AN ABSTRACT OF THE THESIS OF

<u>Karen K. Finley</u> for the degree of <u>Master of Science</u> in <u>Rangeland Resources</u> presented on <u>May 13, 1994</u>. Title: <u>Hydrology and Related Soil Features of Three Willamette Valley Wetland Prairies</u>

Abstract approved: Redacted for Privacy______

The patterns of seasonal water level changes and soil redox potential were measured at three native wetland prairie sites in the Willamette Valley between July, 1991 and July 1993. Baseline data about the soils and hydrological environment of wetland prairies were collected through measurement of water table elevation, soil redox potential, soil texture, and soil nutrient content in six plant communities at three sites. The communities sampled were a *Deschampsia cespitosa-Danthonia californica* community, an *Eleocharis palustris-Mentha pulegium* community, a *Rosa nutkana-Juncus nevadensis* community, a *Vaccinium cespitosum* community, and a *Poa* sp.-*Deschampsia cespitosa* community.

In summer, wetland prairie soils were very dry, hard, and cracked, but between November and April groundwater levels rose to within 15 cm of the soil surface. High water levels and anaerobic soil conditions were observed in all the communities monitored in the three wet prairie sites. In most communities, the water table exceeded the soil surface for several months during the wet period. Redox potential measurements indicated that iron, manganese, and sulfur were reduced during the wet period. There were significant differences in the magnitude and duration of elevated water levels between plant communities found at the study sites. Differences in magnitude and duration of elevated water table on the scale of tens of centimeters partially explain patterns of plant species distribution at two of the wetland prairie sites.

The three wetland prairie sites were found to be extremely different in terms of soil texture, soil organic matter, and soil nutrient content. Rose Prairie soils were poorer in nutrient content and organic matter and much sandier than the soils of the Fisher Butte and Long Tom ACEC sites.

Hydrology and Related Soil Features of Three Willamette Valley Wetland Prairies

by

Karen K. Finley

A THESIS

submitted to

Oregon State University

in partial fulfillment of the requirements for the degree of

Master of Science

Completed May 13, 1994

Commencement June 1995

APPROVED:

Redacted for Privacy

Professor of Rangeland Resources in charge of major Redacted for Privacy

Head of department of Rangeland Resources

Redacted for Privacy

Dean of Graduate School

Date thesis is presented <u>May 13, 1994</u>

Typed by Karen Finley for <u>Karen Finley</u>

ACKNOWLEDGEMENT

÷

I extend special thanks to my major professor, J. Boone Kauffman, for his time, assistance, and support in this project.

Thanks also to Dr. Mark Wilson for his support and for his dedication to the art of teaching, to Dr. Doug Johnson, for being a helpful member of my committee, and to Dr. Patsy Miller, for her interest in my work.

Special thanks to James Beal, U.S. Army Corps of Engineers, Nancy Wogon, Eugene District BLM, and Cathy Macdonald, the Oregon Nature Conservancy, whose genuine interest and dedication to the protection and management of the wet prairies of the Willamette Valley made this project possible.

I am grateful to numerous individuals who assisted me in field work and in analysis of my data, especially to Richard Hayes and the staff of the Fern Ridge Project, U.S. Army Corps of Engineers. Finally, thanks to fellow graduate students and friends, including Cheryl Ingersoll, Deborah Clark, Don Wolf, Jeff Claussen, Kathy Pendergrass, Cheshire Mayrsohm, Richard Case, Brook Leaf, Daniella Roth, and Pedro Gonzales-Flores, all of whom are a constant source of inspiration to me.

TABLE OF CONTENTS

LITERATURE REVIEW 1						
GOAL AND OBJECTIVES 11						
PREDICTIONS 12						
SITE DESCRIPTION						
METHODS 18						
Sampling Design 18 Environmental Characteristics 27						
Water table27Redox potential27Soil temperature29Soil nutrients, pH, and soil texture29Schedule of data collection29Elevation30						
Vegetation Sampling 30 Data Analysis 30						
RESULTS AND DISCUSSION						
Elevation, soil texture and soil nutrients32Groundwater hydrology39						
Patterns of groundwater fluctuation measured in six plant communities						
Soil oxidation-reduction status 54						
Patterns of redox potential fluctuation measured in six plant communities						
Ordination of species and samples by detrended correspondence analysis						
SUMMARY AND CONCLUSIONS						
LITERATURE CITED 8						

LIST OF FIGURES

Figure 1. Wet prairie sites in the vicinity of Eugene, Oregon: Fisher Butte, Rose Prairie, and Long Tom ACEC. Composite of three USGS 15 minute quadrangles: Eugene West (1986), Veneta (1975), and Cheshire (1984).	16
Figure 2. Historical Cadastral Survey map of T17S, R5W, prepared in 1854, showing the former extent of wet prairie ecosystem in the vicinity of present day Fern Ridge Reservoir, with notation reading "Level and gently rolling prairie. Soil first and second rate"	17
Figure 3. Fisher Butte study site with locations of sampling points.	20
Figure 4. Rose Prairie study site with locations of sampling points.	21
Figure 5. Long Tom Area of Critical Environmental Concern study site with locations of sampling points.	22
Figure 6. Transect layout showing plots for sampling plant species cover and location of water wells, platinum-tipped electrodes, and thermocouples. At Fisher Butte and Rose Prairie, most transects are laid out in Y-shaped groups of three.	24
Figure 7. Single sampling point showing instrumentation for monitoring water table, redox potential, and soil temperature.	25
Figure 8. Mean (±1SE) water table elevation recorded in <i>Deschampsia</i> <i>cespitosa</i> community at Fisher Butte between September, 1991 and July, 1993, with corresponding precipitation values from records of Eugene FAA weather station	41
Figure 9. Mean (± 1SE) water table elevations, in centimeters, in six plant communities, September, 1991-July, 1992.	44
Figure 10. Mean (± 1SE) water table elevations measured in five plant communities, September 1992-July, 1993.	46
Figure 11. Mean (±1 SE) redox potential measured at 5 and 25 cm below soil surface in <i>Deschampsia cespitosa</i> community, Fisher Butte, September, 1991-July, 1992.	55
Figure 12. Mean (±1 SE) redox potential in millivolts measured at 25 cm below soil surface in six plant communities, September, 1991-July, 1992	58
Figure 13. Mean (±1 SE) redox potential in millivolts measured at 5 cm below soil surface in six plant communities, September, 1991-July, 1992	61
Figure 14. Water table elevation (in cm) and corresponding redox potential values recorded in the Fisher Butte <i>Deschampsia cespitosa</i> community during the 1991-1992 season.	63

Figure	15. Species plotted in relationship to their scores on DCA 1 and DCA 2. Four letter species acronyms are used to show species positions.	71
Figure	16. Samples plotted in relationship to their scores on DCA 1 and DCA 2	73
Figure	17. Sample scores on DCA 1 shown in relation to percent sand content	82

LIST OF TABLES

Table 1. The published range of redox potential values, in millivolts, at which the transformation of given soil minerals occurs.	4
Table 2. Communities identified at Fisher Butte, Rose Prairie, and the Long Tom ACEC.	19
Table 3. Plant communities identified and sampled by Connelly and Kauffman(1991), the site where they are located, their codes in future tables andfigures, and the number of sampling points installed in each.	26
Table 4. Redox potential values used for evaluation of redox potential in data analysis.	28
Table 5. Mean (and standard error) elevation of plant communities identified at the three study sites, in meters above sea level	33
Table 6. Mean (and standard error) percent sand, silt and clay content of soils sampled at three study sites.	34
Table 7. Mean (and standard error) percent sand, silt and clay content of soils sampled by communities at three study sites.	35
Table 8. Mean (and standard error) organic matter (OM), iron, and sulfate content, and pH of soils sampled at the three study sites, 4 May, 1992.	37
Table 9. Mean (and standard error) organic matter, iron, sulfate, and pH of soils sampled in plant communities at Fisher Butte, Rose Prairie, and Long Tom ACEC, 4 May, 1992. An asterix indicates parameters where communities are not the same at p=0.1 Groups are indicated with superscripts a and b.	38
Table 10. Mean (and standard error) number of bi-weekly visits when the water table elevation was within specified levels, and maximum inundation depth in centimeters, November, 1991 - May, 1992.	49
Table 11. Mean (and standard error) number of semi-monthly visits when the water table elevation was within specified levels, and maximum inundation depth in centimeters, November, 1992 - May, 1993.	52
Table 12. Percentage of visits (to the nearest 5%) when the water table elevation was within specified levels, and maximum recorded elevations, November, 1991-May, 1992 (first row) and November, 1992-May, 1993 (second row). The Long Tom site was not sampled the	
second year.	53

Table 13. Mean number (and standard error) of bi-weekly visits that redox potential, at 5cm below the surface, was at specified level, November, 1991-May, 1992. An asterix indicates that communities are different from one another at p=0.1. Groups are indicated with superscripts a and b.	. 67
Table 14. Mean number (and standard error) of bi-weekly visits when redox potential, at 25 cm below the surface, was at specified level, November, 1991-May, 1992. An asterix indicates that communities are different from one another at p=0.1 Groups are indicated with superscripts a and b.	. 68
Table 15. Species names corresponding to four letter acronyms used in Figure 15.	. 75
Table 16. Percent correlation (r2) between selected environmental variablesand sample scores on DCA 1. Correlations greater than 50% areshown in bold	78
Table 17. Analysis of variance and model fitting results for the regression: Score DCA 1= constant + β_1 Maximum water table depth + β_2 Percent sa content	and 79

PREFACE

The native grasslands of the Willamette Valley are considered to be one of the most endangered natural ecosystems in the state of Oregon (Oregon Natural Heritage Program, 1983). Prior to the advent of Euro-american settlement, upland and lowland wet prairies once covered most of the southern Willamette Valley, interspersed with *Quercus garryana* -dominated woodlands and savanna, *Fraxinus latifolia* swales, and riparian gallery forests of *Populus trichocarpa*, *Quercus garryana*, *Fraxinus latifolia, Acer macrophyllum*, and *Pseudotsuga menziesii* (Habeck 1961, Johannesson et. al 1971). Most of these native ecosystems have been severely altered or destroyed by agricultural and urban development. Only remnants exist today. The most extensive remnants of the wetland prairie form of the ecosystem are located between the city of Eugene, Oregon and the perimeters of Fern Ridge Reservoir in Lane County, Oregon.

Wet prairies are open, seasonally flooded grasslands with high plant species diversity. Dominant native grass species of Willamette Valley wet prairies are *Deschampsia cespitosa* and *Danthonia californica*. These prairies are the habitat of many narrowly endemic and endangered plant species, including *Lomatium bradshawii* (a federally listed endangered species), *Erigeron decumbens* var. *decumbens*, *Horkelia congesta* spp. *congesta*, *Aster curtus*, and *Cicendia quadrangularis*, all of which are listed threatened or endangered by the state of Oregon. The soils on which they occur are characterized by high water table and occasional flooding during at least part of the winter season.

Some wet prairie remnants are managed by the Bureau of Land Management, the U.S. Army Corps of Engineers, and the Oregon Nature Conservancy. They are among the best remaining examples of intact native wet prairies of the Willamette Valley. In addition to their importance as habitat for rare plants, the sites are valuable examples of a unique historic/cultural landscape which is largely lost today. Although species compositions have been somewhat altered by the invasion of Eurasian weeds and hydrology has been altered by roads and channelization activities, the remaining sites are important records of the landscape of Willamette Valley prior to European settlement. As such, they are a model for scientists and land managers who are interested in the restoration and enhancement of degraded grassland sites and former agricultural lands.

The Bureau of Land Management (USDI-BLM), the Fern Ridge Project of the U.S. Army Corps of Engineers (USACE), the Department of Rangeland Resources-Oregon State University (OSU), and the Oregon Nature Conservancy (TNC) have cooperated in studying wetland prairie plant communities since 1988. These studies have focused on description of vegetation and analysis of the effects of fire on these ecosystems (Connelly and Kauffman 1991, Finley and Kauffman 1992, Pendergrass, in preparation).

Prescribed burning has been used on lands administered by the U.S. Army Corps of Engineers Fern Ridge Project, the Eugene District of the BLM, the U.S. Fish and Wildlife Service (USFWS) and the Oregon Nature Conservancy in the Willamette Valley since the mid 1980's in an effort to control increases in woody vegetation and influence species composition. At most sites, the invasion of woody vegetation is considered to be a significant threat to the remaining prairies and to the survival of several of the threatened and endangered species they contain (USFWS 1993, Connelly and Kauffman 1991). Connelly and Kauffman (1991) studied plant community response to periodic burns, and the growth and reproduction of *Lomatium bradshawii* and *Erigeron decumbens* in response to burns.

Other research in wet prairies has been carried out by Frenkel (1987), Kagan (1980), Kaye (1992), Kaye et. al (1994), the Oregon Nature Conservancy (1983, and ongoing), Moir and Mika (1972), and Wilson et. al (1993). These studies have focused on describing plant community composition of wet prairies, the response of the system to prescribed burning, and on the pollination and population biology of *Lomatium bradshawii*. However, no systematic research has been conducted on the relationship of physical environment and the species composition of the prairies.

There is considerable interest in the restoration and enhancement of prairie and wetland communities in various parts of Willamette Valley. However, little information exists about the relationships between plant species distribution and environmental characteristics such as elevation, depth and duration of inundation. There is a critical need for information that will allow managers to make the best possible decisions about the management of remaining native wet prairies. Such efforts share a common need for an understanding of the ecological relationships of native prairie communities.

This project was initiated in order to make a quantitative baseline description of the hydrology and related edaphic features of several wet prairie sites in the southern Willamette Valley.

Botanical Nomenclature:

Unless otherwise noted, botanical nomenclature follows Hitchcock and Cronquist (1973).

Hydrology and Related Soil Features of Three Willamette Valley Wetland Prairies

LITERATURE REVIEW

Soils which are subject to long periods of saturation are referred to as hydric soils. These soils share particular physical/morphological characteristics. Frequently, hydric soils are identified based on morphological features, such as the grey or low chroma colors of their surface or subsurface layers (Munsell 1975). This phenomenon is termed gleying, and indicates a lack of oxidized iron (Schlessinger 1991). Also, hydric soils can be mottled and have numerous concretions, small balls or particles dark in color which are the result of precipitation of dissolved iron and manganese from surrounding soil (Somera 1967). Such morphological characteristics form the basis of hydric soil delineation, which is one of three wetland features commonly applied in wetland delineation (U.S. Army Corps of Engineers 1987).

Research in regions of rice cultivation indicate that morphological characteristics such as gleyed horizons and iron concretions can be induced quickly in soils (Ponnampurna 1984). Bonner and Ralston (1968) showed that gley colors may develop in soils after 25 days under controlled conditions.

However, quantitative relationships between morphological features and specific durations of saturation are unknown (Vepraskas and Ghertal 1991). The correspondence of soil morphology to the seasonality, duration, and intensity of saturation and their persistence through time are not well studied. Morphological indicators of wet soils persist across dry seasons in seasonally flooded ecosystems (Faulkner and Patrick 1992). Wetland soil morphology may persist for decades despite changes in water tables due to erosional downcutting (Kauffman, Bestcha and Platts 1993). Therefore, morphological characteristics alone are inadequate for studies of ecological relationships in wetland systems. Soil scientists are beginning to explore new methods for identification and study of hydric soils.

Faulkner et. al (1989) have proposed that techniques employed for describing dynamics of wetland soils include measurement of dissolved oxygen, redox potential, and water table fluctuation. These measurements can yield information about the depth, frequency, and duration of saturation and inundation. Such characteristics are be sensitive indicators of nature of wetland soil environments across seasons. Some of these techniques were evaluated in Willamette Valley toposequences by Austin (1993).

Inundation or prolonged saturation causes chemical transformations in the soil environment. When oxygen is limited below the soil surface, changes in the chemical state of soil minerals and carbon will occur. Change in the form of soil minerals after waterlogging is both a physical and a biological process (Schlessinger 1991). It proceeds due to the physical restriction of oxygen diffusion from surface of soil into subsurface layers. Oxygen diffusion is minimal in flooded soils once soil pore spaces fill with water (Schlessinger 1991). In response to limited oxygen there are alterations in the activity of soil microbes which use oxygen as the terminal electron receptor in the process of oxidation of organic molecules (Mitch and Gosselink 1986). Oxygen that is present in the soil is depleted by their metabolism. After oxygen is depleted, biological activity is restricted to microbial populations which have the capacity to use mineral elements other than oxygen as electron receptors in their respiration. Through these microbial activities, the oxidized forms of the soil minerals are reduced.

Reduction-oxidation potential, or redox potential, is a measurement of the intensity of reduced conditions. Redox potential (Eh) expresses the tendency of an environment to receive or supply electrons (Schlessinger 1991). It is frequently used to express the intensity of reduced conditions in soil. Laanbroek (1990) studied the processes of mineral reduction in soil and found that Ferric iron (Fe³⁺) is reduced by the microbial organisms *Pseudomonas* ssp., *Clostridium* ssp., and *Alteramonas* ssp. These all have a strong affinity for the oxidized ferrous irons (Laanbroek 1990). Manganese reduction (from Mn⁴⁺ to Mn²⁺) may occur in the presence of microbial metabolites or ferrous ions (i.e. without direct involvement of microbes), but direct contact with *Clostridium* sp. is essential for rapid reduction (Laanbroek 1990).

Because of the different affinities of soil microbes for a given electron receptor, these processes occur more or less exclusively of one another (Laanbroek 1990). The sequence of changes in chemical state of soil by reduction of soil minerals occurs in a predictable fashion (Table 1). For example, oxygen and nitrate will be depleted in the soil before the reduction of ferric iron begins (Mohanty and Dash 1980). After oxygen is depleted, denitrification occurs, then manganese, ferric iron, sulfate and carbon dioxide are reduced in sequence. Sulfur and carbon dioxide are reduced in sequence, forming sulfide and methane (Table 1). Both of these compounds are reduced by the activities of obligate anaerobes (Mohanty and Dash 1980). Soils in which the reduction of carbon to methane occurs are referred to as being "strongly reducing" (Schlessinger 1991). The reverse of the reduction process, the re-oxidation of reduced soil minerals, involves entirely different micro-organisms (Laanbroek 1990). The mechanics of this process are not well understood. It has been observed that the re-oxidation process occurs over a longer period of time (Laanbroek 1990). The reason for this is unknown.

Redox potential is measured as the voltage (resistance), measured in millivolts (mV), which must be applied to prevent the electron flow between the soil environment and a standard electrode (Bohn 1971, Schlessinger 1991). Aerobic environments usually have redox potentials between +300 and +800 mV (Gambrell and Patrick 1978). This value declines rapidly as oxygen is depleted in the soil environment. Denitrification occurs between +200 and +421 mV, when denitrifying bacteria use nitrate as an electron receptor instead of oxygen (Gambrell and Patrick 1978, Schlessinger 1991). Manganese is reduced from Mn⁴⁺ to Mn²⁺ at between 100 and 400 mV, and iron is reduced from Fe³⁺ to Fe²⁺ at -182 to 100 mV. Sulfur becomes reduced between 0 and -215 mV, and carbon is reduced below -150 to -250 mV. Because these reactions occur in sequence, redox potential is a sensitive measure of the degree of reduction in wetland soils (Gambrell and Patrick 1978).

Element	Oxidized	Reduced	Gambrell and	Bohn	Stevenson	Austin
	form	form	Patrick (1978)	(1985)	(1987)	(1993)
Oxygen	O ₂	O ₂ disappears	>300	>400	816	<350
Nitrogen	NO ₃ - Nitrate	N ₂ O, N ₂ , NH4 ⁺	>225	>200	421	200 to 300
Manga- nese	Mn ⁴⁺ Manganic	Mn ²⁺ Manga- nous	>200	<400	396	100 to 300
Iron	Fe ³⁺ Ferric	Fe ² + Ferrous	>110	<300	-182	100 to 200
Sulfur	SO ₄ ²⁻ Sulfate	HS- Sulfide	>-150	0 to -150	-215	0 to -150
Carbon	CO ₂ Carbon dioxide	CH ₄ Methane	>-250	-150 to - 220	-244	-150 to -200

Table 1. The published range of redox potential values, in millivolts, at which the transformation of given soil minerals occurs.

Although redox values have been empirically determined for sequential soil reactions, many reactions occur simultaneously in the soil, so the result is a mixed potential (Bohn 1971). When redox potential is measured *in situ* with a platinum electrode, the value is an expression of the average of all redox reactions occurring in the soil.

In wetland soils, reduced conditions correspond to zones of saturation (Schlessinger 1991). Redox potentials decline rapidly with depth in wetland soil, because oxygen diffusion is so slow (Stolzy et. al 1981).

In wetlands with fluctuating water levels, a progressive decrease in redox potential over time, as soils are flooded, is analogous to changes in redox potential with soil depth (Turner and Patrick 1968). The longer the period of waterlogging lasts, the more the speciation of nitrogen, manganese, iron, sulfur, and carbon (Ernst 1990). The process of reduction begins within a few hours to a few days after waterlogging (Glinski and Stepniewski 1985). Flooding (inundation of the soil surface) enhances the sequence of waterlogging-induced processes because it reduces oxygen diffusion (Ernst 1990).

The intensity of reduced conditions can be expected to fluctuate according to variations in water table depth. The duration and depth of flooding is the primary control of the location and occurrence of anaerobic conditions and related reduction reactions. In seasonally flooded wetlands, there may only be certain periods during the year when the soil environment is anaerobic.

The reduction of soil minerals is largely a microbial process. Its occurrence is mediated by environmental influences on microbial metabolism. Gambrell and Patrick (1978) found that rates of oxygen depletion depended upon air temperature and the availability of organic substances that fueled microbial activities. Iron present in the soil did not reduce despite waterlogging in periods of cold temperatures (below 5 °C) (Pickering and Veneman 1984).

Couto et al. (1985) reported no gleying in soils with low amounts of oxidizable organic matter. Austin (1993) measured redox potentials at 25, 50, and 100 cm depths in Willamette Valley hydric soils, and did not record reducing conditions in deeper strata. He suggested this was due to low amounts of organic matter (<0.11 %) in deeper strata. Organic matter is a critical energy source for the activity of reducing

bacteria. Therefore, organic matter influences redox potential through its effect on soil microbial activity.

There have also been reported instances where particular redox reactions do not occur because the appropriate electron receptor was naturally scarce (Ponnampurna 1984). Somera (1967) attributed high measured redox potential in wet soils of the Willamette Valley to low concentrations of iron.

Although the reduced forms of some minerals and anoxia of the soil environment are known to affect the growth and development of plants, few studies of wetland ecology have explored the relationships between soil anoxia, seasonal flooding, and the distribution of plants in the field. Relationships between redox potential and plant growth have been explored in areas of rice cultivation (Ponnampurna 1984). Jones and Etherington (1970, 1971) have compared the tolerance of related species to inundation and soil anoxia in experimental settings.

Some specific chemical effects of waterlogging on plant growth and reproduction have been studied experimentally. Many researchers have attributed negative plant response to high levels of reduced forms of minerals (Jones 1972, Jones and Etherington 1970, 1971). Lack of oxygen in the root zone inhibits the growth of most plants, and the reduced forms of soil minerals such as ferrous iron and sulfides are known to be phytotoxic (Armstrong 1982, Ernst 1990). However, Martin (1968) demonstrated that wide variation exists between species in their tolerance to ferrous iron. Jones (1972) and Jones and Etherington (1970,1971) found wetland plants to perform better than upland species in the presence of these potential toxins. Differential tolerance or susceptibility to the high concentrations of reduced iron, manganese, and sulphur which may occur in waterlogged soils may affect the composition and spatial distribution of plant species in wetland areas (Martin 1968, Armstrong 1982).

Waterlogging of the rhizosphere induces a number of physiological responses in plants. Exposure of roots to phytotoxins, or to anaerobic conditions in the rhizosphere reduced aboveground productivity and the rate of photosynthesis (Ernst 1990). It may also reduce seed production (van der Sman et al. 1988) or cause death of root apices or of the entire plant (Armstrong 1982).

When green plant parts are flooded and excluded from the ambient air, a reduction in photosynthesis occurs (Ernst 1990). The total submersion of a plant's aboveground parts in water accelerates this sequence (Ernst 1990). Clearly, flood depth

is an important variable in affecting plant distribution, since partial and total flooding can differently affect plants. Seedlings of hardwood tree species have been shown to respond to differences in depth of inundation, and soil anoxia (Iremonger and Kelly 1988, Gunderson et. al 1988, Hosner and Boyce 1962)

Van der Sman et al. (1988) compared the waterlogging tolerance of two annual species typical of wetlands and non-wetland habitats. Frequency, timing, duration, and continuous/intermittent waterlogging treatments were applied to the two species in a multifactorial design. Productivity and seed production of *Chenopodium rubrum*, an occupant of low sandy beaches at times when floods have subsided, was usually suppressed by waterlogging, though early waterlogging had the effect of increasing seed production. *Rumex maritimus*, which inhabits wet mud flats of old river beds, was generally tolerant of waterlogging conditions.

Many plants which are found in wetland areas have structural features which have been shown to promote aerobic conditions in the rhizosphere even though soil is water-saturated. They include hollow stems, aerenchyma, and floating leaves. The likely role of these is to buffer the effect of soil toxins on root cells.

Tolerance to flooding between taxa can be promoted by morphological features which allow greater oxygen exchange between aerial shoots and plant roots. One of these is a capacity to elongate petioles and stems in order to protrude above the water surface, exposing part of plants to air (Blom et al. 1990). Aerenchyma, the porous stem structure common in many wetland species, is considered a morphological adaptation to anoxic conditions. Many wetland plants are more than 50% open pore space. This increased porosity enables longitudinal transport from aerial and photosynthetic oxygen to the rhizosphere (Blom et al. 1990).

Radial oxygen loss in the root zone can decrease the inhibitory affects of nutrient toxicity associated with reduced soils. Radial oxygen loss functions by oxidizing reduced iron and manganese before they can enter the plant (Armstrong 1982). This can be observed in root zone as reddish (oxidized) sediments in the immediate vicinity of the plants roots. Individuals of the salt-marsh dominant *Spartina altiniflora* were found to increase the redox potential of sediments surrounding their roots. Sediments became more oxygenated through the process of radial oxygen loss (Howes et al. 1981).

Many wetland plants are stimulated to produce adventitious roots upon waterlogging. Shallow rooting in the most oxidized layer allows for greater gas exchange between roots and soil. Also, adventitious roots lend plants physical stability when soils are soft and where otherwise water force might undermine the plants' capacity to remain standing (Armstrong 1982). The hormone ethylene is involved in the regulation of this process, and also in the development of aerenchyma (Blom et al. 1990). The internal aeration system of flood-intolerant species is not likely sufficient to sustain an aerobic conditions in the rhizosphere (Blom et al. 1990).

The effects of waterlogging differ according to the time in plants life history that it occurs. Through laboratory experimentation, Van der Sman et al. (1988) determined that waterlogging during an annual plant's rosette stage was less detrimental than waterlogging during a more advanced state of development. Early waterlogging led to an increase in dry weight and seed production in some species. In general, seed production changed more than biomass as a result of waterlogging. This suggests that the timing and duration of soil saturation are important in understanding its influence on plant stress. Iremonger and Kelly (1988) suggest that some woody species may not be affected as adults but are affected as seedlings. Also, the stage/age of a plant is important in determining its response. In general, adult plants are less affected than seedlings. Simply as a function of their small stature, seedlings may be more susceptible than adults to inundation. Aerenchyma may not be fully formed in immature plants.

Few individuals have measured the characteristics of seasonally flooded soil *in situ*, or have examined community response to soil anoxia in natural systems. Green (1991) measured soil redox potential, water table elevation, ferrous iron concentration, nitrate, and ammonium in riparian areas in northeastern Oregon. His data, collected between late June and mid-September 1989, showed that redox potential was different during the growing season between plant communities that he identified. For example, the presence of some species, including *Potentilla gracilis, Achillea millefolium*, and *Poa pratensis*, was limited to areas of low summer water table and oxidized soils. Other species, such as *Glyceria grandis* and *Ranunculus aquatilis*, occurred in greatest abundance where soils were reduced for part of the period sampled (Eh ranged between -151 and -199 mV). The abundance of obligate wetland plant species, as identified by Reed (1988), was significantly correlated with low levels of soil oxygen and low redox potential in a study of seasonally flooded wetlands in California (Josselyn et al. 1990).

There are many examples of changes in the composition of vegetation resulting from changes in water levels (van der Valk and Davis 1978, Kadlek 1962, *and others*). However, there are few studies exploring the mechanisms controlling these changes in composition. Van der valk (1981), who manipulated water table depth in a series of water impoundments, attributed differences in species composition in these artificially constructed wetlands to differences in both depth and duration of inundation. Primary production and seed production are known to be affected by water depth (van der Valk 1987).

Particularly in seasonally flooded wetlands, where dramatic annual changes in the physical environment occur, differences in plant life history pattern may allow taxa to be present in a community without being directly subjected to physical and chemical stresses associated with anaerobic soils. Many annual species, for example, are not subject to wet conditions because of their accelerated lifespan. They may complete their life cycle during dry periods between successive floods (Blom et al. 1990). Josselyn et al. (1990) attributed the absence of certain species in areas of high water to their failure to germinate under water.

Inundation plays a role in determining patterns of dispersal and establishment of plants in wetlands. Seasonal wetting and drying may affect the surface topography of clay soils. Cracking of surface layers is common. This occurs due to shrinking and swelling of clay-based substrates with changes in soil moisture levels. Soil cracking due to rapid drying in seasonally flooded wetlands may provide safe site for some seeds (Hutchings and Russell 1989).

Hydrological processes can also affect the soil's permeability to seed penetration. By maintaining a wet surface or preventing surface cracks, inundation can prevent the downward movement into soil of seeds (Hutchings and Russell 1989). Soil surface topography may be affected by flooding, for example, when overland sheet flow scours the soil surface. This process can create a uniform surface. Mitch and Gosselink (1986) suggest that this scouring process may partially explain the monospecific stands (such as of *Typha* and *Phragmites*) frequently observed in wetlands. It has also been speculated that transport and deposition of sediments, surface water movement, or ponding are important in building or maintaining a spatially heterogenous seed bed (Gosselink and Turner 1978, Kenkel 1988).

The presence of standing and dead vegetation inhibits the movement of seeds in wetlands (Smith and Kadlec 1985). Perennial wet-meadow grasses can trap seeds

dispersed by wind or carried by water (Smith and Kadlec 1985). Floodwaters disperse the seeds of many species, carrying them to places they may establish when the waters subside. For example, the seeds of *Phalaris arundinacea* are transported by floodwaters (Apfelbaum and Sams 1987).

Fluctuations in water depth can influence the rate of establishment of species by controlling populations of seed predators. Waterfowl, insects, and small mammals, which can be important grazers or seed predators, migrate in and out of areas as water level fluctuates (Pederson and Smith 1988). Animals which play a role in the incorporation of seeds into the soil, are also affected by environmental conditions. Earthworms, for example, which are important in incorporating large seeds into soil (Darwin 1882 in Harper 1977), cannot survive in saturated conditions for long periods.

Wetland hydrology also may influence the plant community composition via its effect on germination of seeds. Changes is soil temperature may trigger the germination of many wetland species. Standing water, when it moderates fluctuations in soil temperature, may act to delay germination. The exposure of previously inundated soil breaks dormancy in such species (Smith and Kadlec 1985). In prairie pothole wetlands, recruitment occurs primarily during periods of low water (van der Valk and Davis 1978). High soil moisture inhibited germination of *Carex* spp. in greenhouse experiments (Welling et al. 1988). Variations in soil moisture along a height gradient appeared to cause the different levels of recruitment of *Typha* sp. despite a similarity in its abundance in the seed bank across the gradient (Welling et al. 1988).

Although the dynamics of plant-soil-water relations in wetland systems is little studied, seasonal flooding of the rhizosphere is an important feature in the nutrient dynamics of wetland soils. Saturation of soil surface layers produces anaerobic conditions which in turn affect the state of important soil minerals, such as iron, sulfur, manganese, and carbon. The reduced forms of these minerals can be toxic to higher plants and can reduce their vigor, reproductive output, or cause direct mortality. The physiological effects of anaerobic soil conditions and flooding on vascular plants suggests that information about the physical and chemical dynamics of wet soils is critical to understanding the ecology of natural systems in which seasonal inundation occurs.

GOAL AND OBJECTIVES

The goal of this research project was to describe the patterns of seasonal water level changes and soil nutrient dynamics associated with hydric soil conditions in several native wet prairie sites in the Willamette Valley. Baseline data about the soils and hydrological environment of wetland prairies will provide information about of soil-water-plant relationships in this system. This will provide important background for subsequent research by suggesting relationships between species distribution and physical/chemical environment that can be tested experimentally.

This investigation of the Willamette Valley wet prairie ecosystem specifically addresses the following questions: What are the patterns of (surface) water table fluctuation in this ecosystem? What is the intensity and spatial/temporal pattern of anaerobic conditions in their soils? How well does the distribution of plant species in this ecosystem correspond to edaphic and hydrological patterns ?

In order to describe seasonal changes in the water table and soil environment in the wetland prairie ecosystem, redox potential, water table elevation, and soil temperatures were measured over time.

The correlation between the measured environmental variation and patterns of plant species distribution is also explored. Information about composition of wet prairie communities collected by Connelly and Kauffman (unpublished) were combined with measurements of redox potential and water table elevation in order to describe the relationships between the distribution of species within these sites and the physical environment.

PREDICTIONS

The following relationships between the soil and hydrological environment and the distribution of species were predicted prior to the initiation of field studies. Field observations and a review of existing literature guided these predictions.

1) There are measurable differences in the pattern of water table depth and redox potential between communities and over the course of the season. Communities occupy distinct places over a gradient of water table depth and duration in this order (from highest elevation/longest duration to lowest water table elevation/shortest duration): *Eleocharis palustris, Rosa nutkana/Juncus nevadensis, Deschampsia cespitosa* (both sites) and *Poa* sp./Deschampsia cespitosa, Vaccinium cespitosum.

2) Spatial and temporal differences in water table depth, redox potential, soil nutrients, and soil texture are associated with differences in the distribution of plant species.

3) The variation in composition of plant communities can be partially explained by measurable differences in the water table and the intensity of reduced conditions in the soil.

SITE DESCRIPTION

Measurements of surface water table fluctuation and soil temperature, and reduction-oxidation potential were made at three intact native wet prairies located in the southern Willamette Valley, west of Eugene, Oregon (Figure 1). All three sites are examples of remnant *Deschampsia cespitosa* dominated wetland prairies, and are fragments of an extensive prairie and wetland system which extended throughout the area over a century ago (Figure 2). The prairies host a high diversity of native species, including numerous Willamette Valley endemics. One site, Fisher Butte, is considered one of the finest quality wetland prairies in the Willamette Valley. All three sites have experienced compositional changes. In particular, the cover and density of woody species has increased, and weedy native and non-native species are common.

Two of the sites, Fisher Butte and Rose Prairie, are administered by the Fern Ridge Lake Project of the Portland District of the U.S. Army Corps of Engineers. They occur on the southeastern perimeter of a large reservoir which was constructed for flood control and recreation in 1941. Fisher Butte and Rose Prairie, as examples of intact *Deschampsia cespitosa* -dominated wet prairies, were together designated a Research Natural Area (RNA) in 1989. The North Amazon Unit parcel of the RNA (Rose Prairie) is located at T17S R5W sec. 13, and is approximately 80 hectares in size. Within this parcel, the study area occupies approximately 20 hectares, and is hereafter referred to as Rose Prairie. The second parcel of the RNA, Fisher Butte, is located at T17S R5W secs. 26, 35, and 36 and is approximately 150 hectares in size. Eighty hectares of the parcel are included in the study area for this project.

The soils at both Fern Ridge sites are mapped as Natroy silty-clay loam (SCS 1987). Soils of this series are deep, poorly drained soils formed in mixed fine textured alluvium. They are subject to long periods of flooding from November through May. The surface layer is a very dark grayish brown silty clay loam approximately 13 cm thick, the subsurface layer is a very dark gray clay approximately 53 cm thick. The substratum is dark brown or grayish brown clay to 1.5 meters. Permeability of these layers is very slow, between .15 and .5 centimeters/hr. The water table is perched

(Soil Conservation Service 1987). During the summer the soils become deeply cracked and very hard.

At Fisher Butte, there is a slight, but visible, hydric gradient. This gradient extends from areas that are submerged for part of the year to moist meadows which have wet soils during the winter months, but show only some pooling of water between tussocks of grass during the wettest months. In the wettest portions of the site, the vegetation is dominated by *Eleocharis palustris*, *Mentha pelagium*, and includes *Phalaris arundinacea*, *Typha latifolia*, and *Juncus* spp. The drier portions of the site are a mixed grassland dominated by *Deschampsia cespitosa*, *Danthonia californica*, and *Agrostis* species. At Fisher Butte, there is significant invasion of *Crateagus douglasii*, *Malus* spp., *Prunus* spp., and *Fraxinus latifolia*. in otherwise open prairie. These woody species are mostly small in stature. In many areas of the site, *F. latifolia* seedling density is estimated to be well over 1000/ha (Connelly and Kauffman, 1991).

Rose Prairie has the least degree of woody invasion. At the perimeter of the study area, and contained within the RNA boundary, is a stand of mature, open grown *Quercus garryana*, with some individuals of *Quercus kelloggii* interspersed. *Rubus discolor* and *Rhus diversiloba* are important understory species. Rose Prairie is unique among the three study sites in that it hosts an unusual community of ground covering lichens (*Cladonia* spp.) and *Vaccinium cespitosum* shrubs. In addition, this site has numerous large, slightly elevated mounds with primarily exotic herbaceous vegetation and *Rosa nutkana*. The origin of the mounds is unknown.

The third site, approximately 16 hectares in size, is located at T16S R5W sec. 33 NE. It is adjacent to the Long Tom River, which is channelized at that point as it drains from Fern Ridge Dam. The site is designated a BLM Area of Critical Environmental Concern (ACEC) and is administered by the Eugene District of the USDI Bureau of Land Management. The soil of the Long Tom site is classified as a Natroy-Bashaw series (SCS 1987). Both are soils of alluvial origin, and are deep, poorly drained, of low permeability, and subject to occasional flooding by a perched water table. The soil becomes dry, cracked, and very hard during the dry summer months. This site was grazed by cattle until Spring, 1988, when it was fenced to protect the federally listed endangered species, *Lomatium bradshawii*, which occurs there. It has been occasionally trespass grazed by sheep since then, and is also used by deer. Half of the Long Tom site is vegetated with a *Fraxinus latifolia/Quercus* garryana forest. Within the forest, there are large, open grown oaks with fire scars. These are surrounded by a denser stand of younger trees. This age/size structure indicates that a disruption of the native fire regime has resulted in the conversion of a large portion of this site from a open *Quercus garryana* woodland and *Deschampsia* cespitosa meadow to a dense stand of *Fraxinus latifolia, Quercus garryana*, and *Pseudotsuga menziesii*. Most of the open, grassy, clearing is dominated by alien plant species, with patches of *D. cespitosa* and other native flora remaining. The site is designated an Area of Critical Environmental Concern.

Agencies managing each site have implemented plans to control the succession of woody species with prescribed burns. Portions of all three sites are currently burned. These burns are administered under controlled conditions by BLM personnel and are carried out in fall using wetline hoselays to control fire at the perimeter of burns. Ecological investigations were initiated at the site in 1988 when Fern Ridge Project manager Jim Beal expressed an interest in using prescribed burns to manage the RNA lands.

Pasture, agricultural fields, and suburban residential developments surround the study parcels.



Figure 1. Wet prairie sites in the vicinity of Eugene, Oregon: Fisher Butte, Rose Prairie, and Long Tom ACEC. Composite of three USGS 15 minute quadrangles: Eugene West (1986), Veneta (1975), and Cheshire (1984).



Township Millouth Range JES West Willamette Meridian.

Figure 2. Historical Cadastral Survey map of T17S, R5W, prepared in 1854, showing the former extent of wet prairie ecosystem in the vicinity of present day Fern Ridge Reservoir. Notation reads "Level and gently rolling prairie. Soil first and second rate" (from BLM archives, Portland, OR). The locations of the Rose Prairie and Fisher Butte sites are indicated.

METHODS

Sampling Design

K. Pendergrass Connelly sampled vegetation composition at these sites from 1988-1990. The sampling scheme for this study was designed in order to take advantage of data she collected.

In 1988, Connelly established permanent vegetation transects at Fisher Butte and Rose Prairie. In 1990, she established additional plots at the Long Tom ACEC site. These transects were laid out for two purposes: 1) to describe the composition of wet prairie vegetation; and 2) to describe the effects of prescribed burning on the composition of wet prairie vegetation (Connelly and Kauffman 1991). Connelly stratified her sampling within each site by identifying and sampling within distinct plant communities (Table 2). At Fisher Butte, these were 1) wet prairie vegetation dominated by *Deschampsia cespitosa* and *Danthonia californica*; and 2) wet prairie vegetation dominated by *Rosa nutkana* and *Juncus nevadensis*. At Rose Prairie, Connelly sampled in three distinct communities. 1) wet prairie vegetation dominated by *Deschampsia cespitosa* and *Danthonia californica*; 2) wet prairie vegetation dominated by *Vaccinium cespitosum*, and 3) elevated mounds dominated by *Anthoxanthum odoratum* and *Rosa nutkana*. In 1990, Connelly also sampled vegetation in a *Poa* sp. dominated meadow containing several rare forbs and *Deschampsia cespitosa* at the Long Tom ACEC.

For the purpose of this study, I added additional vegetation transects at the west end of the Fisher Butte site, in an emergent macrophyte community dominated by *Eleocharis palustris* and *Mentha pulegium*. (Table 2). This community was likely created as a result of the construction of an elevated road along the west border of the study site many years ago.

Locations of these plant communities, permanent vegetation transects, and nearby sampling points (where characteristics of the physical environment were measured) are displayed in Figures 3, 4, and 5. Table 2. Communities identified at Fisher Butte, Rose Prairie, and the Long Tom ACEC.

Rose Prairie:	Fisher Butte:	Long Tom ACEC:	
Vaccinium cespitosum community	Deschampsia cespitosa community	Poa sp./Deschampsia cespitosa community	
Deschampsia cespitosa community Anthoxanthum odoratum	Rosa nutkana/Juncus nevadensis community Eleocharis palustris		
mounds	community		

_



Figure 3. Fisher Butte study site with locations of sampling points.



Figure 4. Rose Prairie study site with locations of sampling points.





Non-native grasses

Figure 5. Long Tom Area of Critical Environmental Concern study site with locations of sampling points.

Soil and hydrological data were collected from points located approximately 1.5 m perpendicular from the 15 m point of the permanent vegetation transects (Figure 6). Each sampling point consisted of one water well, two platinum-tipped electrodes for the measurement of redox potential, and two thermocouples for measuring temperature (Figure 7).

Line transects at Fisher Butte and Rose Prairie sites were laid out in a "Y" shape by Connelly in order to facilitate their relocation. Therefore, the points where environmental data were collected along each leg of the "Y" are not strictly independent of one another. The relatively large distances between them (usually at least 10 meters), coupled with the spatial variability of the wet prairie site, made it reasonable to consider them as independent samples.

In Connelly and Kauffman's study, prescribed burn treatments were established as large rectangular blocks. These were oriented east-west across the Fisher Butte site, and in a chevron-shaped pattern at the Rose Prairie site. These treatments are not shown on the figures to avoid confusion.

At Fisher Butte, there were 26 total sampling points, with nine sampling points each in the *Deschampsia cespitosa* and *Rosa nutkana/Juncus nevadensis* communities, and eight in the *Eleocharis palustris* community (Table 3). At Rose Prairie, there were 12 total sampling points. Six were located in each of two communities. At the Long Tom ACEC, two sampling points were located in the *Poa* sp./*Deschampsia cespitosa* community.



Figure 6. Transect layout showing plots for sampling plant species cover and location of water wells, platinum-tipped electrodes, and thermocouples. At Fisher Butte and Rose Prairie, most transects are laid out in Y-shaped groups of three.



Figure 7. Single sampling point showing instrumentation for monitoring water table, redox potential, and soil temperature.
Table 3. Plant communities identified and sampled by Connelly and Kauffman (1991), the site where they are located, their codes in future tables and figures, and the number of sampling points installed in each.

Name of community	Location	Code in figures and tables	Number of samples	
Fisher Butte Deschampsia cespitosa community	Fisher Butte, Fern Ridge RNA	FB-DECE	9 (3 unburned, 3 burned twice, 3 burned three times)	
Rosa nutkana/Juncus nevadensis community	Fisher Butte, Fern Ridge RNA	Rosa-Juncus	9 (3 unburned, 3 burned twice, 3 burned three times)	
<i>Eleocharis palustris</i> community	Fisher Butte, Fern Ridge RNA	ELPA	8 (2 unburned, 3 burned twice, 3 burned three times)	
Vaccinium cespitosum community	Rose Prairie, Fern Ridge RNA	VACA	6 (3 unburned, 3 burned three times)	
Rose Prairie Deschampsia cespitosa community	Rose Prairie, Fern Ridge RNA	RP-DECE	6 (3 unburned, 3 burned three times)	
Anthoxanthum odoratum mounds	Rose Prairie, Fern Ridge RNA	mounds	0 (no instrumentation)	
Deschampsia cespitosa - Poa sp. meadow	Long Tom ACEC	Long Tom	2 (burned twice)	

Environmental Characteristics

Repeated measures of water table elevation, soil redox potential, and soil temperature were taken at each sampling point. Soil texture, organic matter, pH, and iron and sulfate content were determined from samples collected in spring, 1992.

Water table

The elevation of the water table surface was measured by using water wells. These were holes approximately 3.75 cm in diameter drilled to the depth of one meter and lined with lengths of 2.54 cm diameter schedule 40 PVC pipe. The pipe was perforated with numerous small holes to allow free passage of water. After inserting the pipe, the holes were backfilled with pea gravel. The surface was sealed with bentonite clay, although in some areas the clay dissolved during the wet season. A length of fishing line affixed with a plastic fishing float was used to determine the depth of subsurface water in the wells. When the water table was greater than 5 cm above the surface, a meter stick was used to measure its depth.

The soil microtopography was pronouncedly uneven in many places within the study sites. In all instances, the "soil surface" was defined as the low point between small mounds and hummocks.

Redox potential

Redox potentials were measured at depths of -5 and -25 cm with platinumtipped electrodes constructed according to the methods of Mueller et al. (1985) with slight modifications, including the use of Aquaseal® brand sealant to promote a good seal between the copper rod and the platinum wire (Green 1991). Prior to installation, the electrodes were tested in a ph-buffered Quinhydrone solution (Durasnian, 1968). The electrodes were inserted during August, 1991. A thin metal rod was used to poke a hole into the soil for insertion of the electrode. The electrode was inserted so that the platinum tip would have complete soil contact at the desired depth. After installation, electrodes were allowed to equilibrate for at least one week before reading. Readings were made *in situ* with a Beckman PH1-11 pH/mV meter using a single junction Cole Parmer Ag/AgCl electrode as a reference electrode. To assure good electrical contact when the surface soil was dry, a knife was used to break up a small amount of soil and water is added to form a paste (Faulkner et al. 1990).

Prior to analysis, electrode readings were adjusted for the potential of the reference electrode. Soil environmental conditions were interpreted from the reduction-oxidation potential readings using the cut-off values drawn from the literature (Table 4). Austin's (1993) values were given most consideration since they were used in evaluating similar data in Willamette Valley soils.

Soil environment	Range reported in literature (see Table 1)	Cut-off value for evaluation of redox data
Oxygen absent	300-200 mV	<250 mV
Iron reduced	300182 mV	<150 mV
Sulfur reduced	0215 mV	<-150 mV
Strongly reduced	-150250 mV	<-200 mV

Table 4. Redox potential values used for evaluation of redox potential in data analysis.

Soil temperature

Teflon insulated Type K Chromel/Alumel thermocouples were constructed by attaching male "plugs" to Type K Chromel/Alumel teflon coated wire and soldering the opposite (soil) end together. The wires were affixed to wooden dowels (oak) and driven to 5 and 25 cm depths in the soil. An Omega HH-51 digital thermometer was used to record soil temperature to the nearest tenth of a degree celsius. Soil temperature was recorded once at each station at the time of each visit. These visits occurred at nearly the same time of day each visit. The values are rough indications of soil temperature regimes, since soil temperatures can fluctuate during the course of a day. At these depths, however, some buffering of wide daily fluctuations was likely.

Soil nutrients, pH, and soil texture

Soils were sampled from the upper 15 cm for nutrient analyses on 4 May, 1992. Samples were composites taken in the field at each sampling point from several nearby locations. The samples were placed in 1 quart plastic freezer bags, labeled, and frozen on return from the field for analysis of texture, organic matter, pH, sulfate, and iron content. Soil samples were analyzed at the Soils Testing Laboratory, Oregon State University.

Soil organic matter was determined by Walkley-Black method, Total iron content was determined by DPTA method, sulfate content was determined by ion chromatograph, and pH by 1:2 soil to water ratio (Oregon State University Soils Testing Laboratory 1993). Soil particle size analysis (sand, silt, clay) was conducted using the hydrometer method by the Oregon State University Soil Physics Lab.

Schedule of data collection

Soil temperature, redox potential, and water table depth data were collected biweekly from September, 1991 to June, 1992, and monthly from September, 1992 to July, 1993. Soil samples for nutrient analysis were collected on 4-6 May, 1992. Soil samples for texture analysis were collected on 4 February, 1992.

Elevation

The elevation of sampling locations at Fisher Butte and Rose Prairie was recorded using a transit and metric stadia rod, and making use of Corps of Engineers benchmarks near the two sites. The elevation of the Long Tom ACEC site was taken from the U.S.G.S. topographic map (Cheshire quadrangle, 1984).

Vegetation Sampling

K.P. Connelly marked permanent 30 meter transects in each community at each site in order to evaluate the synecological response of these prairie remnants to fire (see Figures 3, 4, and 5). These transects are located in unburned "control" plots and in areas subject to prescribed burns at Corps of Engineers-administered RNAs. The BLM's Long Tom ACEC was partially burned in 1988 and entirely burned in 1990 and 1992.

To minimize duplication of effort, community sampling data collected by Connelly in 1989 was used for analysis. During that year, Connelly's records of species cover were most complete. However, Connelly did not sample vegetation in zones of emergent macrophytic vegetation in the wettest portions of the sites. These areas are at one extreme of the hydric gradient of interest. Therefore, additional transects were marked and read at Fisher Butte in 1991. At Fisher Butte, three 15 m transects of similar design were established in a *Eleocharis palustris-Mentha pelagium* community in the unburned control plot and in the two burn treatments, respectively. At the Long Tom ACEC, two 15 m transects were laid out in two low-lying swales. Cover of each species was estimated in 50 x 50 cm quadrats positioned at every meter mark along the transect.

Data Analysis

Vegetation data collected in the *Eleocharis palustris* community at Fisher Butte in 1991 was compiled with the data collected by Connelly in 1989 (unpublished). The mean cover of each species in six 50 cm^2 quadrats was calculated. Species of very low (trace) abundance were not included in the analysis.

The program DECORANA, a program for detrended correspondence analysis (Hill 1979), was used to explore patterns in the untransformed species/sample data from the sample x species matrix. Although environmental data were not characterized in the Mound (*Anthoxanthum odoratum*) community at Rose Prairie, the samples were included in the ordination. Two primary axes (DCA 1 and DCA 2) were identified, and the array of species plotted against these axes to depict the patterns of species distribution in two dimensional space. The vectors representing two primary ordination axes were compared with measured environmental factors to identify relationships between species distribution and the physical parameters investigated.

A step-wise multiple regression procedure was used to select a best model for explaining the arrangement of sample scores on the principal ordination axes.

To summarize the data describing the physical environment of wet prairie plant communities sampled, data were displayed graphically and summary statistics were calculated based on the number of sampling visits when water table elevation and redox potential were recorded at specific levels between the wet period November and May. For example, the number of bi-weekly visits when water elevation exceeded the surface was calculated for each sample point in the six communities. The calculations express a combination of the magnitude and duration of the environmental conditions which were measured. These values were determined to be the best expression of the intensity of environmental conditions in a single series of values and allowed for statistical comparisons.

The null hypothesis, that a given environmental parameter was the same in all communities, was tested using a non-parametric ANOVA Kruskal-Wallis test based upon ranks (Zar 1984). This test is appropriate for data sets which contain unequal sample sizes. If the null hypothesis was not accepted, multiple comparisons were made to distinguish groups.

RESULTS AND DISCUSSION

Elevation, soil texture and soil nutrients

There was less than a meter difference between the average elevation of Rose Prairie and Fisher Butte sites. The points surveyed within them ranged from 112.88 and 114.60 meters above sea level (ASL). The elevation of the Long Tom ACEC is 102.10 meters above sea level (Table 5). The elevation of the *Anthoxanthum odoratum* community at Rose Prairie was not surveyed. These elevated mounds are approximately 0.5 meter higher than surrounding areas.

By mean elevation, the communities sort in the following order, from highest to lowest (Table 5): Anthoxanthum odoratum (Mounds) community, Vaccinium cespitosum community, Rose Prairie Deschampsia cespitosa community, Fisher Butte Deschampsia cespitosa community, Rosa nutkana/Juncus nevadensis community, Eleocharis palustris community, Long Tom Poa sp./Deschampsia cespitosa community.

The soils at all sites had high silt content (ranging from 36.8-57.3% of total), a common characteristic of the depositional environment of Willamette Valley bottomlands (Soil Conservation Service 1987). The three sites, however, varied substantially in relative amounts of sand and clay (Table 6). Soil texture ranged from silty clay at Fisher Butte to a sandy loam at Rose Prairie.

The soil of the Rose Prairie site is considerably more sandy than at Fisher Butte and the Long Tom ACEC (Table 6). The soils of Rose Prairie contain an average of 49.4% sand, much higher amounts than at the other two sites, which are composed of silt-clays and silty clay loams. In fact, the Long Tom and Fisher Butte soils average almost three times the clay content of Rose Prairie soils. Soils of the Long Tom ACEC were very similar in texture to Fisher Butte.

Within the Fisher Butte site, mean clay content was highest in the *Deschampsia cespitosa* community, intermediate in the *Eleocharis palustris* community, and lowest in the *Rosa nutkana -Juncus nevadensis* community (Table 7). However, these differences were not significant. Soil texture differences were much more pronounced between the Rose Prairie and Fisher Butte sites than between communities within these sites.

Table 5. Mean (standard error) elevation of	plant communities identified at the three
study sites, in meters above sea level.	-

Plant community identity	Mean elevation (SE) in meters above sea level
Rose Prairie Vaccinium cespitosum community	114.43 (0.08)
Rose Prairie Deschampsia cespitosa community	114.29 (0.02)
Fisher Butte Deschampsia cespitosa community	113.78 (0.05)
Fisher Butte Rosa nutkana/Juncus nevadensis community	113.29 (0.06)
Fisher Butte <i>Eleocharis palustris</i> community	113.02 (0.06)
Long Tom ACEC Deschampsia cespitosa/Poa sp.meadow community	102.10

Site	Sand	Silt	Clay	Soil texture class	Soil series (SCS 1987)
Fisher Butte	19.1	48.2	32.7	Silty clay —>	Natroy
n=9	(1.8)	(1.8)	(2.7)	silty clay loam	
Rose Prairie	49.4	40.7	9.9	Loam>	Natroy
n=4	(1.8)	(1.6)	(0.7)	sandy loam	
Long Tom	16.8	54.7	28.6	Silty clay loam	Natroy-
n=2	(7.1)	(2.05)	(5.05)	-	Bashaw

Table 6. Mean (standard error) percent sand, silt and clay content of soils sampled at three study sites.

Site	Sand	Silt	Clay
Fisher Butte			
Rosa-Juncus	22.5	51.2	26.3
n=3	(0.9)	(2.8)	(2.3)
ELPA	16.0	49.6	34.4
n=3	(0.4)	(3.9)	(4.2)
DECE	18.9	43.7	37.3
n=3	(5.2)	(0.9)	(6.0)
Rose Prairie			
DECE	47.2	43.4	9.5
n=2	(1.7)	(0.4)	(1.3)
VACA	51.7	38.1	10.2
n=2	(2.4)	(1.3)	(1.1)
Long Tom	16.8	54.7	28.6
n=2	(7.1)	(2.05)	(5.05)

Table 7. Mean (standard error) percent sand, silt and clay content of soils sampled by community at the three study sites.

Soils at all three sites are acidic. The pH of all points sampled was between 5.3 and 5.5 (Table 8). By site, the mean organic matter content ranged between 2.97 and 10.81%. Mean iron concentration varied between 130 and 302 ppm. Organic matter content and iron concentration were strongly correlated ($r^2=0.88$, p<0.0001) among soil samples, and both were negatively correlated with the percentage of sand ($r^2=-0.79$, p=0.0001, $r^2=-0.62$, p=0.006). Mean sulfate concentration was 8.14 ppm at Fisher Butte. It was 2.58 ppm at Rose Prairie, and 3.71 ppm at the Long Tom ACEC.

Nutrient analyses of soil samples indicated that Rose Prairie is unique among the sites in having the most nutrient poor soils (Table 8). The average organic matter content at this site was 40% lower and iron concentration was 60% lower than was recorded at Fisher Butte and Long Tom ACEC sites.

Variability in the mean sulfate concentrations at Fisher Butte was accounted for by the greater concentrations in the soils of the *Eleocharis palustris* community than in other communities measured (Table 9). In this community, mean sulfate concentration was 15.25 ppm. With the samples from the *Eleocharis palustris* community removed from the data set, sulfate concentrations are not significantly different from those at Rose Prairie (Kruskall-Wallis test p=0.05).

Deschampsia cespitosa and Vaccinium cespitosum communities at Rose Prairie are considerably lower in organic matter than other communities sampled (Table 9). Iron concentration and pH were not significantly different between communities.

Site	Organic matter	Iron (ppm)	Sulfate (ppm) (%)	рН
Fisher Butte	7.18 (0.31)	212 (9.7)	8.14 (1.15)	5.3 (0.03)
Rose Prairie	2.97 (0.18)	130 (17)	2.58 (0.10)	5.3 (0.04)
Long Tom	10.81 (0.77)	302 (12)	3.71 (0.25)	5.5 (0.05)

Table 8. Mean (standard error) organic matter (OM), iron, and sulfate content, and pH of soils sampled at the three study sites, 4 May, 1992.

significantly differ from each other.							
	Rosa-Juncus	FB-DECE	ELPA	VACA	RP-DECE	Long Tom	
pН	5.3	5.3	5.4	5.3	5.4	5.5	
	(0.03)	(0.06)	(0.04)	(0.02)	(0.05)	(0.05)	
Iron (ppm)	199	196	247	146	111	302	
	(9)	(15)	(22)	(22)	(28)	(12)	
Sulfate*	4.83ab	5.12 ^{ab}	15.25ª	2.68 ^b	2.45 ^b	3.70 ^{ab}	
(ppm)	(0.29)	(0.52)	(2.09)	(0.12)	(0.16)	(0.25)	
OM*(%)	6.59ab	7.92ª	7.02ab	3.21b	2.67 ^b	10.80 ^{ab}	
	(0.40)	(0.59)	(0.53)	(0.20)	(0.27)	(0.77)	

Table 9. Mean (standard error) organic matter, iron, sulfate, and pH of soils sampled in plant communities at Fisher Butte, Rose Prairie, and Long Tom ACEC, 4 May, 1992. An asterix indicates parameters where communities are not the same at p=0.1 Groups are indicated with superscripts ^a and ^b. Communities with the same letter do not significantly differ from each other.

Groundwater Hydrology

Patterns of groundwater fluctuation measured in six plant communities

Patterns of measured water table levels and corresponding monthly precipitation in the *Deschampsia community* at Fisher Butte, September 1991 - July 1993, are shown in Figure 8. Total monthly precipitation was calculated from daily records collected by the National Weather Service at the Eugene Airport (Eugene FAA) weather station, 5-8 kilometers away. The general pattern apparent in the Fisher Butte *Deschampsia cespitosa* community was representative of most monitoring points. The water table elevation was within 1 m of the soil surface for six months of the year, and within 25 cm of the soil surface during most of the same period.

The water elevation in wells changed from greater than 1 m below the soil surface (and beyond the scope of instrumentation) to within 20 cm of the surface during a two week period in November 1991 (Figure 8). The rise corresponded with the onset of increased precipitation during the same period. Water levels remained elevated for approximately four months, until late March 1992; this coincided with a period of abnormally low precipitation in February and March 1992. Water table elevations increased to near the surface again for a brief period in mid-April, 1992. In May, 1992, the elevation of water table began to decline, and was more than 1 m below the surface (and out of the scope of measuring devices) by mid June.

In the fall and winter of 1992-1993, a similar pattern in water table elevation was recorded (Figure 8). A sudden rise in water levels, from more than 100 cm to within 10 centimeters of the surface, occurred after the onset of fall rainfall in October. By November, water levels were near or above the surface, and the elevated levels were sustained until June 1993. No drop in water levels occurred during the spring of 1993. In fact, the duration of surface inundation was about seven weeks longer in 1992-1993 than in the previous year. In 1991-1992, the maximum water table elevation in the Deschampsia community was recorded in late February. In 1992-1993, the maximum water table elevation was recorded in the month of March. Neither of these maxima coincided with the months of maximum rainfall.

Overland flow was apparent at both the Fisher Butte and the Rose Prairie sites, particularly in the fall of 1992. Large quantities of black ash produced by the burn at Fisher Butte in September, 1991 were observed to float from east to west

across the site, where it accumulated in the *Eleocharis palustris* community. An elevated road and dike at the western edge of the Fisher Butte site inhibit further water movement, and surface water ponded at this point. The *Eleocharis palustris* community occurs in this area.

Despite differences between the 1991-1992 and 1992-1993 season, the general pattern of hydrologic fluctuation observed over the two year period is one of sharp rise in November coinciding with the onset of winter precipitation (Figure 8). In both years, water table elevations reached the surface after November precipitation exceeded 10 centimeters.

Average monthly precipitation increased until February, and water levels levelled off by December. After initial flooding, additional rainfall didn't result in equivalent increases in the water levels at the prairie sites. The water levels for November-February 1992 were similar to those recorded in the same period in 1993. However, there was a pronounced response of water levels to the drought in the late winter and spring of 1992, and the water table declined sharply below the surface. Precipitation during the months of late 1991 and early 1992 was abnormally low. Compared with the monthly averages of the last three decades, 1992 monthly rainfall was in the 35th percentile for January, the 54th percentile in February, the 14th percentile for March, the 99th percentile for April, the 0th for May, and the 65th percentile for June. The winter of 1991-1992 was one of the driest ever recorded at the Eugene FAA weather station (George Taylor, Oregon State Meteorologist, personal communication, 1993). Figure 8. Mean $(\pm 1SE)$ water table elevation recorded in *Deschampsia cespitosa* community at Fisher Butte between September, 1991 and July, 1993, with corresponding precipitation values from records of Eugene FAA weather station

Figure 8.



42

Maximum water levels recorded between September 1991 and July 1992 spanned from 5 cm below the soil surface at the highest elevation site in Fisher Butte *Deschampsia cespitosa* community to 20 cm above the surface in the *Eleocharis palustris* community at the western end of the Fisher Butte site (Figure 9).

The magnitude of inundation in the *Eleocharis palustris* community was markedly different from that of other communities monitored. There, the surface was inundated by 15-20 cm between November 1991 and late April 1992.

In other communities, water levels were close to the surface during the entire wet period, with shallow water standing 1-5 cm above the surface, or within 5 cm below the soil surface. At Rose Prairie, there was only a 2 cm difference between maximum elevation of water table in two communities where instrumentation was installed. During the 1991-1992 sampling period, water was never observed to exceed the soil surface on the elevated mounds where the *Anthoxanthum odoratum* community occurs.

During the dry spring of 1992, a 40 cm decline in water table elevation was observed in most points monitored. The water level declined in the *Eleocharis palustris* community, as well, but it remained within 5 cm of the soil surface.

The water table was more than 1 meter below the soil surface between June and October 1992, then it rose again to stand above the surface in *Rosa-Juncus* and *Eleocharis palustris* communities, and to within 15 cm of the surface in *Deschampsia cespitosa* communities at both Fisher Butte and Rose Prairie (Figure 10). By December 1992, the groundwater was above the soil surface in all communities. It remained above the surface through June 1993, with the exception of a single date (February 1993) when water levels in the *Vaccinium cespitosum* community fell to 5 cm below the surface. The water table declined to > 1 m below the surface by July 1993 in all communities except in the *Eleocharis palustris* community, where in July 1993 water levels were 20 cm below the surface. Monitoring of water wells was discontinued after that date. During the entire wet period, water depths in the *Eleocharis palustris* community were consistently more than 10 cm deeper than in the other communities. Figure 9. Mean water table (\pm 1SE) elevations, in centimeters, measured in six plant communities, September, 1991-July, 1992. ∇ =Eleocharis palustris community, \bullet =Fisher Butte Deschampsia cespitosa community, \bigcirc =Rosa nutkana /Juncus nevadensis community, \square =Rose Prairie Deschampsia cespitosa community, ∇ = Vaccinium cespitosum community, \blacksquare =Long Tom Poa sp./Deschampsia cespitosa community.





 Figure 10. Mean water table elevations measured in five plant communities, September 1992-July, 1993. No data were collected in May, 1993. The Long Tom site was not sampled during this period. $\nabla = Eleocharis palustris$ community, $\oplus =$ Fisher Butte Deschampsia cespitosa community, $\bigcirc =Rosa$ nutkana/Juncus nevadensis community, $\square =$ Rose Prairie Deschampsia cespitosa community, $\nabla = Vaccinium$ cespitosum community.



47

Magnitude and duration of elevated groundwater conditions.

In 1991-1992, the *Eleocharis palustris* community was inundated most frequently and at the greatest magnitude (Table 10). There, the depth of inundation exceeded 5 cm above the surface during an average of 10.9 visits, or roughly 22 weeks of the 28 week wet period. The average maximum depth of inundation in this community was 22 cm. The Eleocharis community was inundated five centimeters or more above the soil surface an average of 7.2 more visits (approximately 14 weeks) longer than the next closest communities.

The Rosa nutkana/Juncus nevadensis community and Rose Prairie Deschampsia cespitosa communities were similar in terms of the frequency and intensity of elevated water levels (Table 10). Although the water table exceeded the surface for an average of 9 sampling visits in these communities, depths of five centimeters or more above the surface were recorded during only 3 visits. The water table stood above the surface during an average of 4.9-6.3 visits (10-12.6 weeks) in the Fisher Butte-Deschampsia cespitosa , Vaccinum cespitosum , and Long Tom prairie communities. Depths exceeding 5 cm above the soil surface were never recorded at the Long Tom, and observed only once in the Deschampsia cespitosa community at Fisher Butte.

Water levels were within 25 cm of the soil surface in all communities during most of the wet period, but in the *Rosa /Juncus* and *Eleocharis palustris* communities water levels were within 25 cm of the surface more frequently. These differences between communities are due to the fact that water levels in the *Rosa /Juncus* and *Eleocharis palustris* communities did not show the same dramatic response to the dry conditions during the winter/spring of 1992 (see Figure 9).

Table 10. Mean number (standard error) of bi-weekly visits when the water table
elevation was within specified levels, and maximum inundation depth in centimeters.
November, 1991 - May, 1992. An asterix indicates that communities are not all the
same at p=0.1 Groups are indicated with superscripts a and b. Communities with the
same letter do not significantly differ from each other.

Ros	sa-Juncus	FB-DECE	ELPA	VACA	RP-DECE	Long Tom
within 25cm	11.2 ^{ab}	10.7 ^b	12.3a	10.5 ^b	10.3 ^b	9.5 ^b
of surface*	(0.2)	(0.3)	(0.2)	(0.2)	(0.2)	(0.4)
within 5cm	9.7ab	7.1 ^b	11.6ª	7.0 ^b	9.7ab	5.0 ^b
of surface*	(0.3)	(0.7)	(0.2)	(1.0)	(0.3)	(0.0)
above	9.5ab	4.9 ^b	11.5ª	6.3 ^b	9.0ab	5.0 ^b
surface*	(0.3)	(1.0)	(0.3)	(1.1)	(0.4)	(0.0)
5cm or more	3.3 ^b	0.2 ^b	10.9ª	2.3b	3.7ab	0.0 ^b
above surface *	(1.0)	(0.1)	(0.4)	(0.8)	(1.1)	(0.0)
Max. depth	6.1 ^{ab}	2.1 ^b	22ª	8.0ab	6.0 ^{ab}	3.0 ^b
in cm*	(0.9)	(0.9)	(1.8)	(2.4)	(0.7)	(0.0)

_

In 1992-1993, also, the *Eleocharis palustris* community was inundated for the longest period of time and at the greatest magnitude (Table 11). Inundation depth in the *Eleocharis palustris* community exceeded 5 cm above the surface most frequently during the wet period. The maximum depth of inundation was 29.4 cm. The *Eleocharis palustris* community was inundated (above surface) approximately 4 weeks longer than the other communities.

Rosa nutkana/Juncus nevadensis and Rose Prairie Deschampsia cespitosa communities were similar in terms of the frequency and intensity of flooding. Inundation depth exceeded 5 cm a mean of 3.6 visits in Rosa nutkana/Juncus nevadensis community and 2.5 visits in the Rose Prairie Deschampsia cespitosa community. Mean maximum depths recorded in these communities were 10.6 and 8.8 cm.

Depths exceeding 5 cm above the surface were recorded in the Vaccinum cespitosum community on only one visit, and very rarely in the Fisher Butte Deschampsia cespitosa community. The water table was frequently within 5 cm of the surface (7 visits) in Fisher Butte-Deschampsia cespitosa, but only during an average of 5.3 visits in the Vaccinium cespitosum community.

In the 1992-1993 wet period, the hydrologic regime was the same between communities except for the maximum recorded depth and the duration of time greater than 5 cm above the soil surface (Table 11). In 1991-1992, there were significant differences between communities in all five of the calculated parameters (Table 10). The patterns of separation of plant communities into groups is similar in both years: by the Kruskall-Wallis test, the duration and magnitude of flooding in the *Eleocharis palustris* community is consistently greater than in the Fisher Butte *Deschampsia cespitosa* and *Vaccinium cespitosum* communities. In 1991-1992, the Rose Prairie *Deschampsia cespitosa* and *Rosa nutkana/Juncus nevadensis* communities are not significantly different from the *Eleocharis palustris* community for most parameters, but instead form an intermediate group between the extremes.

Water table elevations were recorded twice a month during the 1991-1992 wet period and monthly during the 1992-1993 wet period. In order to make a comparison between the two years, each value presented in Tables 10 and 11 was converted to a percentage of total visits during that period (Table 12).

As discussed above, the 1992-1993 was a much wetter year. Precipitation during this period was normal (based on the 30 year average), while precipitation during the previous winter was below normal. This is reflected in greater magnitude of elevated water levels during the 1992-1993 period (Table 11). However, the maximum depth of the water table was not more than 7.5 cm greater in 1992-1993 than in the previous year at any point. The relative patterns between communities were similar between years, but the total percentage of time when the water table was elevated was greater.

The similarity in hydrologic regime between years, despite the variation in precipitation, indicates that differences observed between communities, in terms of both water table fluctuation and soil redox potential, are likely to be representative of normal years.

Table 11. Mean (and standard error) number of semi-monthly visits when the water
table elevation was within specified levels, and maximum inundation depth in
centimeters, November, 1992 - May, 1993. An asterix indicates that communities are
different from one another at $p=0.1$ Groups are indicated with superscripts ^a and ^b .
Communities with the same letter do not significantly differ from each other.
0 5

	Rosa-Juncus	FB-DECE	ELPA	VACA	RP-DECE
within 25cm of	7	7	7.6	7	7
surface	(0.0)	(0.0)	(0.2)	(0.0)	(0.0)
within 5cm of	7	6.7	7.4	5.3	7
surface	(0.0)	(0.2)	(0.2)	(0.3)	(0.0)
Above surface	6.3	4.7	7.3	4.3	6.5
	(0.4)	(0.7)	(0.2)	(0.9)	(0.2)
Greater than 5cm	3.6ab	0.3 ^b	6.8ª	lp	2.5b
above surface*	(0.3)	(0.2)	(0.1)	(0.5)	(0.6)
Max. depth in	10.6 ^b	4.2 ^b	29.4ª	4.1b	8.8 ^b
cm*	(1.0)	(1.1)	(2.1)	(1.3)	(1.1)

Table 12. Percentage of visits (to the nearest 5%) when the water table elevation was within specified levels, and maximum recorded elevations, November, 1991-May, 1992 (first row) and November, 1992-May, 1993 (second row). The Long Tom site was not sampled the second year.

	Rosa-Juncus	FB-DECE	ELPA	VACA	RP-DECE	Long Tom
within 25cm c	of 80	80	90	75	75	70
surface	90	90	95	90	90	*
within 5cm of	70	50	80	50	70	35
surface	90	85	90	65	90	*
above surface	70	35	80	45	65	35
	80	60	90	55	80	*
greater than	20	0	80	20	25	0
5cm above	45	5	85	0	30	*
surface						
Max. depth in	6.1	2.1	22.0	8.0	6.0	3
cm	10.6	4.2	29.4	4.1	8.8	*

Patterns of redox potential fluctuation measured in six plant communities.

The oxygen status of the soil environment, as indicated by soil reductionoxidation values recorded bi-weekly with platinum electrodes, was extremely dynamic, with variations in reduction-oxidation potential of over 600 millivolts between midsummer and mid-winter. Reduced conditions were present at all points monitored in 1991-1992.

At -5 cm, the soil environment was more sensitive to changes in water table elevation and inundation of the soil surface, and was much more dynamic than at -25 cm, as represented by the patterns in the Fisher Butte *Deschampsia cespitosa* community (Figure 11). At -5 cm, redox potentials became positive for a temporary period during the month of March 1992, when drought conditions produced a sharp decline in water table elevations during the same period. For the most part, redox values at -25 cm indicated no soil response to the droughty spring of 1992. As in this study, Green (1991) found that redox potentials were less variable and dynamic at greater depths (he measured at -5 cm and -30 cm below the surface). He also found fewer differences in soil redox potentials between communities at -30 cm. These differences by soil depth highlight the importance of accounting for depth in ecological studies conducted in seasonally flooded systems. Figure 11. Mean (± 1 SE) redox potential measured at 5 and 25 cm below soil surface in *Deschampsia cespitosa* community, Fisher Butte, September, 1991-May, 1992. \bullet = redox potential at -5 cm, o = redox potential at -25cm.





თ ი Microelectrodes installed at -25 cm depth indicated a drastic change in soil environment corresponding to the rise of water levels in November 1991 (Figure 12). Coinciding with the rise in water table, soils became anoxic and slightly to strongly reduced at all sampling points. The pattern of redox potential at -25 cm coincided with the timing of surface/near surface water levels. Between November 1991 and May 1992 at -25 cm depth, soil redox potentials of the *Rosa nutkana/Juncus nevadensis* community and *Deschampsia cespitosa* communities at Fisher Butte, Rose Prairie, and Long Tom ACEC were frequently less than -150 mV, and occasionally less than -200 mV, indicating that intensely reducing conditions were present for long periods in these communities. In the *Vaccinium cespitosum* community, the redox potential rarely fell below -100 mV. At -25 cm, a response to the temporary drought-induced drawdown was only evident in the *Eleocharis palustris* and *Vaccinium cespitosum* communities. In May 1992, redox potentials rose rapidly at all locations sampled. By 17 June 1992, redox potentials were 250 mV or greater throughout both sites, indicating an oxidized soil environment. Figure 12. Mean (± 1 SE) redox potential in millivolts measured at 25 cm below soil surface in six plant communities, September, 1991-May, 1992. $\nabla = Eleocharis palustris$ community, $\bullet =$ Fisher Butte Deschampsia cespitosa community, $\circ = Rosa$ nutkana/Juncus nevadensis community, $\Box =$ Rose Prairie Deschampsia cespitosa community, $\nabla = Vaccinium$ cespitosum community, $\Xi =$ Long Tom Poa sp./Deschampsia cespitosa community.





Microelectrodes installed at -5 cm depth also indicated that soil anoxia in all communities (Figure 13). As discussed above, the soil environment -5 cm below surface was much more dynamic than at -25 cm. Redox potentials became strongly negative 30 November, 1991 and remained so until March 1992. During that period, soils were strongly reduced. Beginning in March 1992, soil redox potentials rose gradually to over the next month and a half until 4 April 1992, with peaks between 100 and 400 mv. This corresponded to the drop in water levels observed in accompanying wells at the same period(see Figure 9). Redox potential at most locations declined again by mid-April 1992. At most locations, the soils did not become as strongly reduced as previously. By 16 May 1992, soils at all sampling points were oxidized.

The presence and degree of soil anoxia corresponded to the water levels and flooding above the surface indicating that high water levels induced reducing conditions in the soil.(Figure 14). In the Fisher Butte *Deschampsia cespitosa* community, for example, mean redox potentials at both -5 and -25 cm indicated anoxic soils when water table elevation was within 25 cm of surface. Negative values were not recorded at -5 cm below the surface until the water table reached that level. On one date (during the temporary spring drawdown), a very negative value was recorded at -25 cm when water table elevation was more than 40 cm below the surface.

Figure 13. Mean (± 1 SE) redox potential in millivolts measured at 5 cm below soil surface in six plant communities, September, 1991-May, 1992. $\nabla = Eleocharis palustris$ community, $\bullet = F$ isher Butte *Deschampsia cespitosa* community, $\circ = Rosa$ *nutkana/Juncus nevadensis* community, $\Box = Rose$ Prairie *Deschampsia cespitosa* community, $\nabla = Vaccinium$ cespitosum community, $\blacksquare = Long$ Tom *Poa* sp./*Deschampsia cespitosa* community.


 Figure 14. Water table elevation (in centimeters) and corresponding redox potential values recorded in the Fisher Butte *Deschampsia cespitosa* community during the 1991-1992 season. $\blacksquare = -25$ cm; $\neq = -5$ cm.



Figure 14.

64

Intensity and duration of reduced soil conditions.

Summary statistics calculated based on redox potential values reported in the literature (see Tables 1 and 4) indicated important differences between the soil conditions of plant communities studied.

For electrodes at -5 cm below the surface, the greater frequency of redox potentials less than 250 mv and 150 mv indicated that oxygen was absent and iron reduced in the soils of the *Eleocharis palustris* community during approximately 2 more visits (about four weeks longer) than the next nearest communities (Table 13). This was due to differing responses in communities to the droughty spring of 1992: water levels did not diminish dramatically below the surface in the *Eleocharis palustris* community the way they did in other communities. While reduced conditions close to the soil surface were recorded samples from every community, the timing they occur may influence species composition. In the *Eleocharis palustris* community, for example, anoxic conditions were recorded in the month of April, 1992 when other parts of the sites were oxidized (Figure 12), and soils of both the Long Tom and Fisher Butte *Deschampsia cespitosa* communities were oxidized two weeks before they were at Rose Prairie and at the *Rosa nutkana/Juncus nevadensis* community. The relative timing of the onset of oxidized conditions in the spring could play a role in determining the relative success of different species.

At -25 cm, summary statistics based on the cut-off values indicate that the duration of anaerobic conditions at various intensities in the soil of the six communities was similar. The intensity of anaerobic conditions is significantly different between communities only in terms of the number of visits when redox potential was less than - 150 mV (Table 14), where Eh < -150 mV during a mean of 2.1 visits in the *Eleocharis palustris*, compared to a mean of 10.2 visits in the nearby *Rosa nutkana/Juncus nevadensis* community. Why this dramatic difference occurs only at -25 cm is difficult to explain.

There is a trend in the intensity of redox potentials among the communities sampled. Redox potential values at -25 cm are most intense in the *Rosa nutkana/Juncus nevadensis*, Rose Prairie *Deschampsia cespitosa* and *Vaccinium cespitosum* communities, intermediate in Fisher Butte and Long Tom *Deschampsia cespitosa* communities, and least intense in the *Eleocharis palustris* community. Although differences in minimum redox potential recorded by community at -25 cm are not

statistically significant, for the most part the *Eleocharis palustris* community did not become as reduced as others at the -25cm depth, despite fact that inundation of surface was deeper there, and was sufficient to reduce or eliminate oxygen diffusion. A possible explanation for the unique behavior of soils in this community is that they were oxygenated through radial oxygen loss, or excretion of oxygen into the rhizosphere through root tissue (Blom et al. 1990). *Eleocharis* species, and other plants present in this community, possess aerenchyma and rusty patterns along the roots. Because of their relative topographic position, the soils of this community remain somewhat oxygenated by surface and subsurface water movement across it. The higher amounts of sulfate found in the soils of the *Eleocharis palustris* community are probably due to the fact that sulfur does not become reduced. Table 13. Mean number (and standard error) of bi-weekly visits that redox potential, at 5cm below the surface, was at specified level, November, 1991-May, 1992. An asterix indicates that communities are different from one another at p=0.1 Groups are indicated with superscripts ^a and ^b. Communities with the same letter do not significantly differ from each other.

	Rosa-Juncus	FB-DECE	ELPA	VACA	RP-DECE	Long Tom
Oxygen	11.3 ^b	10.4 ^b	13.3ª	10.5 ^b	10.7 ^b	9b
absent*	(0.5)	(0.3)	(0.2)	(0.6)	(0.7)	(1.0)
Iron	9.7ab	8.3 ^b	11.8ª	9ab	10ab	8ab
reduced*	(0.5)	(0.6)	(0.8)	(0.4)	(0.7)	(0.0)
Sulfur	3.2	3.7	4.8	3.5	6.3	3.5
reduced	(1.1)	(1.1)	(1.5)	(1.4)	(1.1)	(1.1)
Strongly	0.7	1	3	1	2	1.5
reduced	(0.7)	(0.6)	(1.2)	(0.6)	(0.7)	(1.1)
Minimum	-156.9	-137.7	-203.7	-160.2	-205.6	-188.3
Eh (mV)	(17.9)	(41.5)	(32.9)	(33.4)	(12.4)	(18.4)

Table 14. Mean number (and standard error) of bi-weekly visits when redox potential, at 25 cm below the surface, was at specified level, November, 1991-May, 1992. An asterix indicates that communities are different from one another at p=0.1 Groups are indicated with superscripts ^a and ^b. Communities with the same letter do not significantly differ from each other.

	Rosa-Juncus	FB-DECE	ELPA	VACA	RP-DECE	Long Tom
Oxygen	13.2	12.7	13.0	11.8	13.4	12.5
absent	(0.3)	(0.2)	(0.3)	(1.1)	(0.4)	(0.4)
Iron reduced	12.7	11.6	11.5	10.5	12.8	12.5
	(0.3)	(0.2)	(0.5)	(1.3)	(0.3)	(0.4)
Sulfur	10.2 ^b	4.9ab	2.1ª	4.3ab	9.2 ^{ab}	6 ^{ab}
reduced*	(1.0)	(1.5)	(1.5)	(1.9)	(0.8)	(0.7)
Strongly	51	1.0	11	15	54	0
reduced	(1.6)	(0.7)	(1.0)	(1.0)	(1.6)	(0.0)
Minimum	-242.4	-180.4	-138.9	-222.4	-223.3	-168.5
Eh (mV)	(17.1)	(15.4)	(33.4)	(33.3)	(8.6)	(2.3)

There is some evidence of a plant effect on redox potential. The most negative redox potentials were recorded in January 1992, although the greatest magnitude of flooding occurred in April 1992. The intensity of reduced conditions subsided somewhat in spring. It is likely that the role of plants in counteracting the anaerobic conditions (through radial oxygen loss) became more important in spring, when the soil was warmer, and plants were more active.

Redox potential was extremely useful in this study for characterizing the presence and intensity of reduced soil conditions in the plant communities of the wet prairie. Redox potential values are within the range reported for other Willamette Valley soils by Austin (1993), who measured soil redox potential in untiled agricultural plots. Austin reported redox potentials of less than 200 mV in the upper horizon of Dayton soils located in Benton county during the same period, but did not record values below -200 mV. Most of Austin's samples were made from depths greater than 25 cm below the surface. He concluded that the biological activity required for greater reduction of soils was limited by lower levels of organic matter deep in the soil profile (Austin 1993). Austin recorded redoximorphic features in all soils which had water table elevation within 25 cm for >10% of the wet period. Iron reduction was most likely to occur within 38 cm of the soil surface, where organic matter was sufficient to fuel biological activity.

In a natural riparian system in NE Oregon, Green (1991) recorded redox potentials between -151 and -197 mV in *Glyceria grandis* and *Carex rostrata* dominated communities during early months of summer. He recorded significantly lower redox potentials in *Glyceria grandis* and *Carex rostrata* dominated communities than in less mesic *Juncus balticus/Poa pratensis* and *Poa pratensis/Carex* spp. communities during early part of the growing season. By August, there were not significant differences in redox potentials between communities. As in this study, Green (1991) recorded wide fluctuations in redox potential over time. The pathways of nutrient cycling may vary dramatically between seasons in seasonally flooded ecosystems. Ordination of species and samples by detrended correspondence analysis

Detrended correspondence analysis of the species/sample data from Fisher Butte and Rose Prairie produced clear patterns of species distribution on two principal axes (Figures 15 and 16). The eigen value of the first solution is 0.877, and second eigen value is 0.633. The full names corresponding to species acronyms in Figure 15 are listed in Table 15.

Sample scores on DCA 1 were highly correlated with the maximum water table elevation recorded (1992-1993: $r^2=0.79$, p< 0.0000, 1991-1992: $r^2=0.54$, p< 0.0000). They were also correlated with the frequency of visits when water table elevation exceeded 5 centimeters above the surface (1992-1993: $r^2=0.68$, p<0.0000, 1991-1992: $r^2=0.60$, p<0.0000). The sample scores on DCA 1 were also significantly correlated with sample elevation ($r^2=0.63$, p<0.0000) and the frequency of visits when water table was within 25 centimeters of the surface (1991-1992: $r^2=$ 0.58, p<0.0000). There were weak but significant correlations between the sample scores on DCA 1 and the frequency of anaerobic conditions ($r^2=0.40$, p<0.0000) and soil texture (percent sand content: $r^2=0.37$, p<0.0000) (Table 16).

The maximum water table depth recorded at sample points (1992-1993 season) and percent sand content of samples were selected from among the variables in Table 16 by a step-wise multiple regression procedure as the best model for explaining the sample scores on DCA 1 (Table 17). The high correlation between the sample scores on the first DCA axis and maximum water table elevation indicates that a considerable amount of the variation in the species cover data is explained by differences the magnitude of wintertime inundation of the soil surface, this being modified by the percent sand content of soils (Table 17).

Figure 15. Species plotted in relationship to their scores on DCA 1 and DCA 2. Four letter species acronyms are used to show species positions. Table 15 shows the species names corresponding to acronyms.





Figure 16. Samples plotted in relationship to their scores on DCA 1 and DCA 2. V=Vaccinium cespitosum community, RD=Rose Prairie Deschampsia cespitosa community, FD=Fisher Butte Deschampsia cespitosa community, RJ=Rosa nutkana/Juncus nevadensis community, E=Eleocharis palustris community, M=mounds.

Figure 16.



74

Species name	Acronym	
Agrostis capillaris	AGCA	
Agrostis exarata	AGEX	
Agrostis spp.	AGRO	
Aira caryopyhlla	AIRA	
Alopecurus	ALPL	
Anthoxanthum odoratum	ANOD	
Aster chilensis	ASCH	
Aster curtus	ASCU	
Beckmannia syzigachne	BESY	
Bidens frondosa	BIFR	
Boisduvalia stricta	BOST	
Brodiaea coronaria	BRCO	
Brodiaea hyacinthia	BRHY	
Briza minor	BRMI	
Cardamine penduliflora	CAPE	
Camassia quamash	CAQU	
Carex spp.	CARX	
Carex rossii	CARO	
Centunculus minimus	CEMI	
Centuarium muhlenbergii	CEMU	
Centuarium umbellatum	CEUM	
Cirsium arvense	CIAR	
Cirsium vulgare	CIVU	
Crateagus douglassii	CRDO	
Danthonia californica	DACA	
Daucus carota	DACA	
Deschampsia cespitosa	DECE	
Downingia yina	DOYI	
Eleocharis acicularis	ELAC	
Eleocharis palustris	ELPA	
Epilobium paniculatum	EPPA	
Epilobium spp.	EPIL	
Erigeron decumbens	ERDE	
Eriophyllum lanatum	ERLA	
Eryngium petiolatum	ERPE	
Festuca arundinacea	FEAR	
Festuca rubra	FERU	
Fraxinus latifolia	FRLA	
Fragaria virginiana	FRVI	
Galium cymosum	GACY	
(continued next page)		

.

Table 15. Species names corresponding to four letter acronyms used in Figure 15.

Galium parisience	GAPA
Gnaphalium palustre	GNPA
Gnaphalium purpureum	GNPU
Gratiola ebracteata	GREB
Grindelia integrifolia	GRIN
Holcus lanatus	HOLA
Hypericum perforatum	HYPE
Hypchaeris radicata	HYRA
Juncus bufonis	JUBU
Juncus nevadensis	JUNE
Juncus ("green")	JUNG
Juncus tenuis	JUTE
Leontodon nudicaulis	LENU
Lichen: Cladonia spp.	LICN
Lomatium bradshawii	LOBR
Lotus formosissimus	LOFO
Lotus purshianus	LOPU
Luzula campestris	LUCA
Lycopus americanus	LYAM
Madia glomerata	MAGL
Mentha pulegium	MEPU
Microseris laciniata	MILA
Montia linearis	MOLI
Myosotis discolor	MYDI
Myosotis laxa	MYLA
Orthocarpus bracteosus	ORBR
Orobanche californica	ORCA
Orthocarpus hispidus	ORHI
Panicum occidentalis	PAOC
Parentucellia viscosa	PAVI
Perideridia oregana	PEOR
Phalaris arundinacea	PHAR
Plagiobothrys figuratus	PLFI
Plantago lanceolata	PLLA
Poa sp.	POA
Polygonum douglasii	PODO
Potentilla gracilis	POGR
Prunella vulgaris	PRVU
Pyrus communis	PYCO
Ranunculus occidentalis	RAOC
Rosa nutkana	RONU
Rumex acetosella	RUAC
Rubus spp.	RUBS
Sanicula bipinnatifida	SABI
Senecio jacobaea	SEJA
Sisyrinchium angustifolium	SIAN
Spiraea douglasii	SPDO
Trifolium dubium	TRDU
(continued next page)	

Table 15 continued:

Vaccinnium cespitosum	VACA
Veronica scutellata	VESC
Viola adunca	VIAD

	DCA 1
Maximum water table depth (1992-1993)	79 %
Maximum water table depth (1991-1992)	54 %
Freq. of water depth >5cm above surface (1992-1993)	68 %
Freq. of water depth >5cm above surface (1991-1992)	60 %
Freq. of water depth <25cm below surface (1992- 1993)	48%
Freq. of water depth <25cm below surface (1991-1992)	58 %
Freq. of anaerobic conditions (Eh <250 mV) at 5cm	40%
Percent sand content	37%
Percent clay content	21%
Percent silt content	31%
Elevation	63 %

Table 16. Percent correlation between selected environmental variables and sample scores on DCA 1. Correlations greater than 50% are shown in bold.

Source Su	um of Squares	DF	Mean Square	F-Rati	o p-value
Model Error Total	922576 1487510 1071287	2 35 37	461228. 4248.86	108.5	.0000
Independent var	iable coeffic	ient	std. error	t-value	p value
Constant Percent sand con Maximum water	225.7 depth 12.6	72 25 54	33.57 0.80 1.17	6.72 -4.04 10.78	0.0000 0.0003 0.0000
R-squared: 0.86	119		Std err	or of estimate:	65.1833

Table 17. Analysis of variance and model fitting results for the regression: Score DCA $1 = \text{constant} + \beta_1$ Maximum water table depth + β_2 Percent sand content

Species including Alisma plantago-aquatica, Beckmannia syzigachne, Bidens frondosa, Eleocharis palustris, Eryngium petiolatum, Lycopus americanus, Myosotis laxa, Phalaris arundinacea, and Spiraea douglasii occur at one extreme of the species array (Figure 15). This position strongly suggests these species' affinity for environmental conditions present at the extreme end of the measured gradient, where maximum water depths are greater than 20 cm. Species at the opposite end of the hydric gradient, which have low scores on the first DCA axis, include Aira caryophylla, Anthoxanthum odoratum, Aster curtus, Carex rossei, Centuculus minimus, Cladonia spp., Comandra umbellata, Crateagus douglasii, Fragaria virginiana, Galium parisience, Horkelia congesta, Heterocodon rariflorum, Hypericum perforatum, Juncus sp., Lotus formossisimus, L. purshianus, Orthocarpus bracteosus, Rorippa curvisiliqua, Parentucella viscosa, Plantago lanceolata, Sanicula bipinnatifida, Vaccinium cespitosum, and Viola adunca. Their position suggests an affinity for environment where the surface is only shallowly inundated and where soils are more sandy.

Lomatium bradshawii, Erigeron decumbens var. decumbens, Aster curtus, and Horkelia congesta subsp. congesta, species of particular interest because of their candidate or protected status as threatened or endangered species, do not occur in the Eleocharis palustris community but they do occur elsewhere. It is likely that these species are intolerant of prolonged inundation more than 5-10 cm above the surface, or that they are unable to compete with other species in areas where these conditions are common. Higher water levels, such as found in the Eleocharis palustris community may limit the tolerance or relative competitive ability of many wet prairie plants. For example, successful germination and establishment of seedlings of some species may be curtailed by high water levels and soil anoxia (Iremonger and Kelly 1988, Gunderson et. al 1988, Hosner and Boyce 1962). Lomatium bradshawii, Aster curtus, and Horkelia congesta subsp. congesta occur in all of the other communities sampled at Rose Prairie and Fisher Butte. Erigeron decumbens does not occur at Rose Prairie, but occurs in both the Rosa nutkana/Juncus nevadensis and Deschampsia cespitosa communities at Fisher Butte. In the species array shown in Figure 15, these rare species occur towards the drier end of the gradient.

Conditions of deeper and more extended inundation in the *Eleocharis palustris* community were probably created by construction of the elevated road which forms the western border of the Fisher Butte site (see Figure 3). The road is a physical barrier to cross-surface water flow, and probably impedes underground flow. *Phalaris arundinacea*, an invasive pest species in wet prairie remnants, occurs in this community. It is probable that deeper or more prolonged flooding promote its occurrence there.

Samples from the Rose Prairie and Fisher Butte sites occupy separate parts of the array when sample scores on DCA 1 are plotted against percent sand content (Figure 17). Since soil texture differences are so pronounced between the two sites of Fisher Butte and Rose Prairie, it is possible that the gradient described by the separation of sites on first axis is partly explained by other (unmeasured) differences between the Fisher Butte and Rose Prairie sites. For example, the sites may have been subjected to different kinds of land use in the past. Such differences between the two sites might be more important in explaining the separation of samples than soil texture. There are much lower levels of iron, sulfate, and organic matter at the Rose Prairie site (Table 8).

The organic matter and nutrient poor soils of Rose Prairie may be responsible for the presence of the *Vaccinium cespitosum/ Cladonia* sp. community at that site.

Vaccinium sp. dominated communities frequently indicate that soils are poor in nutrient content. The relative competitive ability of *Vaccinium cespitosum* and possibly of *Cladonia* sp. may be favored by nutrient poor environments. The occurrence of these patches of *Vaccinium cespitosum* and *Cladonia* sp. provides an interesting and unique component of biodiversity within the wet prairie landscape. It is important to understand that a unique combination of site characteristics may promote their existence, so that the site can be managed for their preservation.

Species with high scores on the second axis (DCA 2) include Anthoxanthum odoratum, Crateagus douglasii, Galium parisience, and Hypericum perforatum. Species with low scores on the second axis are Aster curtus, Carex roseii, Cladonia spp., Gnaphalium parisience, Juncus sp., Panicum occidentalis, and Vaccinium cespitosum. Wet prairie endemics such as Lomatium bradshawii, Erigeron decumbens, and Horkelia congesta, and important native grasses such as Deschampsia cespitosa and Festuca rubra, score at an intermediate point on this axis. Samples from the Vaccinium cespitosum community at Rose Prairie occupy one end of this secondary gradient, while samples from the Fisher Butte communities and Deschampsia cespitosa community at Rose Prairie, and from the Eleocharis palustris community for the most part, occupy the intermediate section in this gradient (Figure 16).

There is a weak but statistically significant correlation between the sample scores on DCA 2 and percent silt and sand contents (silt: $r^2=.0.33$, p=0.0001, sand: $r^2=0.30$, p=0.0004), which indicates that soil texture may be important in explaining the distribution of species. However, the samples with the highest scores on the second axis are from the Mound (*Anthoxanthum odoratum*) community at Rose Prairie, where soil texture and other environmental characteristics were not sampled. Further analysis of soil characteristics of the Mound community might help to identify secondary environmental gradients related to plant species distribution. If the soils are more sandy in the *Anthoxanthum odoratum* community than in other parts of the Rose Prairie site, this would support the hypothesis that soil texture is important in determining the composition and relative abundance of species.

Figure 17. Sample scores on DCA 1 shown in relation to percent sand content. V=Vaccinium cespitosum community, RD=Rose Prairie Deschampsia cespitosa community, FD=Fisher Butte Deschampsia cespitosa community, RJ=Rosa nutkana/Juncus nevadensis community, E=Eleocharis palustris community, M=mounds.

(cr1) 40· 35-Maximum water table elevation, 1992-1993 Е Е 30-Е Е Е 25-Е 20-Е 15-RJ RJ RD RBJ RJ RJ MEDORD RJ RJ 10-RD RD ١ v 5hadipa J FD FD v FD FD -FD-- 0-۷ -5-1 0 100 200 300 400 500 600 700 Sample scores on DCA 1

Figure 17.

အ သ

SUMMARY AND CONCLUSIONS

The results of this study show that the wet prairie sites exhibit a wide range of environmental conditions over the course of a year. In summer soils are very dry, hard, and cracked, but between November and April the groundwater becomes elevated and water stands near to or exceeding the soil surface. Wet prairie plants are exposed to near surface flooding and reducing soil conditions for a six month period annually. The soil elements iron, manganese, and sulfur were reduced during the wet period.

High water levels and anaerobic soil conditions were observed in all the communities monitored in the three wet prairie sites. However, there were significant differences in the duration of anaerobic conditions, and both the magnitude and duration of elevated water levels between plant communities found at the study sites. These differences in wet period water table dynamics and soil texture partially explain the observed patterns of plant species distribution in wet prairie.

For example, in the *Eleocharis palustris* community water depths were regularly 15-20 cm deeper than in the *Rosa nutkana/Juncus nevadensis*, *Vaccinium cespitosum*, or *Deschampsia cespitosa* communities. The maximum recorded water levels in both years were more than 20 cm above the surface in the *Eleocharis palustris* community, while inundation only rarely exceeded 5-10 cm above the surface in *Rosa nutkana/Juncus nevadensis* and *Deschampsia cespitosa* communities. In the *Vaccinium cespitosum* community, water levels were seldom above the soil surface. Plants in the *Eleocharis palustris* community were completely submerged for most of the wet period, while in other communities they were only partially submerged, or not at all.

The Rose Prairie and Fisher Butte sites are different in terms of soil texture, soil organic matter, and soil nutrient content. Rose Prairie soils are much poorer in nutrient content and organic matter than are soils of the Fisher Butte and Long Tom ACEC sites, a probable explanation of the occurrence of the *Vaccinium cespitosum* community at that site. Nutrient and soil texture differences between Rose Prairie and the Long Tom ACEC and Fisher Butte sites are important to consider when decisions are made about future management. Currently, the management of the Fisher Butte and Rose Prairie sites is identical, although it may not be appropriate to use identical management approach for both sites. Further analysis of changes in species abundance

at Rose Prairie and Fisher Butte in response to prescribed fire will be presented by Pendergrass (in preparation). The information that this study provides about soil environmental differences can be revisited in the light of her work.

This baseline information about the surface hydrology of protected sites will provide information to managers who wish to predict or demonstrate whether significant changes occur in protected wet prairie remnants due to on-site management or as a result of off-site activities. The data collected in this study indicates that differences in water table depth on the scale of tens of centimeters may have significant effects on species composition, highlighting the importance of maintaining the present hydrologic regime of remnant prairies. Alterations of hydrology which might affect wet prairie species composition could result from the construction of new roads, filling, tiling, and ditching. For example, prolonged inundation of the soil surface by more than 15 cm of water might result in changes in species composition.

Characteristics such as water table elevation are easy to measure in the field, and are useful to include in future ecological studies in the Willamette Valley wet prairie ecosystem. Monitoring of hydrological and related soil features would be very useful in areas identified for wet prairie restoration. Prior to beginning project activities, information about site hydrology and soils should be collected and used to help determine appropriate species mixtures, or to plan engineered modifications of site hydrology. Restoration projects also provide ecologists an opportunity to test hypotheses about the influence of inundation, elevated water tables, anaerobic soil conditions, and soil texture on the establishment, growth, and reproductive success of various species by measuring the success of various species mixtures in sites with different hydrologic signatures. With careful design and monitoring, the success of projects involving reseeding of native species or removal of pest species can be useful in increasing understanding of environmental controls on species distribution. In this way, restoration activities can increase our understanding of this important and unique Willamette Valley ecosystem.

Studies of hydrology in Willamette Valley grasslands which examine the distribution of species across a broader hydric gradient would be very valuable. In order to successfully answer questions about environmental limitations to the distribution of prairie plant communities, soil and hydrological parameters should be quantified broadly, and include upland Willamette Valley grassland ecosystems as well. Direct gradient analysis of species/environmental data collected at numerous sites is

required to make broad generalizations about species' affinity for environmental conditions. The fragmentation of the native grasslands in the Willamette Valley make field studies of this native ecosystem a challenging task. In remaining sites, past land uses and current management, as well as species biology, are critical factors governing species composition. An alternate experimental approach, where various species are planted into a wide range of hydrologic environments, and monitored for their success, might also be employed.

Some patterns of species distribution at Fisher Butte, the largest of the sites examined, suggest that the competitive ability of native species is reduced in places where soils are not inundated above the surface in winter. For example, the greatest abundance of weedy herbaceous species occurs at the most elevated parts of the Fisher Butte site, (K.Pendergrass personal communication), where the soil surface was only occasionally and shallowly inundated. The Mound community at Rose Prairie, where water levels were never observed to exceed the surface, is dominated by weedy non-native grass, *Anthoxanthum odoratum*. It may be that differential tolerance to prolonged anaerobic conditions or high water table confers a competitive advantage to some native species over some non-native weedy species in other parts of these sites.

The sites measured are seasonally flooded and anoxic (in some cases strongly reducing) for prolonged periods during part of the year. Wet prairie plants are tolerant to these conditions. It would be very worthwhile to study the relative competitive ability of wet prairie natives and non-native and/or invasive species across a broad hydric gradient, and across a gradient of soil texture. Studies of the influence of timing and intensity of inundation, soil anoxia, and soil texture on recruitment of both native and non-native pest plants would also be informative.

Experimental studies of relative success of plant species under different hydrologic regimes, such as *in situ* and *ex situ* studies of the influence of flooding on germination and establishment of plant species of particular interest, such as *Erigeron decumbens* and *Lomatium bradshawii*, would increase understanding of ecology of sensitive plant species and their habitat. They would also be useful for predicting potential impacts of construction, road building, and other activities that might cause alterations in the hydrology of sites occupied by these protected species.

LITERATURE CITED

- Apfelbaum, S.I. and C.E. Sams. 1987. Ecology and control of reed canary grass. Natural Areas Journal 7:69-74.
- Armstrong, W. 1982. Waterlogged soils. Contributed chapter In J.R. Etherington, ed, Environment and Plant Ecology, 2nd edition. Wiley and Sons, London.
- Austin, W. 1993. Duration of saturation and redox potentials in selected Willamette Valley soils. M.S. Thesis, Soils Dept. Oregon State University.
- Blom, C.W.P.M., Bögemann, G.M., Laan, P., van der Sman, A.J.M., van de Steeg, H.M., and L.A.C.J. Voesenek, 1990. Adaptations to flooding in plants from river areas. Aquatic Botany 38: 29-47.
- Bohn H. 1971. Redox Potentials. Soil Science vol 112 (1): 39-45
- Bohn, H., B. McNeal, and G. O'Connor. 1985. Soil chemistry. Second edition. Wiley and sons, New York.
- Bonner, F.T. and C.W. Ralston 1968 Oxidation-reduction potential of saturated forest soils. Soil Science Soc. Am. Proc. 33:111-112
- Connelly, K. C. and J.B. Kauffman. 1991. Ecological effects of fire in Willamette Valley wetland prairies with special emphasis on *Lomatium bradshawii* and *Erigeron decumbens*, two rare endemic plants. Oregon State University
- Cuoto, W., C. Sanzonowicz, and A. De O. Barcellos. 1985. Factors influencing oxidation-reduction processes in a Oxisol with a seasonal water table. Soil Sci Soc. Am. J.49:1245-1248.
- Dirasian, H.A. 1968. Electrode potentials-significance in biological systems. Water and Sewage Works. 115:420-425.

- Ernst, W.H.O. 1990. Ecophysiology of Plants in Waterlogged and Flooded Environments. Aquatic Botany Vol. 38, No. 1, p 73-90.
- Faulkner, S.P. and W.H. Patrick. 1992. Redox processes and diagnostic wetland soil indicators in bottomland hardwood forests. Soil Sci. Am. J. 53:856-865.
- Faulkner, S.P., W.H. Patrick, and R.P. Gambrell. 1989. Field techniques for measuring wetland soil parameters. Soil Sci. Am. J. 53:883-890.
- Finley, K.K. and J.B. Kauffman 1992. Ecological response of *Lomatium bradshawii* and *Erigeron decumbens* var. *decumbens* to prescribed fire. A progress report submitted to the U.S. Army Corps of Engineers, Fern Ridge Project.
- Frenkel, R.E. and Heinitz. 1987. Composition and structure of Oregon ash (*Fraxinus latifolia*) forest in William L. Finley National Wildlife Refuge, Oregon. Northwest Science 61: 203-208
- Gambrell, R.P. and W.H. Patrick. 1978. Chemical and microbiological properties of anaerobic soils and sediments. In Plant Life in Anaerobic Environments. Ann Arbor Sci. Publ. Ann Arbor, MI.
- Glinski, J. and W. Stepenewski. 1985. Soil aeration and its role for plants. CRC Press Inc., Boca Raton, Florida, USA.
- Gosselink, J.G. and R.E. Turner 1978. The role of hydrology in freshwater wetland ecosystems In Freshwater wetlands: Ecological Processes and Management Potential, R.E. Good, D.F. Whigham, and R.L. Simpson, eds., Academic Press, New York, pp 63-78.
- Green, D. M. 1991. Soil conditions along a hydrologic gradient and successional dynamics in a grazed and ungrazed montane riparian ecosystem. Ph.D. dissertation, Oregon State University.

- Green, D.M. and J.B. Kauffman. 1989. Nutrient cycling at the land-water interface: The importance of the riparian zone. pp61-68 in Gresswell, R.E., B.A. Barton, and J.L. Kershner, (eds) Practical approaches to Riparian Resource Management--An Educational Workshop.USDI-BLM publ.#BLM-MT-PT-89-0001-4351.
- Gunderson, L.H., J.R. Stenberg, and A.K. Herndon. 1988. Tolerance of five hardwood species to flooding regimes. pp. 119-132 In D.A.Wilcox,ed.
 Interdisciplinary approaches to freshwater wetlands research. Michigan State University Press, East Lansing, Michigan.
- Habeck, J.R. 1961. The original vegetation of the mid-Willamette Valley. Northwest Science 35: 65-77.
- Harper, J. 1977. Population Biology of Plants. Academic Press, Harcourt Brace Jovanovich. New York.
- Hill, M.O. 1979. DECORANA: A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Section of Ecology and Systematics, Cornell University, Ithaca, New York, USA.
- Hitchcock, C.L., and A. Cronquist. Flora of the Pacific Northwest. University of Washington Press, Seattle, Washington, USA.
- Hosner, J.F. and S.G. Boyce. 1962. Tolerance to water saturated soil of various bottomland hardwoods. Forest Science 8: 180-186.
- Howes, B.L., R.W. Howarth, J.M. Teal, and I. Valiela. 1981. Oxidation-reduction potentials in a salt marsh: specieal patterns and interactions with primary production. Linol. Oceanogr. 26:350-360.
- Hutchings, M.J. and P.J.Russell. 1989. The seed regeneration dynamics of an emergent salt marsh. Journal of Ecology 77: 615-637

- Iremonger and Kelly. 1988. Responses of Four Irish Wetland Tree Species to Raised Soil Water Levels. New Phytologist, Vol. 109(4) 491-497.
- Johannesson, C.L., W.A. Davenport, A.Millet, and S. McWilliams. 1971. The vagetation of the Willamette Valley. Annals of Association of American Geographers. 61:286-302.
- Jones, H.E. and J.R. Etherington. 1970 Comparative studies of plant growth and distribution in relation to waterlogging. I. The survival of *Erica cinearea* L. and *E. tetralix* L. and its apparent relationship to iron and manganese uptake. Journal of Ecology 60: 141-145.
- Jones, H.E. and J.R. Etherington. 1971. Comparative studies of plant growth and distribution in relation to waterlogging. II. An experimental study of the relationship between transpiration and the uptake of iron in *Erica cinarea* L. and *E. tetralix* L. Journal of Ecology 59: 167-178.
- Josselyn, M.N., S.P. Faulkner, and W.H. Patrick. 1990. Relationships between seasonally wet soils and occurrence of wetland plants in California. Wetlands 10 (1): 7-26.
- Kagan, J. S. 1980. The biology of *Lomatium bradshawii* (Apiaceae), a rare plant of Oregon. MS Thesis, University of Oregon. 71pp.
- Kauffman, J.B., Beschta, R.L., and W.F. Platts. 1993. Fish habitat improvement projects in the Fifteenmile Creek and Trout Creek basins in central Oregon: field review and management recommendations. United States Department of Energy, Bonneville Power Administration (DOE/BP 18955-1) 52 pages.
- Kaye, T. 1992. Bradshaw's desert-parsley: population monitoring and pollination biology. Kalmiopsis. Volume 2: 1-4.
- Kaye, T., Connelly, K.C., and K.K. Finley. 1994. Population viability analysis of Lomatium bradshawii, (in progress)

- Kenkel, N.C. 1988. Spectral analysis of hummock-hollow patterns in a weakly minerotrophic mire. Vegetatio 78:45-52.
- Laanbroek H.J. 1990 Bacterial cycling of mineral that affect plant growth in waterlogged soils: a review. Aquatic Botany 38: 109-125.
- Martin , M.H. 1968. Conditions affecting the distribution of Mercuralis perennis L. in certin Cambridgeshire woodlands. Journal of Ecology. 56:777-793.
- Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold, New York.
- Mohanty, S.K. and R.N. Dash 1980. The chemistry of waterlogged soils. pp 389-396 In Wetlands: Ecology and Management. Proceedings of the First International Wetlands Conference, New Delhi, India 10-17, September 1980.
- Moir, W. and P. Mika. 1972. Prairie vegetation of the WEillamtte Valley, Benton Co., Oregon. Report on file at the Forest Science Lab, 3200 Jefferson Way, Corvallis, Or. 97331. Research work unit 1251.
- Mueller S.C., Stolzy, L.H., and G.W. Fick. 1985. Constructing and screening platinum microelectrodes for measuring soi redox potential. Soil Science, vol 139(6) 558-560.
- Munsell Color Company, 1974. Munsell color standards [Reazurin]. Munsell Color Company, Baltimore.
- Oregon Natural Heritage Program, 1983. Survey of Willamette Valley 1981-1983 (a report to the Mason trust). The Nature Conservancy. Portland, Or.
- OSU Soil Testing Laboratory, 1993. Methods of laboratory analysis. (laboratory manual information supplied by OSU Soils Testing Lab).

- Pederson, R.L. and L.M.Smith. 1988. Implications of wetland seed bank research: a review of Great Basin and prairie marsh studies.pp. 81-95 In Wilcox, D.A., ed. Interdisciplinary approaches to freshwater wetlands research. Michigan State University Press, East Lansing Michigan.
- Pickering, E.W. and P.L.M. Veneman. 1984. Moisture regimes and morphological characteristics in a hydrosequence in central Massachusetts. Soil Sci. Soc. Am. J. 50:1281-1289.
- Ponnampurna, F.N. 1984. Effects of flooding on soils. IN T.T. Kozlowski, ed. Flooding and Plant Growth. Academic Press, Orlando. PP 9-45.
- Reed, P.B. 1988. National list of plant species that occur in wetlands: California (Region 0). Biological report 88(26.10) U.S. Fish and Wildlife Service, Office of Biological Services. Washington, D.C.
- Rozema and Blom 1977. Effects of Salinity and Inundation on the Growth of Agrostis Stolonifera and Juncus Gerardii. Journal of Ecology, Vol 65, p 213-222.
- Schlessinger, W.H. 1991. Biogeochemistry: an analysis global change. Academic Press, Inc. San Diego, California.
- Smith, L.M. and J.A. Kadlec. 1985. The effects of disturbance on marsh seed banks. Canadian Journal of Botany. 63 (12) 2133-2137.

Soil Conservation Service. 1987. Soil survey of Lane County, Oregon.

- Somera, R.D. 1967. Iron and Manganese distribution and the seasonal oxidation changes in soil of the Willamette drainage sequence. MS Thesis, Dept. of Soil Science, OSU.
- Stolzy, L.H., D.D. Focht, and H. Flühler. 1981. Indicators of soil aeration stautus. Flora 171:236-265.

Taylor, G. 1993. Personal Communication, Oregon State Meteorologist.

- Thompson, K. and J.P. Grime. 1979. Seasonal variation in the seed banks of hervaceous species in ten contrasting habitats. Journal of Ecology 67: 893-921.
- Turner, F.T. and W.H. Patrick. 1968. Chemical changes in waterlogged soils as a result of oxygen depletion. 9th Internation Congress of Soil Science. The International Society of Soil Science and Angus and Robertson LTD. Sydney, Australia.
- U.S. Army Corps of Egnineers. 1987. Corps of Engineers wetlands delineation manual. Technical report (U.S. Army Corps of Engineers Waterways Experiment Station): Y-87-1 app. C. Vicksburg, Mississippi.
- United States Fish and Wildlife Service. 1993. Portland Field Office. Recovery Plan for *Lomatium bradshawii*.
- Van der Sman, A.J.M., O.F.R van Tongeren, and C.W. P. Blom. 1988. Growth and Reproduction of Rumex maritimus and Chenopodium rubrum Under Different Waterlogging Regimes. Acta Botanica Neerlandica, Vol. 37, No. 4, p 439-450.
- Van der Valk, A.G. 1987. Vegetation dynamics of freshwwater wetlands: a selective review of the literature. Advances in Limnology 27: 27-39.
- Van der Valk, A.G. and C.B. Davis. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes.. Ecology 59:322-335.
- Vepraskas, M.J. and W.R. Ghertal. 1991. Morphological indicators of soil wetness. Proceedings, eighth international soil correlation meeting. Agronomy Department, Louisiana Agricultural Experiment Station and USDA SCS, Alexandria, Louisiana.

- Welling, C.H., Pederson, R.L., and A.G. van der Valk. 1988. Recruitment from the seed bank and the development of zonation of emergent vegetation during the a drawdown in a prairie wetland. Journal of Ecology 76(2):483-496.
- Wilson, M.V., K.P. Connelly, and L.E. Lantz. 1993. Plant species, Habitat, and site information for Fern Ridge Reservoir. Waterways Experiment Station, Army Corps of Engineers, 82 pages.
- Zar, J. 1984 Biostatistical Analysis, 2nd edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.