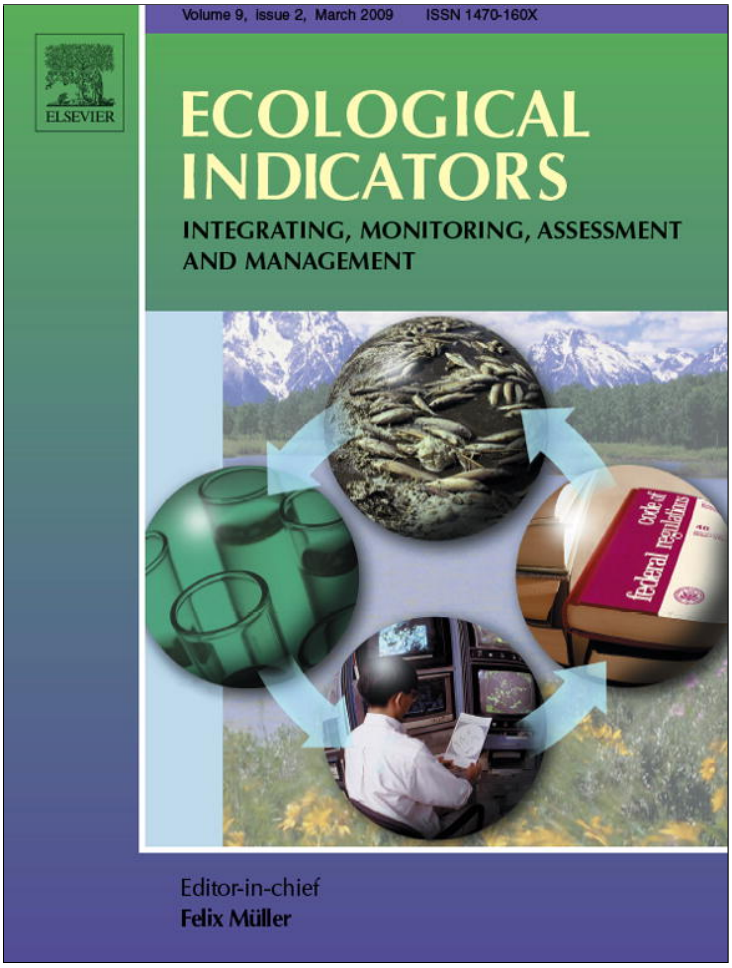
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Low prairie plant communities of wetlands as a function of disturbance: Physical parameters

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ABSTRACT

Understanding how physical parameters within and adjacent to Prairie Pothole Region wetlands affect the surrounding biological communities is important for sound management decisions for agricultural and rangeland settings. We evaluated the wetland, adjacent non-wetland, and landscape physical parameters role in determining low prairie (sub-irrigated) species composition. We first developed hypothetical models using the physical variables collected from 193 wetlands in relation to the existing plant communities. The models were then evaluated using structural equation modeling and a final (alternative) model was developed from these results. The models developed indicated the importance of the low prairie community in proper ecological functioning of associated wetlands. A number of physical parameters measured can be used as indicators of declining plant community condition, one example being the potential of the low prairie plant community to be invaded by exotic species such as *Bromus inermis* Leyss.

1. Introduction

Species composition of low prairie (sub-irrigated) plant communities found adjacent to Prairie Pothole Region (PPR) wetlands are influenced by numerous physical impacts that may occur at the landscape level, within the catchment basin, or in the wetland basin. Species composition of the low prairie, as well as the wetland communities, have been shown to differ due to the type and intensity of impact such as grazing, mowing, cultivation, fire, drought (Dix and Smeins, 1967; Walker and Coupland, 1968, 1970; Stewart and Kantrud, 1971, 1972; Kantrud, 1986; Kantrud et al., 1989a,b; Kantrud and Newton, 1996; NRCS, 2004), sedimentation (Rybicki and Carter, 1986; Hartleb et al., 1993; Jurik et al., 1994; Wang et al., 1994; Adamus, 1996), nutrient loading (Mulligan et al., 1976; Ozimek, 1978; Hough et al., 1989; Adamus, 1996), and pesticide and heavy metal contamination (Adamus, 1996; Kantrud and Newton, 1996). The nature of many of these physical impacts has also introduced several exotic species which have further changed species composition in low prairie plant communities. The degree to which these introduced species contribute to the composition of the plant community is dependent not only on naturally occurring abiotic (Larson et al., 2001) and biotic (Seabloom and van der Valk, 2003a) factors, but also to the degree to which anthropogenic disturbances have directly influenced a plant community as well as altered the landscape surrounding a wetland (Galatowitsch et al., 2000; DeKeyser, 2000; Whited et al., 2000; DeKeyser et al., 2003; Seabloom and van der Valk, 2003a,b).

The rationale for investigating low prairie plant communities across the current landscape of the PPR is the potential of disturbance to cause minor to major shifts in species composition of historic plant communities (Westoby et al., 1989). These shifts to often times "weedy" species could be detrimental to ecosystem functions, or natural processes, such as nutrient cycling, energy flow (Odum, 1985; Hobbie et al., 1993; Rapport and Whitford, 1999), and local climate regulation (Shukla et al., 1990). Since the low prairie is the first

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upland community surrounding all wetlands in the PPR (Dix and Smeins, 1967; Stewart and Kantrud, 1971, 1972), it either partially or fully contains (or lacks) a buffer zone of perennial vegetation. Even though there has been debate on the optimal width of buffer zones for wetlands (Castelle et al., 1992, 1994), these same studies indicate the importance of buffers in providing the local functions of improving water quality, regulating hydrology, and providing fish and wildlife habitat.

Studies in the PPR describing wetland plant communities, including the low prairie, and their compositions after disturbance are dated (Dix and Smeins, 1967; Walker and Coupland, 1968, 1970; Stewart and Kantrud, 1971, 1972). These studies concentrated on describing two extremes; historic climax plant communities found on unbroken rangeland, and secondary successional plant communities that occur after the severe disturbance of cropland tillage. Changes in species composition resulting from other land-uses especially those involving the introduction of foreign species and invasions by foreign species, as related to the surrounding physical parameters either at a local or landscape level in PPR prairie and wetland systems, were not considered in detail. Different plant communities such as those existing in cropland, rangeland, and introduced mono-cultural stands of grass have been shown to differ in the ability to perform specific functions such as impeding sedimentation rate and sequestering carbon (Luo et al., 1997; Gleason and Euliss, 1998; Lal et al., 1998; Follett et al., 2000), or maintaining nutrient levels and the local hydrologic cycle (Detenbeck et al., 2002; Voldseth et al., 2007).

The Natural Resources Conservation Service (NRCS), Army Corps of Engineers (COE), and the North Dakota Department of Health (NDDH) are considering the anthropogenic impacts and their effects on wetland communities and wetland functions by utilizing the Hydrogeomorphic (HGM) model for wetland assessment (Lee et al., 1997; Gilbert et al., 2006). The Environmental Protection Agency (EPA) is also studying the role of the HGM model in obtaining biological and physical data as part of a National Wetland Survey starting in 2011 (Kentula, 2007). Brinson (1993) initially developed a HGM classification system for wetlands based on the correlation of hydrology, geomorphology, and wetland function. Functions being those naturally occurring processes such as nutrient cycling, wildlife habitat, ground water recharge, flood attenuation, and improving water quality (Kirby et al., 2002a,b). The initial development of the HGM model as an assessment tool aimed to measure physical and biological parameters in relation to anthropogenic impacts at the wetland, catchment, and landscape level to estimate the degree to which a wetland is performing ecological functions (Smith et al., 1995). We believe that the measurements of the physical parameters collected during the HGM assessment can be related to low prairie species compositional states based on the current anthropogenic impacts now found on the predominantly agricultural landscape of the PPR. The objective of this research, thus, was to test the efficacy of the physical measurements used in the HGM model in identifying low prairie species composition.

We used structure equation modeling (SEM) to analyze the above relationship similarly to Grace and Pugesek (1997) in their examination of influences on species richness in coastal wetlands. Other uses of SEM has included environmental and biological controls of the distribution of Steppe taxa in Alaska (Wesser and Armbruster, 1991), and environmental and landscape controls on species density of coastal wetlands (Grace and Guntenspergen, 1999). Overall, SEM has been utilized to describe relationships of many biological organisms and their environment (Pugesek et al., 2003). Our study differs from other studies in that we are utilizing a mixture of hydrologic variables, soil variables, and site and non-site landscape variables to describe species composition of low prairie plant communities in the PPR.

2. Materials and methods

2.1. Study area

The research was conducted from 1998 to 2004 in the PPR of Montana, North Dakota, and South Dakota within the Northern Glaciated Plains (NGLP) and Northwestern Glaciated Plains (NWGLP) Level III ecoregions (Fig. 1; Bryce et al., 1998). These regions include a large number of depressional wetlands that can vary in size from less than 0.5 ha to more than 40 ha, have water permanency from a temporary status to permanently flooded, and water quality from fresh to saline (Stewart and Kantrud, 1971, 1972; Cowardin et al., 1979). For this study, low prairie (sub-irrigated) vegetation data was analyzed from 193 low prairie sites adjacent to wetlands that were classified as temporary, seasonal, or semi-permanent.

The NGLP ecoregion has been classified as a transition grassland type between the western mixed grass prairie and the eastern tall grass prairie (Barker and Whitman, 1988), and is geologically an area of glacial drift with flat to rolling topography (Bryce et al., 1998). The remaining rangeland vegetation of the transition grasslands in the NGLP has been classified as a wheatgrass–bluestem–needlegrass association (Barker and Whitman, 1988). The NWGLP is noted as the western most edge of continental glaciation and is characterized by a hilly morainal landscape with numerous depressional wetlands (Bryce et al., 1998). The dominant land-uses in the NWGLP are small grain farming and livestock production, the latter usually being on native rangeland (Bryce et al., 1998).

The low prairie plant community surrounding temporary, seasonal, and semi-permanent depressional wetlands has been described as similar in the composition of dominant species throughout the ecoregions (Dix and Smeins, 1967; Stewart and Kantrud, 1971, 1972). Sedivec and Dhuyvetter (1991) noted that the percentage of the composition of the major graminoid species varied slightly on rangeland across the ecoregions. Most of the variation they noted was in the composition of *Andropogon gerardii* Vitmann (big bluestem), *Panicum virgatum* L. (switchgrass), and *Poa pratensis* L. (Kentucky bluegrass). Stewart and Kantrud (1971, 1972) also described the species composition of the cropland tillage phase of the low prairie community which was a heavily disturbed community consisting of pioneering and invasive species.

2.2. Field methods

A total of 193 temporary, seasonal, and semi-permanent wetland sites were located throughout the NWGLP and NGLP

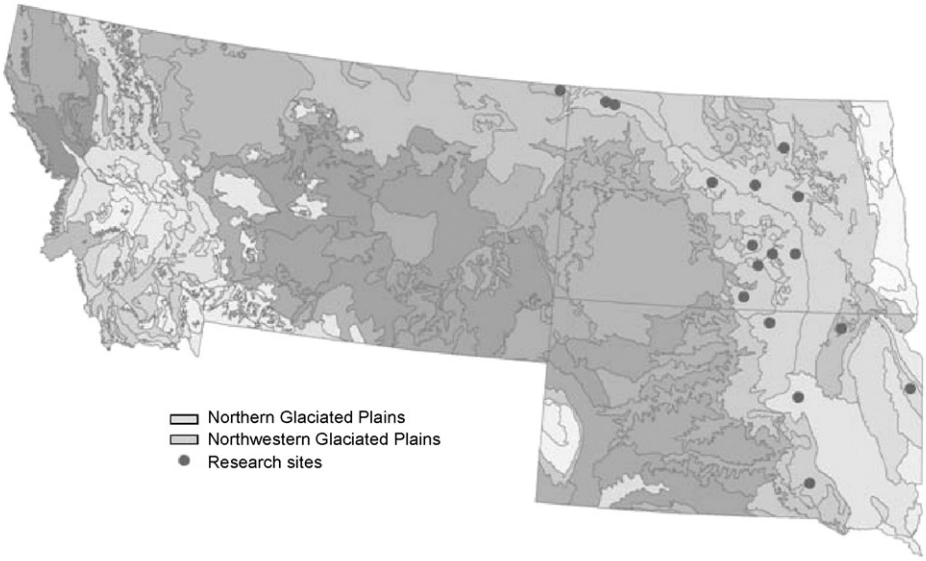

Fig. 1 – Ecoregional map indicating study site locations (modified from Bryce et al., 1998).

ecoregions (Fig. 1), with a high number (89) of these sites concentrated in south-central North Dakota in or near the NWGLP. Low prairie study sites were selected adjacent to these wetlands and selection was based on type and intensity of disturbance (anthropogenic and climatic), which was directly related to the land-use within the wetland and catchment basin, and the predominant climate at the time of the survey. Disturbances and land-uses that were represented included: rangeland grazing (light, moderate, heavy), pasture grazing (light, moderate, heavy), hayland, Conservation Reserve Program (CRP) grasslands, cultivation, urbanization, restored native prairie, idle lands (native and pasture), fire, drought, and pluvial conditions. It should be noted that some anthropogenic disturbances can also magnify naturally occurring wetland processes such as sedimentation, nutrient loading, and anoxia; and may include pesticide or heavy metal contamination.

Each wetland study site was visited one time using a 1-m^2 quadrat method to sample the low prairie plant community. Temporal variability in the development of plant species was accounted for by sampling at or near peak production (late-June through early August) to obtain a record of spring, summer, and fall flowering species. The method was similar to that used by Kantrud and Newton (1996), and has been described in detail by DeKeyser (2000). The method entailed evenly distributing eight 1-m^2 quadrats in the middle of the low prairie (sub-irrigated) exterior zone of all wetlands. Each plant species located within a quadrat was identified and recorded as a primary species, and assigned a cover class similar to those developed by Daubenmire (1959). Following Euliss and Gleason (1997), a cover class category was added for rare species (1 = 0–1%). A secondary species list was also recorded for those species not found within the quadrat, but between quadrat placement.

Environmental variables were collected using the Hydrogeomorphic (HGM) model of wetland functional assessment developed by the NRCS and the COE (Lee et al., 1997). The method involves assigning values to index variables developed by the NRCS and COE. These index variables can be defined as attributes (physical, chemical, or biological) of the wetland being surveyed. The attributes measured included characteristics of the hydrology, soils, biogeochemistry, and the landscape (Table 1). Measurements of the physical parameters of the HGM model, such as grassland buffer width (BUFWID), (Table 2) are based on a set of reference wetlands that are representative of the "range of variability" of wetlands found on the present landscape of the PPR (Smith et al., 1995). The range of variability within the PPR includes managed native prairie through intensively tilled cropland. Our data set includes the initial reference set of wetlands utilized by Lee et al. (1997) to develop the HGM model, and subsequent data gathered are representative of the present landscape in the PPR. All the index variables within the model range from 1 to 0. Once values are assigned to the index variables, the variables are used in functional capacity index equations (Table 1). The equations were developed to measure the level a wetland is performing a particular natural function (i.e. water storage) based on the reference set of wetlands.

2.3. *Statistical methods*

We analyzed the data with structure equation models (SEM) using an approach similar to Grace and Pugesek (1997) who investigated the environmental and biological controls of species richness in coastal wetlands. The target variable to model was species composition since it is most commonly used to assess wetland plant communities, wetland functionality, and class in the PPR (Stewart and Kantrud, 1971; DeKeyser, 2000; DeKeyser et al., 2003; NRCS, 2004).

The SEM method consists of specifying a multivariate dependence model (hypothesis) which generates a covariance matrix that can be tested against an actual covariance matrix generated from field data (Grace and Pugesek, 1997). An important attribute of SEM is that it allows for the construction

Table 1 – Hydrogeomorphic model index variable and function definitions and acronyms

Acronym of hydrogeo morphic index variable	Definition of hydrogeomorphic index variable	Acronym and relation to hypothesized latent variable
WETDEN	Density of wetlands in the landscape within a 1.6 km radius from the wetland center	LCSW: landscape characteristics of the wetlands
WETAREA	Total hectares of wetland area within a 1.6 km radius from the wetland center	
PROXIM	Mean distance of 5 nearest wetlands	
BUFDEN	Grassland buffer density surrounding wetland	LCSNWA: landscape characteristics in the surrounding non-wetland areas
BUFWID	Grassland buffer width surrounding wetland	
BUFCON	Grassland buffer continuity surrounding wetland	
PORE	Soil porosity	SOIL: soil variables
SOM	Soil organic matter	
DETRIT	Detritus (litter) thickness	
MSSWS	Model function: maintenance of static surface water storage. $=(\mathrm{OUT}\times((\mathrm{SOURCE}+\mathrm{UPUSE})/2+(\mathrm{WETUSE}+\mathrm{SED}+\mathrm{PORE}+\mathrm{SUBOUT})/4)/2)^{1/2}$	HYDRO: hydrologic variables
MDWS	Model function: maintenance of dynamic water storage. If OUT is less than 0.75, then function index is 0.0. Otherwise use: $=(\mathrm{OUT}+(\mathrm{SOURCE}+\mathrm{UPUSE})/2+(\mathrm{PORE}+\mathrm{WETUSE})/2)/3$	
OUT[a]	Wetland outlet condition	
UPUSE[a]	Upland land use	
SED[a]	Sediment in the wetland	
SOURCE[a]	Watershed (catchment) source area	
SUBOUT[a]	Subsurface outlet (drain)	
WETUSE[a]	Wetland land use	

[a] Index variable used in the calculation of HGM model function only.

and estimation of conceptual (*latent*) variables when multiple measures or facets (*indicators*) of that variable are available. For example, one can specify that the three estimations (based on the reference set); soil organic matter, pore density, and detritus are different manifestations (*indicators*) of a single *latent* variable of interest called soil properties (McCune and Grace, 2002) (Table 1). The estimation of *latent* variables using multiple *indicators* has been shown to be far more advantageous than use of single indicators. More importantly they provide for the estimation and removal of measurement errors, which add substantial increases in accuracy and precision of the model (Grace and Pugesek, 1997). The major strengths of SEM can be summarized as follows (McCune and Grace, 2002): (1) it provides a robust methodology to statistically evaluate the correspondence between hypothesized models and within model component interrelationships with field data; (2) it allows estimation of unobserved conceptual variables from specific measured variables; (3) it gives an estimation of the strength of direct and indirect pathways between variables within the model; and (4) it provides for the direct estimation of the reliability of predictions.

Our approach for the SEM was as follows: (1) we used non-metric multidimensional scaling (NMS) to ordinate (separately) the species composition of grass and grass-likes and forbs, shrubs, and half-shrubs and select statistically significant compositional axes (McCune and Grace, 2002). These axes defined the grass and grass-like and forb, shrub, and half-shrub species composition, and thus were the predictive variable in the model; (2) we used the environmental variables shown in Table 1 as *indicators* for the four *latent* environmental variables (Table 1, Fig. 2A) that we hypothesize affect species composition; (3) the hypothesized model for species composition is shown in Figs. 3A and 4A with the *latent* variables representing species communities, and the NMS ordination axes being the *indicators*; and (4) the original hypotheses (Figs. 3A and 4A) as well as alternatives were tested for fit using both chi square and root mean square error of approximation (RMSEA) (Pugesek et al., 2003). The standards for fit were a $P > 0.05$ (no differences between model predictions and data), and an RMSEA <0.06.

Table 2 – Example of index value assignment to the HGM model variable grassland buffer width (BUFWID) (Lee et al., 1997)

Model variable definition	Measurement or condition	Index
Mean width of grassland buffer surrounding outermost edge (≥15 m from wetland edge)	Mean buffer width is greater than 15 m wide	1.00
	Mean buffer width is between 11.5 and 15 m wide	0.75
	Mean buffer width is between 7.5 and 11.5 m wide	0.50
	Mean buffer width is between 4 and 7.5 m wide	0.25
	Mean buffer width is between 0 and 4 m wide	0.10
	There is no buffer present	0.00

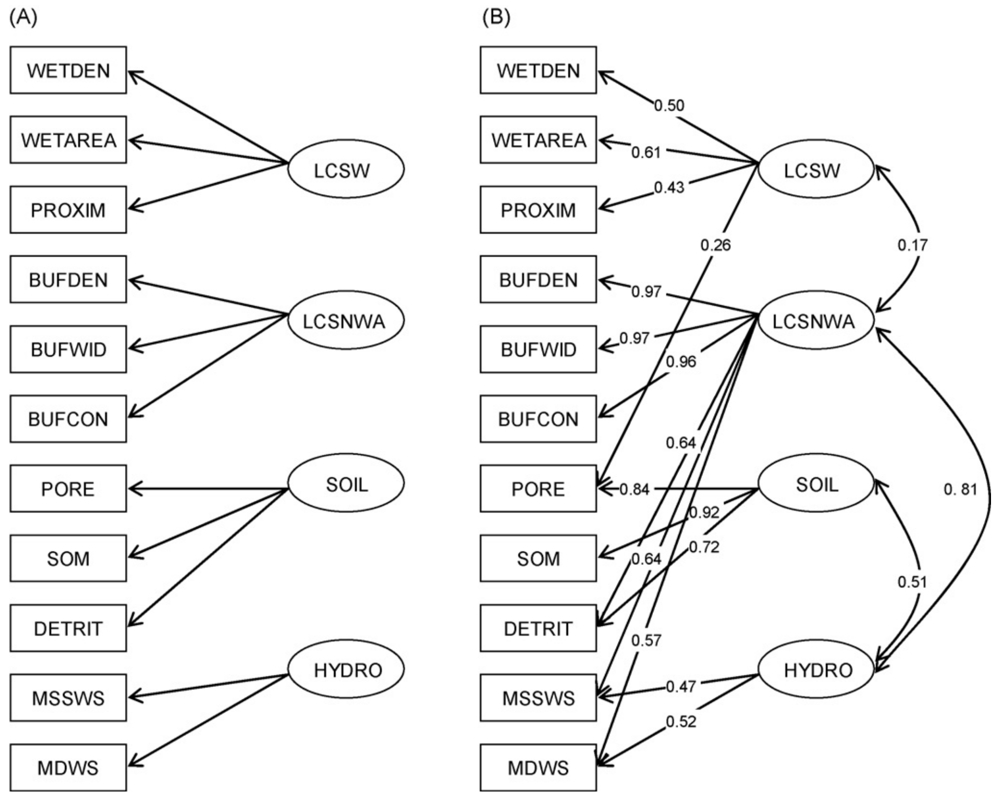

Fig. 2 – Theoretical (A) and fitted (B) structural equation models for the indicator and latent environmental variables developed from the Hydrogeomorphic model index variables and functions. Fitted model statistics: χ^2 = 42.96, P = 0.17, RMSEA = 0.03. The numbers over the arrow of the fitted models represent statistically significant ($P < 0.05$) correlation coefficients. See Table 1 for variable definitions.

The first step of the process was data reduction via ordination of the species' composition space. Ordination consists of extracting from a matrix a few dominant patterns from an infinite number of possible patterns. For that purpose all ordination procedures create new synthetic variables (ordination axes) that identify and separate the deterministic sources of variations from the "random noise" (McCune and Grace, 2002). As an ordination technique we used NMS with the Sorensen distance method because it is extremely well suited for data that are non-normal, non-linear, arbitrary, discontinuous, or otherwise questionable scale (McCune and Grace, 2002). NMS extracts uncorrelated sources of variations (synthetic axes) from a species composition space. We used a Monte Carlo randomization test to identify the statistically significant axes ($P < 0.05$) to be kept for further analysis, thus eliminating "random background noise." These were the axes that defined the species composition space used as predictors in the SEM models. The analysis was conducted separately for forbs and grasses because they perform different roles in the function of grassland communities (Biondini et al., 1989; Johnson and Biondini, 2001). The dominant species that characterized each NMS axis were determine by correlation analysis and selected when R was significant at the $P < 0.01$ level and the error risk for the estimation of R (β = 1-power test) was less than 50% for a 2-tail test at $P < 0.01$ (Zar, 1999).

The initial SEM working hypotheses are shown in Figs. 2A, 3A, and 4A. The environmental component of the SEM model (Fig. 2A) hypothesizes that the environmental variables can be reduced to four major *latent* variables (Table 1): (1) landscape characteristics of the wetlands (LCSW); (2) landscape characteristics of non-wetland areas (LCSNWA); (3) wetland hydrology (HYDRO); and (4) wetland soils (SOIL). The various *indicator* variables for each latent variable are shown in Table 1. The complete SEM model hypothesizes that plant community composition is driven by one of two sets of environmental components: (1) a landscape scale effect involving LCSW and LCSNWA; and (2) a more local effect involving the specific hydrological (HYDRO) and soil (SOIL) characteristics of each wetland.

The SEM models were constructed and tested using the LISREL software (Scientific Software International Inc., Lincolnwood, IL). Alternative models (hypotheses), derived from the initial models (Figs. 2A, 3A, and 4A), were evaluated using a nested analysis technique (Pugesek et al., 2003). In this type of analysis a theoretical initial model is evaluated for both fit and parsimony in comparison with all other models that contain the same causal variables but have different relationship pathways (Grace and Pugesek, 1997). LISREL implements the nested analysis through the evaluation of a series of modification indices and the statistical significance of pathways. Through this process the model with the best fit and parsimony is identified and the parameters estimated. To avoid over fitting, alternative models were accepted only when they could be justified scientifically (Grace and Pugesek, 1997).

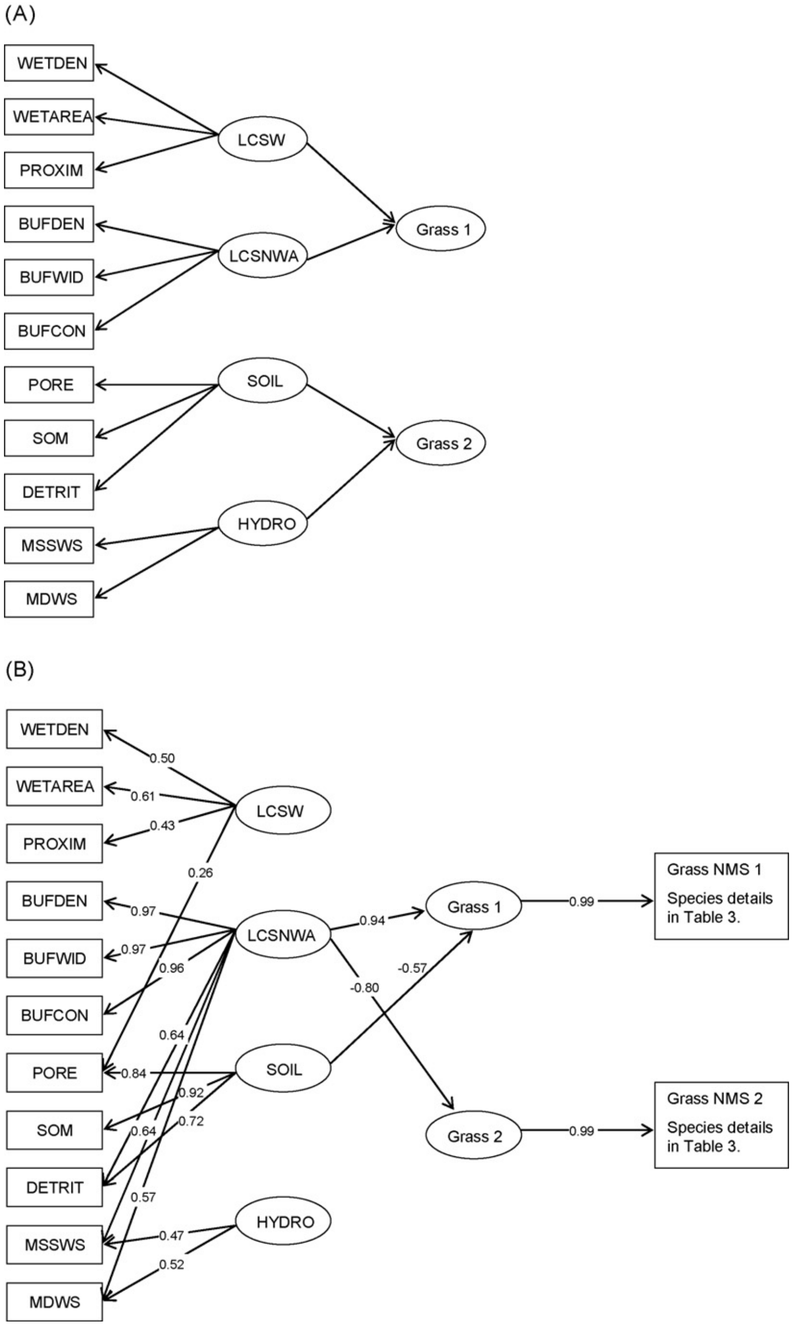

Fig. 3 – Theoretical (A) and fitted (B) structural equation models for the grass and grass-like group as related to the indicator and latent environmental variables. Fitted model statistics: χ^2 = 90.05, P = 0.06, RMSEA = 0.04. The numbers over the arrow of the fitted models represent statistically significant (P < 0.05) correlation coefficients. See Tables 1 and 3 for variable definitions.

3. Results

The final SEM model for the environmental variables is shown in Fig. 2B (χ^2 = 42.96, P = 0.17, RMSEA = 0.03). It was an alternative to the hypothesized model (Fig. 2A) in which: (1) soil porosity (PORE) was an indicator of landscape characteristics of wetlands (LCSW); while (2) soil detritus (DETRIT) and the static and dynamic water surface storage properties of wetlands (MSSWS, and MDWS) were additional indicators of the landscape characteristics of non-wetland areas (LCSNWA). As expected, the landscape characteristics of the wetlands and non-wetland areas (LCSW and LCSNWA) were correlated (R = 0.17, $P < 0.05$), as were the hydrology and soil characteristics of individual wetlands (HYDRO and SOIL, R = 0.51, $P < 0.02$). The analysis; however, also showed a strong link between the hydrology and soil characteristics of each wetland and the landscape properties of the non-wetland areas surrounding the wetland complex (R = 0.81, $P < 0.01$).

The NMS analysis for grasses resulted in two significant ($P < 0.01$) axes that accounted for 74% of the total variability in

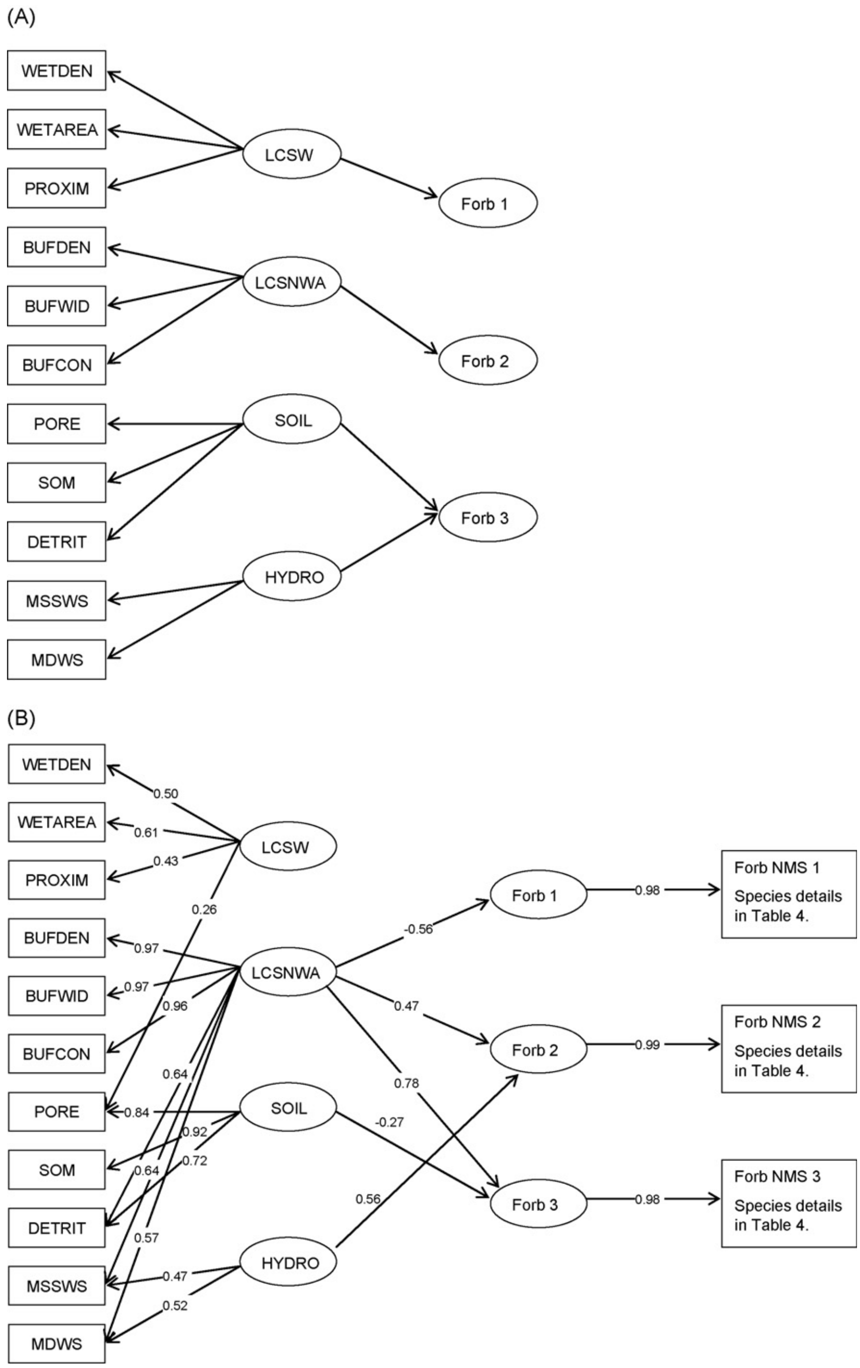

Fig. 4 – Theoretical (A) and fitted (B) structural equation models for the forb, shrub, and half-shrub group as related to the indicator and latent environmental variables. Fitted model statistics: χ^2 = 91.91, P = 0.17, RMSEA = 0.028. The numbers over the arrow of the fitted models represent statistically significant (P < 0.05) correlation coefficients. See Tables 1 and 4 for variable definitions.

species composition (52% and 22%, respectively, for NMS 1 and NMS 2). The species that were significantly correlated with each axis and had error risk for the estimation of *R* of less than 50% are shown in Table 3. NMS 1 was dominated by *Bromus inermis* Leyss. (i.e. invaded native rangeland) and Tame Grasses (i.e. all planted grasses), while NMS 2 was driven by a combination of mostly native grasses and grass-likes and some introduced grasses, the major one being *Poa pratensis* L. with an R^2 = 0.58. In the case of forbs there were three significant (P < 0.01) axes that accounted for 66% of the total variability in species composition (25%, 25%, and 16%, respectively for NMS 1-NMS 3). The species that were significantly correlated with each axes and had error risk for the estimation of *R* of less than 50% are shown in Table 4. NMS 1 was dominated by three annual and biennial species (*Chenopodium berlandieri* Moq., *Lactuca serriola* L., and

Table 3 – Significant correlations for the ordination axes for the grass and grass-like group expressed as R values with $P < 0.01$ and an error risk (β) of less than 50%

Species	NMS 1		NMS 2	
	R[a]	Error risk[a] (β)	R[a]	Error risk (β)
Bromus inermis Leyss.	0.64	0.00		
Tame Grass[b]	0.24	0.23		
Andropogon gerardii Vitmann			−0.35	0.01
Calamagrostis stricta (Timm.) Koel.			−0.22	0.33
Carex brevior (Dew.) Mack. ex Lunnell.			−0.34	0.01
Carex praegracilis W. Boott.			−0.21	0.39
Elymus trachycaulus (Link) Gould ex Shinners			−0.32	0.03
Nassella viridula (Trin.) Barkworth			−0.27	0.12
Panicum virgatum L.			−0.20	0.44
Pascopyrum smithii (Rydb.) A. Love			−0.33	0.02
Poa pratensis L.			−0.76	0.00

[a] All values are significant at $P = 0.01$. β is a 2-tail error risk for R at $P = 0.01$.
[b] If a grass species was physically planted (i.e. CRP) it was placed into the Tame Grass species category.

Sisymbrium altissimum L.). NMS 2 consisted of a combination of eleven mostly perennial native species positively correlated with the axis and three weedy species negatively correlated with the axis. NMS 3 consisted of a perennial forb (*Asclepias syriaca* L) positively correlated to the axis.

The final SEM model for grass composition is shown in Fig. 3B ($\chi^2 = 90.05$, $P = 0.06$, RMSEA = 0.04). It differs from the hypothesized (Fig. 3A) in two ways: (1) the landscape characteristics of wetlands and the hydrology of each wetland did not play a role in structuring grass composition, and (2) the landscape characteristics surrounding non-wetland areas affected (in opposite ways) both grassland axes. *Bromus inermis* Leyss. and Tame Grasses (Grass 1) were: (1) positively correlated ($R = 0.94$, $P < 0.01$) with the landscape characteristics of the areas surrounding the wetland complex (LCSNWA), in particular their size (defined by BUFDEN, BUFWID, and BUFCON; see Tables 1 and 2 for details) which is comprised of native prairies, tame pastures, crops, or a combination, and (2) negatively correlated with the soil variables ($R = -0.57$, $P < 0.01$). The mostly native complex of grasses (Grass 2) were negatively correlated ($R = -0.8$, $P < 0.01$) to the landscape characteristics of non-wetland areas surrounding the wetland complexes.

The final SEM model for forb composition is shown in Fig. 4B ($\chi^2 = 91.81$, $P = 0.17$, RMSEA = 0.028). It differs from the hypothesized (Fig. 4A) in two ways: (1) the landscape characteristics of wetlands did not play a role in structuring forb composition, and (2) two of the forb ordination axes (Forb 2 and Forb 3) were affected by both landscape characteristics of non-wetland areas (LCSNWA) and the soil and hydrological condition of each individual wetland. Forb 1, the annual and biennial species community complex (*Chenopodium berlandieri*

Table 4 – Significant correlations for the ordination axes for the forb, shrub, and half-shrub group expressed as R values with $P < 0.01$ and an error risk (β) of less than 50%

	NMS 1		NMS 2		NMS 3	
	R[a]	Error risk[a] (β)	R[a]	Error risk[a] (β)	R[a]	Error risk[a] (β)
Chenopodium berlandieri Moq.	0.28	0.09				
Lactuca serriola L.	0.24	0.23				
Sisymbrium altissimum L.	0.20	0.44				
Antennaria neglecta Greene			0.21	0.39		
Artemisia absinthium L.			−0.24	0.23		
Astragalus agrestis Dougl. ex G. Don			0.35	0.01		
Chenopodium album L.			−0.26	0.15		
Comandra umbellata (L.) Nutt.			0.21	0.39		
Convolvulus arvensis L.			−0.25	0.19		
Elaeagnus commutata Bernh.			0.22	0.33		
Heuchera richardsonii R. Br.			0.23	0.28		
Liatris ligulistylis (A. Nels.) K. Schum.			0.20	0.44		
Rosa arkansana Porter			0.20	0.44		
Spiraea alba Du Roi			0.23	0.28		
Thalictrum dasycarpum Fisch. & Ave-Lall.			0.25	0.19		
Tragopogon dubius Scop.			0.21	0.39		
Viola pedatifida G. Don			0.36	0.01		
Asclepias syriaca L.					0.21	0.39

[a] All values are significant at $P < 0.01$. β is a 2-tail error risk for R at $P = 0.01$.

Moq., *Lactuca serriola* L., and *Sisymbrium altissimum* L.), was negatively correlated with the landscape characteristics of non-wetland areas ($R = -0.56$, $P < 0.01$). Forb 2, a forb community encompassing a combination of eleven mostly perennial native species and three weedy species (Table 4), was positively correlated with LCSNWA ($R = 0.47$, $P < 0.01$) and the hydrology of each wetland (HYDRO, $R = 0.56$, $P < 0.01$). Forb 3 which was comprised of the perennial forb *Asclepias syriaca* L. was also positively correlated with LCSNWA ($R = 0.78$, $P < 0.01$) but negatively correlated with soil quality ($R = -0.27$, $P < 0.05$).

4. Discussion

The model correlations of the HGM environmental variables indicated relationships between landscape, site, hydrologic, and soil properties (Fig. 2B). The defined landscape characteristics (Table 1) are measured to obtain a sense of wetland drainage within a given region (Lee et al., 1997; Gilbert et al., 2006) in proximity to the assessed wetland. Drainage of wetlands is closely associated with agricultural production (Dahl, 1990), and agricultural production directly influences soil porosity for example (Lee et al., 1997; Gilbert et al., 2006). The LCSNWA site variable consisting of the three buffer variables (Table 1) indicated a correlation between buffer condition, and soil and hydrologic conditions. The correlation of the buffer condition and beneficial litter thickness within the wetland is due to the ability of the buffer to slow sedimentation which can cover plant materials within the wetland (Jurik et al., 1994; Wang et al., 1994; Kantrud and Newton, 1996). This is further supported by the correlations between buffer conditions and hydrologic variables that consider sedimentation in the wetland as well as wetland and upland land-use (Lee et al., 1997; Gilbert et al., 2006). The amount of sediment a wetland receives it directly related to land-use in the PPR (Kantrud et al., 1989b; Gleason and Euliss, 1998), and the mitigation of sediment is related to condition of the buffer (Castelle et al., 1992, 1994).

There is adequate information stating importance of buffer zones in proper functioning of wetland and riparian systems; however, most of this information is focused on ideal width for mitigating catchment basin disturbances (Castelle et al., 1992, 1994). There is little information on the relationship of buffer species composition and wetland function in the PPR.

There is a relationship between grass species composition and soil characteristics and buffer condition (Fig. 3B). Buffers planted into tame grass or invaded by *Bromus inermis* Leyss. (Table 3) had less buffer density, width, and continuity than buffers dominated by native graminoid species. The tame and invaded buffers also lacked soil porosity, organic matter, and optimum detritus levels (Fig. 3B). This could be related to increased sedimentation rates allowed by monocultural stands of grasses as compared to diverse native grasslands (Follett et al., 2000).

The annual and biennial species of Forb 1 (Fig. 4B) are directly associated with cropland tillage (Stewart and Kantrud, 1971, 1972). These species increased in importance as the buffer condition deteriorated. The significant species of Forb 2 were associated with increasing buffer condition and land use away from intense cultivation within the wetland and adjacent non-wetland areas. Forb 2 also was correlated with increasing hydrologic function as well, which is consistent with research comparing cropland versus grassland areas (Gleason and Euliss, 1998). The eleven mostly native species were associated with intact native rangeland and the three weedy species (*Artemisia absinthium* L., *Chenopodium album* L., and *Convolvulus arvensis* L), when found together, were located in introduced or invaded perennial grasslands, or cropland. Forb 3 was correlated with buffer condition and soil properties. The species *Asclepias syriaca* L. was located in introduced or invaded perennial grasslands, when found.

5. Conclusions

The low prairie plant community found adjacent to wetlands plays an important role in wetland functioning given that it is the buffer area referred to in the HGM assessment (Lee et al., 1997). Our modeling of the physical parameters impacting this community indicates the importance to the wetland in maintaining buffer condition and composition, and impacts in the catchment and wetland basins are interrelated with buffer, soil, and hydrologic characteristics. As anthropogenic disturbances such as tillage increase in intensity within the catchment basin, the susceptibility of the low prairie (buffer) community to invasion by undesirable exotic species (e.g. *Bromus inermis* Leyss., *Artemisia absinthium* L., *Convolvulus arvensis* L.) increases. These invasions may be due to a number of factors, such as propagule introductions and increased sedimentation. Our model also indicates that once such an invasion or introduction takes place soil properties such as porosity, soil organic matter, and detritus are affected as well. Appropriate management of the buffer area should be a primary consideration in the PPR because the functions within a wetland are dependent on the low prairie community. Agencies such as the NRCS and land managers should also consider the implications of establishing buffers consisting of solely one species like *Bromus inermis* Leyss. on soil properties, and consider establishing a managed native mixture.

The HGM assessment of the landscape distribution of wetlands (WETDEN, WETAREA, PROXIM; see Table 1) had little relationship to the low prairie community composition. The current HGM assessment method includes landscape measurements such as habitat fragmentation (Gilbert et al., 2006). Other research has indicated landscape characteristics like habitat fragmentation can be related to species composition of wetland plant communities (Galatowitsch et al., 2000; Whited et al., 2000). The redeveloped HGM model includes several other measurements not included in the Lee et al. (1997) model such as sedimentation estimation, soil quality index, and ratio of catchment area to wetland area (Gilbert et al., 2006). Assessment of these improved variables in relation to the low prairie plant community, and all wetland plant communities, should be completed in a similar fashion as they are developed. By doing so, significant physical parameters and insights to proper management of these ecosystems will be identified.

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