A Test of Vegetation-related Indicators of Wetland Quality in the Prairie Pothole Region

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Abstract - This study was part of an effort by the U.S. Environmental Protection Agency to quantitatively assess the environmental quality or "health" of wetland resources on regional and national scales. During a two-year pilot study, we tested selected indicators of wetland quality in the U.S. portion of the prairie pothole region (PPR). We assumed that the amount of cropland versus non-cropland (mostly grassland) in the plots containing these basins was a proxy for their quality. We then tested indicators by their ability to discriminate between wetlands at the extremes of that proxy. Amounts of standing dead vegetation were greater in zones of greater water permanence. Depth of litter was greater in zones of greater water permanence and in zones of basins in poor-quality watersheds. Amounts of unvegetated bottom were greater in basins in poor-quality watersheds; lesser amounts occurred in all wetlands during a wetter year. Greater amounts of open water occurred during a wetter year and in zones of greater water permanence. When unadjusted for areas (ha) of communities, plant taxon richness was higher in wet-meadow and shallow-marsh zones in good-quality watersheds than in similar zones in poor-quality watersheds. Wet-meadow zones in good-quality watersheds had greater numbers of native perennials than those in poor-quality watersheds. This relation held when we eliminated all communities in good-quality watersheds larger than the largest communities in poor-quality watersheds from the data set. We conclude that although amounts of unvegetated bottom and plant taxon richness in wet-meadow zones were useful indicators of wetland quality during our study, the search for additional such indicators should continue. The value of these indicators may change with the notoriously unstable hydrological conditions in the PPR. Most valuable would be indicators that could be photographed or otherwise remotely sensed and would remain relatively stable under various hydrological conditions. An ideal set of indicators could detect the absence of stressors, as well as the presence of structures or functions, of known value to major groups of organisms.

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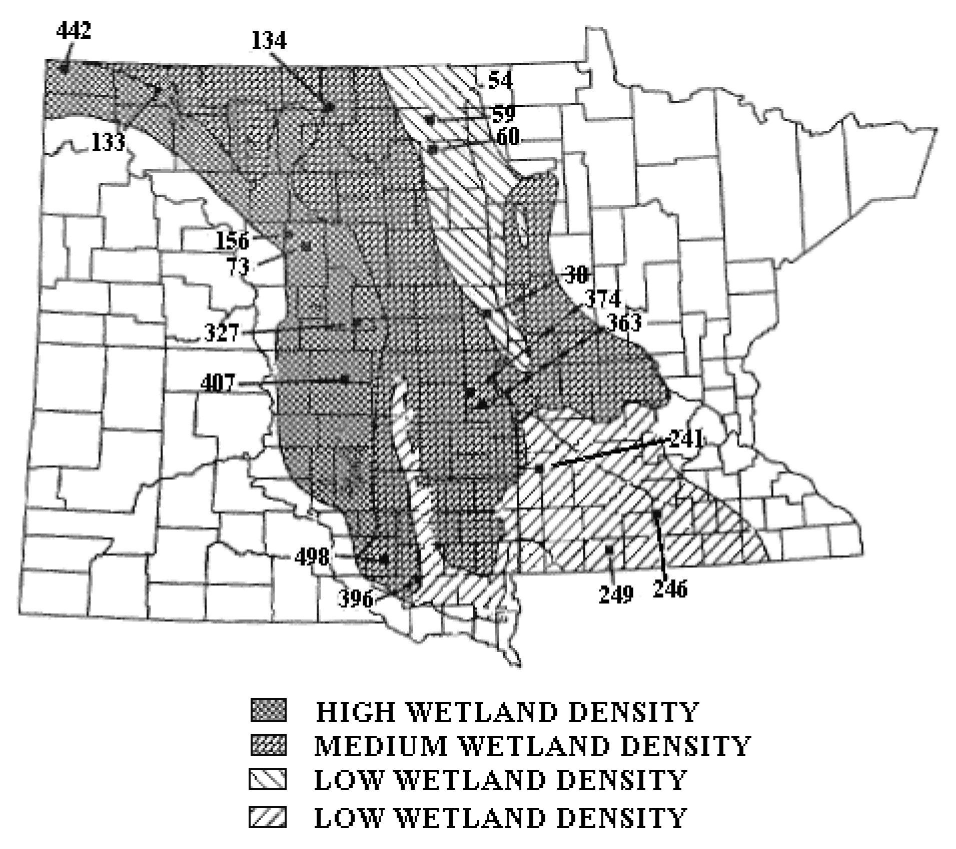
Introduction

In 1989, the U.S. Environmental Protection Agency (EPA) initiated the Environmental Monitoring and Assessment Program (EMAP). Part of the program (EMAP-Wetlands) is intended to provide quantitative assessments of the status and long-term trends in the ecological "health" of wetland resources on both regional and national scales. Short-term goals of EMAP-Wetlands are to develop standardized protocols to measure and describe the environmental quality of wetlands, report estimates of wetland quality in selected regions, and develop formats for reporting program results. Longer-term goals include trend detection and diagnostic analyses to identify plausible causes for degraded or improved wetland quality.

EMAP-Wetlands will implement its program using a phased approach in high-priority regions. The program selected prairie wetlands as a national priority. These wetlands are of high value to waterfowl and other wildlife but suffer losses due to agricultural drainage and flood control projects. These losses are of concern to public and private conservation agencies. In 1992, the EPA and the U.S. Fish and Wildlife Service's Northern Prairie Wildlife Research Center jointly initiated a pilot project designed to test indicators of wetland quality in the PPR. A major objective of the project was to test selected landscape- and field-level indicators of environmental quality of wetlands by discriminating between wetlands in highly disturbed (agricultural) and less disturbed (grassland) landscapes. Wetland quality is difficult to define *a priori*, so the approach was to select study wetlands within these landscapes as a proxy for wetlands within "impaired" and "healthy" landscapes. A panel of individuals with regional experience in wetland research proposed a list of wetland attributes to test. These attributes included those at the landscape level as well as those related to the wetland fauna, vegetation, hydrology, pedology, water and soil chemistry, and anthropogenic and climatic stressors.

Here we report the results of tests dealing with vegetation in wetlands lying in extremely-disturbed and slightly-disturbed landscapes. Extreme disturbance of prairie wetlands is almost entirely attributable to agriculture, where over half the wetland basins can be cultivated, even in a wet year (Stewart & Kantrud, 1973). We tested the indicator value of abundance and species richness of vascular hydrophytes, amounts of standing dead vegetation, litter, open water. and unvegetated bottom. We also tested the area of plant communities and the average water depth in those communities within selected wetland zones.

Selection of Study Areas



We stratified the PPR into four regions based on wetland density. A high-density region approximately coincides with the Missouri Coteau. This is a large belt of glacial moraine generally trending northwest to southeast across the Dakotas and characterized by collapsed hummocky topography or dead-ice moraine (Bluemle, 1977). A medium-density region approximately coincides with the drift plain, an area of glacial drift with less relief than, and lying east of, the Missouri Coteau. We recognized two low-density regions. The first is the Red River Valley of eastern North Dakota and western Minnesota. The Red River Valley is not a valley, but mostly the bed of glacial Lake Agassiz. The second is southern Minnesota, an area physiographically similar to the drift plain region except that most basin wetlands are drained.

We selected wetlands under the assumption that those in cropland-dominated watersheds would be in a more degraded state than those in grassland-dominated watersheds. We then tested indicators by their discriminate between wetlands at the extremes of that proxy. Therefore, we used the ratio of area of cropland to total upland on plots as a proxy for wetland quality. We selected wetlands from an existing large sample (n = 422) of 10.4-km^2 (4 mi^2) plots used for a mallard simulation model (Cowardin et al. 1988). We mapped wetlands on each plot according to the classification Cowardin et al. (1979), and the uplands according to a simplified classification that included grassland and cropland (Cowardin et al., 1988).

We calculated the ratio of area of cropland to total area of upland on each plot. Plots with the largest ratios (maximum amounts of cropland) and smallest ratios (maximum amounts of grassland) represented poor-and good-quality watersheds, respectively. From plots within each of the four regions (Figure 1), we selected four, the two with the largest and the two with the smallest ratios of cropland.

Figure 1. Prairie pothole region of Minnesota and the Dakotas showing strata based on wetland density and location of 10.4-km^2(4mi^2) plots containing study wetlands.

We further constrained plot selection by the rule that each pair of plots must contain at least two temporary, two seasonal, and two semipermanent wetland basins (Stewart & Kantrud,1971). These correspond to palustrine emergent temporarily flooded, palustrine emergent seasonally flooded, and palustrine emergent semipermanently flooded wetlands of Cowardin et al. (1979). These basin wetlands are identified on National Inventory (NWI) maps and are the most common wetlands in the PPR. We maintained separation between landscapes of high and low cropland:upland ratios in all regions except the Red River Valley where there were few available plots and few semipermanent wetlands basins. In that region it was impossible to maintain a meaningful separation, so we dropped the requirement of having semipermanent wetland basins.

We modified the sample because of refusal of access by several landowners. When refusal resulted in inability to obtain two wetland basins of each class in each extreme pair of plots, we selected the next most extreme plot, redrew wetland basins and again contacted landowners. We repeated this procedure using our original constraints until the sample was complete. We further altered the process at the end of the 1992 field season because drought and access denials resulted in almost no data from the low-wetland-density strata. We dropped those strata from the sample and selected two new samples from the high and the medium wetland density strata for study the following year.

We classified wetland basins (Cowardin, 1982) using a modification of Stewart & Kantrud's (1971) classification. We first grouped all wetland polygons (mapping units used by NWI) classified in the data set according to Cowardin et al. (1979) into basins. We then used the polygon with the most permanent water regime to determine the Stewart & Kantrud (1971) class for the group of polygons included in the basin. We assigned a random number to each wetland basin in each wetland class in each region. We prepared a sorted list of these random numbers for the pairs of plots representing good and poor quality. We selected the top two wetlands in each wetland basin class if they met the following constraints: (1) were not mapped as linear or point features (mostly drainage ditches and dugouts constructed for watering livestock), (2) did not contain dugouts or lacustrine wetland (permanently flooded lakes), or (3) were not temporary or seasonal wetlands that overlapped the plot boundary. This procedure biases the selection process against large temporary and seasonal basins but was unavoidable because we could not classify multi-polygon basins outside the plot boundary. We included semipermanent basins that were partly within the plot because we knew the basin class by default. Exclusion of these wetlands would bias the sample against large basins. We also rejected all basins in good-quality plots surrounded by cropland and basins in poor-quality plots surrounded by upland other than cropland.

A few landowners rescinded permission after fieldwork began. In these cases, we gathered remaining data from the nearest available wetland basin of the same class. For purposes of analysis, we redefined watershed quality for some wetlands based on the cropland:upland ratio for the individual basins. This was necessary because of classification errors in the original data used in the selection process and major landscape changes. All plots and basins were in Minnesota, North Dakota, or South Dakota. Further details on the plot and basin selection process are in "Report on pilot test of indicators of wetland condition" (1994; unpublished draft) available from U.S. Environmental Protection Agency, Environmental Research Laboratory, 200 S.W. 35th St., Corvallis, OR 97333.

Methods

Field

We studied 40 basins in 1992 and 36 in 1993. We studied 32 of these basin one of the two years only and 21 in both years. We selected July and the first week of August for field surveys because peak standing crops occur during these months in the north-temperate United States (Bernard, 1974). A soils and sediment research team accompanied us in the field. We visited study basins in a general south-to-north route to help compensate for the approximately two-week difference in phenology between the southernmost and northernmost plots. We used county road maps, NWI maps, and high-level, black-and-white aerial photographs of the 10.4-km^2 plots to locate the study basins in the field.

We delineated wetland zones on low-level, color aerial photographs of each basin taken in mid-June of the same year. Although vegetation usually forms a virtual continuum around prairie wetlands, zonation is usually evident (Johnson et al., 1985). Zones are areas closely related to degree of water permanence and have characteristic assemblages of plants (Steward & Kantrud, 1971). Peripheries of wet-meadow zones were usually considered the boundaries of the study wetlands. In cropland, these boundaries were often difficult to determine and were estimated, based on basin overflow (spill) elevations, soil characteristics, and vegetation. On the low-level photographs, we also delineated plant communities within zones. Plant communities are defined by Westhoff & Van der Maarel (1973) as vegetation in relatively uniform environments with floristic composition and structure relatively homogeneous and distinct from surrounding vegetation. Many zones had a single plant community. In a few instances, drastic water-level increases, cultivation, or rapid crop growth in late June or early July made portions of the low-level photograph obselete. In those cases, we delineated zone and community boundaries using whatever reference points (boulders, haystacks, fencelines) were available.

If a wetland was subject to different land uses, as is often the case where basins are fenced or in multiple ownership, we restricted sampling to communities in the portion of the wetland with predominant land use. Within this area, we further restricted sampling to plant communities occupying at least 10 percent of the area. We numbered all plant communities, noted their land use, and assigned them to wetland zones of Stewart & Kantrud (1971).

We used a modified method of Barker & Fulton (1979) for vegetation sampling. We sampled vegetation along the long axis through the center of each plant community to avoid edge effects. We paced the long axis and threw a marker buoy overhead at each of five roughly equidistant points along the axis. At the point of impact, we centered a 1-m^2 quadrat frame (Figure 1).

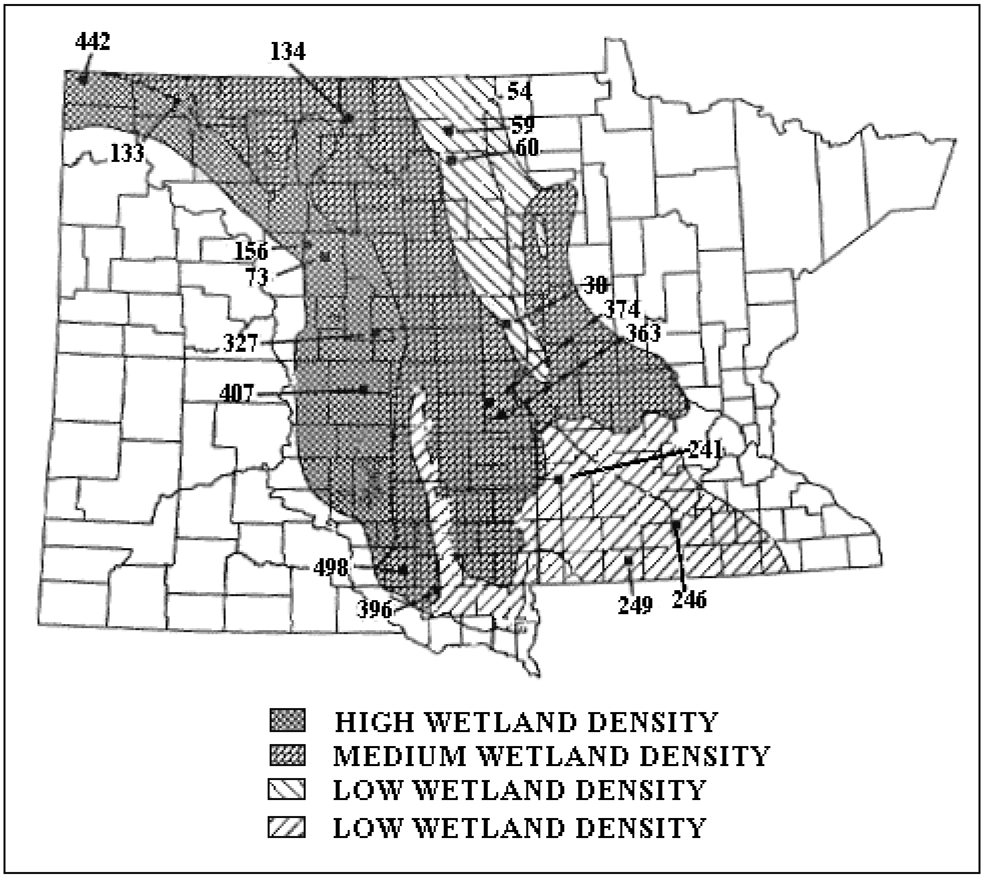


Figure 1. Prairie pothole region of Minnesota and the Dakotas showing strata based on wetland density and location of 10.4-km^2($4mi^2$) plots containing study wetlands.

We assigned a Daubenmire (1959) cover class to each macrophyte taxon in the quadrat, but here we report only information on species richness. We noted plant taxa not encountered in the quadrats while walking between quadrats. Total taxa recorded inside and outside the quadrats were summed to provide a measure of taxon richness for each community.

We identified nearly all plants to species, but identified a few only to genus or family. We were unable to identify four plants. We classified all pteridophytes and spermatophytes as to life history (annual or biennial, perennial, native, or introduced) from standard floras. After we completed the plant sampling, the soils and sediment researchers cored the bottom substrate at the center of each quadrat with a hand auger and measured litter depth to the nearest cm. The fresh litter cores were recognizable as undecomposed or partially decomposed fallen vegetation. We considered the bottom of the litter layer the point where decomposing material changed from fibric (peat) to hemic (muck) or where plant remains became unrecognizable as such when observed through a 10 x hand lens. We measured water depth to the nearest cm at the centers of quadrats and marked their locations on the field photographs. Within each quadrat, we also estimated the percentages of unvegetated bottom, open water, and percentage of standing dead vegetation.

Analytical

At the end of each field season, we scanned and georeferenced the low-level aerial photos of each basin with a map and image processing system (Skrdla, 1992) to determine areas of the sampled plant communities. On each image, we classified all polygons within the basin as to wetland zone and community and marked the locations of quadrats. We also classified artificial wetland types within the basins (e.g., excavated dugouts for livestock watering) and uplands within the basins (e.g., spoils or rockpiles). Data were averaged across the five quadrats within each community prior to analysis.

We used analysis of variance (ANOVA) techniques to assess the effects of watershed quality and year on total zone area. Because approximately half of the sample wetland basins were measured in both 1992 and 1993, the design was a repeated measures with year serving as the repeated-measures factor. ANOVAs were done separately for each of the five zones: low-prairie, wet-meadow, shallow-marsh, deep-marsh, and fen.

We also used ANOVA techniques to assess the effects of watershed quality, zone, and year on all response variables measured at communities within zones (Table 1).

Table 1. Response variables

A. Variable measured at zone within wetland basin:
    1. Area of zone (ha)
B. Variable measured at quadrats within communities within zones (all analyses were done by first averaging across quadrats):
    1. Water depth (cm)
    2. Percent standing dead vegetation
    3. Length (cm) of litter core
    4. Percent unvegetated (bare) bottom
    5. Percent open water
    6. Percent vegetation
C. Variables measured at communities within zones:
    1. Area of community (ha)
    2. Total plant species
    3. Total perennial introduced plant species
    4. Total perennial native plant species
    5. Total annual introduced plant species
    6. Total annual native plant species

The sampling design was a split-plot with repeated measures. Each basin was assumed to be the independent whole-unit, with zone and community combination being the sub-unit (see Figure 2).

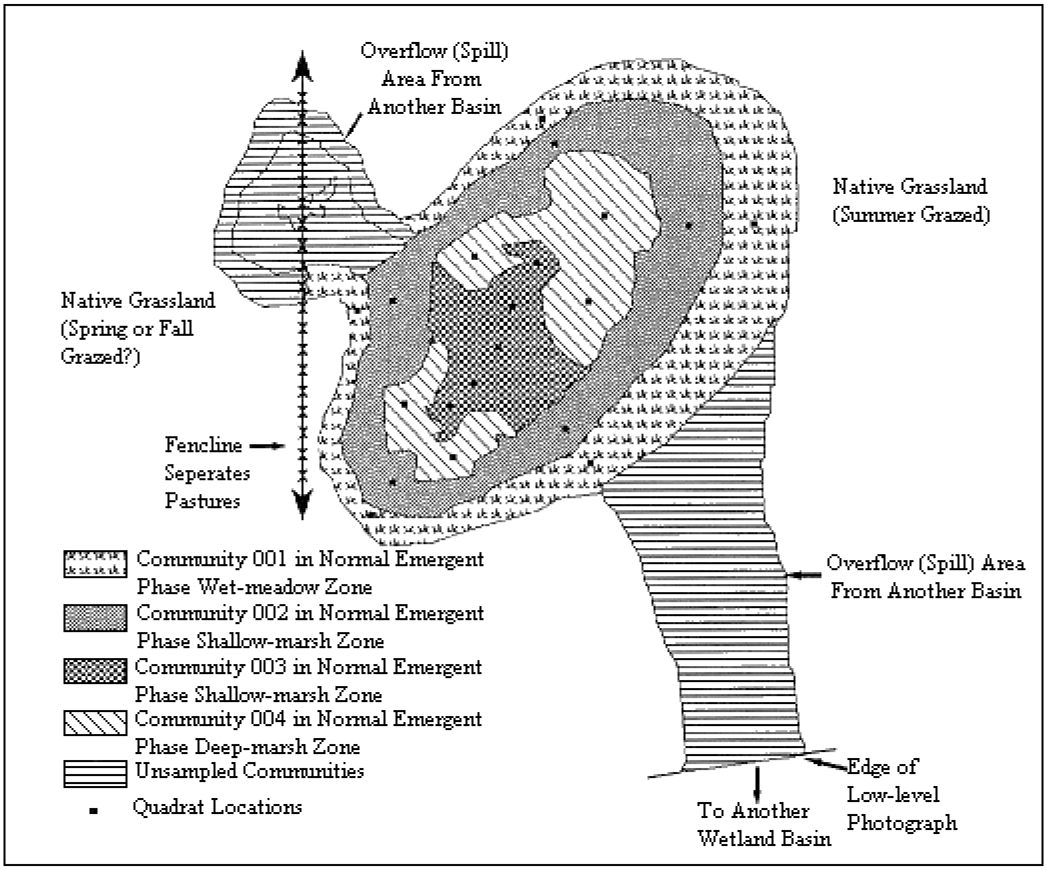


Figure 2. Study wetland showing sampled and unsampled hydrophyte communities, location of quadrats, and land-use of uplands.

The fen and low-prairie areas were combined with wet-meadows. Because approximately half of the sample wetland basins were measured in both 1992 and 1993, year served as the repeated-measures factor. However, because of the highly unbalanced design structure (Table 2), the three-way interaction effect and least-squares means of wetland quality by zone by year were not fully estimable for the repeated-measures design. Therefore, we randomly deleted one year's data on basins that were used in both 1992 and 1993 (Table 2 footnote). This allowed basin to become "nested" within year and wetland quality and thus made the three-way interaction testable, albeit with slightly less power, and all least-squares means estimable. This procedure eliminated the need to consider the repeated-measures aspect as part of the analysis. We report the least-squares means from this "balancing" approach as all combinations among year, water quality, and zone. Multiple passes were made through the data with a different random selection each pass. In all passes, ANOVAs yielded similar conclusions. We used Fisher's protected least significant difference (LSD) to isolate differences in least-squares means following significant effects in the ANOVAs (Milliken & Johnson, 1984) where applicable. We considered $\propto = 0.05$ to be significant.

Table 2. Sampling design lay-out. Single (X or x) or multiple communities (number) were sampled within deep-marsh (DM), shallow-marsh (SM), or wet meadow (WM) zones in basins in good- and poor-quality watersheds, 1992-1993

Identification number	**1992**	**1993**

Plot	Basin	DM	SM	WM	DM	SM	WM
Good-quality watersheds							
73	29	X	X	X	x	x	x[a]
374	100	x	x	x	X	X	X
374	225	X	X	X	x	2	x
442	301	x	x	x	X	X	X
156	22		X	X		x	x
363	22	x		x	X		X
363	58		X	X		x	x
442	93		x	x		X	X
442	295		X	X	x	x	x
73	86			X			x
156	24			x			X
156	26			X			x
156	42			x			X
374	272						
		2			2		
374	65			x			X
60	58		X	X			
60	128			X			
249	50		X	X			
249	86		X	X			
59	111		X	X			
396	106			X			
396	107			X			
396	130		X	X			
407	67						X
407	109						X
498	146				X	X	X
498	227						
498	277				X	X	X
133	386					X	X
407	168				X	X	X
Total communities		5	13	24	9	13	23
Grand Total							87
Poor-quality watersheds							

134	140		2			X	X
134	165		X			x	x
134	270			X			x
134	406		x	x	X	X	X
134	432			X			x
442	260			x			X
442	261			X			x
442	281		x	x		X	X
38	62			X			
54	39			X			
59	42	X	X	2			
134	272			X			
241	3	X	X	2			
241	48			2			
246	34			X			
246	37			X			
246	53		X	X			
133	370						2
133	380					X	X
134	158						X
327	72					X	X
327	117					X	2
327	147					X	X
Total communities		3	8	17	1	8	16
Grand Total							53

[a] Data from communities designated by lower case x's and underlined numbers were not used in ANOVAs or for estimating least-squares means for response variables measured at community level (see methods).

Footnote:

Effects	**Type**	**No. levels**	**Levels**
Basin quality	Fixed	2	Good, poor
Wetland zone	Fixed	3	Deep-marsh,
			shallow-marsh, wet-meadow
			(includes fen and

			low prairie)
Year of study	Fixed	2	1992,1993
Wetland basin	Random	-	-
Community[a]	Random	-	-

[a] Community by zone was considered the sampling unit and randomness assumed.

All ANOVAs were conducted using the general linear model procedure (PROC GLM) of SAS (SAS 1989). Least-squares means (SAS 1989) were computed and reported when adequate data were available for ANOVAs. Otherwise, arithmetic means are reported. Effects considered fixed and random are listed in Table 2 footnote. For most of the response variables, we conducted the ANOVAs both in the original unit of measurement and using a ln(Y+ 1) transformation (Steel & Torrie, 1980). However, we do not report the results of the transformation because ANOVA results were similar for both transformed and untransformed data; this indicates no gross departures from ANOVA assumptions for untransformed data (see Conover (1980):337). Least-squares means in tables are at the highest-order interaction for reporting purposes, with standard errors based on ANOVA mean-squared error terms.

Results

Total zone area (low-prairie and fen separated from wet-meadow)

There were no significant differences between watershed qualities for total area (ha) of low-prairie (F1,51 = 1.20, p = 0.278), wet-meadow zone (F1,51 = 1.79, p = 0.187), shallow-marsh zone (F1, 51 = 2.00,p = 0.163), deep-marsh zone (F1,51 = 1.25 p = 0.268). and fen zone (F1, 51 = 0.65, p = 0.422).

Communities

Number and area

Basins in poor-quality watersheds tended to have slightly fewer communities per basin (Table 3).

Table 3. Numbers of surveyed wetland plant communities among basin classes in good- and poor-quality watersheds and mean numbers of communities per basin, 1992-1993

Watershed quality basin class[a]	**1992**		**1993**		**Mean no. communities[b] per basin**
	Basins	**Communities**	**Basins**	**Communities**	
Good					
Temporary	8	13	6	7	1.4
Seasonal	7	13	6	12	1.9
Semipermanent	6	15	6	18	2.8
Poor					
Temporary	7	7	6	8	1.2
Seasonal	6	10	6	12	1.8
Semipermanent	6	14	6	15	2.4
Total	40	72	36	72	

Of the communities, 80 (57%) were in wet-meadow zones, 42 (30%) in shallow-marsh zones, and 18 (13%) in deep-marsh zones (Table 4).

There were no significant effects of year, watershed quality, or zone on mean area of communities (ANOVA: all p > 0.11). Total area of the 140 analyzed plant communities was 176 ha, including 91 percent (160 ha) in good-quality watersheds and 9 percent (16 ha) in poor-quality watersheds.

Water depth

Water depth varied with year and zone (F2,36 = 4.44, p = 0.019; Table 5), but there were no significant watershed quality effects. Increased precipitation resulted in higher water depths in 1993 (F1,49 = 6.49, p = 0.014). Depths were higher in zones of greater water permanence (F2,36 = 20.54,p = 0.001).

Standing dead vegetation

Percent of standing dead vegetation did not vary by year or watershed quality (F1,49 = 0.35, p = 0.555; Table 5). However, greater amounts of standing dead vegetation were found in zones of greater water permanence (F2,36 = 6.78,p = 0.001).

Table 4. Number and least-squares means(+ or - SE) of community areas among Stewart and Kantrud(1971) wetland zones in good- and poor-quality watersheds, 1992-1993

Watershed quality Zone	**1992**		**1993**	
	n[a]	**Mean area(ha)**	**n**	**Mean area(ha)**
Good				
Wet-meadow	24	0.74 (0.54)	23	2.84 (0.59)
Shallow-marsh	13	0.59 (0.81)	13	2.20 (0.99)
Deep-marsh	5	0.60 (1.88)	9	3.48 (1.08)
Total	42		45	
Poor				
Wet-meadow	17	0.40 (0.66)	16	0.08 (0.66)
Shallow-marsh	8	0.28 (1.55)	8	0.42 (0.93)
Deep-marsh	3	0.02 (1.63)	1	0.37 (2.65)
Total	28		25	
Grand Total	70		70	

[a] n=Number of communities; least-squares means are based on fewer (see Table 2). [a] Wetland basins classified according to original sample draw.
[b] Averaged across zones.

Litter
Depth (cm) of litter varied with watershed quality, zone, and year ($F_{2,36} = 4.70, p = 0.015$). Depth of litter was higher in zones of greater water permanence and in zones in poor-quality watersheds (Table 5). Effects of watershed quality alone were non-significant.

Unvegetated bottom
Percent unvegetated bottom varied with year ($F_{1, 49} = 4.53$, $p = 0.038$) and quality ($F_{1,49} = 10.03$, $p = 0.003$; Table 6). Greater amounts of unvegetated bottom were found in sample wetland basins in poor-quality watersheds and lesser amounts occurred in all wetlands during the wetter year of 1993.

Open water
Greater amounts of open water occurred during the wetter year of 1993 ($F_{1,49} = 5.12$, $p = 0.028$; Table 6), and in zones of greater water permanence ($F_{2,36}= 6.06$, $p = 0.0328$), but effects of watershed quality alone were non-significant.

Table 5. Least-square means(+ or - SE) water depth, percent standing vegetation, and litter depth of plant communities[a] of wet-meadow, shallow-marsh, and deep-marsh zones in wetlands in good- and poor-quality watersheds, 1992-1993

Watershed quality Zone	**Water-depth(cm) Year**		**Standing dead vegetation(%) Year**		**Litter depth(cm) Year**	
	1992	**1993**	**1992**	**1993**	**1992**	**1993**
Good						
Wet-meadow	2.2 (2.8)	3.6 (3.0)	6.6 (1.1)	2.0 (1.2)	0.3 (0.3)	0.2 (0.4)
Shallow-marsh	7.9 (4.2)	23.4 (5.1)	8.0 (1.6)	3.1 (2.0)	0.2 (0.5)	1.7 (0.6)
Deep-marsh	26.3 (9.8)	44.4 (5.6)	17.0 (3.7)	10.5 (2.1)	0.0 (1.2)	1.3 (0.7)
Poor						
Wet-meadow	0.4 (3.4)	8.1 (3.4)	2.1 (1.3)	1.5 (1.3)	1.0 (0.4)	0.0 (0.4)
Shallow-marsh	2.9 (8.0)	37.0 (4.8)	0.1 (3.0)	0.6 (1.9)	2.7 (1.0)	0.0 (0.6)
Deep-marsh	28.7 (8.4)	38.8 (13.6)	8.0 (3.2)	3.8 (5.2)	6.7 (1.0)	0.0 (1.7)

Table 6. Least-square means(+ or - SE) of percent unvegetated bottom and percent open water in plant communities[a] of wet-meadow, shallow-marsh, and deep-marsh zones in wetlands in good-and-poor-quality watersheds, 1992-1993

Watershed quality Zone	**Unvegetated bottom(%)Year**		**Open water(%)Year**	
	1992	**1993**	**1992**	**1993**
Good				
Wet-meadow	2.0 (2.4)	0.9 (2.6)	4.3 (3.6)	3.2 (3.9)
Shallow-marsh	10.9 (3.5)	1.0 (4.3)	8.3 (5.4)	35.6 (6.5)
Deep-marsh	12.4 (8.3)	0.5 (4.7)	1.7 (12.5)	34.6 (7.1)
Poor				
Wet-meadow	46.5 (2.8)	15.2 (2.8)	0.6 (4.3)	18.4 (4.3)
Shallow-marsh	-[b]	19.4 (4.0)	2.8 (10.2)	36.5 (6.1)
Deep-marsh	-	17.3 (11.6)	9.1 (10.7)	40.4 (17.5)

[a] Sample sizes for communities as in Table 4; least-squares means are based on fewer(see Table 2).
[b] Least-square means were poorly estimated for poor quality shallow-and deep-marsh zones in 1992; observed means are 43.7, 0.0, and 0.0 for wet-meadow, shallow-marsh, and deep-marsh zones, respectively.

Plant species richness

We recorded 298 plant "taxa" during the study. These were 217 wetland pteridophytes and spermatophytes (73%) listed for the northern plains (Reed 1988) and 50 upland spermatophytes (17%) listed in the National List of Scientific Plant Names (U.S.D.A. 1982). Also included were 31 (10%) other "taxa" formulated for the study. These were certain non-vascular plants including the macroalgae *Chara* spp., two liverworts (*Riccia fluitans* and *Ricciocarpus natans*), and the aquatic moss *Drepanocladus* spp. Also included were unidentified plants (e.g., Gramineae unidentified) seen only in early growth stages. A list of plants recorded on the study areas is available from the authors.

Total taxa recorded was higher in all zones of basins in good-quality watersheds (Table 7). Ratios of total taxa recorded in good- versus poor-quality watersheds varied from a low of about 1.6:1 in wet-meadow zones to a high of about 3.4:1 in deep-marsh zones. When unadjusted for community size, taxon richness varied by zone ($F_{2,36} = 17.35$, $p = 0.0001$) and watershed quality ($F_{2,49} = 3.94$, $p = 0.053$), with richness higher in wet-meadow zones and shallow-marsh zones in good quality than in similar zones of poor-quality. As a partial test of the effects of community size, we eliminated from the data set 17 communities in good-quality watersheds larger than the largest communities in poor-quality watersheds (1.43 ha). Effects of zone remained significant ($F_{2,28} = 15.09$,$p = 0.0001$), whereas effects of watershed quality were not significant ($F_{1,46} = 2.59$, $p = 0.114$). The only significant correlation between taxon richness and community size was for communities of deep-marsh zone within good-quality watersheds ($r = 0.77$, $P = 0.0013$).

Table 7. Total plant taxa and least-squares means(+ or - SE) taxon richness for communities in wet-meadow, shallow-marsh, and deep-marsh zones in wetlands in good- and poor-quality watersheds, 1992-1993[a]

1992						
	Good-quality			**Poor-quality**		
Zone	**n[b]**	**No.taxa**	**Mean taxon richness**	**n**	**No. taxa**	**Mean taxon richness**
Wet-meadow	24	173	23.8 (1.7)	17	104	11.1 (2.0)
Shallow-marsh	13	90	12.0 (2.5)	8	47	1.7 (4.8)
Deep-marsh	5	31	2.4 (5.9)	3	15	0.0 (5.1)
Total communities	42			28		
1993						
	Good-quality			**Poor-quality**		
Zone	**n[b]**	**No. taxa**	**Mean taxon richness**	**n**	**No. taxa**	**Mean taxon richness**
Wet-meadow	23	166	25.4 (1.8)	16	89	14.8 (2.0)
Shallow-marsh	13	74	12.8 (3.1)	8	49	8.2 (2.8)
Deep-marsh	9	47	7.4 (3.4)	1	8	9.5 (8.3)
Total communities	45			25		

[a] Means unadjusted for community area. Some taxa common to more than one zone.
[b] n=Number of communities; least-squares means are based on fewer (see Table 2).

Plant types

Perennial native plants dominated all zones of basins in good-and poor-quality watersheds (Table 8). We found greatest numbers of these plants (116 taxa) in wet-meadow zones of basins in good-quality watersheds during the wetter year of 1993. We observed smallest numbers (7 taxa) that year in deep-marsh zones of basins in poor-quality watersheds. Mean number of native perennials varied by zone and watershed quality (F2 36 = 2.79, p = 0.075). Wet-meadow zones in good-quality watersheds had greater numbers of native perennials than those in poor-quality watersheds. This relation also held when we eliminated 17 communities in good-quality watersheds larger than the largest communities in poor-quality watersheds from the data set (F2,28 = 2.76, p = 0.081). Ratios of native perennials to introduced perennials varied by watershed quality and zone when adjusted as above for community size (F2 28 = 3.37, p = 0.049). With this adjustment, the ratio of native perennials to introduced perennials was marginally greater in good-quality watersheds than in poor-quality watersheds for wet-meadow zones only. We found greater numbers of introduced perennials in basins in good-quality watersheds. Ratios of native annuals to introduced annuals, when adjusted for community size, did not vary by zone or watershed quality.

Discussion

Wetland "health" or quality remains unquantifiable and there are no standards against which the degree of degradation of a wetland can be tested. The wetlands we studied, typical of all basin wetlands in the PPR, are inherently unstable ecosystems. Water supplies are variable, unpredictable, and often from sources with no hydrologic connection to the basins. Our findings suggest that stresses from agriculture add to this instability. These stresses may be direct or internal, as when farmers use the basins to raise crops, or indirect or external through siltation and chemical run-off from the watersheds. Perturbations such as tillage, seeding, fertilizing, and chemical spraying are common; farmers have used many wetland watersheds in the PPR for cropland almost continuously since the late 1800s.

Table 8. Total numbers of perennial, introduced, and annual (includes biennial) or native plant taxa in communities in wet-meadow, shallow-marsh, and deep-marsh zones of sample wetland basins in good-and-poor quality watersheds, 1992-1993

	Total number of plant taxa			
	1992		**1993**	
Zone	**Watershed quality**		**Watershed quality**	
Plant type	**Good**	**Poor**	**Good**	**Poor**
Wet-meadow				
Perennial-Native	109	59	116	43
Perennial-Introduced	17	10	16	11
Annual-Native	22	19	14	19
Annual-Introduced	12	8	8	9
Life history unknown	13	8	9	7
Shallow-marsh				
Perennial-Native	45	28	48	29
Perennial-Introduced	9	5	7	5
Annual-Native	24	9	11	10
Annual-Introduced	6	2	3	3
Life history unknown	6	3	5	1
Deep-marsh				
Perennial-Native	16	11	29	7
Perennial-Introduced	2	2	5	0
Annual-Native	8	0	3	1
Annual-Introduced	0	0	1	0
Life history unknown	5	2	9	0

The initial direct disturbance to a wetland by repeated cultivation for seedbed preparation is severe. Cultivation probably affects all stages in the plant regeneration cycle, an important mechanism in the maintenance of plant species diversity (Grubb, 1977). Plowing severs rhizomes of the native perennial hydrophytes and overturns and dries the sod; repeated discing and harrowing may follow for a year or more before planting. These operations totally eliminate most of these plants. After this stage, farmers regularly cultivate entire basins of lesser water permanence for crop production or to control weeds whenever water levels permit. Farmers also regularly cultivate the wet-meadow and shallow-marsh zones of basins of greater water permanence. Indeed, during this study, over 77 percent of the area of all wet-meadow zones in poor-quality watersheds had been cultivated recently. These cultivation stresses are thus in a sense predictable and do not allow the original native plant community to re-establish itself. However, some plants are adapted to repeated disturbances of bottom substrates; such disturbances may eliminate competitive dominants, thereby allowing subordinates to occupy the disturbed sites (Wilson & Keddy, 1986). In frequently cultivated wetlands in the PPR, these subordinates consist of a few rapidly maturing annuals (e.g., *Gratiola neglecta*) and relatively short, deep-rooted perennials (e.g., *Polygonum amphibium*).

Besides direct tillage, additional stressors common to plant communities in frequently cultivated wetlands are inputs of silt, pesticides, and fertilizers. Silt comes from adjacent uplands, but wetlands often receive direct inputs of pesticides and fertilizers. It is generally unknown whether these stressors have antagonistic, synergistic, or additive effects (sensu Turner, 1985) on the structure and function of these communities. However, fertilizers normally increase productivity and decrease species richness in most wetland plant communities studied (Vermeer & Berendse, 1983). Herbicides commonly used on row crops in the region seem to greatly decrease both production and species richness of hydrophytes.

Farmers often leave wetlands of greater water permanence idle because potential crop yields are poor due to high salinities or sandy bottom substrates, or because of the potential for miring or damaging equipment on large boulders. Nevertheless, these basins also accumulate agricultural nutrients, and many have large amounts of standing dead vegetation. Deposits of silt from the adjacent cropped uplands sometimes accumulate in the peripheral zones to form a barrier or build mud deltas in interior zones. We noted silt accumulations that virtually eliminated the wet-meadow zone of several study wetlands.

Idle conditions cause many changes to the wetland biota. Woody plants, particularly *Salix* spp. and *Populus* spp., invade idle prairie wetlands, especially where earlier cultivation disturbs wet-meadow zones. Idle coastal marshes show decreased plant species richness and numbers of vegetation types present; vegetation mosaics there tend to be coarse-grained (Bakker, 1985, Andresen et al., 1990). Idleness also allows formation of monotypic stands of robust emergents that shade out shorter plants and reduce avian diversity and abundance (Jones & Lehman, 1987; Hellings & Gallagher, 1992). For some plants, such shading can be more important than the effects of herbivory and competition on seedling establishment (Bergelson, 1990). Buildup of litter and organic material from emergent species in prairie wetlands can reduce water depth or eliminate shallow-water areas (Ward, 1942, 1968; Walker, 1959; Hammond, 1961).

Native plants in the region are adapted to hydrologic changes, fire, and mammalian herbivory. In pre-agricultural times, these natural forces probably created some sort of normal, but unknown, homeostatic behavior of the grassland ecosystem. Livestock grazing is currently the dominant land-use practice in grassland-dominated watersheds in the region, although haying is also common. The most common sources of livestock water in regional pastures are natural basin wetlands. Nevertheless, ranchers construct many livestock-watering facilities, some in natural basin wetlands. Prairie wetlands are basically wet grasslands. Lack of grazing in grasslands is now abnormal; under such situations obligate grazophiles can disappear (McNaughton, 1979, 1986). Ratios of standing crop to litter can fall as plant communities age without grazing (Bazely & Jeffries, 1986). Conversely, livestock grazing, particularly in spring and fall, maintains species richness in meadow grasslands (Smith & Rushton, 1994). Grazing in long-idled salt marshes slowly enhances species diversity and creates fine-grained vegetation mosaics (Bakker, 1985). Grazing by cattle of monodominant stands of Typha Xglauca Godr. decreases live stems, dead stems, and litter (Schultz, 1987). Grazing thus may remove much organic matter and create open water areas where submersed plants flourish. Although we did not analyze the effects of grazing, most of the basins we studied in good-quality watersheds were grazed by cattle. Such basins generally had higher plant species diversity. There is a threshold to tolerance for grazing, however, even in prairie wetlands, because long-term overgrazing and trampling can reduce the shallower zones to nearly bare soil.

Although an average of less than four percent of the area of wet-meadow zones we studied was currently mowed, mowing and removing emergent vegetation (haying) for livestock feed or bedding is a common practice in the PPR. Most mowing occurs in watersheds that farmers seed to perennial forage crops such as alfalfa or mixtures of alfalfa and grasses. However, farmers also often use larger wetlands in annually tilled watersheds for hay production. Livestock producers consider some native species, such as Scolochloa festucacea, excellent forage. They sometimes seed introduced species, such as Phalaris arundinacea, in wetland basins. Forage production depends on wet land zone and water levels before and during harvest. Producers mow many wet-meadow zones nearly every year, whereas they can cut hay (sometimes only used for bedding) from deep-marsh zones only after a series of dry years. Most observers agree that long-term use of basins for hay tends to increase the abundance of certain emergents (Smeins, 1967; Walker & Coupland, 1968,1970; Stewart & Kantrud, 1972).

Cultivation of various emergent wet-meadow and shallow-marsh communities during dry years seems to create coarse-grained vegetation mosaics with fewer communities. Farmers regularly convert old annular stands of weedy annuals, drawdown species, or early successional vegetation to crop or fallow monotypes. Although not statistically significant, communities we studied in good-quality watersheds tended to be larger. This probably reflects the greater use for pastures, rather than cropland, of tracts containing larger wetlands. Landowners also used some larger wetlands in poor-quality watersheds for hay or pasture. If farmers do not cultivate wet-meadow zones and if siltation is not severe, these wetlands appear similar to those in good-quality watersheds. However, farmers cultivate nearly all basins in poor-quality watersheds for crop production or weed control whenever bottom substrates are dry.

Greater percentages of standing dead vegetation in the deeper, more permanent zones likely reflect reduced accessibility of these zones to livestock and farm equipment. We expected much greater amounts of dead vegetation and increased litter depth in deep-marsh zones in poor-quality watersheds because of siltation and lack of grazing, cultivation, or other mechanisms that reduce plant biomass. However, sample sizes for deep-marsh zones were too small (n = 3 and n = 1 for 1992 and 1993, respectively) to detect differences. Agricultural and pastoral operations tended to reduce standing dead vegetation in the less-permanent zones of both watershed types. Livestock grazing pressure in these zones in basins in good-quality watersheds probably was insufficient to greatly reduce standing dead vegetation.

As with standing dead vegetation, litter core lengths were naturally greater in zones of greater water permanence, likely because of reduced accessibility to machinery and livestock. Another factor could be greater biomass production because the more-permanent zones usually support taller, more robust plant species. Nevertheless, the presence of surface water limits access by machinery more than cattle. Thus, litter depth among zones varied significantly only in basins in poor-quality watersheds because these basins were usually ungrazed. There were no significant effects due to watershed quality alone. The irregular destruction of litter by machinery in basins in poor-quality watersheds likely was not much greater than that caused by the often season-long livestock hoof action and herbivory that compress or reduce the litter layer in grazed basins. A single pass by tillage equipment often tears narrow openings in vegetation and can leave much of the litter layer intact. Also, basins in poor-quality watersheds often receive inputs of fertilizer from their adjacent cropped uplands that could increase plant biomass in areas where root systems are not directly destroyed by tillage.

The greater percentages of unvegetated bottom found in wet-meadow zones of wetlands in poor-quality watersheds undoubtedly reflect the effects of cultivation. Communities in these watersheds tended to have large amounts of unvegetated bottom regardless of water levels. Herbicides can further reduce plant populations in cultivated wetlands. Farmers use herbicides directly on cropped wetlands but also sometimes treat non-cropped wetlands to prevent introduced perennial grasses with hydrophytic tendencies, such as *Agropyron repens*, from spreading to the uplands. Livestock grazing, except when extremely intense such as in heavily trampled barnyards or feedlots, seldom creates unvegetated bottoms.

Percentage open water naturally increased in all zones as water levels rose after the drought of 1992 and preceding years. The expectation that basins in good-quality watersheds would have greater amounts of open water held for all zones during the relatively dry year of 1992. But in the following relatively wet year, the differences were less obvious, particularly in zones of lesser water permanence. Wet-meadow zones in basins in poor-quality watersheds had more open water than basins in good-quality watersheds in 1993. We attribute this to the flooding of bare tilled soils created by cultivation.

In summary, in poor-quality watersheds, the hydrology of prairie wetlands combines with a variety of agricultural practices to create unnatural, coarse-grained patterns in wetland vegetation or basins devoid of vegetation. Open water or unvegetated areas can lie adjacent to areas with greater amounts of litter than are found where grazing is the predominant land use.

Plant species richness was lower in wet-meadow zones in basins in poor-quality watersheds. We generally found more annuals, both native and introduced, during the drier year. This likely reflects the increased occurrence of drawdown species that pioneer on bare mud flats and upland species that invade wetlands during drought. An obvious pattern in tilled wetlands is the replacement of native perennials with cultivated crop plants. However, tillage also creates favorable conditions for introduced perennials as well as native and introduced annuals, of which many are classified as noxious weeds. These are usually the target of additional tillage operations in and around the basins. Herbicides applied to crops growing in the basins may further reduce species richness. Special herbicides may kill nearly all vegetation ("chemical fallow") in uplands and wetlands scheduled for summerfallow.

We conclude that amounts of unvegetated bottom and plant species richness successfully discriminated between wetlands in good- and poor-quality watersheds. Intensively tilled prairie wetlands with large amounts of unvegetated bottom show poor use by aquatic or marsh birds. For example, in the 1960s, these wetlands comprised about one-fourth of the total area of basin wetlands in the North Dakota portion of the PPR. During this period, only 4.4 percent of the ducks (Kantrud & Stewart, 1977) and less than 0.5 percent of the other birds (Kantrud & Stewart, 1984) were observed on these basins. Nevertheless, there is a need for additional indicators of the general quality of prairie wetlands. Most valuable would be indicators that could be photographed or otherwise remotely sensed. A ideal set of indicators could detect the absence of stressors, as well as the presence of structures or functions, of known value to major groups of organisms. We recommend that more data from a larger, random sample of wetlands, rather than from wetlands in the extremely good- and poor-quality watersheds we studied, be collected during the operational phase of EMAP. Such efforts, if successful, should allow the construction of empirical models that will use explanatory variables measured on the uplands, such as ratios of major land use practices within the wetland watersheds, to predict indicators of wetland quality in those wetlands.

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