CHARACTERIZATION OF SOIL/VEGTATION ON FLOOD IRRIGATED HAYFIELDS IN GRAND TETON NATIONAL PARK, WYOMING: A PREDICTIVE EVALUATION TOOL FOR AGRICULTURAL WETLANDS

by

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ABSTRACT

The Elk Ranch hayfield in Grand Teton National Park (GTNP) has been historically flood-irrigated since the early 20th Century. The park service is now considering closing irrigation to restore native plant communities and enhance Spread Creek fisheries and will need information on the extent of irrigation-created wetlands and how irrigation cessation would change the vegetative component of the ranch. The main objective of this study was to assess the relation between soil and vegetation characteristics of wetland community types at the ranch and to determine if any of the relationships could be used to differentiate between naturally occurring and irrigation created wetlands. Vegetation data were collected from transects centered on a soil pit at 28 randomly located sample points throughout the hayfield. Twenty-six of the 28 sample plots were classified as wetland based on criteria listed by the US Fish and Wildlife Service. Bray-Curtis dissimilarity and nonmetric multi-dimensional scaling were used to analyze percent foliar cover, wetland index value (WIV), soil texture, percent organic matter, redox contrast and abundance, and depth to groundwater and soil saturation for each of the sampled points. The WIV and redox contrast had the greatest dissimilarity (D^2), 0.90, and 0.71 respectively across the hayfield. The other measured characteristics had D^2 values ranging from 0.23 to 0.49 and were strongly correlated with the WIV and redox contrast measures. However, inclusion of these measures contributed little to the differences already identified. Categorical organization of WIV and redox measures indicated that naturally occurring wetlands could be differentiated from wetlands created by flood irrigation in former upland vegetation communities. Combining wetland index value and soil redox contrast suggests park managers could identify wetland community types likely to remain or transition following cessation of flood irrigation at the Elk Ranch. Additional testing at other GTNP sites will be necessary to test the broad application of this approach and refine the assessment categories.

INTRODUCTION

Flood irrigation often creates agricultural wetlands through changes in hydrology and vegetative structure; a large portion of such wetlands would be lost if irrigation ceased (Peck and Lovvorn 2001). As in natural wetlands, even small hydrologic changes can potentially change wetland species dominance (Dwire et al. 2006). For example, as depth to groundwater increases, there is often a corresponding decrease in wetland plant species cover (Youngblood et al. 1985).

Dwire et al. (2006) studied three native meadow complexes, wet, moist, and dry, and found that the small-scale (average site size is 28 km2) environmental distribution of meadow vegetation was driven by the depth of seasonal water tables and associated soil conditions. In wet meadow communities, obligate species like *Carex* dominated and the soils were anaerobic all year (Dwire et al. 2004 and 2006). In these studies anaerobic conditions were determined when redox potential was less than + 300 mV. In moist meadow communities, areas with short periods of inundation, there was high water table fluctuation and the soils were anaerobic (reducing) in the spring and aerobic (oxidizing) in the fall. In dry meadow communities, a mixture of facultative grasses and forbs dominated, the soils had no water table fluctuation and were consequently aerobic all year (Dwire et al. 2004, 2006). While this approach was informative, measuring redox potential required expensive equipment and laboratory time; limiting the number of sites that could be studied. Vepraskas (1999) suggested a more economical and straightforward field method for acquiring redox potential information; observing redox features.

Application of the knowledge of natural wetland system processes to irrigation influenced wetland systems would enhance the development of an ecologically based guide for the management of agricultural wetlands. Because the occurrence and abundance of wetland vegetation reflects hydrological processes in both natural wetlands and those created through flood irrigation, wetland indicator scores could provide a useful predictive tool for anticipating the effects of irrigation management (groundwater decline or increase) on riparian vegetation (Coles-Ritchie et al. 2007, Stromberg et al. 1996). Having such a tool to monitor the impact of human activities on agricultural wetland function and subsequent management effectiveness is essential for long-term sustainability (Coles-Ritchie et al. 2007). Rehabilitation and long-term management of former agricultural land in national parks and wildlife refuges are an area where a predictive evaluative tool would be useful.

The Elk Ranch hay field in Grand Teton National Park (GTNP) (Figure 1) has been flood irrigated since the early 1900s but the park service is now considering closing irrigation to restore native vegetation communities and enhance the fishery of Spread Creek, the origin of the irrigation water. Consequently, park ecologists are seeking information on the extent of irrigation-created wetlands within the Elk Ranch hayfields and how irrigation cessation would change the vegetative component of the local landscape.

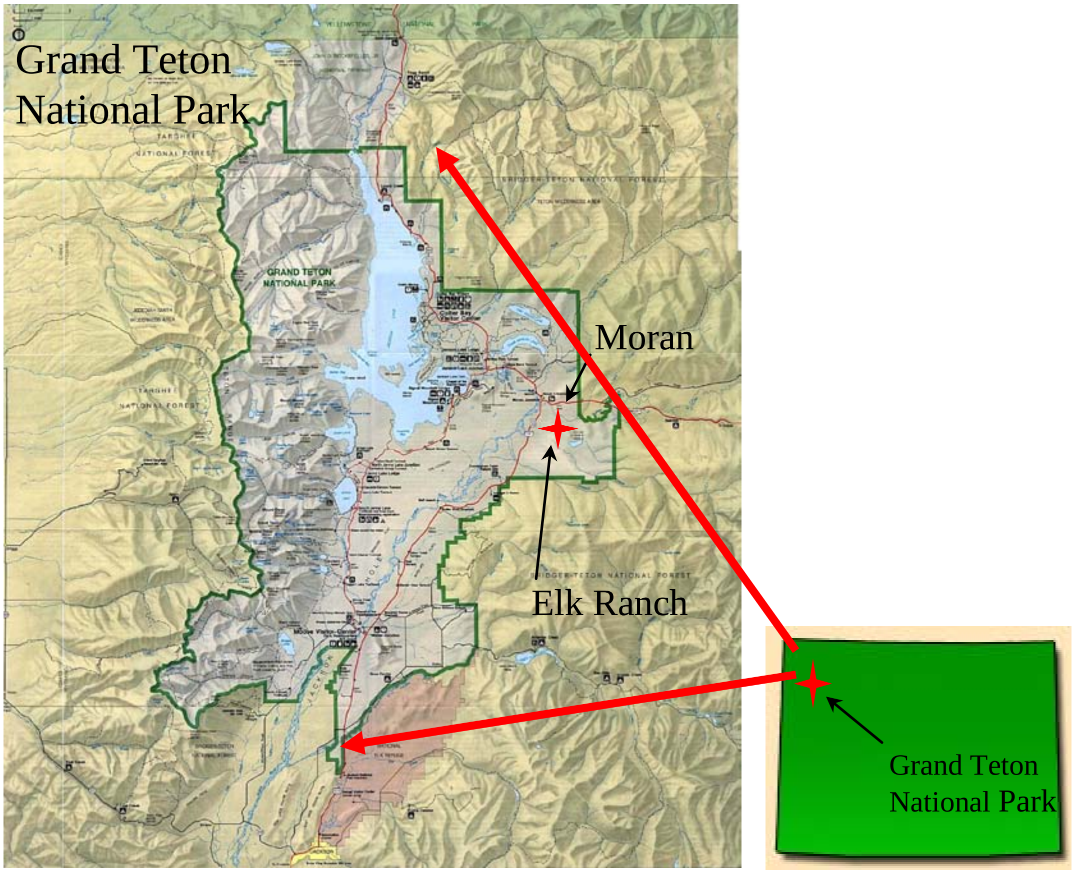

Figure 1. Map of Wyoming and Grand Teton National Park with star indicating Elk Ranch study site location.

The main objective of this study was to evaluate the relation between soil and vegetation characteristics of wetland community types (c.t.) existing within hayfield boundaries. This information would then be used to accomplish a second objective, to determine if those relations could be used to differentiate between natural and irrigation-created wetlands. If this proved feasible, the identified criteria could be tested in the restoration of formerly irrigated hayfields in other portions of GTNP. Accordingly, the null hypothesis of this study was that there are no small-scale (similar to Dwire et al.) differences in vegetative and soil characteristics across flood-irrigated hayfields at the Elk Ranch.

LITERATURE REVIEW

Introduction

Wetlands are identified by three parameters: 1) hydrophytic vegetation, 2) hydric soils, and 3) wetland hydrology (Wetland Training Institute, Inc. 2001). Hydrophytic vegetation is adapted to periodically saturated, anaerobic soil conditions (Wetland Training Institute, Inc. 2001). Hydric soil is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions that support growth and regeneration of hydrophytic vegetation (USDA Natural Resource Conservation Service 1985). Wetland hydrology is an area having soil saturation or inundation for at least five percent of the growing season in a majority of years (Wetland Training Institute, Inc. 2001). Areas without all three parameters would not be classified as a wetland.

The Vegetation Component

Vegetation is the least restrictive of the three recognized parameters (Janisch and Molstad 2004). Classification of wetland vegetation ranges from Obligate (OBL) with 99 percent probability of occurring in a wetland, to Upland (UPL) with a one percent chance of occurring in a wetland (Resource Management Group 1993). However, if there is not a regional record for a species occurring in a wetland the vegetative species is classified as upland or if there is insufficient data for a wetland classification, the vegetative species is given a No Indicator (NI) rating (Resource Management Group 1993). Fifty percent or more of the sites vegetative species must be classified as obligate to facultative to qualify as wetland (Wetland Training Institute, Inc. 2001).

Wetland plant species distribution is driven by short- and long-term shallow-groundwater depths and the consequential soil conditions (Dwire et al. 2006, Pockman and Sperry 2000). In wetlands, the presence and abundance of vegetation varied with depth to groundwater (Stromberg et al. 1996). As groundwater declined, the obligate wetland plant abundance declined (Stromberg et al. 1996 and Youngblood et al. 1985). This concurs with results from Law et al. (2000) indicating that the interaction between soil texture, coarse fragment content, and ground water levels dictated species abundance at a particular site.

The Soil Component

Wetland soils are subject to groundwater interactions, litter accumulation and decomposition, burrowing animals, root activity, surface runoff, erosion, flooding, and sediment loading (Bruland and Richardson 2005). These interactions create site-specific variability dictating vegetative patterns.

Hydric soils are indicated by one or more of the following characteristics: Histosol, histic epipedon, sufidic odor, aquic moisture regime, gleyed or low chroma colors, redoximorphic features, concretions, high organic content in surface layer in sandy soils, organic streaking in sandy soils, or listed on a local or national hydric soils list (Wetland Training Institute, Inc. 2001). The indicators for hydric soil are formed principally by iron, manganese, sulfur, or carbon compound accumulation or loss (USDA Natural Resources Conservation Service 1998). The most common of the indicators are related to Fe/Mn depletions or concentrations; redoximorphic features (USDA Natural Resources Conservation Service 1998).

Soil color diversity, even relatively small differences, can be environmentally noteworthy such as in mottled and non-mottled facies (Wells et al. 2002). The development of reducing conditions and redoximorphic features in soils are dependent on saturation of sufficiently long duration to develop anaerobic soil, adequate organic carbon, and proper temperatures for soil microbial activity, and sufficient Fe and Mn in the soil (D'Amore 2004, USDA Natural Resources Conservation Service 1998). The contrast and abundance of redoximorphic features in wetland soils varies with parent material. For instance, in soils with low concentrations of Fe/Mn, which are often of low chroma, organic carbon accumulations must be used for identification of hydric soils (USDA Natural Resources Conservation Service 1998).

The Hydrologic Component

Hydrology is the most restrictive of the three wetland parameters (Janisch and Molstad 2004). Wetland hydrology is characterized by one or more of the following primary indicators: inundation, saturation in upper 30 cm, water marks (a line on an upright surface depicting the maximum standing water level reached during inundation), drift lines (an accumulation of debris along a contour line depicting the height of an inundation event) sediment deposits, or drainage patterns in the wetland (Wetland Training Institute, Inc. 2001). Wetland hydrology can also be characterized by two or more of the following; oxidized root channels in the upper 12 inches, water-stained leaves, local soil survey data, or a positive facultative-neutral test (greater than 50 percent of the vegetation is classified facultative to obligate) (Wetland Training Institute, Inc. 2001).

Inundation frequency and depth to groundwater have the greatest influence on vegetation composition followed by soil texture (Stromberg et al. 1996). Wetland sites that had the longest period of flooding had more above ground vegetative biomass than the wetland sites with shorter flood duration (Ray and Inouye 2007). Vegetation, especially herbaceous, associated with shallow groundwater depth had a narrow range for depth to groundwater (Stromberg et al. 1996). Species such as Torrey's rush (*Juncus torreyi* Coville) and sand spikerush (*Eleocharis montevidensis* Kunth) would be the first to decline in response to groundwater decline (Stromberg et al. 1996)

Relatively few data have been found effective for predicting the impacts on riparian vegetation from a change in hydrology (Stromberg et al. 1996). Nonetheless, long-term hydrologic changes, such as drought or change in irrigation practices, are likely to result in substantial change in montane wetland plant communities and their function (Austin et al. 2007). In the study *The Importance of Flood Irrigation in Water Supply to Wetlands in the Laramie Basin, Wyoming, USA*, it was observed that flood irrigation contributed 65% of the wetland inflows. This was a critical element to the sustainability of the wetlands in the valley. Replacing the existing flood irrigation with a more efficient irrigation system or removing the irrigation would result in a loss of a high fraction of the existing wetland (Peck and Lovvorn 2001). Even though decreasing flood irrigation would increase river flows, the total area of wetlands and the relative areas of wetland types in the area would be reduced and/or altered from the present state (Peck and Lovvorn 2001).

The main objective of this study was to assess the relation between soil and vegetation characteristics of wetland community types in the flood irrigated hayfields of the Elk Ranch, Grand Teton National Park, Moran, Wyoming. A secondary objective was to determine if those relations could be used to differentiate between natural and irrigation-created wetlands. If this proved feasible, the identified criteria could be tested in predicting impacts on wetland community types following cessation of hayfield irrigation in semi-arid environment of the Northern Rocky Mountains of Montana and Wyoming. The null hypothesis of this study was that there are no differences in vegetative and soil characteristics across flood-irrigated hayfields at the Elk Ranch.

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METHODS

Study Area

The study site, approximately 6.3 km2 (1557 ac), has been an irrigated hayfield within the boundary of the Elk Ranch Unit of GTNP (Figure 2) since ca. 1905. Average annual precipitation, measured at Moran (1.5 km north of Elk Ranch), is 600 mm, average annual minimum temperature is -6.7ºC, and average annual maximum temperature was 10.4ºC (Western Regional Climate Center 2005). The elevation of this mountain valley study site is between 2048 m and 2084 m. The hayfield is located on alluvial valley fill, 500 m upslope of the Snake River.

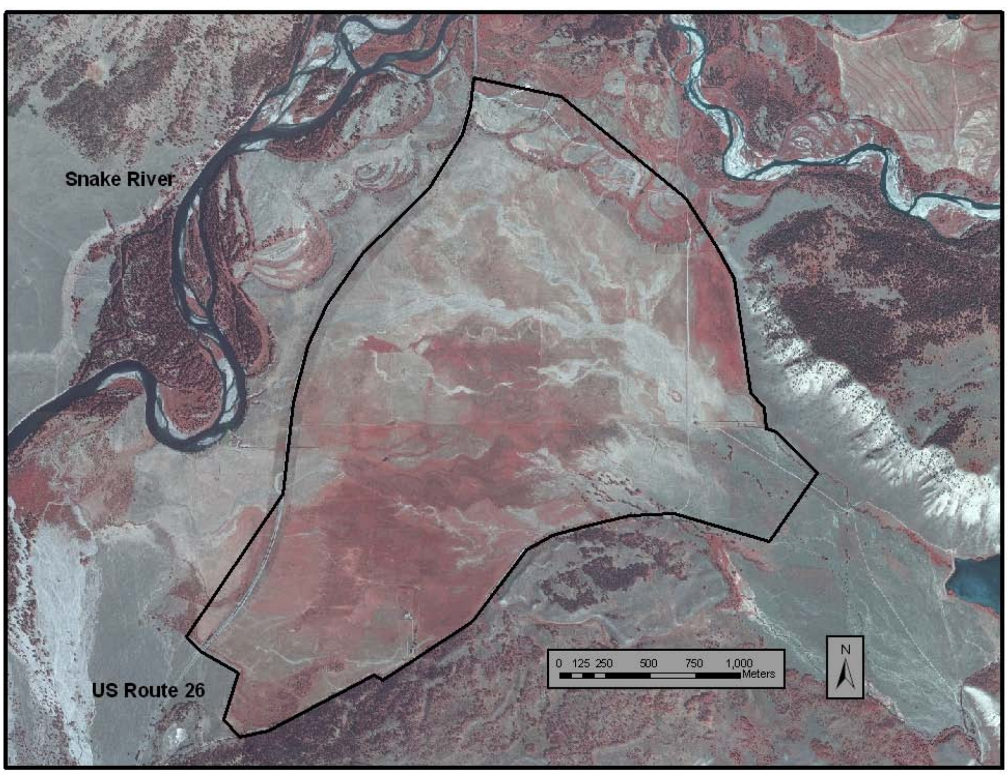

Figure 2. Elk Ranch study site Moran, Wyoming.

Current hay field vegetation is dominated by the following community types (c.t.): beaked sedge (*Carex utriculata* Boott) c.t., water sedge (*C. aquatilis* Wahlenb.) c.t., Nebraska sedge (*C. nebrascensis* Dewey) c.t., Baltic rush (*Juncus balticus* Willd.) c.t., and Kentucky bluegrass/Timothy (*Poa pratensis* L. / *Phleum pratense* L.) c.t. (Youngblood et al. 1985). The majority of the study area was located in the Slocum-Silas Loams soil unit with two sample points located in the Tineman Gravelly-Loam soil unit and two other points located in the Cryaquolls-Cryofibrists complex soil unit (Young 1982).

Field Sampling

Sampling plots were randomly located across the Elk Ranch hayfield (Figure 3) in July 2006 by first blocking the hayfield based on vegetative patterns reflected in an unframed aerial photograph (Wyoming Geographical Information Systems 2009). Four sample points were randomly selected from a numbered grid in each block. Individual plots were 80m in diameter to accommodate the vegetation sampling protocol. Vegetation, soil, and wetland hydrology data were then collected from each sample plot following the procedure described by the Wetland Training Institute, Inc. (2001) (Table 1).

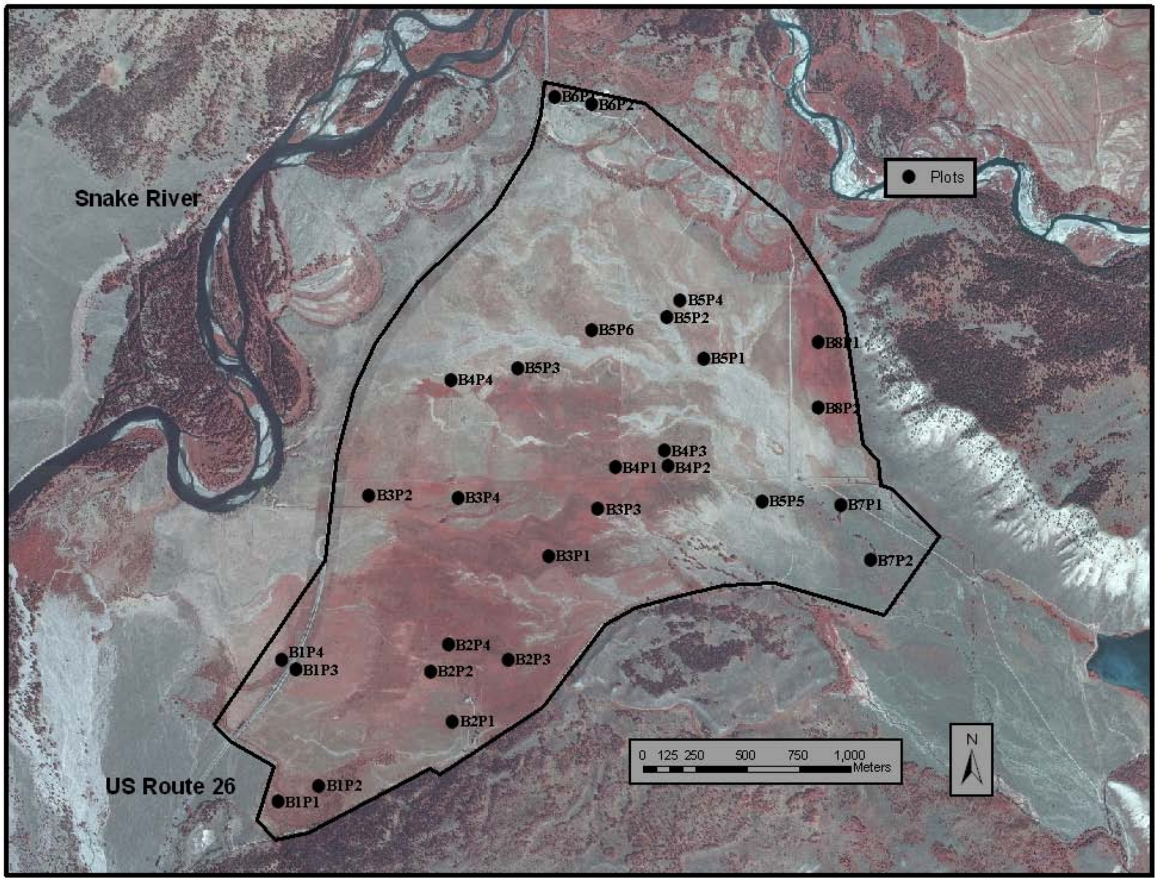

Figure 3. Sample plots at the Elk Ranch study site Moran, WY.

Table 1. The three criteria for wetland identification; hydrophytic vegetation, hydric soil, and wetland hydrology, and the indicators used at the Elk ranch.

Criteria	Indicators
Hydrophytic vegetation	More than 50 percent of the dominant vegetation at site are obligate, facultative wet, or facultative on lists of plant species that occur in wetlands
Hydric soils[1]	Histic epipedon, reducing conditions, gleyed soil, soil matrix chroma of 2 or less in soils with redox features, soil matrix chroma of 1 or less in soils without redox features, soils appearing on hydric soils list.
Wetland hydrology[1, 2]	Drainage patterns, visual observation of inundation, and visual observation of saturation in upper 30 cm.

[1] Only indicators found at the Elk Ranch are listed. For a full list of wetland criteria indicators see Wetland Training Institute, Inc. (2001).
[2]Wetland hydrology must be present for five to 12 percent of the growing season (Wetland Training Institute, Inc. 2001)

Vegetation Sampling

The Wetland Training Institute wetland delineation method was expanded to include a detailed description of the apparent c.t. through foliar cover estimates (Daubenmire 1968). Cover estimates were made at 5 meter intervals along four 20-meter transects centered on the soil sampling pit representing each random sample point (Figure 3). Vegetation was identified following Vascular Plants of Montana (Dorn 1984) and indicator status of each recorded species was obtained from the national wetland plant list (Resource Management Group 1993) and the 1993 supplement (Reed 1993). Upon completion of the vegetation survey, each recorded plant species was assigned a wetland index value (WIV) ranging from one (upland, 1 percent probability of occurring in a wetland) to 100 (obligate, 100 percent probability of occurring in a wetland) for statistical analysis of potential wetland vegetation assemblages (Table 2) (Coles-Ritchie et al. 2007).

Table 2. The wetland indicator status, its probability of occurring in a wetland, and its wetland indicator value (derived from Coles-Ritchie et al. 2007).

Wetland indicator status	Probability of species occurring in a wetland		Wetland indicator value
Obligate (OBL)	99%		100
Obligate – (OBL-)			92
Facultative wet + (FACW+)			83
Facultative wet (FACW)	67-99%	75	
Facultative wet – (FACW-)			67
Facultative + (FAC+)			58
Facultative (FAC)	34-66%	50	
Facultative – (FAC-)			42
Facultative upland + (FACU+)		33	
Facultative upland (FACU)	1-33%		25
Facultative upland – (FACU-)		17	
Upland + (UPL+)			8
Upland (UPL)	<1%		1

Soil Sampling

A soil pit, located in the center of each plot, was excavated to a depth of 51 cm (Wetland Training Institute, Inc 2001) unless inhibited by an impenetrable layer (Figure 3). Soil profiles exposed at each pit were photographed and characterized with: a) in-field description of texture using the USDA-NRCS standard texturing method (Schoeneberger et al. 1998), b) moist soil color using the Munsell color chart, c) quantity and contrast of mottling (Schoeneberger et al. 1998), and d) quantity and size of roots present in the profile (Schoeneberger et al. 1998). The qualitative redox contrast values were assigned a quantitative value ranging from zero to three: prominent redox features equal three, distinct redox features equal two, faint redox features equal one, and no redox features equal zero (Dr. David Roberts, Montana State University, personal communication). A 150-gram sample from each soil horizon was collected for further analysis at the Montana State University campus. Sample plot locations were recorded using a global positioning system for future monitoring by the GTNP.

Wetland Hydrology Sampling

In addition to vegetation and soil data, wetland hydrology was also described at each soil pit by noting inundation, depth to free water in soil test pits, depth to soil saturation (recognized as a glistening soil surface), and topographic drainage patterns as described in the Field Guide for Wetland Delineation: 1987 U.S. Army Corps of Engineers Manual (Wetland Training Institute, Inc 2001).

Laboratory Analyses

In the laboratory, soil samples oven dried at 120 degrees Celsius. Sub-samples of the 150-g soil samples were then tested for presence of calcareous content with 10 percent hydrochloric acid applied to the ped surface to determine reaction (Tan 2005). Samples were then ground and sieved through a number 10 sieve to determine soil fines and rock fragment composition of the samples. The Hydrometer Method (Tan 2005) was used to verify earlier soil textural class evaluations. Finally, total organic matter content of the soils was determined through the Loss on Ignition Method (Ball 1964).

Statistical Analyses

All data were analyzed using the R statistical program (R Development Core Team 2008). Vegetation data were analyzed as percent foliar cover and WIV (percent cover * WIV, e.g. 30 percent cover with an 83 WIV equals 24.9). Soil data were analyzed as depth to groundwater, depth to saturation, and depth to redox features, redox contrast, redox abundance, and percent organic matter. Vegetation and soil data were analyzed with Bray and Curtis ordination (BC) and nonmetric multi-dimensional scaling (NMDS) to identify dissimilarity (D2) of vegetation and soil characteristics among sample plots (Kent and Coker 1992, Quinn and Keough 2002, R Development Core Team 2008). Points with $D^2 = 0.0$ would be identical to each other while points with $D^2 = 1.0$ would be completely dissimilar (Kent and Coker 1992).

RESULTS

Vegetation

Twenty-six of the twenty-eight sample plots met the three criteria for wetland classification (Tables 1 and 3). Even though sample plots B7P1 and B7P2 did not meet the hydrophytic vegetation parameter, they were still included in statistical comparisons.

Table 3. Sample plot attributes, Elk Ranch, Moran WY, based on wetland criteria (Wetland Training Institute, Inc. 2001).

Sample Plot	Hydrophytic vegetation[1]	Hydric soil[1]	Wetland hydrology[1]
B1P1	Yes	Yes	Yes
B1P2	Yes	Yes	Yes
B1P3	Yes	Yes	Yes
B1P4	Yes	Yes	Yes
B2P1	Yes	Yes	Yes
B2P2	Yes	Yes	Yes
B2P3	Yes	Yes	Yes
B2P4	Yes	Yes	Yes
B3P1	Yes	Yes	Yes
B3P2	Yes	Yes	Yes
B3P3	Yes	Yes	Yes
B3P4	Yes	Yes	Yes
B4P1	Yes	Yes	Yes
B4P2	Yes	Yes	Yes
B4P3	Yes	Yes	Yes
B4P4	Yes	Yes	Yes
B5P1	Yes	Yes	Yes
B5P2	Yes	Yes	Yes
B5P3	Yes	Yes	Yes
B5P4	Yes	Yes	Yes
B5P5	Yes	Yes	Yes
B5P6	Yes	Yes	Yes
B6P1	Yes	Yes	Yes
B6P2	Yes	Yes	Yes
B7P1	No	Yes	No
B7P2	No	Yes	No
B8P1	Yes	Yes	Yes
B8P2	Yes	Yes	Yes

[1]Met one or more of the criterion stated in Table 1.

Soil

All twenty-eight sample points met one or more of the criterion for hydric soils (Tables 3 and 4). Seventeen soil sample pits had a matrix chroma of one with redox features; nine soil sample pits had a matrix chroma of one without redox features; one soil sample pit had a matrix chroma of two with redox features; and one soil sample pit had a histic epipedon (Table 4). Twenty-six (93 %) of the 28 sample plots were located within areas identified on the nationally listed hydric soils. Soils at sample points B1P1 and B7P1 could not be reconciled with either the local or national hydric soils lists.

Table 4. Soil sample moist color, redox contrast, redox abundance, soil texture, and soil classification at the Elk Ranch, Moran, WY.

Sample point	Moist color[1]	Redox contrast[2, 3]	Redox abundance[3, 4]	Soil texture[5]
B1P1	N/A	None	None	Organic
B6P2	2.5Y 3/1	None	None	Loamy Sand
B7P1	10YR 2/1	None	None	Sandy Loam
B7P2	10YR 3/1	None	None	Sandy Loam
B1P4	10YR 2/1	None	None	Silt loam
B2P4	10YR 2/1	Faint	Few	Sandy Loam
B1P3	10YR 3/1	Faint	Many	Silt loam
B3P3	10YR 2/1	Distinct	Few	Silt loam
B4P4	10YR 2/1	Distinct	Few	Silt loam
B2P2	10YR 2/1	Distinct	Common	Loam
B2P1	10YR 2/1	Distinct	Common	Sandy Loam
B3P2	7.5YR 2.5/1	Distinct	Many	Loam
B5P1	10YR 2/1	Distinct	Many	Sandy Loam
B3P4	10YR 3/1	Distinct	Many	Silt loam
B4P3	10YR 2/1	Distinct	Many	Silt loam
B5P3	10YR 2/1	Distinct	Many	Silt loam
B5P5	10YR 3/1	Distinct	Many	Silt loam
B5P6	10YR 2/1	Distinct	Many	Silt loam
B2P3	10YR 2/1	Prominent	Few	Sandy Loam
B6P1	10YR 4/1	Prominent	Common	Sandy Loam

Table 4 continued

B1P2	2.5Y 3/1	Prominent	Common	Silty Clay
B8P1	10YR 3/1	Prominent	Many	Loam
B3P1	10YR 2/1	Prominent	Many	Sandy Loam
B4P1	10YR 2/1	Prominent	Many	Sandy Loam
B4P2	10YR 2/1	Prominent	Many	Sandy Loam
B5P2	10YR 3/1	Prominent	Many	Sandy Loam
B5P4	10YR 3/1	Prominent	Many	Silt loam
B8P2	10YR 2/1	Prominent	Many	Silt loam

[1]Data not included in statistical analysis
[2]Soil data were from the upper 40 cm of the soil profile.
[3]Values included in statistical analysis: 0=None; 1=Faint; 2=Distinct; and 3=Prominent.
[4]Values included in statistical analysis: 0=None; 1=Few; 2=Common; and 3=Many
[5]Soil percent sand, silt, and clay data were averaged from two sub-samples of the upper 40 cm of the soil profile.

Wetland Hydrology

Criteria was met at the study site met for wetland hydrology for five to 12.5 percent of the 165-day growing season, of 8.25 to 20.6 days (Trelease et al. 1970, Wetland Training Institute, Inc. 2001). Growing season length encompassed the irrigation schedule; 4 May 2007 to 4 July 2007 and the same dates the previous year, 2006. (Bill Lawrence, Grand Teton National Park Service, personal communications). Twenty-six of the 28 sample plots had wetland hydrology (Tables 3 and 5).

Table 5. Sample plot depth to saturation, depth to groundwater and sample point wetland hydrology indicator assessed after 30 minutes during soil pit evaluation at the Elk Ranch.

Sample plot	Depth to groundwater (cm)	Depth to saturation (cm)	Wetland hydrology indicator[1]
B1P1	0	0	Inundated
B6P2	12	0	Saturation in upper 30cm
B1P3	25	0	Saturation in upper 30cm
B3P4	30	0	Saturation in upper 30cm
B5P5	33	18	Saturation in upper 30cm
B2P4	40	0	Saturation in upper 30cm
B3P1	40	20	Saturation in upper 30cm
B5P1	56	30	Saturation in upper 30cm
B3P3	>64	3	Saturation in upper 30cm
B4P3	>64	20	Saturation in upper 30cm
B1P2	>64	23	Saturation in upper 30cm
B6P1	>64	30	Saturation in upper 30cm
B4P2	>64	35	Drainage pattern in wetland
B1P4	>64	43	Drainage pattern in wetland
B2P3	>64	46	Drainage pattern in wetland
B2P1	>64	>64	Drainage pattern in wetland
B2P2	>64	>64	Drainage pattern in wetland
B3P2	>64	>64	Drainage pattern in wetland
B4P1	>64	>64	Drainage pattern in wetland
B4P4	>64	>64	Drainage pattern in wetland
B5P2	>64	>64	Drainage pattern in wetland
B5P3	>64	>64	Drainage pattern in wetland
B5P4	>64	>64	Drainage pattern in wetland
B5P6	>64	>64	Drainage pattern in wetland
B8P1	>64	>64	Drainage pattern in wetland
B8P2	>64	>64	Drainage pattern in wetland
B7P1	>64	>64	No wetland hydrology
B7P2	>64	>64	No wetland hydrology

[1]Wetland hydrology indicator was not used in statistical analysis.

Statistical Analyses

The following parameters were statistically analyzed: depth to saturation, depth to groundwater, depth to redox features, redox abundance, redox contrast, organic matter, percent vegetation cover by species, and WIV (Table 6). WIV and soil redox contrast were the vegetative and soil parameters with the greatest difference among plots. The WIV had a D^2 of 0.90 and soil redox contrast had a D^2 of 0.71. When graphically displayed (Figure 4), the further the points are from each other indicates a greater dissimilarity. The sample points in the lower left corner of the graph, represent sites with a weighted WIV of 29, an upland point, while, sample points in the upper right corner of the graph, had a weighted WIV of 100, an inundated wetland point (Figure 4). The contrast contour lines represent sample point redox feature intensity; faint, distinct, and prominent. Sample points with prominent redox features (indicating high water fluctuation) were on the left-center of the graph while sample points with faint to no mottling (indicating low to no water fluctuation) were along the graph edges (Figure 4).

Table 6. Measured wetland characteristic and its associated dissimilarity (D^2) for plots at the Elk Ranch, Moran, WY.

Measured characteristic	Dissimilarity (D^2)of plots
Wetland index value	0.90
Redox contrast	0.71
Depth to groundwater	0.49
Redox abundance	0.47
Organic matter	0.40
Depth to saturation	0.37
Foliar cover	0.23

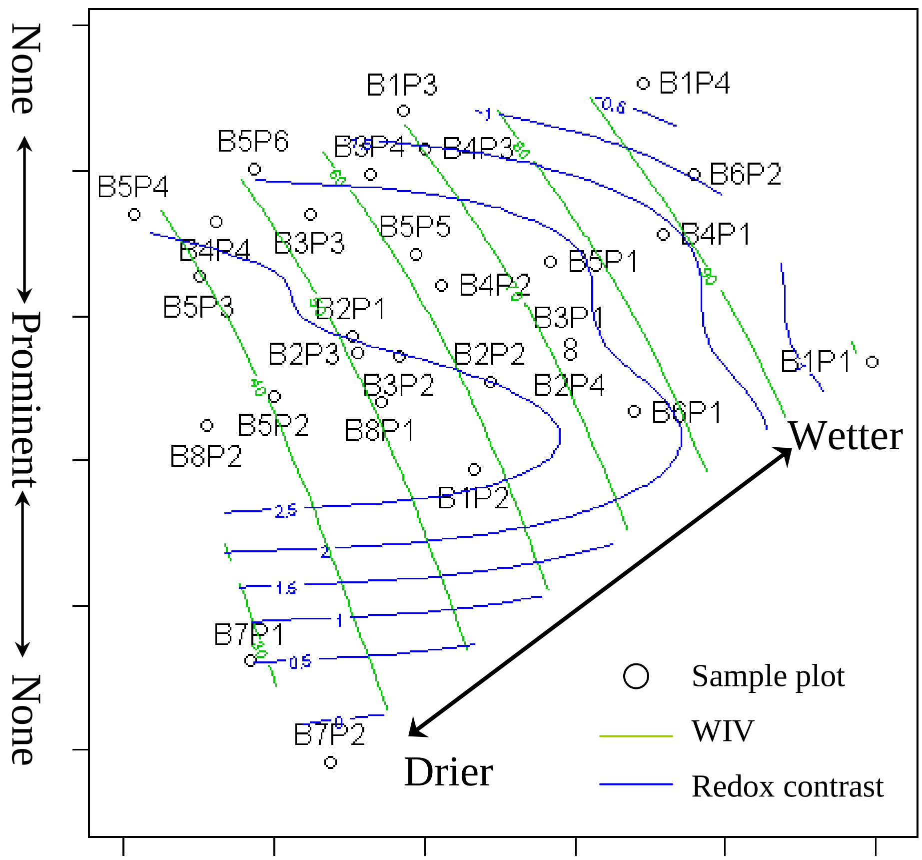

Figure 4. A nonmetric multi-dimensional scaling of the weighted averages of the wetland index value (green) and weighted average soil redox contrast values (blue) contour lines for all 28 sample points at the Elk Ranch, GTNP, Moran, WY.

DISCUSSION

The null hypothesis was rejected because of the unique combination of wetland species and soil characteristics associated with plant community types in the Elk Ranch hayfield. Combining WIV and soil redox contrast indicates wetland community types that are likely to remain following the cessation of flood irrigation as well as community types that are likely to transition to upland should irrigation stop at the Elk Ranch (Figure 5).

The calculated WIV dissimilarity D^2 = 0.90 indicates the plant communities differ across the Elk Ranch hayfields. This agrees with patterns reported from naturally occurring meadows (Dwire et al. 2004). The dissimilarity of the soil redox contrast, D^2 of 0.71, reflects hayfield soil conditions ranging from no redox features (no groundwater fluctuation) to sites with distinct and prominent redox features, indicating substantial fluctuation of groundwater and oxygen. These findings are also consistent with the finding of Dwire et al. (2006) that natural meadow vegetation distribution strongly reflects local environmental gradients driven by seasonal water-table depths.

Soils with no redox features are most likely constantly wet or dry; soils with faint redox features will be encountered most often at sites that are wet or dry most of the year with very little water fluctuation. Vegetation with an average WIV of 75 or greater has a 75+% probability of wetland occurrence, while vegetation with an average WIV of 50 or less will occur 50% or less of the time in wetland communities. Consequently, c.t. reflects redox feature occurrence, the probability of species occurrence in wetlands, and the observed measure of 50+ percent of all vegetation at the sample point being wetland indicators (Table 7).

Sites with a WIV score greater than 75 and faint or no redox features would likely remain wetland should the Park Service stop irrigation (Table 7). For example, study plots B1P1 and B2P4, are representative of this combination of wetland characteristics (Table 8 and Figure 5). Therefore, both sites are likely natural wetlands and would continue to exist if irrigation stops. Sites that would continue as upland species community types would have low WIV (50 or lower) score and no redox features like plots B7P1 and B7P2 (Table 8 and Figure 5).

Table 7. The combination of soil redox contrast and average wetland index value used for predicting community type response at the Elk Ranch hayfield, Moran, WY.

Soil redox contrast[1]	Average wetland index value	Predicted community type response
None or faint	>75	Remain as wetland
None or faint	75 – 50[2]	Response uncertain
None or faint	<50	Remain as upland
Distinct	>75	Remain as wetland
Distinct	75 – 50	Response uncertain
Distinct	<50	Transition to upland
Prominent	>75	Remain as wetland
Prominent	75-50	Response uncertain
Prominent	<50	Transition to upland

[1]Soil data were from the upper 40 cm of the soil profile.
[2]None of the collected data fell into this category

Table 8. Predicted community type transition following cessation of flood irrigation at the Elk Ranch, Moran, WY.

Sample plot	Soil redox contrast [1]	Weighted average WIV [2]	Predicted c.t. response [3]
B7P1	None	31.22	Remain as upland
B7P2	None	32.33	Remain as upland
B6P2	None	92.25	Remain as wetland
B1P4	None	92.66	Remain as wetland
B1P1	None	100.00	Remain as wetland
B1P3	Faint	74.85	Remain as wetland
B2P4	Faint	83.07	Remain as wetland
B4P4	Distinct	40.52	Transition to upland
B5P3	Distinct	42.15	Transition to upland
B2P1	Distinct	42.59	Transition to upland
B3P3	Distinct	47.39	Transition to upland
B3P2	Distinct	52.61	Response uncertain
B2P2	Distinct	62.55	Response uncertain
B5P5	Distinct	62.75	Response uncertain
B5P1	Distinct	66.32	Response uncertain
B5P6	Distinct	66.85	Response uncertain
B3P4	Distinct	72.09	Response uncertain
B4P3	Distinct	75.80	Remain as wetland
B8P2	Prominent	29.50	Transition to upland
B5P4	Prominent	32.09	Transition to upland
B2P3	Prominent	39.49	Transition to upland
B5P2	Prominent	40.16	Transition to upland
B8P1	Prominent	49.12	Transition to upland
B4P2	Prominent	62.64	Response uncertain
B1P2	Prominent	63.25	Response uncertain
B6P1	Prominent	76.00	Remain as wetland
B4P1	Prominent	78.41	Remain as wetland
B3P1	Prominent	84.91	Remain as wetland

[1]Soil data were from the upper 40 cm of the soil profile.
[2]Wetland index value (WIV)
[3]Community type (c.t.)

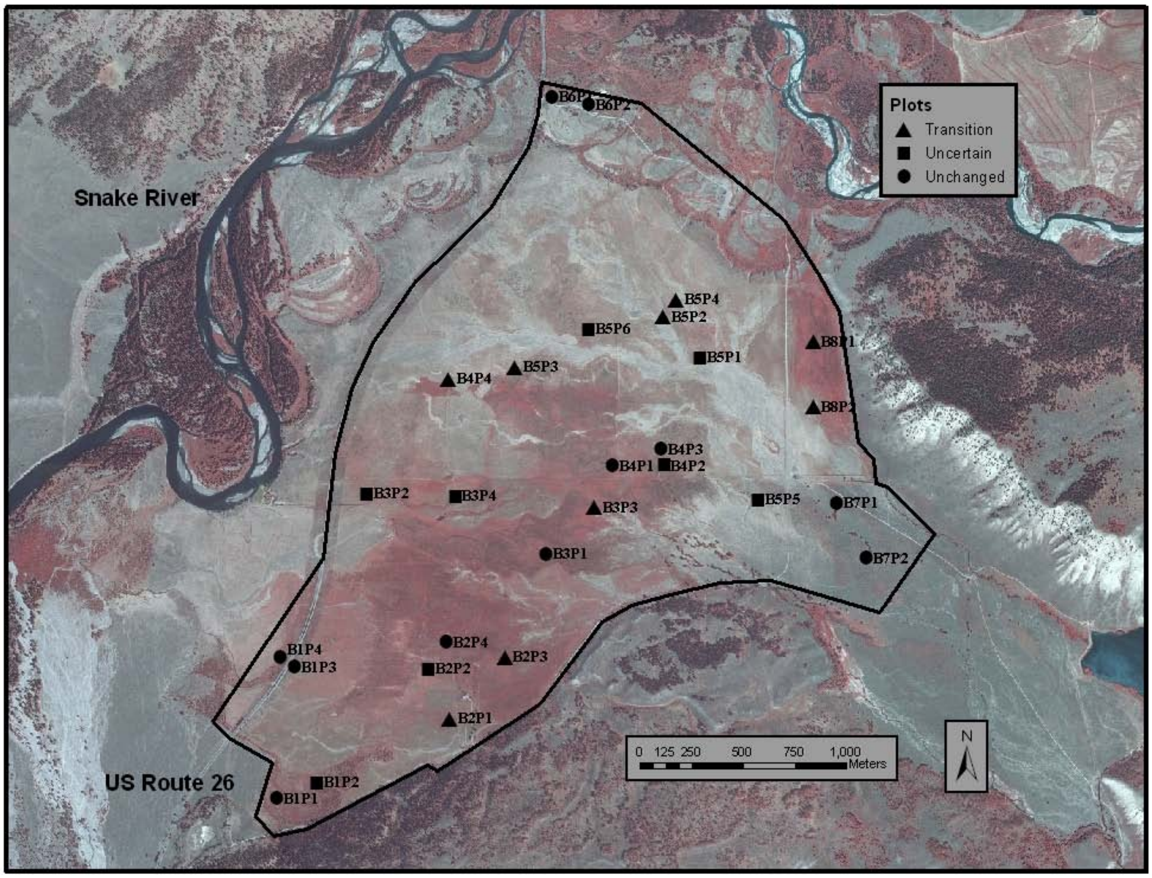

Figure 5. Elk Ranch study area sample plots. Sample plots that would transition to upland with ceasing flood-irrigation are depicted with a triangle, plots with an uncertain response are depicted with squares, and plots that would remain unchanged are depicted with a circle.

The response to irrigation cessation on sites with a WIV score between 75 and 50 and distinct redox contrast, falling between redox feature contour lines 1.5 and 2.5, (Figure 4) is uncertain as to whether the site remains a wetland or transitions to an upland state (Table 7). Response of study plots like B3P4 and B5P1 would be difficult to predict because it is unknown whether naturally occurring groundwater fluctuations or flood irrigation create the wetland hydrology that supports these wetland community types (Table 8 and Figure 5). The tufted hairgrass (*Deschampsia cespitosa* (L.) P. Beauv.) c.t.

would be representative of such areas. However, it should be noted that community type descriptions from Youngblood et al. (1985) suggest that tufted hairgrass c.t. and Baltic rush c.t. are likely to shift to drier c.t. when irrigation is suspended. Areas with a WIV score lower than 50 coupled with distinct mottling, plots B3P3 and B4P4 for example, are likely to be irrigation-induced wetlands because the lower occurrence of wetland species and distinct soil mottling suggests alternating periods of wet and dry conditions arising from historic flood irrigation. Therefore, at the Elk Ranch, sites with distinct mottling and a WIV less than 50 suggest an irrigation driven wetland hydrology rather than natural hydrology like at sites B1P1 and B2P4.

Soils with prominent mottling are likely to have wide hydrologic fluctuation (Wetland Training Institute, Inc. 2001), such as the fluctuation that occurs with flood irrigation and drying to accommodate hay harvest or grazing. However, the response to cessation of irrigation is uncertain in areas with a WIV score between 75 and 50 and prominent mottling (Table 7), falling above the contour line 2.5 (Figure 4), such as plot B1P2 (Table 8). These sites probably have both groundwater and irrigation influence and may continue as wetland species dominated sites after irrigation cessation. Sites with a WIV score lower than 50 and prominent mottling, plots B5P2 and B8P1 , are probably upland sites turned into artificial wetlands after years of flood irrigation (Tables 7 and 8). Sites such as these will probably revert quickly to native upland once irrigation stops.

Implications

Combination of WIV and soil redox contrast provides a more objective tool for evaluating flood-irrigated land for potential changes in wetland community presence or absence following management changes. While useful for identifying areas in the Elk Ranch hayfields, the addition of shallow groundwater monitoring, an ongoing study, could broaden this technique for use at other abandoned farmlands in Grand Teton National Park. Continued monitoring of this and other sites, like the Kelly hayfields, can be used to develop a refined version of this field assessment. Successful application at the Kelly hayfields would indicate potential utility of this technique for other abandoned hayfield renovation projects throughout the Northern Rockies.

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APPENDICES

APPENDIX A

SOIL TEXTURE AND PERCENT CLAY, SILT, SAND, AND ORGANIC MATTER IN THE UPPER 40 CM OF THE SOIL PROFILE WITHIN THE ELK RANCH.

Appendix A. Soil texture, percent clay, silt, sand, and organic matter in the upper 40 cm of the soil profiles within the Elk Ranch.

Sample Point	Soil texture[1]	% Clay[1]	% Silt[1]	% Sand[1]	% Organic matter[1]
B1P1	Organic	0	0	95	3.1
B1P2	Silty Clay	50	50	5	1.2
B1P3	Silt loam	26	79	11	2.0
B1P4	Silt loam	26	79	7	3.6
B2P1	Sandy Loam	16	20	51	0.7
B2P2	Loam	20	37	43	1.0
B2P3	Sandy Loam	8	22	70	0.7
B2P4	Sandy Loam	6	12	51	2.8
B3P1	Sandy Loam	8	19	61	1.4
B3P2	Loam	24	43	34	0.8
B3P3	Silt loam	26	78	5	2.3
B3P4	Silt loam	25	77	7	2.5
B4P1	Sandy Loam	8	18	42	2.8
B4P2	Sandy Loam	13	28	59	0.8
B4P3	Silt loam	25	76	13	0.9
B4P4	Silt loam	24	76	9	0.8
B5P1	Sandy Loam	7	17	57	1.3
B5P2	Sandy Loam	9	22	69	0.7
B5P3	Silt loam	25	76	7	0.8
B5P4	Silt loam	24	76	9	0.7
B5P5	Silt loam	24	76	8	1.0
B5P6	Silt loam	20	69	12	0.9
B6P1	Sandy Loam	9	26	40	2.3
B6P2	Loamy Sand	2	11	86	0.4
B7P1	Sandy Loam	9	34	58	1.0
B7P2	Sandy Loam	8	29	63	0.5
B8P1	Loam	14	28	39	1.7
B8P2	Silt loam	19	66	10	0.6

[1]Soil data were averaged from two sub-samples of the upper 40 cm of the soil profile.

APPENDIX B

THE FIVE MOST DOMINANT VEGETATION SPECIES PER SAMPLE PLOT, THE ASSOCIATED WETLAND INDICATOR VALUE, AND WETLAND INDEX VALUE AT THE ELK RANCH, MORAN, WY.

Appendix B. The five most dominant vegetation per sample plot, the associated wetland indicator status, and wetland index value at the Elk Ranch, Moran, WY.

Sample Plot	Vegetation [1, 2]	Wetland indicator status[3]	Wetland index value
B1P1[4]	CARUTR	OBL	100
	Litter	NA	NA
B1P2	JUNBAL	FACW+	83
	POAPRA	FAC	50
	Litter	NA	NA
	Carex spp.	NA	NA
	POTGRA	FAC	50
B1P3	Litter	NA	NA
	JUNBAL	FACW+	83
	CARAQU	OBL	100
	CARMIC	FAC	50
	BROINE	Not listed [5]	NA
B1P4	CARNEB	OBL	100
	CARUTR	OBL	100
	Litter	NA	NA
	DESCES	FACW	75
	GEUMAC	FACW-	67
B2P1	POAPRA	FAC	50
	PHLPRA	FAC-	42
	TAROFF	FACU	1
	Litter	NA	NA
	FESPRA	FACU+	33
B2P2	CARUTR	OBL	100
	POAPRA	FAC	50
	TAROFF	FACU	1
	JUNBAL	FACW+	83
	Litter	NA	NA
B2P3	POAPRA	FAC	50
	PHLPRA	FAC-	42
	TAROFF	FACU	1
	Litter	NA	NA
	FESPRA	FACU+	33
B2P4	CARUTR	OBL	100
	JUNBAL	FACW+	83
	POAPRA	FAC	50
	Litter	NA	NA
	Carex spp.	NA	NA
B3P1	JUNBAL	FACW+	83
	POAPRA	FAC	50
	Litter	NA	NA

Appendix B continued.

	CARMIC	FAC	50
	MUHMIN	FAC+	58
B3P2	CARUTR	OBL	100
	TAROFF	FACU	1
	PHLPRA	FAC-	42
	Litter	NA	NA
	POAPRA	FAC	50
B3P3	CARMAC	FAC-	42
	TAROFF	FACU	1
	PHLPRA	FAC-	42
	JUNBAL	FACW+	83
	CARAQU	OBL	100
B3P4	Litter	NA	NA
	CARAQU	OBL	100
	CARNEB	OBL	100
	TAROFF	FACU	1
	JUNBAL	FACW+	83
B4P1	Litter	NA	NA
	JUNBAL	FACW+	83
	CARUTR	OBL	100
	CARNEB	OBL	100
	CARPHA	FACU	1
B4P2	POAPAL	FAC	50
	JUNBAL	FACW+	83
	Litter	NA	NA
	CARNEB	OBL	100
	PHLPRA	FAC-	42
B4P3	MUHMIN	FAC+	58
	CARNEB	OBL	100
	Litter	NA	NA
	CARAQU	OBL	100
	Bare ground	NA	NA
B4P4	Litter	NA	NA
	PHLPRA	FAC-	42
	FESPRA	FACU+	33
	POASEC	Not listed	NA
	TAROFF	FACU	1
B5P1	JUNBAL	FACW+	83
	Litter	NA	NA
	POAPAL	FAC	50
	CARMIC	FAC	50
	TAROFF	FACU	1
B5P2	POACOM	FACU+	33

Appendix B continued

	PHLPRA	FAC-	42
	POAPRA	FAC	50
	TAROFF	FACU	1
	Litter	NA	NA
B5P3	CARMAC	FAC-	42
	Litter	NA	NA
	PHLPRA	FAC-	42
	TAROFF	FACU	1
	CARNEB	OBL	100
B5P4	POASEC	Not listed	NA
	Bare ground	NA	NA
	PHLPRA	FAC-	42
	Litter	NA	NA
	BROINE	Not listed	NA
B5P5	Litter	NA	NA
	POAPRA	FAC	50
	JUNBAL	FACW+	83
	Aster spp.	NA	NA
	CARAQU	OBL	100
B5P6	CARAQU	OBL	100
	POASEC	Not listed	NA
	PHLPRA	FAC-	42
	Litter	NA	NA
	DESCES	FACW	75
B6P1	JUNBAL	FACW+	83
	Litter	NA	NA
	Moss	Not listed	NA
	CARNEB	OBL	100
	CARUTR	OBL	100
B6P2	Litter	NA	NA
	CARNEB	OBL	100
	Moss	Not listed	NA
	CARUTR	OBL	100
	JUNBAL	FACW+	83
B7P1	POACOM	FACU+	33
	ARTTRI	Not listed	NA
	Litter	NA	NA
	LUPARG	Not listed	NA
	TAROFF	FACU	1
B7P2	POACOM	FACU+	33
	Litter	NA	NA
	ARTTRI	Not listed	NA
	STICOM	Not listed	NA

Appendix B continued

	CIRFOL	FAC-	42
B8P1	POACOM	FACU+	33
	Litter	NA	NA
	POAPRA	FAC	50
	CARMIC	FAC	50
	PHLPRA	FAC-	42
B8P2	POAAMB	Not listed	NA
	Litter	NA	NA
	PHLPRA	FAC-	42
	TAROFF	FACU	1
	POAPRA	FAC	50

[1] Only the five most dominant vegetation species per plot is listed.
[2] Vegetation is listed as six-letter scientific abbreviation.
[3] Wetland indicator status identification from Resource Management Group, Inc. 1993 and Reed et al. 1993.
[4] Plots with less than five vegetation species listed had less than five species per plot
[5] Term “Not listed” means that the species was not listed on the regional or national wetland species list.