A large portion of the Mission Valley is cultivated. The study area was on the Ninepipe Wildlife Management Area, which is managed for waterfowl habitat. Parcels of land in the Ninepipe area that were managed at differing intensities of land use were used in the study design. Sites were all within 3 km of one another (Figure 2).

Some of the Nine Pipe Wildlife Management Area is cultivated every other year with a cereal grain crop, a portion of which is left unharvested for waterfowl food and cover. Wetlands sampled in these areas will be referred to as the "current" group to reflect continuing cultivation. Cultivation historically occurred as close to water's edge as soil conditions would allow farm machinery to operate effectively. Impacts to vegetation associated with cultivation include physical disturbance and the introduction of species during drawdown periods. The local topography, featuring low slopes of 2-8%, allows some runoff to occur. Because crop fertilization was infrequent and application of herbicides was only occasional (J. Grant, 1997, personal communication), chemicals carried by runoff probably did not affect these wetlands greatly.

A nearby area of land on the Nine Pipe Wildlife Management Area was once cultivated in a similar manner, but was retired from cultivation and seeded with tame grasses and legumes 10 to 12 years ago (J. Grant, 1997, personal communication). These sites will be referred to as the "retired" group. If past and current agricultural practices

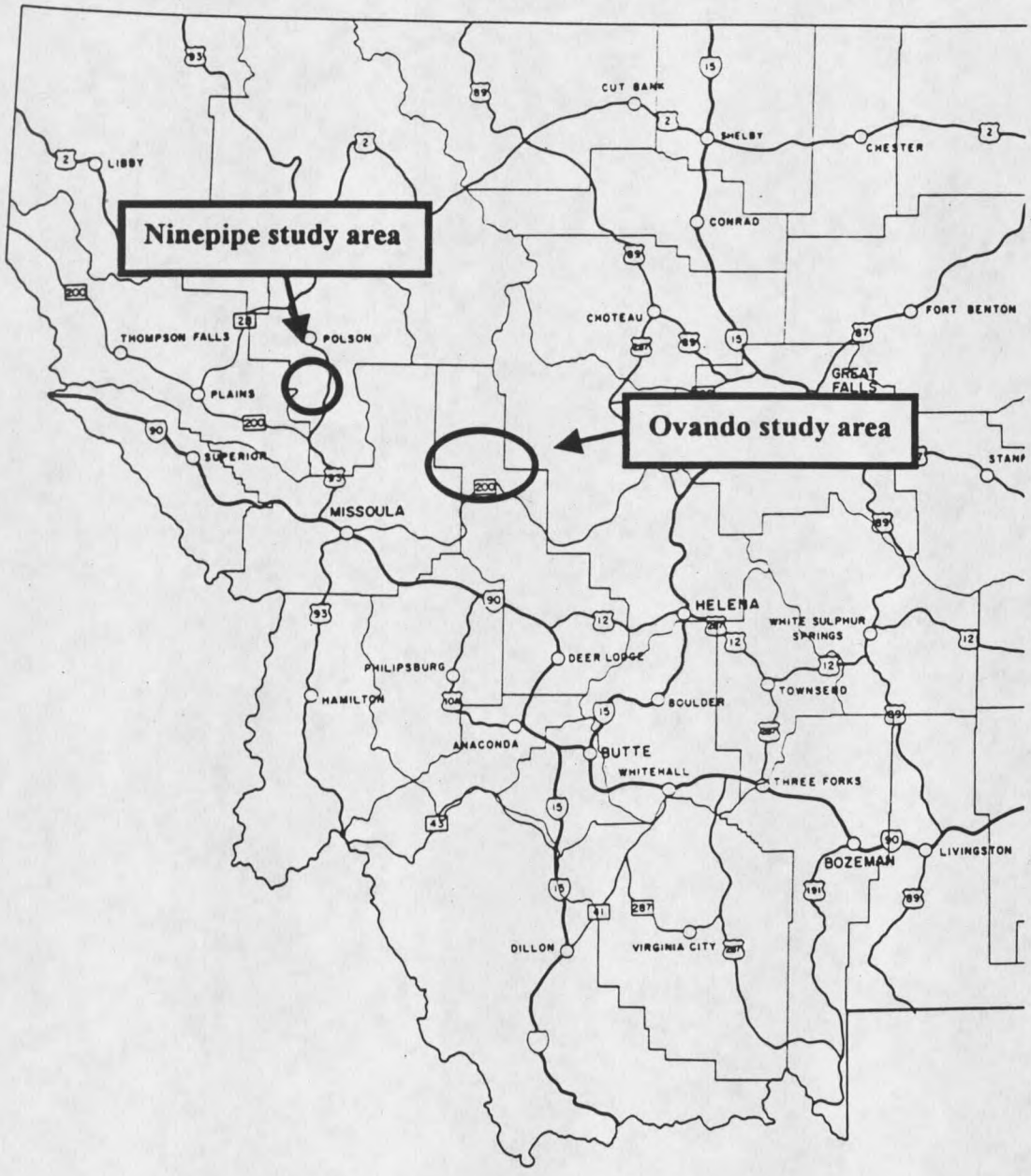

Figure 1. Location of the Ninepipe and Ovando study areas in western Montana.

Table 1. Environmental characteristics and land use information for the Ninepipe study area. All sites were within a 3-km range.

Characteristic	Reference sites	Retired sites	Current sites
Number of sites	4	4	4
Land use	idle	retired from cultivation	currently cultivated
Legal description[1]	NW 1/4 S36, T20N, R20W	NW 1/4 S26, T20N, R20W	NE 1/4 S27, T20N, R20W
Aspect[1]	SW	SW	SW
Elevation[1] [m (ft)]	930 - 933 (3,050 - 3,060)	930 - 933 (3,050 - 3,060)	930 - 933 (3,050 - 3,060)
Mean annual precip.[2] [cm (in)]	41 - 46 (16 - 18)	41 - 46 (16 - 18)	41 - 46 (16 - 18)
Mean annual temp.[2] [°C (°F)]	8 (46)	8 (46)	8 (46)
Soil landform[3]	lake plains / moraines	lake plains / moraines	lake plains / moraines
Soil parent material[3]	glaciolacustrine deposits/till	glaciolacustrine deposits	glaciolacustrine deposits
Land use history	grazed up to 50 years ago; never cultivated [4]	retired from cultivation 10-12 years ago and pasture seeded w/ tame grasses and legumes[4]	cultivated field; evidence of recent tillage through wetland edges
Current influences	undisturbed pasture, low-density roads and houses nearby	infrequent herbicide application [4]	cultivation, infrequent fertilizer/ herbicide application [4]

[1] U.S.G.S. Charlo and Fort Connah quadrangles, 7.5 minute series.

[2] MAPS Atlas-A land and climate information system (Caprio et al. 1994).

[3] Soil Survey of Lake County Area, Montana (NRCS 1997).

[4] John Grant, Montana Department of Fish, Wildlife, and Parks, Wildlife Area Manager, 1997, personal communication.

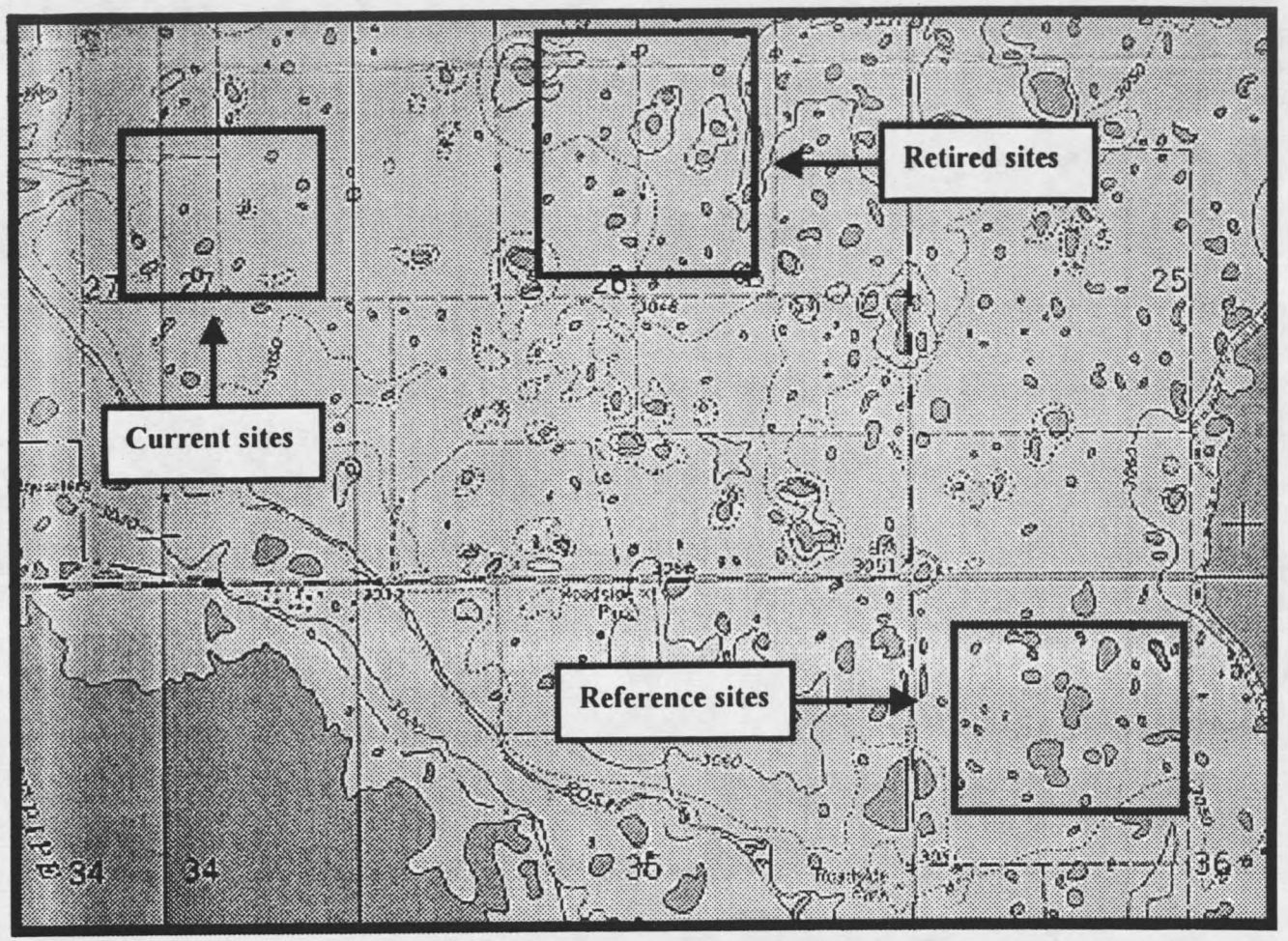

Figure 2. Location of study sites in the Ninepipe Wildlife Management Area. Adapted from U.S.G.S. Charlo and Fort Connah quadrangles, 7.5 minute series.

are assumed to be similar, the retired sites can be treated as intermediate with respect to disturbance and recovery between currently cultivated and reference groups. However, because retired sites and adjacent fields were seeded, they do not represent completely passive successional development.

Some land on the Nine Pipe Wildlife Management Area has never been cultivated and contains the least impacted sites available for this study. These sites will be referred to as the "reference" group, to which the retired and cultivated sites are compared. This land was grazed from settlement until approximately 50 years ago. These uncultivated pastures are small (a quarter section or less) and adjacent to a highway, and therefore are likely to have some low-level human impacts.

Rock piles created historically by farmers aided site selection. Farmers removed rocks from cultivated areas and piled them into wetlands (J. Grant, 1997, personal communication). These 0.3 to 0.6 meter high rock piles are now under water. Presence of rock piles in wetlands indicates that they were wet regularly enough that farmers thought they were not losing arable ground and that water levels were sometimes low enough to permit farmers to drive equipment well into the wetlands. Presence of rocks implies fluctuations between periods of extended seasonal or semi-permanent ponding and periods dry enough to allow cultivation well inside current wetland boundaries. Rock piles were present in all current and retired wetlands sampled.

Grazing impacts were studied in the Ovando area, east-northeast of Missoula, Montana (Figure 1). Environmental characteristics and land uses are summarized in Table 2. Because sites in the Ovando area were further away from one another than those at Ninepipe, background variation among sites was likely to be greater (Figure 3). In

Table 2. Environmental characteristics and land use information for the Ovando study area. All sites were within a 30-km range.

Characteristic	Reference	Retired	Current
Number of sites	4	4	4
Land use	idle, game range	retired from grazing	currently grazed
Legal description[1]	E 1/2 S21, N 3/4 S27, T15N, R14W	E 1/2 S21, T14N, R11W	W1/2 S15, T15N, R13W
Aspect[1]	S	S	S
Elevation[1] [m (ft)]	1,268 - 1,280 (4,160 - 4,200)	1,305 - 1,329 (4,280 - 4,360)	1,250 - 1,262 (4,100 - 4,140)
Mean annual precip.[2] [cm (in)]	36 - 41 (14 - 16)	46 - 51 (18 - 20)	41 - 46 (16 - 18)
Mean annual temp.[2] [°C (°F)]	6 (42)	4 (39)	5 (41)
Soil landform[3]	moraines	alluvial fans / stream terraces	mountains / moraines
Soil parent material[3]	alpine till	alluvium / colluvium / outwash	till
Land use history	grazed up to 50 years ago[4]	pasture retired 15 years ago from heavy grazing without rest[5] tussocks, pockmarked soil visible	pasture grazed through 1996 using moderate stocking rates and seasonal pasture rotation[6]
Current influences	elk refuge	wildlife use	livestock grazing, wildlife use

[1] U.S.G.S. Woodworth, Ovando, and Marcum Mountain quadrangles, 7.5 minute series.

[2] MAPS Atlas-A land and climate information system (Caprio et al. 1994).

[3] Soil Surveys of Missoula and Powell County Areas, Montana (NRCS 1995, NRCS undated).

[4] Mike Thompson, Montana Department of Fish, Wildlife, and Parks, Wildlife Biologist, 1997, personal communication.

[5] Greg Neudecker, U.S. Fish and Wildlife Service, Wildlife Biologist, 1997, personal communication.

[6] Joe Brewster, Bandy Ranch manager, 1997, personal communication.

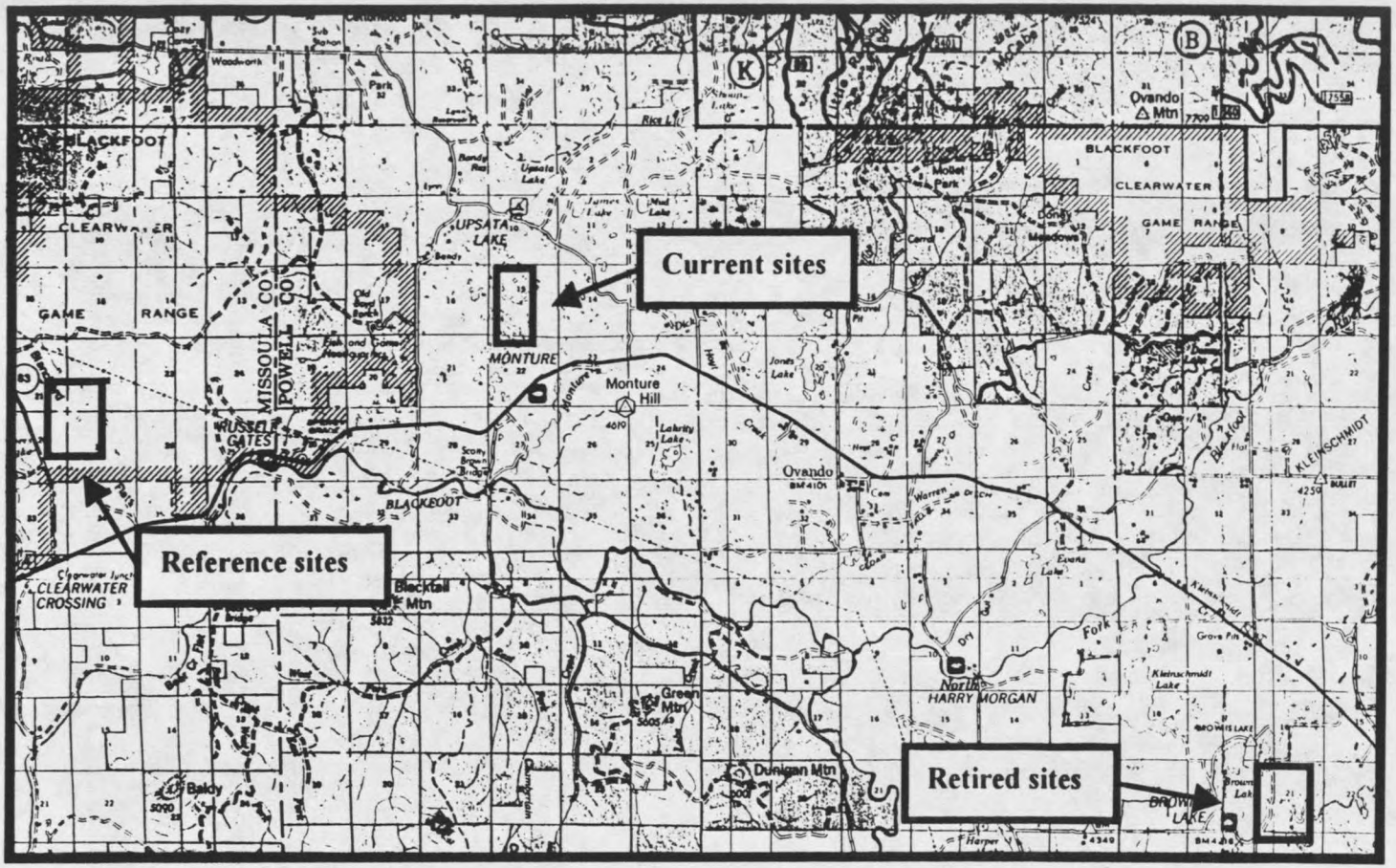

Figure 3. Location of study sites in the Ovando Valley. Reference sites are located in the Blackfoot Clearwater Game Range, retired sites are located in the Blackfoot Waterfowl Production Area, and currently grazed sites are found on the Bandy Ranch. Adapted from Lolo National Forest map.

addition to eating wetland plants, cattle often congregate around water, trample vegetation and soil, and impact water quality (Nader et al. 1998, Kauffman and Krueger 1984). Thus effects on vegetation may include both physical impacts and nutrient inputs.

Currently grazed sites were on a half-section pasture of the Bandy Ranch, a research area managed by University of Montana. Pastures were grazed annually using a seasonal rest-rotation system through the summer of 1996, the year prior to data collection (J. Brewster, 1997, personal communication). These are referred to as the "current" sites.

Retired sites were on a USFWS Waterfowl Production Area, which had not been grazed by cattle for 15 years. Although specific records were not available, USFWS land managers believed use was without rest and heavier than the land could sustain (G. Neudecker, 1997, personal communication). Similarity of historical grazing impacts on retired and currently grazed sites could not be evaluated. If impacts were similar, rested sites can be treated as intermediate between currently grazed and reference sites. If not, however, differences due to succession will be confounded with differences in original level of impact.

Reference sites were located on the Blackfoot-Clearwater Game Range, owned by Montana Department of Fish, Wildlife, and Parks. This refuge had not been grazed by livestock for 50 years (M. Thompson, 1997, personal communication). Comparison of grazing impacts between reference and retired and currently grazed sites was complicated by grazing by wild animals, particularly elk, on the Game Range.

Sampling and Analysis

Hydrologic Measurements

A staff gage was installed at the center of each wetland. Distances from the top of the gage to the sediment, and from the top of the gage to water surface, were recorded in June, July, August, and September. As a supplement to staff gage measurements, stakes were placed at water's edge in June, July, and August to track water level changes.

Shallow open wells (100 cm) were installed in August in six to eight of the unflooded quadrats in each wetland. Wells were placed from within 0.5 meter of water's edge to about 3 meters horizontally from water's edge. Water levels were measured in September. Depths to the water table were graphed against ground surface elevation to evaluate use of surface elevation as an index of each quadrat's position on a hydrologic gradient.

Nested shallow (40 cm) and deep (110 cm) piezometers were installed at each wetland in June. July, August, and September water levels were compared to estimate relative pressure heads between the deep and shallow piezometers and to infer vertical direction of flow.

Water Chemistry and Physical Measurements

Water was collected in late June, early July, and late August. Water samples were collected at the center of each wetland using a bottle attached to a pole to assure that

samples were not affected by disturbance caused by walking. Samples were collected 20-30 cm below the water surface.

Samples were unfiltered in accordance with past Montana Department of Environmental Quality (DEQ) research protocol (R. Apfelbeck, 1997, personal communication). Samples for analysis of major ions were preserved with nitric acid in the field. Total concentrations of calcium, magnesium, potassium, sodium, iron, manganese, sulfur, and phosphorus were analyzed by inductively coupled plasma (ICP) emission spectrometry. Water collected for analysis of sulfate and phosphate levels was not preserved chemically but was frozen upon return from the field every night. Sulfate and phosphate were analyzed by ion chromatography. Nitrate and nitrite were preserved with sulfuric acid in the field and analyzed colormetrically. Preservation methods followed Standard Methods for the Examination of Water and Wastewater (American Public Health Association 1989). Water samples were analyzed by the Soil Analytical Laboratory at Montana State University, Bozeman.

Other water quality data were collected in the field using a Horiba U-10 Water Quality Checker. These field data included temperature, pH, and electrical conductivity. Salinity is commonly represented by electrical conductivity measurements (Cowardin et al. 1979). During the first sampling period, bromcresol green-methyl red alkalinity was determined nightly using a 10 ml aliquot and titrating with 0.01 N HCl to a 4.6 pH endpoint. In the second and third sampling period I used a 20 ml aliquot and titrated with 0.02 N HCl to a 4.6 pH endpoint. Physical and chemical characteristics of water samples are reported in Appendix A, Tables 15, 16, and 17.

Sediment Chemistry and Physical Measurements

Sediment samples for chemical analysis were collected once in late June. Each sample was collected by wading into the wetland past the emergent vegetation zone and as close to the middle as water depth would allow efficient sampling. Sediment was taken from the upper 20 cm using a shovel, stored in plastic bags and frozen until delivered to the Soil Analytical Laboratory at Montana State University, Bozeman. Samples were analyzed for concentrations of ammonium, nitrate, total Kjeldahl nitrogen (TKN), and Olsen phosphorus. Calcium, sodium, magnesium, and potassium concentrations were determined to estimate Sodium Adsorption Ratio (SAR).

Sediment samples for physical analysis and additional chemical analyses were taken in early July. Samples were taken along a transect that extended from the deepest part of the wetland to the outer edge of the wetland. The transect was divided into three equal sections and three evenly spaced samples were taken in each of the three sections. Cores were taken from the upper 15 cm of the substrate. Samples from each section were composited and analyzed for particle size distribution, pH, and electrical conductivity. The hydrometer method was used for particle size analysis. Electrical conductivity and pH were measured in saturated paste extracts. Organic matter was estimated by loss on ignition. During data analysis I concluded that it would be more effective to analyze data for the entire transect rather than three arbitrary sections, so values for the three sections were averaged. Physical and chemical characteristics of sediment are reported in Appendix A, Table 18.

Vegetation Sampling

In July a map of each wetland was drawn approximately to scale. In August, a random systematic sampling design was used to quantify vegetation (Thompson 1992). A grid was overlaid on the map of each wetland, and a subgrid was overlaid on one section of the grid. A sampling location was randomly selected within this smaller grid and the equivalent subgrid sample was systematically repeated throughout the rest of the major grid. Because the transect lines forming the grid were spaced approximately the same for all wetlands sampled, sampling effort was proportional to each wetland's size. The vegetation was patchy, and this method efficiently provided a representative and unbiased sample. Sampling by zones was rejected because zonation was not found to be truly concentric or consistent within or among wetlands.

A 0.5 x 1.0-meter quadrat frame was placed at each sampling location. Species were identified according to Dorn (1984) and Hitchcock and Cronquist (1973). I estimated percent cover visually for each species as well as for litter, rock, bare earth, and water. Cover estimates were maintained as percentages throughout data analysis. Voucher specimens were deposited at the Montana State University, Bozeman, herbarium.

Vegetation data were organized for analysis by first dividing the data into two strata, canopy species and ground cover. Submergent species were included with ground cover. Species that were submerged due to water levels in 1997 but that ordinarily would be found in moist but not flooded soil, such as *Mentha arvense* or *Cirsium arvense,* were treated as canopy species. This study primarily examined wetland vegetation at the

community level by comparing relative abundance of species and species groups among land uses. Raw relative abundance data for each species are reported in Appendix B, Table 19.

Groups of vascular plants were defined prior to the study, including life history groups (annual/perennial), lifeform groups (grasses, forbs, grasslike plants, submerged species), native and introduced species, weedy species, and dominant species. Some groups were defined after initial data analysis was completed: native perennials, native grasslike plants, and weedy annual and perennial species. These generally were refinements of groups defined before analyzing data. Individual species were selected for statistical analysis based on graphical data exploration. Several species groups and species were selected for investigation based on metrics under development in other states, including species with persistent litter, non-vascular ground cover (in this study, only moss), the *Carex* genus, and *Utricularia vulgaris*. Relative abundance of dominant species was calculated in three ways: relative abundance of the single most dominant species in each wetland, the combined relative abundance of the first and second most dominant species, and the combined relative abundance of the first, second, and third most dominant species. Group designations for each species are summarized in Appendix B, Table 20. Time of and reasons for inclusion of each species and species group and expected direction of response to disturbance are summarized in Appendix B, Table 21.

Vegetation data were expressed in terms of relative abundance, frequency, and species richness for each wetland. These variables are all used commonly in vegetation analysis (BLM 1996). I evaluated these alternative measures because there is limited

information on using vegetation for multimetric indices to guide analyses. I expected that relative abundance would be most informative, based on other researcher's experience with macroinvertebrate indices. However, frequency was examined concurrently because it is a less time consuming observation than cover estimation and thus would be efficient to use for management. When data were explored graphically, the relative abundance data showed land use effects more clearly than frequency or richness. Therefore, remaining statistical analyses examined relative abundance only.

Topographic Measurements

Elevations of important points at each wetland site were surveyed in August: open water surface, stakes marking the water's edge in June, July, and August, staff gages, unflooded quadrats, piezometers, and wells. A benchmark was installed and surveyed for future hydrologic research on these sites.

Water surface elevation in September was designated as baseline elevation (0 cm) for each wetland and all other elevations were expressed relative to this elevation. In this manner elevation of vegetation quadrats and well measurements were standardized relative to water surface elevation for all wetlands. Because vegetation was sampled in August and well measurements were made in September, quadrat elevations were corrected for the drop in water level between August and September.

Distribution of species in relation to elevation was compared between land uses. Elevations of all quadrats in which a particular species was found were compiled. Comparisons were made for all species that had two or more observations in both the reference subset and either the retired or current subset within the range of elevations

shared between subsets. Elevation distributions of retired and current subsets were compared separately to elevation distributions at reference sites.

Statistical Analysis

Differences among land use groups were tested using analysis of variance (ANOVA) or median tests. All statistical analyses were completed in SAS (SAS Institute, Inc., Cary, NC). Ninepipe and Ovando data sets were analyzed separately. Untransformed data were analyzed by one-way ANOVA unless data failed tests for normality and equal variance. If data failed these tests, they were log-transformed and retested. If transformed data failed tests for normality and equal variance, a test comparing medians of land use groups was used.

After ANOVA, retired and currently impacted sites were compared to reference sites using Dunnett's test, which compares treatments to a single control. There is no equivalent test for pairwise comparisons following a median test. Data analyzed with a median test generally included one or more land use groups with many zero values.

Differences between land use group means were considered significant at $p<0.10$. This liberal p value was used because my main goal was to detect changes. From a land management perspective, awareness of possible changes in wetlands and the ability to act on indications of land use impacts is more important than being certain that change is occurring (Mapstone 1995).

Overall trends in changes in vertical distributions of rooted, vascular species were also compared among subsets using a sign (+/-) test. Only species that were present in reference sites and one or both disturbed land use groups were evaluated. The mean

elevation was calculated for each species excluding quadrats at elevations not present in both land use groups. If the mean of the retired or currently impacted sites was higher than that of the reference sites, a "+" sign was assigned; if lower, a "-" was assigned. Where means differed between land use groups by one cm or less, the means were considered equal and not used in the statistical comparison. The proportion of species with lower mean elevations (- score) in the retired or current sites than reference sites was tested at significance levels of $p < 0.10$.

RESULTS

Hydrology

Surface water levels dropped an average of 35 cm during the growing season but all sites remained flooded (Table 3). Piezometers indicated that 23 sites were recharging groundwater by September (Table 4). Three wetlands in the Ninepipe area and four wetlands in the Ovando area received groundwater discharge initially, but as water levels fell over the summer, sites were no longer supplied by groundwater and instead acted to recharge groundwater. I was unable to discern flow direction at one wetland in the Ovando reference area because of data collection errors in July and dry piezometers in August and September. This site probably was also a seasonal discharge or a recharge site because water levels dropped at rates similar to those in other Ovando reference recharge wetlands.

There was a clear difference in the pattern of groundwater depth relative to ground elevation at the Ninepipe and Ovando areas (Figure 4). Water levels in the Ninepipe area indicated that beneath exposed areas of wetlands, groundwater dropped away from the wetland water surface. Depth to water increased at nearly twice the rate of increase in ground surface elevation around the wetland. In contrast, increasing water depth in the Ovando wells corresponded almost directly to increasing ground surface elevation, indicating that groundwater was nearly level with water surface in the wetlands.

Table 3. Monthly water depths in depressional wetlands in the Ninepipe and Ovando areas. Reference, retired, and current refer to land use categories that are explained in the text. Water depths were determined by measurement of a staff gage centrally located in wetlands and surveying stakes placed at water's edge each month. Measurements are in cm. The absence of sites 2 and 6 reflects their elimination during final site selection.

	month				net
site	June	July	August	September	decrease
			Ninepipe		
			Reference		
1	97	93	82	77	19
3	105	102	87	86	20
4	80	72	54	33	47
5	73	68	45	36	37
			Retired		
7	96	89	69	61	35
8	124	108	90	84	40
9	73	67	46	33	39
10	84	78	60	50	34
			Current		
11	72	71	53	46	26
12	65	63	40	34	32
13	81	75	52	45	36
14	50	47	26	19	32
			Ovando		
			Reference		
15	213	210	195	186	27
16	86	84	77	59	27
17	86	76	45	33	54
18	114	94	49	29	85
			Retired		
19	114	112	101	89	24
20	47	58	39	34	13
21	59	47	42	37	21
22	104	99	78	66	38
			Current		
23	114	108	92	83	31
24	187	176	152	130	56
25	216	211	194	185	31
26	265	261	247	240	25

Table 4. Direction of groundwater flow in depressional wetlands in the Ninepipe and Ovando areas. Reference, retired, and current refer to land use categories that are explained in the text. Direction of flow was infered from piezometers open at 40 cm and 110 cm below ground surface. ND = no data. Asterisks, * and **, signify that the shallow or deep piezometer, respectively, was dry, preventing calculation of hydrologic gradient. The absence of sites 2 and 6 reflects their elimination during final site selection.

	month		
site	July	August	September
		Ninepipe	
		Reference	
1	ND	discharge	recharge
3	recharge	recharge	*
4	recharge	recharge	*
5	discharge	recharge	recharge
		Retired	
7	recharge	recharge	recharge
8	discharge	recharge	recharge
9	recharge	recharge	recharge
10	recharge	recharge	recharge
		Current	
11	recharge	recharge	recharge
12	recharge	recharge	recharge
13	recharge	ND	recharge
14	recharge	ND	*
		Ovando	
		Reference	
15	discharge	recharge	recharge
16	*	recharge	recharge
17	ND	*	**
18	recharge	recharge	recharge
		Retired	
19	discharge	recharge	recharge
20	discharge	recharge	recharge
21	discharge	recharge	recharge
22	recharge	recharge	recharge
		Current	
23	*	recharge	recharge
24	*/**	recharge	recharge
25	*/**	recharge	recharge
26	*/**	recharge	recharge

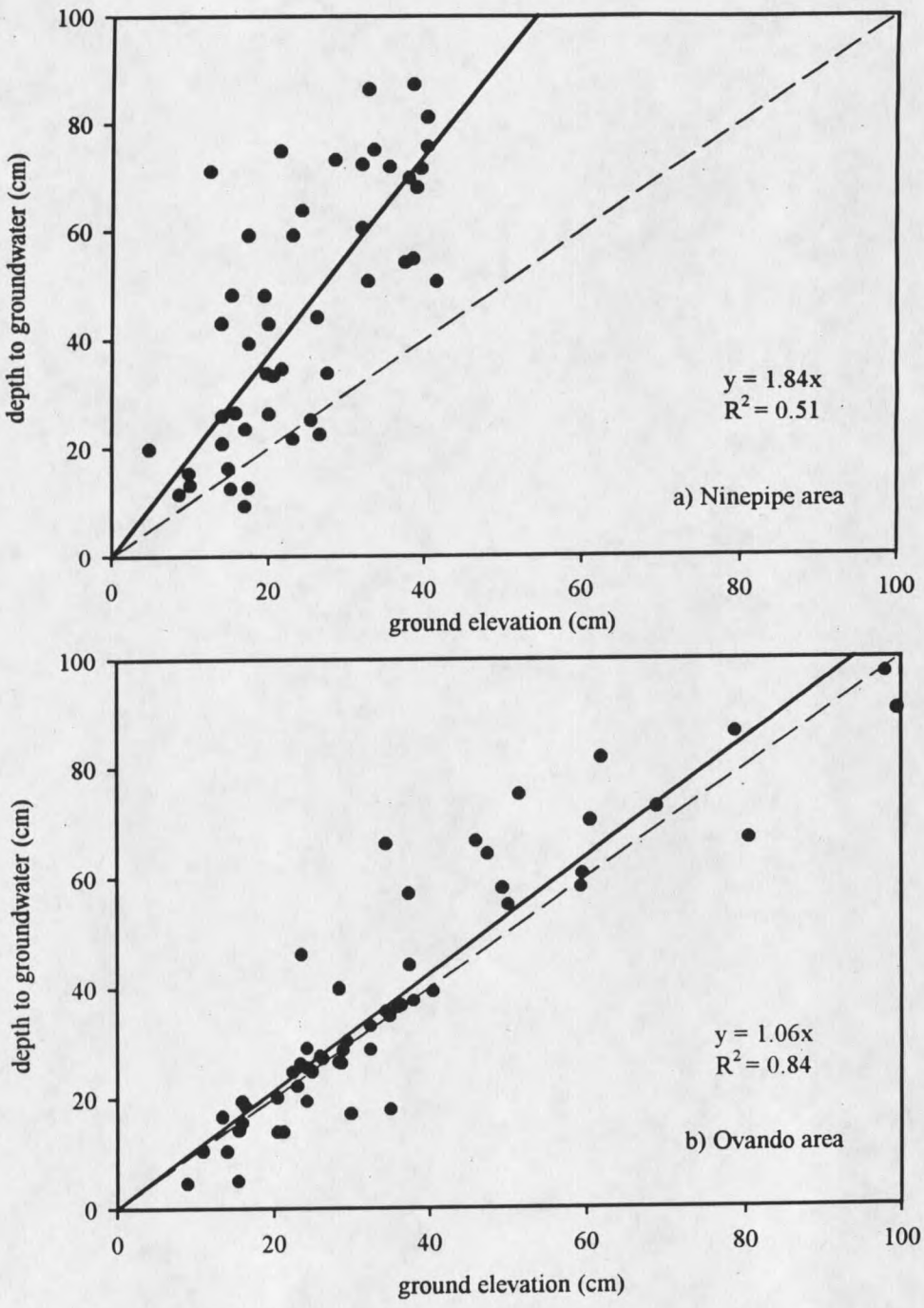

Figure 4. Depth to groundwater relative to ground surface elevation in depressional wetlands in the (a) Ninepipe and (b) Ovando areas. Well water depths and wetland water surface levels were measured in September and converted to relative elevations based on surveying wells, staff gages, and ground surface elevation. Ground surface elevations are reported relative to water surface elevation (0) in each wetland. Dashed lines represent groundwater depth relative to surface elevation if expected groundwater was level with the surface water in each wetland; that is, if depth to groundwater equaled surface elevation. Solid lines represent best-fit linear regressions of depth and surface elevation.

Water and Sediment Characteristics

Field measurements related to background environmental characteristics of water are reported for the Nine Pipe area (Table 5) and the Ovando area (Table 6). In the Ninepipe area there were no significant differences among land uses in any sampling period. In the Ovando area, the only significant difference among land uses was for water temperature in June. Significant differences in water temperature were not seen in July or August. Electrical conductivity (EC) did not differ significantly among subsets in the Ninepipe or Ovando areas. When selected, all sites had EC below 800 µS/cm (µmhos/cm), the upper limit for freshwater (Cowardin et al. 1979). Some sites rose above 800 µS/cm by August, but the highest value was only 879 µS/cm, less than a 10% deviation from the freshwater criteria.

Hydrogeochemistry was similar within the Ninepipe and Ovando areas but concentrations of dominant cations and anions differed between the two areas (Figure 5). The Ninepipe sites were dominated by bicarbonate and sodium. In the Ovando area, bicarbonate was the dominant anion and magnesium and calcium were equally dominant cations.

Nutrient concentrations in water generally did not differ significantly among land uses for either the Ninepipe areas (Table 7) or Ovando sites (Table 8). In the Ninepipe area, nitrate differed significantly between reference and retired sites in August. This difference was not found in June or July. In the Ovando area, total phosphorus varied

Table 5. Physical and chemical characteristics of water in depressional wetlands in the Ninepipe area. Reference, retired, and current refer to land use categories that are explained in the text. Data were collected in late June (period 1), early July (period 2) and late August (period 3). Electrical conductivity (EC), pH, and temperature were measured on site using a Horiba U-10 Water Quality Checker near the center of each wetland. Alkalinity was measured by titration, which was performed within twelve hours after collecting water samples. Electrical conductivity is reported in uS/cm, which is directly equivalent to umhos/cm. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or $\log_{10}$ transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix A, Tables 15, 16, and 17 for raw data.

		Reference		Retired		Current							Retired–	Current–
variable	period	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
EC (uS/cm)	1	450	215	274	39	414	182	A	U	1.29	0.32	253	-178	-40
pH	1	6.9	0.5	6.7	0.2	7.1	0.4	A	U	1.23	0.34	0.6	0.3	0.1
temperature (°C)	1	20.8	4.3	18.8	3.3	20.0	2.5	A	U	0.34	0.72	5.3	-2.0	-0.8
alkalinity (mg $CaCO_3$/l)	1	218	111	117	12	189	88	A	L	1.61	0.25	126	-101	-28
EC (uS/cm)	2	469	237	273	47	454	194	A	U	1.49	0.28	276	-198	-18
pH	2	7.1	0.2	6.6	0.2	7.1	0.8	A	U	1.35	0.31	0.8	-0.5	0.0
temperature (°C)	2	21.1	3.1	22.3	3.2	18.7	1.7	A	U	1.81	0.22	4.3	1.3	-2.4
alkalinity (mg $CaCO_3$/l)	2	214	117	116	17	191	93	A	U	1.40	0.30	134	-98	-23
EC (uS/cm)	3	574	291	323	76	607	265	A	U	1.82	0.22	356	-253	33
pH	3	7.0	0.6	7.0	0.6	6.9	0.3	A	U	0.03	0.97	0.8	-0.05	-0.1
temperature (°C)	3	19.8	1.9	20.3	2.8	21.2	2.4	A	U	0.34	0.72	3.7	0.5	1.4
alkalinity (mg $CaCO_3$/l)	3	272	148	139	29	263	120	A	U	1.79	0.22	171	-133	-9

Table 6. Physical and chemical characteristics of water in depressional wetlands in the Ovando area. Reference, retired, and current refer to land use categories that are explained in the text. Electrical conductivity (EC), pH, and temperature were measured on site using a Horiba U-10 Water Quality Checker near the center of each wetland. Data were collected in late June (period 1), early July (period 2) and late August (period 3). Alkalinity was estimated by titration, which was performed within twelve hours after collecting water samples. Electrical conductivity is reported in uS/cm, which is directly equivalent to umhos/cm. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or $\log_{10}$ transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix A, Tables 15, 16, and 17 for raw data.

		Reference		Retired		Current							Retired–	Current–
variable	period	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
EC (uS/cm)	1	528	176	657	54	450	189	A	U	1.90	0.21	235	133	-75
pH	1	7.4	0.2	7.3	0.2	7.1	0.4	A	U	0.79	0.48	0.4	-0.1	-0.2
temperature (°C)	1	21.4	4.3	15.3	1.8	16.9	1.6	A	U	4.88	0.04 *	4.4	-6.1 *	-4.5 *
alkalinity (mg $CaCO_3$/l)	1	256	68	313	23	213	94	A	U	2.13	0.18	105	57	-43
EC (uS/cm)	2	525	200	651	46	441	183	A	L	2.18	0.17	499	366	-84
pH	2	7.5	0.5	7.2	0.2	7.7	0.3	A	U	2.34	0.15	0.5	-0.2	0.3
temperature (°C)	2	21.3	2.3	19.3	4.3	24.3	3.0	A	U	2.36	0.15	5.0	-2.0	3.0
alkalinity (mg $CaCO_3$/l)	2	243	76	305	19	210	91	A	U	1.92	0.20	107	63	-33
EC (uS/cm)	3	542	239	695	54	468	204	A	U	1.59	0.26	284	155	-73
pH	3	7.5	0.7	7.2	0.2	7.1	0.2	A	U	1.21	0.34	0.7	-0.4	-0.5
temperature (°C)	3	18.6	4.0	17.2	2.6	17.6	2.6	A	U	0.21	0.81	4.8	-1.4	-1.0
alkalinity (mg $CaCO_3$/l)	3	259	106	346	20	233	103	A	U	1.87	0.21	132	86	-26

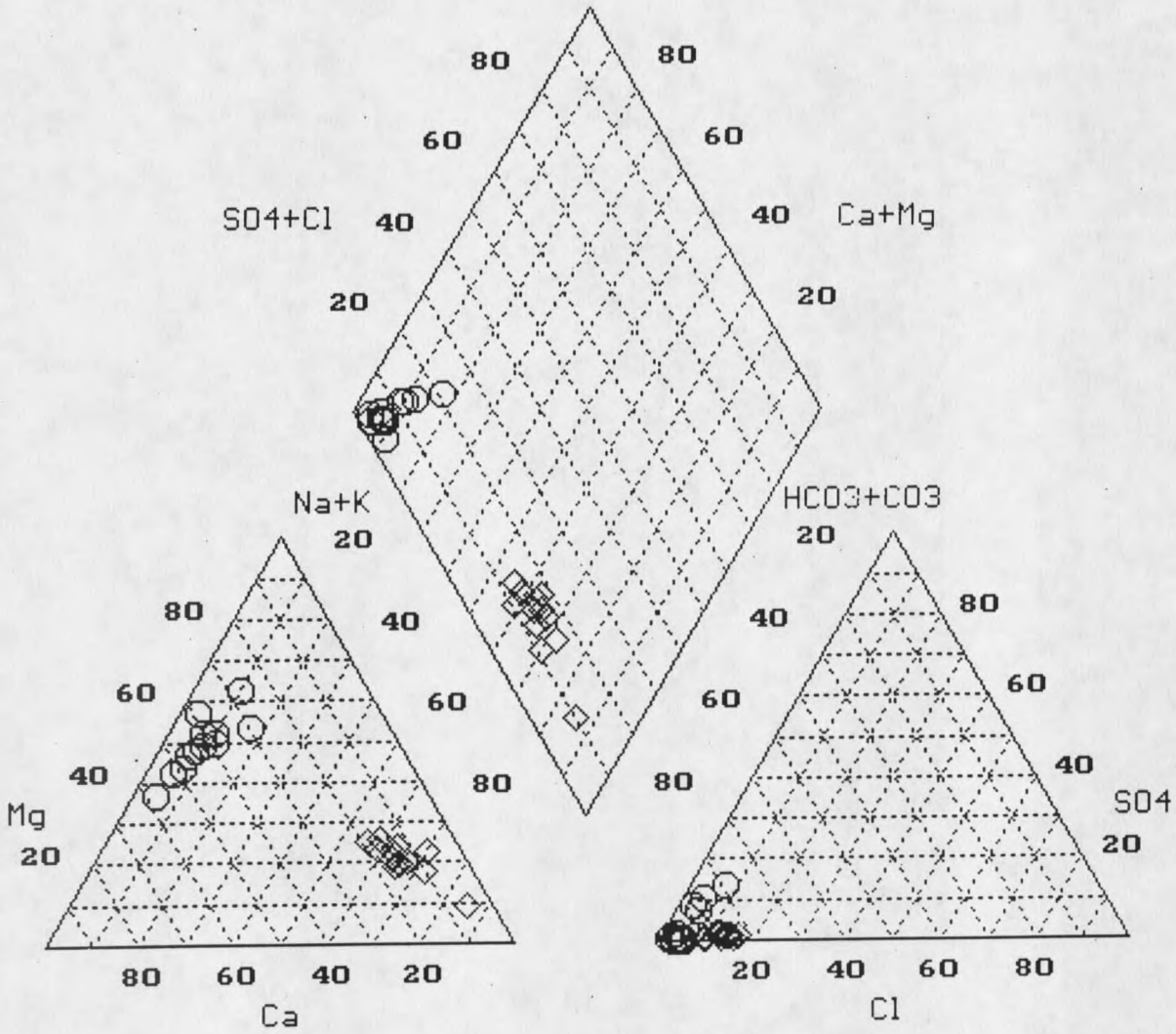

Figure 5. Chemical composition of water in depressional wetlands in the Ninepipe and Ovando areas. Ninepipe area wetlands are represented by diamonds and Ovando area wetlands are represented by circles. Water samples were collected in late June. See Appendix A, Table 15 for raw data.

Table 7. Nutrient concentrations in water in depressional wetlands in the Ninepipe area. Reference, retired, and current refer to land use categories that are explained in the text. Data was collected in late June (period 1), early July (period 2) and late August (period 3). All concentrations are mg/l. Phosphate (PO_4) values below 0.01, and nitrate (NO_3) and ammonium (NH_4) values below 0.1 have a lower analytical accuracy than data above these values. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or log_{10}-transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix A, Tables 15, 16, and 17 for raw data.

		Reference		Retired		Current							Retired–	Current–
variable	period	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
NO_3	1	0.04	0.03	0.03	0.04	0.02	0.01	A	U	0.66	0.54	0.04	-0.02	-0.01
NH_4	1	0.09	0.04	0.14	0.05	0.11	0.06	A	U	0.78	0.49	0.07	0.02	0.04
P	1	1.06	0.91	0.55	0.17	0.84	0.52	A	U	0.71	0.52	0.94	0.52	-0.23
PO_4**	1	2.29	2.33	0.34	0.10	1.13	0.98	A	L	2.0	0.19	0.67	-0.61	-0.24
NO_3	2	0.05	0.02	0.04	0.02	0.04	0.01	A	U	0.30	0.75	0.03	0.00	-0.01
NH_4	2	0.09	0.05	0.10	0.02	0.08	0.05	A	U	0.24	0.79	0.06	0.01	-0.01
P	2	1.02	0.96	0.56	0.15	0.96	0.47	A	U	0.66	0.54	0.96	-0.47	-0.06
NO_3	3	0.06	0.03	0.03	0.01	0.04	0.01	A	U	2.9	0.104	0.031	-0.033 *	-0.025
NH_4	3	0.12	0.05	0.09	0.06	0.13	0.06	A	U	0.62	0.56	0.09	-0.04	0.01
P	3	1.11	1.11	0.55	0.16	1.09	0.35	A	U	0.90	0.44	1.04	-0.57	-0.02
PO_4	3	2.14	2.76	0.32	0.15	0.78	0.42	A	L	0.93	0.43	0.78	-0.45	-0.04

**PO_4 values are reported as total molecular mass of phosphate per liter. To convert to phosphorus as phosphate, multiply by 0.33. Other values are reported as mass of nitrogen or phosphorus per liter.

Table 8. Nutrient concentrations in water in depressional wetlands in the Ovando area. Reference, retired, and current refer to land use categories that are explained in the text. Data was collected in late June (period 1), early July (period 2) and late August (period 3). All concentrations are mg/l. Phosphate (PO_4) values below 0.01, and nitrate (NO_3) and ammonium (NH_4) values below 0.1 have a lower analytical accuracy than data above these values. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or log_{10}-transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. No significant differences were found ($p < 0.10$). See Appendix A, Tables 15, 16, and 17 for raw data.

		Reference		Retired		Current							Retired–	Current–
variable	period	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
NO_3	1	0.01	0.01	0.02	0.01	0.02	0.01	A	U	0.91	0.44	0.01	0.01	0.01
NH_4	1	0.04	0.03	0.02	0.01	0.03	0.01	A	U	1.73	0.23	0.03	-0.02	0.00
P	1	0.33	0.45	0.15	0.01	0.09	0.02	M	U	---	0.03	---	---	---
PO_4**	1	0.40	0.80	0.00	0.00	0.00	0.00	M	U	---	0.37	---	---	---
NO_3	2	0.01	0.00	0.01	0.01	0.01	0.00	M	U	---	0.37	---	---	---
NH_4	2	0.05	0.03	0.03	0.02	0.05	0.02	A	U	0.71	0.52	0.03	-0.02	0.00
P	2	0.29	0.35	0.11	0.02	0.11	0.03	A	L	0.59	0.58	0.46	-0.21	-0.19
NO_3	3	0.07	0.08	0.02	0.01	0.02	0.01	A	L	2.37	0.15	0.45	-0.36	-0.41
NH_4	3	0.16	0.19	0.23	0.22	0.12	0.11	A	U	0.37	0.70	0.27	0.07	-0.04
P	3	0.18	0.18	0.06	0.01	0.08	0.02	M	U	---	0.12	---	---	---
PO_4	3	0.26	0.30	0.00	0.00	0.00	0.00	M	U	---	0.03	---	---	---

**PO_4 values are reported as total molecular mass of phosphate per liter. To convert to phosphorus as phosphate, multiply by 0.33. Other values are reported as mass of nitrogen or phosphorus per liter.

significantly among land uses in June. Because the median test was used, pairwise comparisons were not made. Mean phosphorus concentrations were 50% lower in retired sites than reference sites and 70% lower in currently grazed than reference sites. Total phosphorus values did not differ significantly during other months. Phosphate varied significantly among the Ovando land use groups in August. Again, because the median test was used, pairwise comparisons were not made; however, means indicated that phosphate was present at low but detectable levels in reference sites but was below detection limits in both retired and current sites. This tendency toward higher mean total phosphorus and phosphate values in reference sites than retired or current sites was observed during all months, although differences were not significant except as reported above.

There were no significant differences in sediment geochemistry in the Ninepipe area (Table 9). SAR varied significantly among land use groups in the Ovando area (Table 9), but because a median test was used, specific land use groups were not compared. However, mean SAR for the retired subset was an order of magnitude higher than for reference or currently grazed subsets. Sediment pH and EC did not differ significantly between the reference sites and other land use groups in the Ovando area.

Differences in nutrient concentrations in sediments were found among land use groups in the Ninepipe area (Table 10). Ammonium was significantly higher at retired than reference sites. Total phosphorus was significantly greater on retired and currently cultivated sites than reference sites. There were no significant differences in sediment chemistry among land uses in the Ovando area (Table 10).

Table 9. Geochemical characteristics of sediment in depressional wetlands in the Ninepipe and Ovando areas. Reference, retired, and current refer to land use categories that are explained in the text. Samples used for SAR determination were collected in late June. Samples used for pH and electrical conductivity (EC) determination were collected in early July. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or log_{10}-transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix A, Table 18 for raw data.

	Reference		Retired		Current							Retired–	Current–
variable	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
						Ninepipe							
SAR	6	5	3	1	3	2	A	U	0.67	0.54	5	-2	-2
pH	8.1	0.8	7.5	0.2	7.7	0.3	A	U	1.7	0.24	0.8	-0.6	-0.4
EC (uS/cm)	1024	875	471	136	581	200	A	U	1.2	0.33	807	-553	-440
						Ovando							
SAR	0.4	0.1	3	5	0.4	0.1	M	U	-----	0.03 *	-----	-----	-----
pH	8.0	0.4	8.3	0.2	7.9	0.3	A	U	1.5	0.27	0.5	0.3	0.0
EC (uS/cm)	468	231	541	128	401	93	A	U	0.75	0.50	249	73	-68

Table 10. Nutrient concentrations in sediment in depressional wetlands in the Ninepipe and Ovando areas. Reference, retired, and current refer to land use categories that are explained in the text. Samples were collected in late June. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or log_{10}-transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix A, Table 18 for raw data.

	Reference		Retired		Current							Retired–	Current–
variable	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
						Ninepipe							
TKN (%N)	0.55	0.15	0.45	0.06	0.46	0.14	A	U	0.78	0.49	0.19	-0.10	-0.09
NH_4 (mg/kg)	37	19	87	28	62	16	A	U	5	0.03 *	33	50 *	25
NO_3 (mg/kg)	9	7	5	3	7	6	A	U	1	1	9	-5	-2
P (mg/kg)	30	11	51	10	57	14	A	U	6	0.02 *	18	21 *	27 *
						Ovando							
TKN (%N)	0.73	0.15	0.95	0.31	1.09	0.39	A	U	1.4	0.29	0.46	0.22	0.36
NH_4 (mg/kg)	42	23	22	18	33	13	A	U	1	0.4	28	-19	-9
NO_3 (mg/kg)	14	5	20	12	23	15	A	U	1	1	18	6	9
P (mg/kg)	42	32	30	15	20	4	A	U	1	0.4	31	-12	-21

Ninepipe area substrates had higher clay contents than the Ovando substrates (Figure 6); sediments in nine out of 12 sites were clays or silty clays and three were silty clay loams. In contrast, sediment in 10 out of 12 Ovando sites classified as loams, silty loams, or clay loams; two fell low in the clay category.

Vegetation

In the Ninepipe area, life history groups showed the strongest differences between reference and currently or previously cultivated sites (Table 11). Perennial species differed significantly between reference sites and currently cultivated or retired sites. Because a median test was used, pairwise comparisons among land uses were not made. However, mean values for cultivated sites were 15% less than for reference sites, while means for retired sites were slightly higher than for reference sites.

Native perennials showed greater differences between reference and cultivated sites than all perennials combined. Relative abundance of native perennials was significantly lower on cultivated than reference sites, reflecting a 40% decrease in mean values. Retired sites were not significantly different from reference sites. Relative abundance of all native species did not differ significantly among land use groups, although values tended to be lower on cultivated than reference sites.

Annuals were significantly less abundant in retired sites than in reference sites; in fact, they were virtually absent. Although the difference was not statistically significant, the mean relative abundance of annuals was four times greater at reference sites than

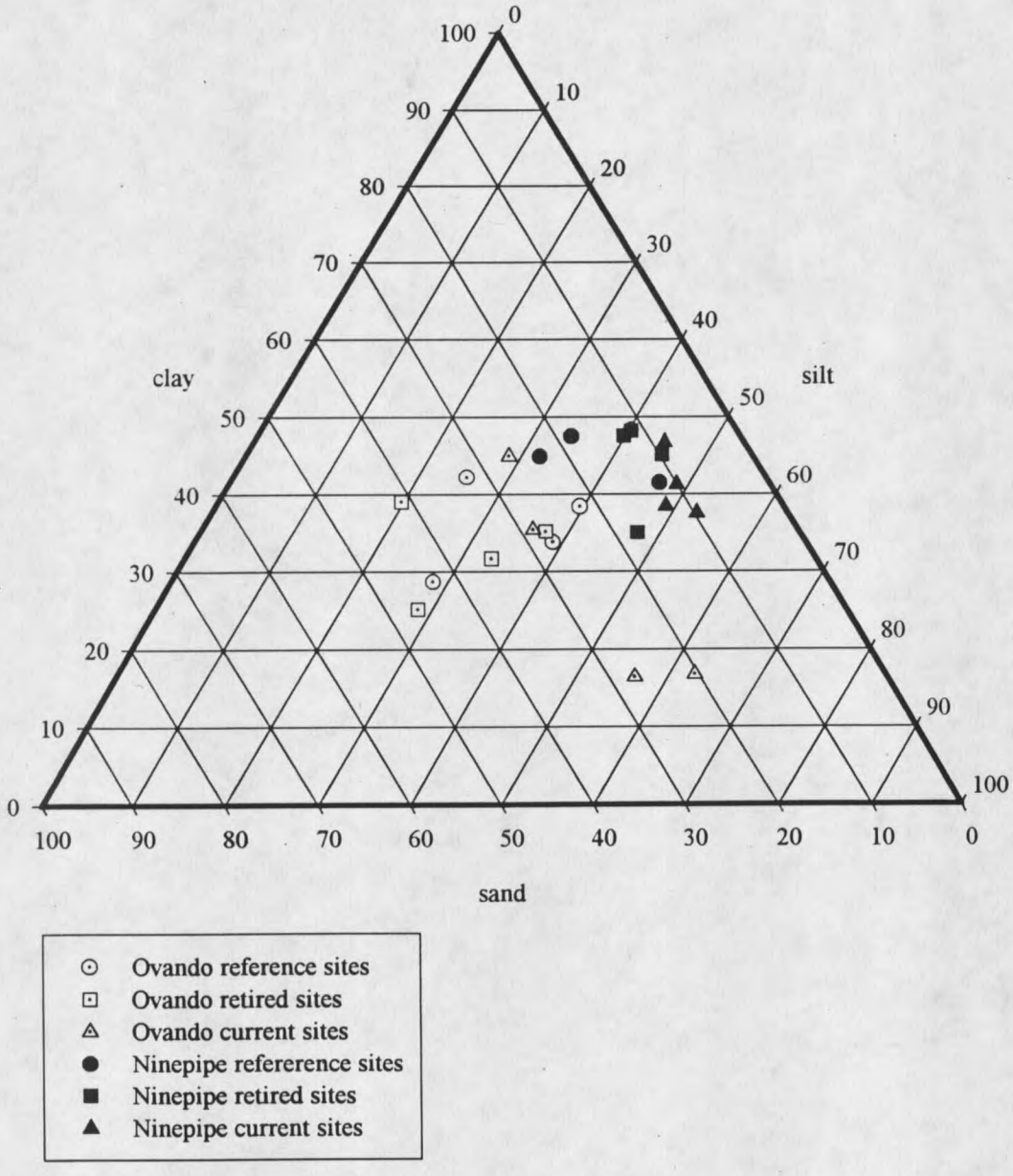

Figure 6. Sediment particle–size distributions in depressional wetlands in the Ninepipe and Ovando areas. Ninepipe land use groups are represented by solid symbols and Ovando land use groups are represented by open symbols. Samples were collected in early July. See Appendix A, Table 18 for raw data.

Table 11. Composition of vegetation in depressional wetlands in the Ninepipe area: a) relative abundance of species groups, b) relative abundance of selected species, and c) species richness. Reference, retired, and current refer to land use categories that are explained in the text. Vegetation was sampled in late August. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or log_{10}-transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix B, Table 19 for relative abundance data for individual species. See Appendix B, Table 20 for summary of group designations for each species.

	Reference		Retired		Current							Retired–	Current–
variable	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
a) Species groups													
Annuals	0.05	0.05	0.001	0.001	0.19	0.14	A	L	11.5	0.003 *	1.14	-1.42 *	1.08
Perennials	0.95	0.06	0.999	0.001	0.80	0.13	M	U	-----	0.01 *	-----	-----	-----
Natives	0.71	0.17	0.67	0.30	0.50	0.19	A	U	0.94	0.43	0.35	-0.04	-0.21
Non-natives	0.29	0.17	0.29	0.30	0.43	0.21	A	U	0.51	0.62	0.36	0.01	0.15
Native perennials	0.69	0.17	0.67	0.30	0.31	0.16	A	U	3.9	0.06 *	0.34	-0.03	-0.38 *
Weedy	0.51	0.26	0.64	0.23	0.48	0.23	A	U	0.49	0.63	0.37	0.12	-0.04
Weedy annuals	0.02	0.04	0.00	0.00	0.00	0.00	M	U	-----	0.11	-----	-----	-----
Weedy perennials	0.48	0.28	0.64	0.23	0.48	0.23	A	U	0.53	0.61	0.39	0.16	-0.01
Grasses	0.23	0.17	0.33	0.30	0.47	0.17	A	U	1.2	0.36	0.34	0.10	0.24
Grasslikes	0.39	0.17	0.29	0.19	0.39	0.25	A	U	0.32	0.74	0.32	-0.10	-0.01
Grasslike perennials	0.39	0.17	0.29	0.19	0.23	0.19	A	U	0.78	0.49	0.28	-0.10	-0.16
Forbs	0.13	0.10	0.03	0.03	0.08	0.07	A	U	1.9	0.21	0.11	-0.10	-0.05
Moss	0.11	0.11	0.000	0.001	0.001	0.003	A	L	12.0	0.00 *	1.36	-2.62 *	-2.67 *
Submergents	0.07	0.14	0.002	0.004	0.06	0.13	M	U	-----	1.00	-----	-----	-----
Spp. with persistent litter	0.51	0.12	0.52	0.21	0.09	0.06	A	U	12.3	0.00 *	0.22	0.02	-0.42 *
1st most dominant spp.	0.38	0.08	0.48	0.18	0.44	0.13	A	U	0.52	0.61	0.21	0.10	0.06
1st & 2nd most dominant spp.	0.61	0.16	0.71	0.16	0.66	0.12	A	U	0.48	0.64	0.23	0.10	0.05
1st, 2nd, & 3rd most dominant spp.	0.74	0.19	0.89	0.10	0.78	0.05	A	U	1.5	0.28	0.20	0.15	0.04
Tillage tolerant spp.	0.18	0.03	0.17	0.12	0.23	0.22	A	U	0.17	0.85	0.23	-0.01	0.05

Table 11. (continued)

variable	Reference mean	Reference s.d.	Retired mean	Retired s.d.	Current mean	Current s.d.	test	trans.	F	P	MSD	Retired–Reference	Current–Reference
b) Species or genera													
Agropyron **spp.**	0.00	0.00	0.04	0.05	0.06	0.08	M	U	-----	0.06 *	-----	-----	-----
Phalaris arundinacea	0.16	0.22	0.29	0.29	0.39	0.19	A	U	0.98	0.41	0.37	0.13	0.24
Juncus balticus	0.24	0.17	0.13	0.16	0.01	0.03	A	U	2.7	0.12	0.21	-0.10	-0.22 *
Eleocharis **spp.**	0.15	0.01	0.14	0.09	0.36	0.25	M	U	-----	0.40	-----	-----	-----
Eleocharis ovata	0.002	0.004	0.000	0.001	0.15	0.16	M	U	-----	0.28	-----	-----	-----
Eleocharis palustris	0.11	0.07	0.14	0.09	0.17	0.17	A	U	0.25	0.79	0.18	0.03	0.06
Carex spp.	0.009	0.019	0.000	0.000	0.002	0.005	A	U	-----	0.58	-----	-----	-----
Typha latifolia	0.23	0.13	0.35	0.16	0.06	0.04	A	U	5.6	0.03 *	0.19	0.11	-0.18
c) Species richness, vascular plants	17.3	9.5	7.5	3.0	15.7	1.7	A	N	3.2	0.1 *	9.0	-9.8 *	-1.5

currently cultivated sites. Species richness followed a pattern similar to annuals. Richness did not differ significantly between reference and cultivated sites, but was significantly lower in the retired than reference sites.

Agropyron spp. differed significantly among land uses, apparently increasing with disturbance. The median test was used, so pairwise comparisons between land use groups were not made. However, there were no *Agropyron* spp. in reference sites, while relative abundance of this genus was 4% in the retired sites and 6% in currently cultivated sites. In the Ninepipe wetlands, the *Agropyron* genus was primarily composed of *A. repens* and *A. smithii*, and some *A. trachycaulum*; inconsistent field identification of species required grouping the wheatgrass genus.

Relative abundance of species with persistent litter decreased significantly from reference sites to currently cultivated sites. Within this group, *Juncus balticus* decreased significantly from reference to currently cultivated sites. *Typha latifolia* showed significant differences among land use groups in ANOVA, but no significant differences in pairwise comparisons when currently and previously cultivated sites were compared to reference sites. However, mean relative abundance of *T. latifolia* was 50% higher in retired sites than reference sites and 75% lower in cultivated sites than reference sites. The relative abundance of moss as a fraction of ground cover was significantly lower in both the retired and currently cultivated groups than the reference group.

Fewer differences among land uses were found in the Ovando area (Table 12) than in the Ninepipe area. In the Ovando area, the combined relative abundance of the three most dominant species present on each site was significantly higher in the currently grazed sites than in the reference sites. *Juncus balticus* was significantly lower in

Table 12. Composition of vegetation in depressional wetlands in the Ovando area: a) relative abundance of species groups, b) relative abundance of selected species, and c) species richness. Reference, retired, and current refer to land use categories that are explained in the text. Vegetation was sampled in late August. Means were compared by ANOVA (A) or a median test (M) using untransformed (U) or log10-transformed (L) values. The Minimum Significant Difference (MSD) is the critical value for pairwise comparisons using Dunnett's test. "Retired–Reference" and "Current–Reference" refer to differences between land use group means. Asterisks (*) designate significant differences ($p < 0.10$). See Appendix B, Table 19 for relative abundance data for individual species. See Appendix B, Table 20 for summary of group designations for each species.

	Reference		Retired		Current							Retired–	Current–
variable	mean	s.d.	mean	s.d.	mean	s.d.	test	trans.	F	P	MSD	Reference	Reference
a) Species groups													
Annuals	0.003	0.005	0.001	0.001	0.000	0.000	A	L	0.55	0.59	1.18	-0.27	-0.57
Perennials	0.98	0.04	0.99	0.01	0.98	0.03	M	U	-----	1.00	-----	-----	-----
Natives	0.93	0.08	0.93	0.05	0.94	0.03	A	U	0.13	0.88	0.08	0.01	0.02
Non-natives	0.07	0.08	0.06	0.05	0.04	0.03	A	U	0.50	0.62	0.09	-0.01	-0.04
Native perennials	0.92	0.08	0.93	0.05	0.94	0.03	A	U	0.16	0.86	0.09	0.01	0.02
Weedy	0.07	0.08	0.02	0.01	0.01	0.01	A	U	2.0	0.19	0.07	-0.05	-0.06
Weedy annuals	0.000	0.000	0.001	0.001	0.000	0.000	M	U	-----	0.11	-----	-----	-----
Weedy perennials	0.07	0.08	0.02	0.01	0.01	0.01	A	U	2.0	0.19	0.07	-0.05	-0.06
Grasses	0.05	0.04	0.06	0.05	0.04	0.03	A	U	0.20	0.82	0.06	0.01	0.00
Grasslikes	0.73	0.17	0.88	0.04	0.84	0.09	A	U	1.9	0.21	0.17	0.15	0.10
Grasslike perennials	0.72	0.19	0.88	0.04	0.84	0.09	A	U	1.9	0.21	0.19	0.16	0.12
Forbs	0.22	0.18	0.06	0.02	0.12	0.06	A	L	0.93	0.43	0.62	-0.37	-0.09
Moss	0.01	0.02	0.01	0.01	0.004	0.006	A	L	0.49	0.63	1.73	0.60	-0.15
Submergents	0.08	0.11	0.06	0.07	0.08	0.07	A	U	0.11	0.90	0.13	-0.03	0.00
Spp. with persistent litter	0.21	0.19	0.16	0.14	0.13	0.09	A	U	0.34	0.72	0.23	-0.06	-0.08
1st most dominant spp.	0.40	0.14	0.54	0.27	0.51	0.08	A	U	0.68	0.53	0.28	0.14	0.11
1st & 2nd most dominant spp.	0.57	0.18	0.71	0.15	0.73	0.07	A	U	1.6	0.25	0.21	0.14	0.16
1st, 2nd, & 3rd most dominant spp.	0.66	0.15	0.81	0.09	0.82	0.05	A	U	3.1	0.10 *	0.16	0.15	0.16 *
Grazing tolerant spp.	0.140	0.120	0.150	0.140	0.070	0.060	A	U	0.54	0.60	0.17	0.01	-0.07

Table12. (continued)

variable	Reference mean	Reference s.d.	Retired mean	Retired s.d.	Current mean	Current s.d.	test	trans.	F	P	MSD	Retired–Reference	Current–Reference
b) Species or genera													
Agropyron spp.	0.01	0.02	0.003	0.004	0.001	0.001	A	L	0.17	0.84	1.38	0.00	-0.33
Poa pratensis	0.02	0.02	0.01	0.01	0.003	0.005	A	U	1.1	0.37	0.02	-0.02	-0.01
Juncus balticus	0.11	0.09	0.04	0.03	0.02	0.02	A	U	3.1	0.10 *	0.09	-0.08	-0.09 *
Eleocharis spp.	0.26	0.21	0.04	0.02	0.35	0.21	A	L	10.9	0.00 *	0.46	-0.76 *	0.16
Eleocharis palustris	0.24	0.22	0.04	0.02	0.34	0.21	A	L	10.3	0.00 *	0.48	-0.75 *	0.18
Carex spp.	0.36	0.25	0.70	0.13	0.44	0.10	A	U	4.4	0.05 *	0.26	0.34 *	0.08
Carex atherodes	0.20	0.19	0.35	0.32	0.40	0.14	A	U	0.80	0.48	0.35	0.15	0.20
Mentha arvense	0.06	0.07	0.02	0.01	0.02	0.01	A	L	0.24	0.79	0.90	-0.25	0.00
Potamogeton spp.	0.07	0.10	0.04	0.07	0.04	0.04	A	U	0.23	0.80	0.11	-0.03	-0.03
Utricularia vulgaris	0.003	0.003	0.02	0.03	0.03	0.04	A	L	1.4	0.30	1.17	0.81	0.72
c) Species richness, vascular plants	12.3	4.4	16.0	3.7	14.3	1.3	A	U	1.2	0.30	5.3	2.0	3.8

currently grazed sites than in the reference sites. *Eleocharis palustris* and the total relative abundance of all *Eleocharis* spp. were significantly lower in the retired group than the reference group. *Carex* spp. were significantly more abundant on retired than reference sites.

Vertical Distribution of Vegetation

Mean elevations a significant majority of individual species' distributions were lower in currently impacted sites than in reference sites for the Ninepipe area (Table 13) and Ovando area (Table 14). When species were grouped by lifeform, grasses and forb species' distributions shifted in both directions, but elevations of grasslike species, which represented almost a third of the species compared, were all lower in disturbed than reference wetlands. Species elevations did not differ significantly between reference and retired subsets in either study area. It is noteworthy that in both study areas, wetland boundaries defined by vegetation were lower at currently impacted and retired sites than at reference sites.

Table 13. Comparison of vertical distribution of plant species in depressional wetlands in the Ninepipe area. Reference, retired, and current refer to land use categories that are explained in the text. Elevations are reported as cm above or below the level of surface water. Mean elevations of retired and current groups were considered greater (+) or less than (–) reference groups. If the difference was less than or equal to 1 cm, the mean elevations were considered equal (=). Comparisons were only made for species and ranges of elevation present in both land use groups. The number of species with lower mean elevation in disturbed sites was compared to the number of species with higher mean elevation using a nonparametric sign (+/–) test. Asterisks (*) designate significant differences ($p < 0.10$).

Species	n	mean elevation	n	mean elevation	+/–
	Reference		Current		
Alisma triviale	4	29	8	22	–
Cirsium arvense	8	37	2	34	–
Sonchus asper	7	36	2	18	–
Carex athrostachya	3	34	2	22	–
Eleocharis acicularis	4	29	4	20	–
Eleocharis ovata	3	38	9	23	–
Eleocharis palustris	11	23	30	-1	–
Juncus balticus	23	26	2	-2	–
Epilobium ciliatum	14	30	2	28	–
Phalaris arundinacea	13	7	41	2	–
Poa palustris	11	25	8	27	+
Polygonum amphibium	4	3	6	-29	–
Rumex maritimus	6	34	2	26	–
Potamogeton pectinatus	9	-55	21	-32	+
Solanum dulcamara	7	-11	4	5	+
Typha latifolia	37	-13	25	-26	–
				total (+/–) =	3/13 *
	Reference		Retired		
Eleocharis palustris	3	2	11	3	=
Juncus balticus	8	12	5	4	–
Agrostis spp.	1	10	2	15	+
Phalaris arundinacea	9	-3	14	-4	=
Poa palustris	2	-8	5	14	+
Polygonum amphibium	4	3	8	-15	–
Potamogeton pectinatus	9	-55	1	-42	+
Typha latifolia	33	-17	35	-22	–
				total (+/–) =	3/3

Table 14. Comparison of vertical distributions of plant species in depressional wetlands in the Ovando area. Reference, retired, and current refer to land use categories that are explained in the text. Elevations are reported as cm above or below the level of surface water. Mean elevations of retired and current groups were considered greater (+) or less than (–) reference groups. If the difference was less than or equal to 1 cm, the mean elevations were considered equal (=). Comparisons were only made for species and ranges of elevation present in both land use groups. The number of species with lower mean elevation in disturbed sites was compared to the number of species with higher mean elevation using a nonparametric sign (+/–) test. Asterisks (*) designate significant differences ($p < 0.10$).

Species	n	mean elevation	n	mean elevation	+/–
	Reference		Current		
Cirsium arvense	3	-35	5	7	+
Carex atherodes	39	-60	42	-103	–
Carex spp.	7	-2	17	-5	–
Eleocharis palustris	51	-36	47	-46	–
Scirpus acutis	4	-52	14	-100	–
Juncus balticus	16	3	13	0	–
Mentha arvense	10	-4	11	3	+
Stachys palustris	4	29	4	-15	–
Utricularia vulgaris	10	-59	30	-80	–
Agrostis alba	2	29	5	8	–
Poa pratensis	2	29	3	29	=
Polygonium amphibium	23	-56	33	-80	–
Potamogeton gramineus	18	-56	16	-99	–
Potamogeton pectinatus	26	-94	11	-132	–
Ranunculus spp.	2	-60	2	-19	+
Potentilla anseria	2	31	5	15	–
				total (+/–) =	3/12 *
	Reference		Retired		
Cirsium arvense	3	-35	8	12	+
Drepanocladus spp.	27	-40	9	-24	+
Carex atherodes	26	-18	21	-31	–
Carex spp.	7	-2	3	22	+
Eleocharis palustris	46	-27	26	-4	+
Scirpus acutis	4	-52	58	-34	+
Juncus balticus	16	3	15	11	+
Mentha arvense	10	-4	31	-8	–
Stachys palustris	4	29	10	12	–
Utricularia vulgaris	8	-44	51	-41	+
Agrostis alba	2	29	9	10	–
Poa pratensis	2	29	7	17	–
Polygonium amphibium	17	-29	30	-18	+
Potamogeton gramineus	12	-17	6	-31	–
Potamogeton pectinatus	13	-44	2	-34	+
Ranunculus spp.	2	-60	2	11	+
Potentilla anseria	2	31	7	17	–
				total (+/–) =	10/7

DISCUSSION

Site Characteristics

The interpretation of results of the vegetation analysis depends substantially on how similar sites are in respects other than land use. Environmental data showed that wetlands differed between the two study areas in important ways but were similar within each study area.

I chose sites that were as similar as possible using narrow site selection criteria. Study wetland environments were similar in the most important characteristics affecting vegetation in glaciated depressional wetlands: hydrologic regime and salinity. All had semi-permanent or extended seasonal hydrologic regimes and electrical conductivity (EC) values in the freshwater range through most of the growing season. Piezometer data also support the interpretation that the wetlands are fed mainly by precipitation and surface runoff rather than groundwater. All wetlands were acting as groundwater recharge areas by September and most were recharge sites at all times. Low EC values at all sites are typical of precipitation and runoff fed wetlands. These data suggest that sites were all similar in water source.

These observations contrast with research findings for prairie potholes in the Dakotas. In the Dakotas, semi-permanent wetlands are usually groundwater flow-through or discharge wetlands (Kantrud et al. 1989). It is possible that low permeability in bottom soils allow these recharge wetlands in western Montana to maintain collected water for a longer period of time. Alternatively, a more positive climatic water balance

may allow precipitation and runoff to offset evapotranspiration and percolation losses for longer periods than typically observed in Dakota "recharge" wetlands.

Despite similarities in hydrology and EC across all wetlands, environmental data collected showed that wetlands differed between the Ninepipe and Ovando areas in important ways. Soil surveys show sodic soils mapped throughout the Ninepipe study area. This information is corroborated by my findings: hydrogeochemical analysis showed sodium dominated waters, and SAR values, although not high enough to be rated sodic, were an order of magnitude higher in the Ninepipe than the Ovando area. Sodicity can influence plant growth (Sparks 1995). The particle size distribution of sediments also differed between study areas. Finally, the 100-km distance and 300-m difference in elevation contributed to basic climatic differences; temperatures were an average 3° C higher in the Ninepipe area than the Ovando area.

In addition to differences in hydrogeochemistry, SAR, sediment clay content, and climate, reference site vegetation appeared to differ substantially between the Ninepipe and Ovando areas. Ninepipe sites were dominated by *Typha latifolia* and Ovando sites by *Carex atherodes* and other Cyperaceae. Ninepipe reference sites exhibited a generally higher relative abundance of weedy and non-native species compared to the Ovando reference sites. These differences in vegetation may be related to the natural environmental differences described above, or may be related to higher overall levels of human influence in the Mission Valley as compared to the Ovando Valley. Considering these differences, I concluded that the two areas had significant environmental contrasts and that effects of land use on vegetation should not be compared quantitatively between these areas.

The environmental contrasts described above likely reflect differences in underlying geology. Hydrogeochemistry differed distinctly between study areas, but hydrology was broadly similar. Water chemistry is a largely a function of the configuration of the water table surrounding a wetland (Sloan 1970), associated flow patterns, and subsurface geology (Van Voast and Novitzki 1968). Because hydrology was similar, it is likely that hydrogeochemical differences between Ninepipe and Ovando wetlands resulted from differing geologic characteristics of the glacial deposits underlying the wetlands rather than differences in relative contributions of precipitation and groundwater.

Soil parent materials in the Ninepipe and Ovando areas are derived from the Belt Series (Veseth and Montagne 1980) and reworked by glaciation (S. Custer, 1997, personal communication). Considering similarities in underlying material, the hydrogeochemical differences between the two areas is striking. The Nine Pipe and Ovando sites may differ because glacial till derived from different Belt Series lithologies weathers to soils with different physical and chemical properties (Veseth and Montagne 1980). Presumably, this would be true with glaciolacustrine sediment and outwash as well. Different Belt Series lithologies may also explain the differences in clay content between the Nine Pipe and Ovando sediments. However, these differences may also reflect modes of deposition, as glaciolacustrine sediments typically have high concentrations of fine particles.

Few differences were observed within each study area. As stated above, hydrologic regime, water source, and EC were all similar. Other environmental data showed few and inconsistent differences between sites in each land use group. There

were no significant differences in any of the data collected to characterize natural environmental conditions in the Ninepipe sites. Ninepipe sites were also likely to be similar because they were less than 3 km apart.

Environmental characteristics of reference and currently grazed sites in the Ovando area did not substantially differ. The only significant difference observed was for temperature on one occasion. Sites retired from grazing were more likely to differ environmentally from the reference sites due to distance and, possibly, mode of deposition of the soil parent material. Retired sites in the Ovando area were 30 km from reference sites, while the currently grazed sites were 10 km from reference sites. Soil surveys indicate that reference and currently grazed sites are on glacial till, whereas Ovando retired sites overlie outwash. In spite of these differences, hydrogeochemical, soil physical, and hydrologic data for the retired sites fell well within the range of variation of the reference and currently grazed sites. The single exception was SAR, which was significantly higher on retired sites.

Overall, results showed that background environmental variation among sites with different land uses was minimal in the Ninepipe area, and that reference and currently grazed sites in the Ovando area were also very similar. Observed characteristics of sites retired from grazing did not indicate clear differences from reference sites but unmeasured differences might result from their separate location. I infer that differences observed in vegetation within the Ninepipe and Ovando areas were more likely due to land use than natural site differences. The observational approach taken, the reliance on existing land uses, and limitations of the wetlands available for study prevented randomization of treatments and interspersion of replicates. Consequently, inferences

about effects of land use on wetland vegetation should be viewed with caution. These constraints are common in studies of environmental impacts. Although influences other than land use cannot be excluded, environmental differences among sites were minimized. Considering evidence of physical disturbance, differences in vegetation likely were caused by land use.

Land Use Impacts

Cultivation and grazing may influence vegetation in wetlands either directly, through physical impacts to the vegetation and soil, or indirectly, via changes in water quality, sediment chemistry, or other factors. I assumed that the most likely indirect effects of cultivation and grazing on vegetation were differences in nutrient concentrations in the water and sediment. In this study, I found limited evidence for elevated nutrient concentrations in areas currently or previously cultivated or grazed but considerable evidence of direct, physical impacts to vegetation and soil.

There were few differences in water or sediment nutrient concentrations among land uses in either study area. In the Ninepipe area, ammonium concentrations in the sediment were greater in retired sites than reference sites. Sediment phosphorus was much greater in retired and currently cultivated sites than reference sites. In Ovando, phosphorus concentrations in water were sometimes greater in the reference sites than disturbed sites, which was opposite to my expectations. There were no significant differences in sediment nutrient levels among land uses in the Ovando area.

Apparent elevation of sediment phosphorus levels in impacted Ninepipe sites may reflect cultivation. Phosphorus can be increased in areas disturbed by cultivation because phosphorus associated with sediment is deposited in wetlands receiving eroded soils (Neely and Baker 1989). Because phosphorus is not lost to the atmosphere and is retained in several solid phase forms, elevated concentrations can persist in sediments for extended periods.

Sediment ammonium levels in the Ninepipe area also could reflect cultivation, but total nitrogen levels did not vary with land use. Nitrogen is more mobile and transient in the environment than phosphorus because it is more readily leached into groundwater and can be lost by denitrification. In addition, because fertilization was infrequent in the Ninepipe area (J. Grant, 1997, personal communication), nitrogen inputs would not have been elevated as much as they would be in more intensively farmed cropland.

The absence of differences in surface water nutrient concentrations suggests that cultivation may not strongly affect water chemistry if fertilization is limited or that the effects of cultivation are transient. In contrast, sediment may be altered more than water, or impacts may persist for a longer time. Thus, it may be more useful to sample soils and sediments than water to evaluate some types of disturbance. Because cultivation without regular fertilization is atypical, water quality in the cultivated and retired sites sampled may represent relatively moderate cultivation effects without the high fertilizer inputs that frequently occur in other cultivated areas. Sampling wetlands in areas with more intensive farming might reveal greater differences in water quality. Cultivation in the prairie pothole region causes significant contamination of wetlands by nitrate, which is

predominantly carried by groundwater, and phosphorus, which is primarily carried on sediment (Neely and Baker 1989).

Although superficially different, both grazing and cultivation cause direct physical disturbance of vegetation and soil. Cultivation is a more severe disturbance than grazing, but both remove shoots, damage root systems and soil structure, and may introduce or promote non-native or weedy species. Direct observations in the field and discussions with land managers provided evidence of physical disturbance.

Signs of physical alteration were observed around wetlands in both study areas, particularly in the Ninepipe area. I observed recent furrows through the edges of some wetlands in currently cultivated areas. Water-level fluctuations allow farmers to till soil during dry years within the area that I observed as inundated (J. Grant, 1997, personal communication). When water levels rose to the levels seen during the 1997 field season, the visible effects of prior cultivation on outer portions of these wetlands remained. Vegetation data, discussed in the next section, are consistent with this interpretation.

In the Ovando area, cattle were seen grazing wetland edges and sometimes standing in the middle of flooded wetlands near my study sites. Pastures at the Bandy Ranch are grazed using moderate stocking rates and seasonal rotation of three pastures among spring, summer, and fall (J. Brewster, 1997, personal communication). Because management of the currently grazed area does not promote overgrazing, it is unlikely that the impacts that were observed in the currently grazed sites represent severe disturbance that may be incurred in areas grazed without management practices to reduce ecological impacts. The previous grazing regime at retired sites was not well documented, but was reported to be continuous over seasons and years, probably with excessive stocking rates

(G. Neudecker, 1997, personal communication). At one retired site, saturated areas pockmarked with shallow indentations and pedestalled grass and sedge tussocks protruding above water surface may have reflected past disturbance.

Overall, it is likely that differences seen in vegetation in both study areas were due primarily to physical effects, not indirect effects of water and sediment chemistry. Evidence of physical disturbance was clear in both study areas and was supported by information from land managers about land use history. The evidence for physical disturbance was corroborated by patterns of vegetation. There was scant evidence of differences in water quality. Increases in sediment phosphorus in cultivated areas might affect vegetation. The following discussion of vegetation treats differences among land uses as reflections of community response to disturbance and resulting successional processes. While recognizing the assumptions inherent in interpreting observed differences among land use groups as changes caused by disturbance and succession, the relatively successful control of background variation reduces the risk of misinterpretation.

Vegetation

Ecological Patterns Related to Land Use

Patterns of differences in wetland vegetation among land uses in the Ninepipe and Ovando areas were consistent with direct, physical impacts of cultivation and grazing. Cultivation resulted in greater differences between the reference and currently impacted plant communities than grazing did, and the findings in the Ninepipe area were generally

consistent with other research on cultivation. Wetlands in the Ovando area showed fewer significant differences in vegetation among land uses. Most of these differences were for different plant groups and species than those that exhibited significant differences in the Ninepipe area. Some of the findings in the Ovando area did not correspond with reported information on effects of grazing on wetlands.

In the Ninepipe area, several major life history groups differed strongly between reference and currently or previously cultivated sites. Perennials, annuals, and native perennials differed among land uses. Differences in these groups across reference, retired, and currently impacted sites appeared to reflect regression to early successional plant communities in currently cultivated sites and subsequent partial recovery from disturbance in retired sites, which are common effects of cultivation in depressional wetlands (Stewart and Kantrud 1971) and upland sites (Tilman 1988).

Perennial species were less abundant on cultivated sites than either reference sites or retired sites. Annuals were a major component of communities on currently cultivated sites, a minor component on reference sites, and virtually absent from retired sites. Physical disruption of the soil and vegetation creates openings ideal for the establishment of annuals (Peterson et al. 1996, Tilman 1988, Millar 1973). Annuals are early successional species and are often the most important species in plant communities immediately following tillage (Peterson et al. 1996, Tilman 1988). In the wetlands I studied, annuals were most abundant on currently cultivated sites but weedy perennials were more than twice as abundant as annuals on these sites.

Vegetation of retired sites reflected successional processes. The complete dominance by perennials appeared to result from succession, not seeding. Although the

field these sites occupied was seeded back to tame grasses and legumes when retired (J. Grant, 1997, personal communication), the seeded species did not dominate retired sites. Eighty-five percent of grass cover was *Phalaris arundinacea* and no legumes were present on these sites. It is possible that wetland areas were not seeded or that upland grasses were seeded but failed to establish or survive in the saturated soil of the wetlands.

The rarity of annuals on retired sites implies that annuals have declined since cultivation stopped. Constant disturbance by cultivation favors some annual species, while other annual species coexist in reference sites. When cultivation ceased, populations of annual species that increased with frequent disturbance by cultivation presumably were eliminated by competition, mortality, and low reproduction. Rapid successional changes such as this are common following cessation of disturbance (Tilman 1988). Strong dominance of retired sites by *Typha latifolia*, *Phalaris arundinacea*, *Eleocharis palustris* and *Juncus balticus* may exclude annuals that are common in reference sites.

Species richness followed a pattern similar to annuals and consistent with successional processes. Richness was similar on reference and cultivated sites but was halved on retired sites. While cultivation did eliminate some species, it also allowed different species to establish, hence the similar number of species between reference and cultivated sites. However, when cultivation halted, the number of annual species declined drastically. Other researchers have observed that the cessation of cultivation of potholes is followed by a progressive decrease in the number of species as small, rapidly growing annuals are excluded (Walker and Coupland 1970).

Native perennials differed much more between reference and cultivated sites than perennials in general. Perennials made up 80% of cover or more in all land uses; relative abundance of all native species did not differ significantly among land uses, although native perennials comprised over 60% of cover in reference and retired areas but less than 30% of cover in cultivated areas. Because native and exotic annuals and early successional perennials can exploit disturbed sites, cultivation can result in smaller increases in exotic species than might be expected. Different native species were abundant under different land uses. For example, the native annual *Eleocharis ovata* was one of the most prevalent annuals on cultivated sites. Dix and Smeins (1967) note that cultivated depressions are often mudflats during the first few years after disturbance and provide excellent seedbeds for weedy species, both native and introduced.

Weedy species did not increase with cultivation because reference sites had a relatively high proportion of weeds, not because weeds were uncommon on disturbed sites. High weed cover on reference sites was possibly due to a highway bordering one side of the pasture and some other human disturbance in the surrounding area. Some grasses adapted to disturbance did increase with disturbance in the Ninepipe area. *Agropyron* spp., primarily *A. repens*, *A. smithii*, and some *A. trachycaulum*, increased with disturbance in the Ninepipe area. All three species are rhizomatous. *A. repens* is a notorious, aggressive weed (Hitchcock and Cronquist 1973) and frequently dominates abandoned fields early in succession (Tilman 1988, Samuel and Hart 1994). *A. smithii* is well known for its rapid increase on abandoned cultivated fields in the western U.S., particularly in swales and other moist areas (Samuel and Hart 1994).

The type of land use affecting a wetland can influence vegetation response. Species with persistent litter decreased from reference to currently cultivated sites in this study. *Typha latifolia* and *Juncus balticus*, the most abundant species with persistent litter on my sites, decreased from reference to cultivated sites. These two rhizomatous perennials accounted for half of the cover in reference and retired sites but only 7% of cover in cultivated sites. This decrease was opposite to my expectations based on the findings of the Minnesota Pollution Control Agency (MPCA).

The contrast between my results and those of MPCA may reflect the different types of disturbance studied. The main wetland impacts investigated by MPCA were poor water quality from stormwater drainage and agricultural runoff (M. Gernes, 1997, personal communication), rather than physical disturbance by cultivation. MPCA found that species with persistent litter increased with land use impacts, possibly due to increased nutrients or tolerance to other pollutants. *Typha* spp. has been found to increase in abundance when subjected to increased agricultural runoff (Gunderson and Loftus 1993, Koch and Reddy 1992). It is noteworthy, however, that species with persistent litter were a minor component in the single tilled wetland sampled by MPCA (M. Gernes, 1997, personal communication); this is consistent with my findings. These species may tolerate water quality changes but not direct physical disturbance by cultivation.

Moss, too, apparently cannot withstand physical disturbance. Moss cover was lower on disturbed sites. In upland range, livestock trampling destroys cover provided by algae, moss, and lichens (Thurow 1991). Presumably a more severe disturbance, such as cultivation, has similar or greater effects. The number of non-vascular taxa (liverworts,

mosses, and lichens) is used as a metric by the MPCA. MPCA views the presence of these taxa as a sign of a relatively unimpacted wetland (M. Gernes, 1997, personal communication).

While the many vegetation changes in the Ninepipe area suggested strong influence by land use, there were fewer clear changes in the Ovando area. At the level of life history and life form groups, currently grazed, retired, and reference wetlands were similar. All were dominated by grasslike perennials ($\bar{x} \geq 72\%$), mainly *Carex* spp., *Eleocharis* spp., and *J. balticus*. Perennials were $\geq 98\%$ of vascular plant canopy cover, and natives were $\geq 93\%$ of plant cover. Annuals averaged a fraction of one percent for each land use.

In the Ovando area, the relative abundance of the three most dominant species present on each site differed between reference and currently grazed wetlands. On currently grazed sites, the top three dominants made up over 80% of the total vegetative cover compared to 66% on the reference sites. Increased dominance by a few species reduces the value of common diversity indices (Magurran 1988). Moderate grazing sometimes enhances species diversity (Bakker and Ruyter 1981).

Both *J. balticus* and *Poa pratensis* are thought to increase under grazing, though responses depend on site hydrology and other conditions (Hansen et al. 1995). Kantrud et al. (1989) and Stewart and Kantrud (1972) list *J. balticus* as common on grazed sites in the prairie potholes region. In the wetlands I studied, *J. balticus* was lower on grazed than reference sites and *P. pratensis* did not differ.

The lower abundance of *Eleocharis palustris* on retired sites compared to reference sites contradicts reports that *Eleocharis palustris* increases in dominance under

moderate grazing (Walker and Coupland 1970). It is unlikely that once established *E. palustris* would decline dramatically when grazing ceased on retired sites, because it is an important dominant in undisturbed sites in the prairie pothole region as well as increasing with grazing disturbance (Walker and Coupland 1970). Hansen et al. (1995) describe *E. palustris* as an early colonizer that also persists in wetlands. *E. palustris* tended to increase on currently cultivated sites, which, although not statistically significant, is more consistent with the views of Hanson et al. (1995) and Walker and Coupland (1970).

The genus *Carex* was significantly greater on retired than reference sites. Again, this finding was counter to my expectations. The MPCA concluded that high relative abundance of the genus *Carex* indicates a relatively undisturbed wetland (Mark Gernes, 1997, personal communication). It is possible that the environmental differences between reference and retired sites in the Ovando area influenced the relative abundances of the genus *Carex* and *Eleocharis* in the retired sites.

When I grouped and examined species that other researchers have observed to increase in abundance with tillage or grazing, I found no significant difference between reference and retired or currently impacted sites. This may reflect floristic differences between my sites and the study areas of other researchers, despite the fact that studies examined were taken from the glaciated plains areas of the Dakotas and Canada. Because many species on my sites could not be identified as either increasing, decreasing, or not responding to tillage or grazing, the ability to use these groups to discern differences between land use groups was probably reduced.

Vertical Distribution of Vegetation

Vertical distributions of many species appeared to shift to lower elevations at disturbed sites. The observed boundary between wetland and upland communities, as defined by vegetation, was lower (closer to wetland water surface) in retired and currently used sites compared to reference sites in both study areas. Mean elevations of a significant majority of species were lower in currently impacted sites than reference sites. Grasses and forb species did not shift consistently in one direction, but grasslike species, which were almost a third of the species statistically tested, all shifted downward in mean elevation on impacted sites.

This analysis excluded the higher elevations that were present in the reference wetlands but absent in disturbed sites. If the full range of elevations present in the reference sites were included in the analysis, the shift would have been more pronounced. Lower mean elevations of species in the currently cultivated and grazed sites may be due to disturbance at the edges of the wetlands. Higher elevations are drier and therefore more accessible to both farm machinery and cattle. Cultivation, trampling, and herbivory by livestock may damage plants (Walker and Coupland 1967, Spaeth et al. 1996) and eliminate some species from higher elevations. In the Dakotas, the upper wet meadow area of depressional wetlands is most easily and heavily disturbed (Peterson et al. 1996).

Vertical distributions did not differ significantly between reference and retired sites. Vegetation on retired sites may not have significantly altered distribution because wetland plants may have been able to recolonize higher elevation, disturbed areas with suitable environments.

These results may indicate that recovery from impacts is also related to the duration and frequency of inundation annually and over long-term hydrologic cycles. The upper areas are subject to more frequent impacts than lower areas that are exposed to disturbance less often. Farther in the wetland the soil is saturated more often and therefore is accessible to disturbance less often.

It is possible that there is a level of repeated physical impact with which the soil structure or microsite hydrology is changed irreversibly, preventing or retarding recolonization by wetland species. The reduced extent of wetland vegetation in cultivated and retired sites may reflect such frequent or severe disturbance. Changes in vegetation during recovery are most likely at elevations exposed to disturbance but not altered irreversibly. The similarity of distributions between reference and previously impacted sites may reflect recovery in areas with moderate levels of disturbance.

Conclusion

Results suggest that vegetation in depressional wetlands in western Montana is altered substantially by cultivation and to a lesser degree by grazing. Differences in vegetation cannot be attributed to land use with certainty in observational studies such as this one. However, background variability among study wetlands was limited by study design and site selection, and background variation was evaluated during the study. The most important environmental controls on depressional wetland vegetation–hydrologic regime and salinity–were similar across all sites.

Long-term hydrologic variation related to climate is an important factor that works over much longer time scales than investigated in this study. Because vegetation may not adjust immediately to water level changes related to climate cycles, associations between site hydrology and vegetation can appear inconsistent during these extended changes (Kantrud et al. 1989). In this study, distributions of plant species relative to water depth and other hydrologic indicators appeared to be consistent with known relationships. However, interpretation of patterns of vegetation would be aided by better understanding of how long-term hydrologic fluctuations influence vegetation.

Effects of land use on vegetation were more likely from direct effects of physical disturbance than from indirect effects of elevated nutrient concentrations in the water or sediment. I based this conclusion on the magnitude of observed physical disturbance compared to the relatively small differences in nutrient concentrations among land uses. Furthermore, changes in vertical distribution of species may reflect greater intensity of physical disturbance in the drier, outer portions of these wetlands.

It is important to recognize that the low level of fertilization in the Ninepipe area was atypical of most cultivated fields and that levels of nutrients observed in the grazed areas may have not reflected conditions in more heavily grazed areas. Investigation of more typical cultivated areas with higher fertilization rates would provide a better test of possible nutrient impacts. Indirect effects of nutrient inputs may alter the direct effects of physical disturbance on vegetation. Some species may respond differently to these different types of disturbance. Contrasting responses of the same species in this study compared to those of MPCA could reflect the relative importance of physical disturbance and nutrient enrichment in each study area. Understanding effects of nutrient enrichment

on vegetation would provide more complete information on the range of impacts caused by agricultural land use.

Currently impacted wetlands sampled in the Ovando area were subjected to relatively moderate levels of grazing. This may be one reason that few differences in vegetation were found among land uses in the Ovando area. Additionally, 15 years may have allowed substantial recovery from the relatively heavy grazing that took place on the retired sites. My results did not provide evidence of major impacts by grazing. Well-managed grazing may not damage vegetation substantially beyond short-term impacts and the potential recovery may be good even after heavy grazing. However, research with better understanding and control of grazing histories and with better interspersion of land uses is needed to verify these interpretations.

While cultivated and grazed areas both experienced physical disturbance, the differing intensity of disturbance between cultivation and grazing were also probably important in this study. Cultivation had major effects on vegetation, resulting in early successional conditions in currently cultivated sites. Grazing appeared to have much weaker effects on vegetation than cultivation. Grazing generally is not as damaging as cultivation; Walker and Coupland (1967) state that cultivation is by far the most drastic type of disturbance affecting prairie wetlands. Consequently, it may be more difficult to quantitatively discern effects of grazing than cultivation.

Selection of appropriate reference sites is important and sometimes controversial. I interpret my results as evidence that land use differences can be detected even when reference sites are not pristine. One concern in interpreting results in the Ninepipe area is that the isolated quarter section of native pasture containing reference wetlands appeared

to be affected by surrounding land use. The similar abundance of weedy species on reference, retired, and currently cultivated sites may indicate some human influence in reference sites. Vegetation in the reference site closest to the highway consistently diverged from other reference sites, possibly reflecting subtle disturbance or opportunities for colonization by ruderal species. Given the relatively high population levels and extensive cultivation in the Mission Valley, these were the least disturbed reference sites available in the area. Despite these limitations of reference sites, which would be expected to make them more like the impacted wetlands, many differences in vegetation were found. On the other hand, moderate levels of grazing may have made differences in vegetation less obvious, and any impacts to reference areas such as grazing by elk would further obscure land use effects.

Vegetation on sites retired from cultivation and grazing did not represent a simple quantitative intermediate between reference and currently impacted wetlands. Vegetation in previously cultivated areas was consistent with literature describing early stages of succession after cultivation ceases. This is not surprising but complicates use of vegetation to evaluate impacts. The effects of time since disturbance on potential indicators of biological condition need more research.

RECOMMENDATIONS

The results of this study suggest that land use impacts affect vascular plant community composition in a measurable and ecologically rational way in depressional wetlands in western Montana. Vascular plants show good potential for use as metrics to assess wetland condition and human influence in wetlands. Because changes in vegetation were greater for cultivation than grazing, plant-based metrics are more likely to succeed in assessing impacts of cultivation.

While the statistical evaluation of ecological differences is a more conventional way to examine ecological data, graphical evaluation is often used by applied ecologists during initial development of bioindicators (Karr and Chu 1997). According to this perspective, biological trends may be discerned from visual interpretation of graphs even when they are not reflected in statistical results. This approach essentially uses non-statistical criteria to identify potential metrics.

In addition to the variables that showed statistically significant differences among land uses, some other groups and species showed promise as metrics when evaluated graphically. These groups are discussed below. The additional groups and species discussed in this section were selected based on the number of sites with values that overlapped between reference and currently impacted groups. A group was selected if not more than one reference site overlapped with more than one currently impacted site. This graphical criterion was selected because the most valuable quality of a metric is to clearly and consistently distinguish between reference and impacted sites.

Most of the groups identified using this criterion were also significantly different statistically; these groups were discussed in the previous chapter. Here I only discuss the additional groups and species identified that did not show statistically significant differences between reference and currently impacted sites. This includes groups that did not differ in pairwise comparisons between land uses and groups for which the median test was used, which did not allow pairwise comparisons. Differences between reference and currently impacted sites are emphasized because they showed impacts most clearly and logically and because interpretation of retired sites is complicated by lack of information about site history. In addition, retired sites in the Ovando area were separated from reference sites by a considerable distance.

In the Ninepipe area, several additional groups and species were identified. Relative abundance of annual species a showed clear increase from reference to currently cultivated sites. This increase is consistent with research from the glaciated northern plains, where annuals increased in tilled depressional wetlands (Peterson et al. 1996, Millar 1973).

There was a clear increase in the relative abundance of *Agropyron* spp. from reference to cultivated sites, with low overlap between land use groups. This genus was composed primarily of *A. smithii*, *A. repens*, and smaller amounts of *A. trachycaulum*. These species are all rhizomatous, and as discussed in the previous chapter, *A. smithii* and *A. repens* are aggressive colonizers of disturbed sites. *Phalaris arundinacea* also showed low overlap between reference and currently cultivated sites. *P. arudinacea* is an invasive grass that can alter its form and mode of reproduction in response to

environmental conditions (Galatowitsch and McAdams 1994). This grass can exploit disturbed conditions in a way similar to the *Agropyron* group.

Eleocharis spp. increased from reference to currently cultivated sites. This increase was driven primarily by increases in *E. ovata* and *E. palustris*. *E. ovata* showed clear separation between land uses. *E. ovata* is a native annual that likely increased in response to the disturbance in the cultivated sites. Although differences in *E. palustris* were not statistically significant and values overlapped, the mean value for the currently cultivated sites was 50% greater than the reference sites.

In the Ovando area, fewer species or groups were identified graphically. *E. palustris* clearly increased from reference to currently grazed sites. This finding is consistent with reports that *E. palustris* increases with grazing in prairie potholes (Walker and Coupland 1970).

The relative abundance of the two most dominant species was greater on grazed than reference sites, corroborating the statistically significant increase in dominance shown by the three most dominant species. As discussed in the previous chapter, increased dominance contradicts research suggesting grazing increases diversity of vegetation in wetlands (Bakker and Ruyter 1981).

Utricularia vulgaris showed low overlap between groups, increasing in relative abundance with grazing. In contrast, the Minnesota Pollution Control Agency considers the presence of this species indicative of relatively unaltered sites (M. Gernes, 1997, personal communication). Differences between my results and those of MPCA may reflect differences in the dominant type of disturbance between the two studies. Impacted sites sampled by MPCA were influenced mainly by changes in water quality. Because *U.*

vulgaris is a submergent species, it would likely be more sensitive to water quality changes than most emergent species that dominated my sites. Submergent species respond to water quality more than emergent species (Adamus and Brandt 1990).

Recommended Metrics

Most, though not all, metric recommendations are based on results for cultivated areas in the Ninepipe area. Response of each potential metric is discussed in terms of relative abundance based on statistical results and graphical evaluation. Words in parentheses indicate whether the recommendation is based on findings for cultivation or grazing. Most responses are also supported by research literature.

(1) **Annual species.** (Cultivation) The increase in annuals indicates physical disturbance that shifts plant community composition to an earlier successional state. This result is well-supported by literature documenting that physical disturbance often promotes an increase in annual species (Tilman 1988).

(2) **Native perennial species.** (Cultivation) Native perennial species decrease on physically disturbed sites. This group shows the effects of physical disturbance even more clearly than annuals, perennials, or native species.

(3) ***Eleocharis.*** (Cultivation and grazing) The genus *Eleocharis* includes *Eleocharis* species that were found to increase with disturbance in this study, including *E. palustris* and *E. ovata*, as well as species reported by other researchers to increase with cultivation and grazing, such as *E. acicularis* (Stewart and Kantrud 1989, Millar 1973, Walker and Coupland 1970).

(4) **Moss (or all non-vascular ground taxa: moss, lichens, liverworts).** (Cultivation) Mosses appear not to tolerate cultivation. Moss was virtually absent from currently cultivated sites in the Ninepipe area.

(5) **"Aggressive" grasses.** (Cultivation) Several grasses in the Ninepipe area, including *Agropyron repens*, *A. smithii*, and *Phalaris arundinacea*, increased after cultivation and persisted on retired sites. These species are known to be aggressive colonizers of disturbed sites. Other species may warrant further investigation for inclusion in this group. For instance, Millar (1973) identifies *Alopecurus aequalis*, *Beckmannia syzigachne*, *Glyceria grandis*, and *G. pulchella* as species that increase in response to soil-exposing events, including cultivation.

(6) ***Juncus balticus.*** (Cultivation) *J. balticus* appears to decline substantially with cultivation. Verifying decline with other physical disturbance, including grazing, would increase its value as a metric. More work needs to be done to evaluate its response to grazing. Although my results indicated that *J. balticus* decreased with grazing, some authors report the opposite (Hansen et al. 1995, Stewart and Kantrud 1989).

Some species or groups that showed significant statistical differences or low overlap between land uses when graphed are not included here as potential metrics: species with persistent litter, relative abundance of the most dominant species, and *Utricularia vulgaris*. These groups may merit further investigation but warrant greater caution before being proposed as metrics. Of course, all groups proposed above need further research to verify and quantify responses to land use.

The group of species with persistent litter was not included because it is not well-defined, ecologically. Better understanding of the response of specific species in this group to disturbance is needed. Many of the species included are common emergents of undisturbed sites. Decomposition of their litter and their role in nutrient cycling needs to be examined further if this is to be a logical group. Relative abundance of the most dominant species in each wetland increased in currently grazed sites in the Ovando area. This opposes findings of Bakker and Ruyter (1981). There was no clear increase in the most dominant species in the currently cultivated sites. The response of *U. vulgaris* observed in this study was contradicted by MPCA researchers (M. Gernes, 1997, personal communication).

Two additional observations related to vegetation distribution may provide a basis for metrics, but need further research. Distributions of several species apparently shift downward with disturbance, while other opportunistic species tend to occupy areas vacated in upper elevations. This pattern makes sense because disturbance tends to be greatest in drier, outer areas. More research would be needed to identify disturbance-sensitive species that tend to be excluded from upper zones and opportunistic species that increase there. A metric might be based on the relative distribution of disturbance-sensitive and opportunistic species. Another possible metric related to elevation could be based on the mean elevations of grasslike species, which showed the most consistent differences among land uses. Lower mean elevations may indicate disturbance. It may be possible to compare elevation of grasslike species to species that tolerate disturbance. For either of these potential metrics, it would be important to evaluate contributing

species and to distinguish responses to hydrologic fluctuations from responses to disturbance.

Spectral greenness of vegetation also should be investigated. I observed more brown leaf matter on *Typha latifolia* on currently cultivated sites than in reference or retired sites. Production and biomass may also be useful measurements. *T. latifolia* in currently cultivated sites appeared to be shorter and less dense than on reference or retired sites. On the other hand, *T. latifolia* plants in retired sites were clearly taller than in the reference sites, possibly due to stimulation or thinning by past disturbance.

Conclusion

Overall, vegetation shows strong potential for use in a multi-metric index of biological integrity of depressional wetlands in this region. This study and other research have documented that certain features of vegetation respond consistently to physical disturbance. Because this study primarily investigated the impacts of physical disturbance, other studies are needed to learn how vegetation varies with other impacts, such as nutrient enrichment or sedimentation. If vegetation response to several types of disturbance is consistent, a robust index could be developed. Alternatively, different responses might be used to distinguish types of disturbance and levels of impairment. The potential metrics suggested above need to be measured on other sites to test them with independent data and to obtain more information on their range of variability in relation to land use intensity and other factors. Ultimately, controlled studies of

vegetation response to land use change are needed to provide insights not possible with observational studies.

Development of plant groups that clearly respond to human influence would also benefit from more systematic designation of the species included and excluded. Clear criteria for group inclusion must be determined and species meeting those criteria must be identified. Determinations should ultimately be based on controlled research rather than informal observation. Groups that would particularly benefit from such work include species with persistent litter, weedy species, and grazing and cultivation tolerant species.

One challenge to using a vegetation-based index is that it is difficult to select a single area that is truly representative of an entire wetland without introducing bias, even if the sampling area is selected randomly. Therefore, use of a systematic random sample around the entire perimeter of the wetland, similar to the approach used in this study, is needed to avoid bias and to obtain adequate coverage of natural variation in vegetation within a wetland. One possible approach is to use transects that extend radially from the center of the wetland and are sampled at regular intervals out to the edge of emergent vegetation. Vegetation may not need to be sampled across the open water portion of wetlands to use the potential metrics recommended above.

The fact that values of some variables, such as abundance of annuals, were not intermediate for retired sites complicates development of metrics to indicate different levels of biological integrity. Simple numerical scales may not be appropriate for some metrics. More studies need to be done to relate biological integrity and vegetation change to time since disturbance. Metrics should account for succession.

Long-term hydrologic fluctuations on these sites present a final challenge. Long-term studies need to be undertaken in this region to evaluate how vegetation and proposed metrics are influenced by natural variation. Studies need to deal with the practical issue of whether the sampling location needs to be adjusted for hydrologic variation and how lags in vegetation response to hydrologic cycles may affect distribution and composition of wetland vegetation.

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APPENDICES

APPENDIX A

WATER AND SEDIMENT DATA

Table 15. Physical and chemical characteristics of water collected in late June in depressional wetlands in the Ninepipe and Ovando areas. Numbered sites are categorized as Ninepipe (N) or Ovando (O) study areas and either Reference (RF), Retired (RT) or Current (C) land use groups. Reference, retired, and current refer to land use categories that are explained in the text. Electrical conductivity (EC), pH, and temperature were measured on site using a Horiba U-10 Water Quality Checker near the center of each wetland. Alkalinity was estimated by titration, which was performed within twelve hours after collecting water samples. Laboratory analysis was performed by the Soil Analytical Laboratory at Montana State University, Bozeman. Electrical conductivity is reported in uS/cm, which is directly equivalent to umhos/cm. Phosphate (PO_4) values below 0.01, and nitrate (NO_3) and ammonium (NH_4) values below 0.1 have a lower analytical accuracy than data above those values.

Area	Group	Site	pH	EC	Temp.	Alkalinity	NO_3	NH_4	P	PO_4	Ca	Cl	Fe	K	Mg	Mn	Na	S	Si	SO_4
				uS/cm	°C	mg $CaCO_3$/L	----------mg/L----------													
N	RF	1	7.6	675	27.1	340	0.07	0.12	1.27	2.89	10.6	11.20	1.59	11.5	12.7	0.13	136.1	4.92	14.6	10.81
N	RF	3	6.7	290	17.9	138	0.02	0.05	0.48	0.64	10.9	8.32	2.98	12.3	5.3	0.68	42.9	1.12	2.4	0.75
N	RF	4	6.4	250	18	110	0.02	0.07	0.25	0.30	7.7	7.50	1.41	16.0	3.4	0.24	36.8	1.49	1.5	1.58
N	RF	5	7.1	586	20.1	283	0.06	0.13	2.27	5.33	6.2	14.00	2.48	9.3	4.1	0.44	131.9	2.54	8.6	1.92
N	RT	7	6.5	270	16.7	118	0.01	0.20	0.76	0.45	6.2	8.45	3.63	15.8	3.8	0.43	39.0	0.97	3.8	1.09
N	RT	8	6.5	238	17.2	105	0.08	0.11	0.36	0.23	6.6	7.30	2.28	12.9	3.6	0.31	33.3	1.20	1.0	1.12
N	RT	9	6.8	259	17.5	113	0.01	0.09	0.51	0.37	7.7	6.18	2.57	16.0	3.7	0.15	35.9	1.53	2.6	1.97
N	RT	10	6.8	328	23.7	133	0.02	0.14	0.58	0.29	6.8	9.85	3.28	15.2	4.4	0.29	56.9	1.76	2.0	1.67
N	C	11	7.6	581	17.3	273	0.02	0.08	0.97	1.70	17.3	15.70	1.54	22.5	8.7	0.1	96.1	2.87	9.6	5.46
N	C	12	7.1	560	18.7	258	0.02	0.18	1.48	2.21	17.5	13.70	3.25	33.4	10.6	0.6	74.1	1.75	17.4	1.69
N	C	13	6.7	240	20.7	110	0.02	0.13	0.62	0.32	8.9	6.66	4.18	18.0	4.4	0.56	28.9	1.64	17.0	2.14
N	C	14	6.9	274	23.1	118	0.03	0.05	0.27	0.27	6.9	10.65	1.41	21.9	4.5	0.17	35.3	1.11	13.4	0.40
O	RF	15	7.4	381	19.8	193	0.00	0.03	0.08	0.00	51.1	0.90	0.03	5.1	12.0	0.01	4.3	0.27	5.5	0.25
O	RF	16	7.5	784	24.3	350	0.02	0.07	1.01	1.60	58.2	13.85	0.04	32.6	38.5	0.11	32.3	15.59	29.0	43.15
O	RF	17	7.5	453	25.4	225	0.02	0.03	0.13	0.00	32.1	2.64	0.10	21.7	27.4	0.08	8.8	0.56	6.3	0.52
O	RF	18	7.0	492	16	255	0.00	0.01	0.13	0.00	49.5	1.38	0.05	4.6	26.9	0.06	5.5	1.18	8.9	2.15
O	RT	19	7.3	688	17.9	330	0.02	0.02	0.15	0.00	64.2	6.00	0.01	9.6	33.1	0.05	19.7	7.08	8.0	17.98
O	RT	20	7.3	664	13.7	295	0.02	0.01	0.15	0.00	64.3	4.27	0.01	4.0	27.9	0.02	17.4	9.77	7.3	21.78
O	RT	21	7.5	698	14.5	335	0.01	0.01	0.14	0.00	67.0	5.52	0.01	5.1	31.5	0.01	24.6	10.03	4.9	27.30
O	RT	22	7.1	577	15.1	290	0.01	0.02	0.17	0.00	65.2	2.72	0.05	8.1	24.1	0.06	10.1	2.13	13.2	4.24
O	C	23	7.4	683	15.4	333	0.02	0.03	0.08	0.00	68.9	5.02	0.02	20.8	32.7	0.06	10.0	1.36	30.0	1.87
O	C	24	6.7	229	15.8	108	0.02	0.05	0.08	0.00	25.9	2.30	0.11	6.5	8.5	0.1	2.8	0.28	12.7	0.16
O	C	25	6.9	390	17.4	183	0.01	0.02	0.13	0.00	45.2	3.67	0.06	8.3	13.7	0.08	4.3	0.75	12.9	0.97
O	C	26	7.5	499	18.8	230	0.02	0.03	0.09	0.00	52.4	4.33	0.06	16.1	20.9	0.11	7.1	0.77	19.0	0.96

* PO_4 values are reported as total molecular mass of phosphate per liter. To convert to phosphorus as phosphate, multiply by 0.33. NO_3 and NH_4 are reported as mass of nitrogen per liter, and all other values are reported as mass per liter.

Table 16. Physical and chemical characteristics of water collected in early July in depressional wetlands in the Ninepipe and Ovando areas. Numbered sites are categorized as Ninepipe (N) or Ovando (O) study areas and either Reference (RF), Retired (RT) or Current (C) land use groups. Reference, retired, and current refer to land use categories that are explained in the text. Electrical conductivity (EC), pH, and temperature were measured on site using a Horiba U-10 Water Quality Checker near the center of each wetland. Alkalinity was estimated by titration, which was performed within twelve hours after collecting water samples. Laboratory analysis was performed by the Soil Analytical Laboratory at Montana State University, Bozeman. Electrical conductivity is reported in uS/cm, which is directly equivalent to umhos/cm. Phosphate (PO_4) values below 0.01, and nitrate (NO_3) and ammonium (NH_4) values below 0.1 have a lower analytical accuracy than data above those values.

Area	Group	Site	pH	EC	Temp.	Alkalinity	NO_3	NH_4	P	Ca	Fe	K	Mg	Mn	Na	S	Si
				uS/cm	°C	mg $CaCO_3$/L	mg/L										
N	RF	1	7.3	750	17.8	350	0.04	0.08	1.12	13.6	0.73	10.5	14.6	0.08	135.1	4.04	12.7
N	RF	3	6.8	305	19.6	123	0.03	0.05	0.36	10.9	2.61	12.5	5.3	0.37	42.3	1.06	0.3
N	RF	4	7.2	240	25.1	110	0.03	0.06	0.26	7.9	1.84	13.4	3.3	0.19	35.8	1.33	0.5
N	RF	5	7.2	582	21.7	273	0.08	0.16	2.34	6.5	2.44	8.0	4.1	0.56	130.6	2.53	6.3
N	RT	7	6.5	263	19.6	113	0.03	0.12	0.67	6.0	2.80	15.6	3.8	0.42	38.5	0.96	1.7
N	RT	8	6.5	232	22.4	98	0.02	0.07	0.34	6.7	2.11	12.3	3.7	0.57	32.6	1.13	0.3
N	RT	9	6.6	261	26.8	115	0.07	0.11	0.60	7.9	2.81	15.8	3.9	0.19	36.5	1.53	1.1
N	RT	10	6.9	335	20.5	138	0.05	0.10	0.61	6.7	3.32	14.7	4.3	0.42	55.3	1.73	1.5
N	C	11	8.4	640	17.4	288	0.04	0.14	1.13	19.2	2.04	21.6	9.4	0.67	101.9	2.35	4.8
N	C	12	6.9	600	18.0	253	0.04	0.08	1.47	18.5	3.38	35.2	11.0	0.60	78.8	1.56	9.9
N	C	13	6.5	274	18.0	113	0.03	0.07	0.92	10.4	5.92	19.0	4.9	1.01	30.8	1.46	16.2
N	C	14	6.7	301	21.2	110	0.03	0.03	0.34	7.6	1.46	23.5	4.8	0.17	37.2	1.18	11.8
O	RF	15	7.9	337	22.1	165	0.01	0.01	0.05	44.4	0.01	5.5	12.2	0.01	4.3	0.23	3.8
O	RF	16	7.7	811	23.9	348	0.01	0.06	0.81	60.3	0.02	35.0	41.0	0.07	34.2	15.35	31.0
O	RF	17	6.9	466	18.5	223	0.01	0.04	0.20	33.5	0.16	23.3	28.4	0.33	9.2	0.47	5.9
O	RF	18	7.4	484	20.6	235	0.01	0.08	0.11	48.2	0.05	4.5	29.4	0.04	6.0	0.93	3.7
O	RT	19	7.5	669	23.5	315	0.01	0.03	0.08	66.5	0.01	9.4	34.7	0.03	20.1	6.75	5.9
O	RT	20	7.0	654	14.7	290	0.01	0.05	0.11	65.9	0.01	5.1	33.1	0.02	19.0	11.66	5.8
O	RT	21	7.4	695	16.7	328	0.00	0.04	0.13	68.3	0.02	5.6	34.3	0.01	27.0	8.80	3.8
O	RT	22	7.1	587	22.3	288	0.01	0.01	0.13	68.3	0.04	8.3	26.4	0.07	10.9	1.87	12.8
O	C	23	8.1	668	26.7	323	0.01	0.03	0.12	70.1	0.01	21.3	35.1	0.02	11.0	1.24	31.2
O	C	24	7.5	235	26.4	110	0.01	0.06	0.09	27.6	0.07	6.7	9.1	0.06	3.0	0.30	13.0
O	C	25	7.5	370	23.8	170	0.01	0.04	0.10	46.2	0.04	8.5	14.6	0.03	4.5	0.70	10.6
O	C	26	7.8	490	20.3	238	0.01	0.07	0.15	53.7	0.05	16.3	21.8	0.06	7.4	0.75	19.1

* PO_4 values are reported as total molecular mass of phosphate per liter. To convert to phosphorus as phosphate, multiply by 0.33. NO_3 and NH_4 are reported as mass of nitrogen per liter, and all other values are reported as mass per liter.

Table 17. Physical and chemical characteristics of water collected in late August in depressional wetlands in the Ninepipe and Ovando areas. Numbered sites are categorized as Ninepipe (N) or Ovando (O) study areas and either Reference (RF), Retired (RT) or Current (C) land use groups. Reference, retired, and current refer to land use categories that are explained in the text. Electrical conductivity (EC), pH, and temperature were measured on site using a Horiba U-10 Water Quality Checker near the center of each wetland. Alkalinity was estimated by titration, which was performed within twelve hours after collecting water samples. Laboratory analysis was performed by the Soil Analytical Laboratory at Montana State University, Bozeman. Electrical conductivity is reported in uS/cm, which is directly equivalent to umhos/cm. Phosphate (PO_4) values below 0.01, and nitrate (NO_3) and ammonium (NH_4) values below 0.1 have a lower analytical accuracy than data above those values.

Area	Group	Site	pH	EC	Temp.	Alkalinity	NO_3	NH_4	P	PO_4	Ca	Fe	K	Mg	Mn	Na	S	Si
				uS/cm	°C	mg $CaCO_3$/L	mg/L											
N	RF	1	7.67	840	21.9	415	0.05	0.06	0.96	2.07	17.9	0.35	13.2	18.7	0.12	172.0	4.60	8.6
N	RF	3	6.35	370	17.5	160	0.05	0.14	0.35	0.09	13.6	3.34	15.3	6.7	0.31	55.0	1.27	2.4
N	RF	4	6.62	280	20.5	130	0.04	0.10	0.43	0.33	9.0	2.94	14.4	3.7	0.66	48.6	1.68	1.1
N	RF	5	7.37	810	19.4	383	0.11	0.18	2.73	6.06	8.8	3.25	10.1	5.3	0.50	198.0	4.12	6.5
N	RT	7	6.59	320	18.3	140	0.03	0.06	0.77	0.48	5.7	3.73	19.5	4.6	0.34	51.7	1.54	3.1
N	RT	8	6.55	260	18.4	110	0.02	0.05	0.39	0.12	5.4	3.04	13.3	4.3	0.36	41.8	1.31	1.3
N	RT	9	6.85	280	24.3	128	0.03	0.17	0.48	0.38	8.0	2.30	16.9	4.1	0.48	48.4	1.74	2.1
N	RT	10	7.83	430	20.1	178	0.04	0.06	0.56	0.28	8.6	3.74	19.9	5.5	0.81	78.3	2.19	0.7
N	C	11	6.52	830	19	363	0.04	0.08	0.62	0.66	24.3	1.10	27.0	12.8	0.28	142.4	2.12	2.5
N	C	12	7.21	840	19.3	370	0.05	0.22	1.35	1.39	24.7	3.05	50.0	15.6	1.86	128.8	2.15	5.6
N	C	13	6.84	340	22.8	148	0.03	0.09	1.35	0.47	13.4	8.39	23.3	6.2	1.14	45.8	1.73	16.5
N	C	14	7.05	420	23.6	170	0.03	0.12	1.06	0.59	10.4	5.16	34.3	6.3	1.38	60.9	2.03	8.5
O	RF	15	7.56	346	18.70	168	0.19	0.09	0.04	0.00	45.4	0.01	6.5	13.9	0.01	4.7	0.28	9.4
O	RF	16	8.08	879	24.20	408	0.03	0.06	0.18	0.08	64.3	0.01	43.5	51.2	0.02	42.9	15.77	31.4
O	RF	17	6.50	542	16.10	260	0.03	0.44	0.44	0.67	38.3	0.15	31.6	32.4	0.33	11.1	0.68	3.5
O	RF	18	7.97	402	15.30	203	0.02	0.05	0.06	0.28	28.5	0.02	5.3	31.0	0.01	6.8	0.47	0.1
O	RT	19	7.34	683	16.70	340	0.02	0.45	0.06	0.00	67.5	0.01	10.4	37.6	0.01	21.4	5.96	1.1
O	RT	20	7.27	726	18.90	365	0.01	0.02	0.05	0.00	82.9	0.03	7.2	42.8	0.05	24.5	13.82	5.5
O	RT	21	6.94	745	13.70	358	0.02	0.38	0.06	0.00	77.5	0.03	5.3	36.7	0.03	27.9	7.22	2.0
O	RT	22	7.05	625	19.40	320	0.03	0.06	0.06	0.00	72.1	0.04	9.6	30.0	0.07	12.3	1.59	10.5
O	C	23	7.30	716	15.20	363	0.02	0.10	0.08	0.00	65.4	0.01	21.9	39.9	0.03	12.5	1.05	30.7
O	C	24	6.84	241	20.40	120	0.02	0.03	0.11	0.00	29.1	0.07	7.4	10.2	0.05	3.3	0.27	17.0
O	C	25	6.89	391	15.60	193	0.02	0.28	0.06	0.00	47.8	0.05	9.3	16.0	0.04	4.9	0.50	8.2
O	C	26	7.22	525	19.00	258	0.01	0.07	0.08	0.00	54.6	0.03	18.5	23.9	0.02	8.1	0.70	13.4

* PO_4 values are reported as total molecular mass of phosphate per liter. To convert to phosphorus as phosphate, multiply by 0.33. NO_3 and NH_4 are reported as mass of nitrogen per liter, and all other values are reported as mass per liter.

Table 18. Physical and chemical characteristics of sediment in depressional wetlands in the Ninepipe and Ovando areas. Nutrient and geochemical concentrations were determined by the Soil Analytical Laboratory at Montana State University, Bozeman from samples collected in late June. Texture, EC, and pH were determined using standard laboratory methods from samples collected in early July.

Area	Group	Site	pH	EC	TKN	NH_4	NO_3	Na	Ca	Mg	P	clay	sand	silt
				uS/cm	% N	mg/kg						%		
N	RF	1	9.0	2,043	0.37	28	2	712	2462	440	29	38	22	40
N	RF	3	7.6	369	0.73	15	17	82	11320	1080	16	29	43	28
N	RF	4	7.4	223	0.59	58	4	272	1458	880	31	42	32	25
N	RF	5	8.6	1,462	0.50	45	14	1184	1698	1060	43	34	27	39
N	RT	7	7.8	461	0.42	82	3	250	1294	1880	60	32	35	33
N	RT	8	7.3	423	0.47	59	5	224	1456	1840	38	35	27	38
N	RT	9	7.3	340	0.52	125	9	162	1422	1260	52	39	41	20
N	RT	10	7.5	659	0.39	81	2	382	1092	580	53	25	46	28
N	C	11	8.2	822	0.35	40	2	448	1850	1660	45	35	29	36
N	C	12	7.8	656	0.49	64	9	392	1466	1020	52	17	20	63
N	C	13	7.4	358	0.34	79	2	134	1270	700	77	16	27	56
N	C	14	7.6	490	0.64	64	14	200	1540	860	51	45	26	29
O	RF	15	7.8	320	0.52	13	10	44	5124	880	9	48	11	40
O	RF	16	8.5	780	0.81	53	21	96	10480	1260	40	48	18	34
O	RF	17	7.6	270	0.73	65	10	70	3306	306	84	41	12	47
O	RF	18	7.9	500	0.87	36	15	46	5322	558	32	45	23	32
O	RT	19	8.4	540	1.12	26	14	136	10720	330	17	48	11	40
O	RT	20	8.2	720	1.16	7	37	180	11960	318	39	35	18	48
O	RT	21	8.1	460	1.05	9	18	148	13280	276	17	45	10	45
O	RT	22	8.4	440	0.49	46	10	1068	1662	274	45	48	13	40
O	C	23	8.1	500	1.38	37	42	88	9220	482	23	38	10	53
O	C	24	7.9	290	1.43	39	25	56	6600	394	19	41	10	49
O	C	25	8.2	450	0.93	42	16	62	11320	226	25	47	9	45
O	C	26	7.5	360	0.61	14	7	72	8040	418	15	38	13	49

APPENDIX B

VEGETATION DATA

Table 19. Relative abundance of plant species in depressional wetlands in the Ninepipe and Ovando areas. Plant cover data collected in late August. Numbers 1-103 are canopy species; numbers 200-217 are ground cover and surface categories. Species codes are defined in Table 20.

Species Number	Species Code	Wetland Sites																							
		1	3	4	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	ALI PLA	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	SAG CUN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
3	CIC DOU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	SIU SUA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
5	ART BIE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	ART LUD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	AST JUN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
8	BID CER	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	CIR ARV	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.15	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00
10	GNA PAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	LAC SER	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	SON ASP	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	ROR PAL	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	THL ARE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	DRE SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.10	0.02	0.00	0.00	0.00	0.00	0.00
16	DIA ARM	0.01	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	CHE SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	CAR ATH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.02	0.45	0.23	0.30	0.00	0.32	0.78	0.22	0.33	0.50	0.53
19	CAR ATHR	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	CAR LAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.00
21	CAR MIC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	CAR NEB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00
23	CAR ROS	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.78	0.17	0.00	0.00	0.00	0.00	0.00
24	CAR SPP.	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.01	0.20	0.14	0.00	0.03	0.00	0.00	0.10	0.05	0.01	0.00
25	ELE ACI	0.14	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00
26	ELE OVA	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.36	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	ELE PAL	0.00	0.15	0.16	0.13	0.13	0.01	0.20	0.22	0.07	0.21	0.01	0.39	0.14	0.56	0.14	0.11	0.05	0.06	0.01	0.04	0.60	0.42	0.16	0.17
28	ELE SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
29	SCI ACU	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.04	0.00	0.00	0.14	0.01	0.26	0.01	0.00	0.00	0.08	0.02
30	SCI MAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	DIP SYL	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	ELA CAL	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	EQU FLU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	EQU SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 19. (continued)

Species Number	Species Code	Wetland Sites																							
		1	3	4	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
35	EQU SYL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36	TRI HYB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	MYR SIB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	HIP VUL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	HYP PER	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	HYP FOR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	JUN BAL	0.23	0.31	0.00	0.41	0.27	0.00	0.00	0.27	0.00	0.00	0.05	0.00	0.10	0.24	0.09	0.03	0.02	0.05	0.07	0.01	0.02	0.05	0.02	0.00
42	JUN BUF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	JUN ENS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	JUN LON	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	TRI MAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	MEN ARV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.16	0.01	0.03	0.02	0.02	0.03	0.01	0.03	0.00
47	STA PAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	LEM MIN	1.00	0.74	0.21	0.00	0.15	0.22	0.00	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	UTR VUL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.06	0.00	0.02	0.01	0.01	0.03	0.10	0.00
50	EPI PAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
51	EPI CIL	0.03	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	AGR SMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	AGR SPP.	0.00	0.00	0.00	0.00	0.11	0.02	0.00	0.03	0.00	0.17	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	AGR TRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
55	AGR ALB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.10	0.00	0.00	0.02	0.00	0.01	0.00	0.08
56	AGR SCA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	AGR SPP.	0.00	0.00	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	ALO AEQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	ALO PRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
60	AVE FAT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	BEC SYZ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
62	BRO JAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	CAL NEG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
64	CAT AQU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
65	PHA ARU	0.06	0.08	0.49	0.00	0.24	0.70	0.22	0.00	0.63	0.33	0.43	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66	PHL PRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
67	POA PAL	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
68	POA PRA	0.09	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.00	0.02	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.00

Table 19. (continued)

Species Number	Species Code	Wetland Sites																							
		1	3	4	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
69	POA SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
70	POA TRI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
71	POL MON	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72	LIN SEP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
73	POL AMP	0.00	0.05	0.00	0.00	0.01	0.00	0.03	0.07	0.00	0.01	0.00	0.00	0.36	0.00	0.01	0.00	0.02	0.02	0.01	0.00	0.01	0.03	0.11	0.17
74	POL CON	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
75	POL DOU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
76	POL LAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
77	POL PER	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
78	RUM CRI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
79	RUM MAR	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	POL SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
81	POT GRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.14	0.00	0.00	0.00	0.14	0.00	0.02	0.06	0.02
82	POT PEC	0.28	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.04	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.00
83	CEN MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
84	RAN AQU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
85	RAN GME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
86	RAN SCE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87	RAN SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
88	RIC NAT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
89	GEU MAC	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	GEU SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
91	POT ANS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
92	POT GRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	POT RIV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94	ROS WOO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	GAL APA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	SAL EXI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
97	PEN SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	GRA NEG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99	PEN CON	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	SOL DUL	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
101	SPA SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
102	TYP LAT	0.33	0.06	0.34	0.20	0.23	0.20	0.55	0.41	0.10	0.07	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
103	VIO SPP.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 19. (continued)

Species Number	Species Code	Wetland Sites																							
		1	3	4	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
200	water	0.78	0.68	0.31	0.46	0.65	0.60	0.65	0.68	0.57	0.84	0.69	0.69	0.58	0.60	0.90	0.32	0.79	0.51	0.57	0.77	0.81	0.80	0.68	0.88
201	dry soil	0.03	0.13	0.04	0.35	0.00	0.05	0.00	0.00	0.02	0.04	0.01	0.03	0.00	0.00	0.02	0.06	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00
202	algae	0.17	0.08	0.00	0.00	0.03	0.11	0.32	0.16	0.04	0.05	0.13	0.01	0.32	0.06	0.00	0.06	0.07	0.12	0.06	0.01	0.12	0.01	0.11	0.04
203	litter	0.17	0.32	0.17	0.05	0.04	0.01	0.01	0.02	0.01	0.03	0.05	0.15	0.01	0.02	0.01	0.02	0.07	0.25	0.21	0.05	0.03	0.04	0.01	0.04
204	moss	0.08	0.26	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.01	0.03	0.01	0.01	0.00	0.00	0.00
205	sat. soil	0.11	0.03	0.14	0.00	0.09	0.00	0.00	0.04	0.01	0.05	0.11	0.10	0.00	0.04	0.06	0.07	0.00	0.01	0.00	0.01	0.00	0.00	0.03	0.00
206	unkn. submer.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
207	unkn. forb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
208	unkn. grass	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00
210	unkn. emer.	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
211	rock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
213	litter/wrack	0.00	0.00	0.10	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
215	bulrush litter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.09	0.00	0.00	0.00	0.00	0.00
216	cattail litter	0.42	0.21	0.01	0.03	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
217	woody debris	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00

Table 20. Species group designations for depressional wetlands in the Ninepipe and Ovando areas. X designates characteristics which were conflicting or could not be ascertained through the available literature.

Species Number	Species Code	Genus - Species[1]	Annual/ Perennial[1]	Native/ Non-native[1]	Grass/Grass-like/ Forb/Shrub	Weedy[1]	Persistent Litter[2]	Tillage Tolerant[3]	Grazing Tolerant[3]
			(A/P)	(N/NN)	(G/GL/F/S)	(W)	(P)	(T)	(G)
1	ALI PLA	*Alisma plantago-aquatica* L.	P	N	F			T	G
2	SAG CUN	*Sagittaria cuneata* Sheld.	P	N	F				
3	CIC DOU	*Cicuta douglasii* (DC.) Coult. & Rose	P	N	F	W			
4	SIU SUA	*Sium suave* Walt.	P	N	F				G
5	ART BIE	*Artemesia biennis* Willd.	A	N	F			T	
6	ART LUD	*Artemesia ludoviciana* Nutt.	P	N	F	W			G
7	AST JUN	*Aster junciformis* Rydb.	P	N	F				
8	BID CER	*Bidens cernua* L.	A	N	F				
9	CIR ARV	*Cirsium arvense* (L.) Scop.	P	NN	F	W			
10	GNA PAL	*Gnaphalium palustre* Nutt.	A	N	F	W			
11	LAC SER	*Lactuca serriola* L.	A	NN	F	W			
12	SON ASP	*Sonchus asper* (L.) Hill	P	NN	F	W			
13	ROR PAL	*Rorippa palustris* (L.) Besser	A	N	F			T	
14	THL ARE	*Thlaspi arevense* L.	A	NN	F	W		T	
15	DRE SPP.	*Drepanocladus* sp.	X	X	F				G
16	DIA ARM	*Dianthus armeria* L.	A	NN	F	W			
17	CHE SPP.	*Chenopodium* sp.	A	X	F				
18	CAR ATH	*Carex atherodes* Spreng.	P	N	GL				
19	CAR ATHR	*Carex athrostachya* Olney	P	N	GL				
20	CAR LAN	*Carex lanuginosa* Michx.	P	N	GL				
21	CAR MIC	*Carex microptera* Mack.	P	N	GL				
22	CAR NEB	*Carex nebrascensis* Dewey	P	N	GL				
23	CAR ROS	*Carex rostrata* Stokes	P	N	GL				
24	CAR SPP.	*Carex* spp.	P	N	GL				
25	ELE ACI	*Eleocharis acicularis* (L.) R. & S.	P	N	GL			T	G
26	ELE OVA	*Eleocharis ovata* (Roth) R. & S.	A	N	GL				
27	ELE PAL	*Eleocharis palustris* (L.) R. & S.	P	N	GL			T	G
28	ELE SPP.	*Eleocharis* spp.	X	N	GL				
29	SCI ACU	*Scirpus acutus* Muhl.	P	N	GL		P		G
30	SCI MAR	*Scirpus maritimus* L.	P	N	GL				

Table 20. (continued)

Species Number	Species Code	Genus - Species[1]	Annual/ Perennial[1] (A/P)	Native/ Nonnative[1] (N/NN)	Grass/Grass-like/ Forb/Shrub (G/GL/F/S)	Weedy[1] (W)	Persistent Litter[2] (P)	Tillage Tolerant[3] (T)	Grazing Tolerant[3] (G)
31	DIP SYL	*Dipsacus sylvestris* Huds.	A	NN	F	W	P		
32	ELA CAL	*Elatine californica* Gray	A	N	F				
33	EQU FLU	*Equisetum fluviatile* L.	P	N	F				
34	EQU SPP.	*Equisetum* spp.	P	N	F				
35	EQU SYL	*Equisetum sylvaticum* L.	P	N	F				
36	TRI HYB	*Trifolium hybridum* L.	P	NN	F	W			
37	MYR SIB	*Myriophyllum spicatum* L.	P	N	F				
38	HIP VUL	*Hippuris vulgaris* L.	P	N	F				
39	HYP PER	*Hypericum perforatum* L.	P	NN	F	W			
40	HYP FOR	*Hypericum formosum* H. B. K.	P	N	F				
41	JUN BAL	*Juncus balticus* Willd.	P	N	GL		P		G
42	JUN BUF	*Juncus bufonius* L.	A	N	GL	W			
43	JUN ENS	*Juncus ensifolius* Wikst.	P	N	GL				
44	JUN LON	*Juncus longistylis* Torr.	P	N	GL				
45	TRI MAR	*Triglochin maritimum* L.	P	N	F				
46	MEN ARV	*Mentha arvensis* L.	P	N	F				
47	STA PAL	*Stachys palustris* L.	P	N	F				
48	LEM MIN	*Lemna minor* L.	A	N	F				G
49	UTR VUL	*Utricularia vulgaris* L.	X	X	F				G
50	EPI PAN	*Epilobium paniculatum* Nutt.	A	N	F				
51	EPI CIL	*Epliobium ciliatum* Raf.	P	N	F	W			
52	AGR SMI	*Agropyron smithii* Rydb.	P	N	G			T	G
53	AGR SPP.	*Agropyron* spp.	P	X	G				
54	AGR TRA	*Agropyron trachycalum* (L.) Beauv.	P	N	G				
55	AGR ALB	*Agrostis alba* L.	P	NN	G				
56	AGR SCA	*Agrostis scabra* Willd.	P	N	G	W			
57	AGR SPP.	*Agrostis* spp.	P	N	G				
58	ALO AEQ	*Alopecurus aequalis* Sobol.	P	N	G			T	G
59	ALO PRA	*Alopecurus pratensis* L.	P	NN	G				
60	AVE FAT	*Avena fatua* L.	A	NN	G	W			
61	BEC SYZ	*Beckmannia syzigachne* (Steud.) Fern.	A	N	G	W		T	G

Table 20. (continued)

Species Number	Species Code	Genus - Species[1]	Annual/ Perennial[1] (A/P)	Native/ Nonnative[1] (N/NN)	Grass/Grass-like/ Forb/Shrub (G/GL/F/S)	Weedy[1] (W)	Persistent Litter[2] (P)	Tillage Tolerant[3] (T)	Grazing Tolerant[3] (G)
62	BRO JAP	*Bromus japonicus* Thunb.	A	NN	G	W			
63	CAL NEG	*Calamagrostis neglecta* (Ehrh.) G. M. & S.	P	N	G				
64	CAT AQU	*Catebrosa aquatica* (L.) Beauv.	P	N	G				
65	PHA ARU	*Phalaris arundinacea* L.	P	X	G	W			
66	PHL PRA	*Phleum pratense* L.	P	NN	G	W			G
67	POA PAL	*Poa palustris* L.	P	NN	G				
68	POA PRA	*Poa pratensis* L.	P	NN	G	W			
69	POA SPP.	*Poa* spp.	P	X	G				
70	POA TRI	*Poa trivialis* L.	P	NN	G				
71	POL MON	*Polypogon monspeliensis* (L.) Desf.	A	NN	G				
72	LIN SEP	*Linanthus septrionalis* Mason	A	N	F				
73	POL AMP	*Polygonum amphibium* L.	P	N	F		P	T	
74	POL CON	*Polygonum convolvulus* L.	A	NN	F	W	P	T	
75	POL DOU	*Polygonum douglasii* Greene	A	N	F		P		
76	POL LAP	*Polygonum lapathifolium* L.	A	NN	F	W	P	T	
77	POL PER	*Polygonum persicaria* L.	A	N	F	W	P		
78	RUM CRI	*Rumex crispus* L.	P	NN	F	W			
79	RUM MAR	*Rumex maritimus* L.	A	N	F				
80	POL SPP.	*Polygonum* spp.	X	X	F		P		
81	POT GRA	*Potamogeton gramineus* L.	P	N	F				G
82	POT PEC	*Potamogeton pectinatus* L.	P	N	F				
83	CEN MIN	*Centunculus minimus* L.	A	N	F				
84	RAN AQU	*Ranunculus aquatilis* L.	P	N	F			T	G
85	RAN GME	*Ranunculus gmelinii* DC.	P	N	F				
86	RAN SCE	*Ranunculus sceleratus* L.	A	N	F			T	
87	RAN SPP.	*Ranunculus* spp.	X	X	F				
88	RIC NAT	*Ricciocarpus natans*	X	X	X				G
89	GEU MAC	*Geum macrophyllum* Willd.	P	N	F				
90	GEU SPP.	*Geum* spp.	P	N	F				
91	POT ANS	*Potentilla anserina* L.	P	N	F				
92	POT GRA	*Potentilla gracilis* Dougl.	P	N	F				

Table 20. (continued)

Species Number	Species Code	Genus - Species[1]	Annual/ Perennial[1] (A/P)	Native/ Nonnative[1] (N/NN)	Grass/Grass-like/ Forb/Shrub (G/GL/F/S)	Weedy[1] (W)	Persistent Litter[2] (P)	Tillage Tolerant[3] (T)	Grazing Tolerant[3] (G)
93	POT RIV	*Potentilla rivalis* Nutt.	A	N	F				
94	ROS WOO	*Rosa woodsii* Lindl.	P	N	SH		P		
95	GAL APA	*Galium aparine* L.	A	N	F	W			
96	SAL EXI	*Salix exigua* Nutt.	P	N	SH		P		
97	PEN SPP.	*Penstemon* spp.	X	N	F				
98	GRA NEG	*Gratiola neglecta* Torr.	A	N	F			T	
99	PEN CON	*Penstemon confertus* Dougl.	P	N	F				
100	SOL DUL	*Solanum dulcamara* L.	P	NN	F	W			
101	SPA SPP.	*Sparganium* spp.	P	X	F		P		
102	TYP LAT	*Typha latifolia* L.	P	N	H	W	P		
103	VIO SPP.	*Viola* spp.	P	N	F				
200		water							
201		dry bare ground							
202		algae							
203		litter							
204		moss							
205		saturated bare ground							
206		unidentified submerged sp.							
207		unidentified forb sp.			F				
208		unidentified grass sp.			G				
210		unidentified emergent sp.							
211		rock							
213		litter/wrack							
215		dead bulrush							
216		dead cattail							
217		dead bush							

[1] Dorn 1984, Gleason and Cronquist 1973.

[2] Mark Gernes, Minnesota Pollution Control Agency, 1997, Personal Communication.

[3] Kantrud et al. 1989, Millar 1973, Stewart and Kantrud 1972, Walker and Coupland 1970, Walker and Coupland 1968, Dix and Smeins 1967.

Table 21. Rationale for inclusion of a) species groups, b) species, and c) species richness in vegetation analysis. Groups and species are identified according to their inclusion before (B) or after (A) examining the raw data. Original groups were included based on ecological generalizations (E) or research findings by Minnesota Pollution Control Agency (M) or the EPA Biological Assessment for Wetlands Work Group (G). Ecological generalizations or research findings and expected response to increased land use impacts are briefly explained for all groups and for species included before the study began.

Variable	Inclusion	Basis	Ecological generalization or research finding	Expected response
a) Species groups				
Annuals	B	E	Life cycle often adapted to disturbance	Increase
Perennials	B	E	Life cycle often not adapted to disturbance	Decrease
Natives	B	E	Disturbance often allows competition from non-natives	Decrease
Non-natives	B	E	Disturbance often allows non-natives to establish	Increase
Native perennials	A	---	Natives, perennials often decrease with disturbance	Decrease
Weedy	B	E	Life cycle adapted to disturbance	Increase
Weedy annuals	A	---	Annual life cycle and weedy spp. adapted to disturbance	Increase
Weedy perennials	A	---	Weedy spp. adapted to disturbance	Increase
Grasses	B	E	Some spp. more palatable to cattle	Decrease
Grasslikes	B	E	Some spp. sensitive to disturbance	Decrease
Grasslike perennials	A	---	Some grass-likes, perennials decrease w. disturbance	Decrease
Forbs	B	E	Some spp. less palatable to cattle, have weedy characteristics	Increase
Moss	B	M	Some spp. sensitive to physical disturbance	Decrease
Submergents	B	E	Respond to changes in nutrients and light availability	Increase
Spp. with persistent litter	B	M	Persistent litter is associated with some weedy spp.	Increase
1st most dominant spp.	B	G	Dominance may increase with disturbance	Increase
1st & 2nd most dominant spp.	B	G	Dominance may increase with disturbance	Increase
1st, 2nd, & 3rd most dominant spp.	B	G	Dominance may increase with disturbance	Increase
Tillage tolerant spp.	B	E	Spp. appear to tolerate or establish after physical disturbance	Increase
Grazing tolerant spp.	B	E	Species unpalatable or able to withstand grazing pressure	Increase

Table 21. (continued)

Variable	Inclusion	Basis	Ecological precept or research finding	Expected response
b) Species or genera				
Agropyron spp.	A	---	----------	--------
Phalaris arundinacea	A	---	----------	--------
Juncus balticus	A	---	----------	--------
Eleocharis spp.	A	---	----------	--------
Eleocharis ovata	A	---	----------	--------
Eleocharis palustris	A	---	----------	--------
Carex spp.	B	M	Some spp. are sensitive to disturbance	Decrease
Typha latifolia	A	---	----------	--------
Poa pratensis	A	---	----------	--------
Carex atherodes	A	---	----------	--------
Mentha arvense	A	---	----------	--------
Potamogeton spp.	A	---	----------	--------
Utricualria vulgaris	B	M	Sensitive to water quality changes	Decrease
c) Species richness, vascular plants	B	E	Moderate disturbance allows new species to establish	Increase

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