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Ecosystem Services Derived from Wetland Conservation Practices in the United States Prairie Pothole Region with an Emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs

Professional Paper 1745

U.S. Department of the Interior
U.S. Geological Survey

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Edited by Robert A. Gleason, Murray K. Laubhan, and Ned H. Euliss, Jr.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.123	hectare meter (ha-m)
acre-foot per acre (acre-ft·acre^{-1})	0.3048	hectare meter per hectare (ha-m·ha^{-1})
	Mass	
pound (lb)	454	gram (g)
pound (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per acre (ton·acre^{-1})	2.24	megagram per hectare (Mg·ha^{-1})

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
hectare meter (ha-m)	8.107	acre-foot (acre-ft)
hectare meter per hectare (ha-m·ha^{-1})	3.281	acre-foot per acre (acre-ft·acre^{-1})
	Mass	
gram (g)	0.0022	pound (lb)
kilogram (kg)	2.205	pound (lb)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram per hectare (Mg·ha^{-1})	0.446	ton per acre (ton·acre^{-1})

List of Abbreviations

CEAP	Conservation Effects Assessment Project
CRP	Conservation Reserve Program
DOI	United States Department of the Interior
FQI	Floristic Quality Index
FSA	Farm Service Agency
MLRA	Major Land Resource Area
NLCD	National Land Cover Data
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NWI	National Wetlands Inventory
RUSLE	Revised Universal Soil Loss Equation
SOC	Soil Organic Carbon
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VOC	Vegetation Organic Carbon
WRP	Wetlands Reserve Program

Executive Summary–Ecosystem Services Derived From Wetland Conservation Practices in the United States Prairie Pothole Region with an Emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs

Edited by Robert A. Gleason, Murray K. Laubhan, and Ned H. Euliss, Jr.

Implementation of the U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) has resulted in the restoration of approximately 2,200,000 ha (5,436,200 acres) of wetland and grassland habitats in the Prairie Pothole Region. These restored habitats are known to provide various ecosystem services; however, little work has been conducted to quantify and verify benefits on program lands (lands enrolled in the CRP and WRP) in agriculturally dominated landscapes of the Prairie Pothole Region. To address this need, the U.S. Geological Survey (USGS), in collaboration with the USDA Farm Service Agency and Natural Resources Conservation Service, initiated a study to develop and apply approaches to quantify changes in ecosystem services resulting from wetland restoration activities funded by the USDA. To accomplish this goal, the USGS conducted a comprehensive, stratified survey of 204 catchments (wetland and surrounding uplands contributing runoff to the wetland) in 1997 and 270 catchments in 2004 to gather data necessary for estimating various ecosystem services. In 1997 and 2004, the surveys included catchments with seasonal and semipermanent wetlands that were restored as part of USDA conservation programs, as well as nonprogram catchments in native prairie. Additionally, in 2004 data collection was expanded to include temporary wetlands for all treatments and nonprogram cropped catchments for all wetland classes: temporary, seasonal, and semipermanent. A key element in the sample design is that catchments span an alteration gradient ranging from highly altered, such as cropland, to minimally altered, such as native prairie. Therefore, we evaluated restoration programs by comparing changes in program (restored) catchments to nonprogram (cropland and native prairie) catchments. Information collected during both surveys included easily measured soil, vegetation, and morphological variables that were used to estimate the following ecosystem services: plant community quality and richness, carbon sequestration, floodwater storage, sediment and nutrient reduction, and potential wildlife habitat suitability. In this report, we evaluate the extent that these ecosystem services changed in restored wetlands relative to cropland and native prairie baselines. In most cases, our results indicate restoration activities funded by the USDA have positively influenced ecosystem services in comparison to a cropped wetland baseline; however, most benefits were only considered at a site-specific scale, and better quantification of off-site benefits associated with conservation programs will require detailed spatial data on all land areas enrolled in conservation programs.

Principal Findings

Plant Community Quality and Richness

Restoration practices improved upland floristic quality and native species richness relative to cropped catchments, but upland floristic quality and native species richness of restored catchments did not approach the full site potential as defined by native prairie catchments. In general, restoration activities also improved wetland floristic quality and native species richness relative to cropped wetland baselines; however, the magnitude and significance of change varied depending on physiographic region and response variable evaluated. Causal factors for these relationships were not examined, but they may be related to the frequency and extensiveness of cropping that can vary by catchment type (temporary, seasonal, semipermanent). Ultimately, determining the adequacy of restoration techniques solely on the basis of floristic quality and richness is ill advised because plant community composition can change rapidly in response to natural variation in abiotic factors and processes as well as in response to human-induced restoration and management activities.

Carbon Sequestration

Catchments with a history of cultivation, including those that have been restored and those with cropland, had less soil organic carbon (SOC) in the upper soil profile (0–15 cm [0–6 in]) than did native prairie catchments.

Differences in SOC between native catchments and those with a cultivation history varied from 12 to 26 percent depending on physiographic region and catchment zone. On the basis of the average difference in SOC (15 $Mg \cdot ha^{-1}$ [6.7 $tons \cdot acre^{-1}$]) between restored and native prairie catchments, we estimate that restored catchments on program lands (444,574 ha [1,098,542 acres]) have the potential to sequester 6,662,355 Mg (7,341,915 tons) of SOC, assuming that all such lands can assimilate carbon to the extent measured for native prairie. We did not detect a significant increase in SOC stocks in restored catchments relative to cropland baselines, nor were we able to demonstrate a relationship between carbon content and time since restoration. Explanations for our inability to detect changes in restored catchment SOC stocks are discussed. On the basis of published SOC sequestration rates, we estimate that catchments on program lands could sequester 222,287 $Mg \cdot yr^{-1}$ (244,960 $tons \cdot yr^{-1}$) of SOC and, since enrollment, may have sequestered 2,712,714 Mg (2,989,411 tons) of SOC. In addition, 715,094 Mg (788,034 tons) of organic carbon may be stored in the plant biomass on program lands.

Floodwater Storage

We estimate that wetland catchments on program lands in the Prairie Pothole Region could intercept precipitation across approximately 444,574 ha (1,098,542 acres) and store approximately 56,513 ha-m (458,151 acre-ft) of water if wetlands filled to maximum capacity. This amount equates to an average storage volume of 0.34 $ha\text{-}m \cdot ha^{-1}$ (1.1 $acre\text{-}ft \cdot acre^{-1}$) of wetland. Our water storage estimates are likely conservative because the data we used tend to underestimate area of wetlands on program lands. Further, our estimates of maximum wetland water storage do not account for dynamic hydrologic processes that attenuate the rate at which wetlands fill and overflow. For example, establishment of perennial cover in upland catchments reduces water received by wetlands by enhancing evapotranspiration and soil water holding capacity and infiltration. Consequently, the potential flood storage service provided by wetlands is greater than the maximum water storage value reported in this study. Regardless, these estimates suggest that wetlands on program lands have significant potential to intercept and store precipitation that otherwise might contribute to “downstream” flooding; however, we could not quantify the potential floodwater storage services because detailed spatial data on the location of program lands and wetland resources in relation to contributing and noncontributing areas within watersheds currently are not available. Availability of such data will facilitate application of models to better quantify dynamic floodwater-storage benefits at both site-specific and watershed scales.

Reduction of Sedimentation and Nutrient Loading

Conversion of cultivated cropland to herbaceous perennial cover as part of the CRP and WRP reduced total soil loss from uplands (276,021 ha [682,048 acres]) by an estimated average of 1,760,666 $Mg \cdot yr^{-1}$ (1,940,254 $tons \cdot yr^{-1}$). For this area, we estimate that nitrogen and phosphorus losses would be reduced by 5,102 $Mg \cdot yr^{-1}$ (5,622 $tons \cdot yr^{-1}$) and 68 $Mg \cdot yr^{-1}$ (75 $tons \cdot yr^{-1}$), respectively. Assuming that reduction in annual losses remains static, we estimate a cumulative soil loss reduction of 21,156,125 Mg (23,314,050 tons) and a cumulative reduction in nitrogen and phosphorus losses of 60,772 Mg (66,971 tons) and 798 Mg (879 tons), respectively, since restoration. A primary benefit of reduced soil erosion is that wetland depressions do not become filled and thereby maintain the topographic relief that is critical to sustaining all ecosystem services derived from wetlands. Reduction of soil erosion will almost certainly reduce the delivery of sediments to sensitive offsite ecosystems such as lakes, streams, and rivers; however, we did not evaluate the effects of this process with this study.

Potential Wildlife Habitat Suitability

We examined the effects of CRP enrollment on potential habitat suitability by comparing nesting area and vegetation obstruction measures in CRP tracts to published habitat requirements of 10 bird species in a single North Dakota township (93.2 km^2 [36.0 mi^2]). Effects of conservation programs included an increase in number of grassland areas that exceeded published nesting area requirements for the five area-sensitive grassland bird species that we evaluated and for which information was available. Published information on upland vegetation obstruction measurements at nesting sites was available for nine of the species evaluated. Comparisons of this information with vegetation obstruction data collected near the township indicate that restored seasonal catchments may provide suitable nesting habitat for all nine species. In contrast, restored temporary and restored semipermanent catchments may provide nesting habitat for seven and eight of the nine species, respectively. Our results suggest that restored catchments, regardless of wetland type, provide at least some necessary resources for a diversity of bird species that cropland catchments do not. The justification for this type of approach is discussed, as are the underlying assumptions and data requirements needed to apply the approach.

Chapter A: Background and Approach to Quantification of Ecosystem Services

By Robert A. Gleason and Murray K. Laubhan

Introduction

Conservation programs administered by the U.S. Department of Agriculture (USDA) have significantly influenced landscape conditions in the Prairie Pothole Region of the United States. Approximately 2,200,000 ha (5,436,200 acres) in the Prairie Pothole Region are enrolled in either the Conservation Reserve Program (CRP) or Wetlands Reserve Program (WRP). The ecosystem services provided by lands in these programs are diverse, ranging from improvements in local and broad-scale environmental conditions, such as air and water quality, and reduction of hazard risks, such as floodwater storage, to an improved ability to conserve the Nation's biological resources and provide increased recreational opportunities (Knutsen and Euliss, 2001; Allen and Vandever, 2003). Collectively, these services provide benefits valued by a broad spectrum of American society; however, the failure to quantify the full range of benefits provided by these programs has led to increasing scrutiny regarding their actual value. For example, the President's Budget and Performance Integration Initiative requires that Federal programs demonstrate effectiveness, accurately account for the expenditure of program dollars, and document results achieved. Consequently, developing approaches that meet these new accountability guidelines is critical to ensuring the continued funding of Federal conservation programs. This is particularly relevant for both the CRP and WRP, which have not yet achieved a rating of "effective" according to the Program Assessment Rating Tool administered by the Office of Management and Budget.

In response to this need, the USDA Farm Service Agency (FSA) and the USDA Natural Resources Conservation Service (NRCS) pooled resources with the U.S. Department of the Interior (DOI) U.S. Geological Survey (USGS) to conduct a study to quantify the environmental effects of USDA and DOI wetland conservation practices in the Prairie Pothole Region. This collaborative venture was advantageous because the needs of each agency were valuable to the other agencies. A primary interest of the USDA was to quantify the environmental effects of conservation practices implemented by private landowners enrolled in USDA conservation programs, especially the CRP administered by the FSA and the WRP administered by the NRCS. Similarly, the DOI was interested in quantifying the effects of conservation practices implemented on private lands through the Partners for Fish and Wildlife Program (PFWP) administered by the U.S. Fish and Wildlife Service (USFWS). The PFWP is a primary mechanism for delivering voluntary on-the-ground habitat improvements on private lands for the benefit of trust species. In administering the PFWP program, the USFWS often works closely with the NRCS and the FSA to help deliver many Farm Bill conservation programs. This work also benefits the USGS mission of conducting research to provide science-based information for better management of the Nation's natural resources, especially natural resources managed on public lands by the USFWS and other agencies within the DOI.

This study also addresses the Wetlands Component (other components include cropland, grazing land, and wildlife) of the USDA's Conservation Effects Assessment Project (CEAP) National Assessment. The CEAP is a multiagency, national effort to develop science-based approaches to quantify and periodically report the status of ecosystem services derived from conservation practices implemented through Farm Bill programs. Conservation practices to be assessed through CEAP include, but are not limited to, conservation buffers, erosion control, wetlands conservation and restoration, wildlife habitat establishment, grazing, tillage, irrigation water, nutrient reduction, and pest control (Natural Resources Conservation Service, 2005). The CEAP Wetlands Component was initiated in 2004 and consists of 10 regional assessments conducted in agricultural landscapes (fig. A–1). The USDA selected the Prairie Pothole Region for the first assessment because a 1997 regional survey conducted by the USGS Northern Prairie Wildlife Research Center provided the only known regional database and study design that conformed to the conceptual framework of the CEAP Wetlands Component, including sampling USDA program wetlands along an alteration gradient to quantify ecosystem services. From a programmatic perspective, the Prairie Pothole Region also was ideal because conservation of depressional prairie pothole wetlands is achieved primarily on the basis of wetland compliance provisions (the "swampbuster" provision) of the 1985 Farm Bill, and a significant number and area of wetlands have been restored as part of the CRP and the WRP. In addition, Prairie Pothole Region wetlands are nationally and internationally critical habitats for avian species of economic and ecological importance, and restored prairie potholes have the potential to sequester significant amounts of atmospheric carbon (CO_2-C) in soils, thus providing a greenhouse gas reduction service (Gleason and others, 2005; Euliss and others, 2006). Finally, the combined financial resources of the USDA and USGS provided an unprecedented opportunity to collaborate on quantifying wetland ecosystem services at a regional scale.

The goal of this report is to provide information describing the development and application of approaches used to estimate changes in five ecosystem services that result from implementation of conservation programs in the Prairie Pothole Region: restoration of native plant communities, atmospheric carbon sequestration, floodwater storage, reduction of sediment and nutrient inputs, and wildlife habitat enhancement. The focus is on prairie potholes, but plant community composition, soils, and topography of lands surrounding potholes also were evaluated because upland conditions are integral to understanding wetland processes and resulting benefits. The information contained in this report is of a general nature and is based on a combination of data collected and analyzed as part of this study and the authors' collective knowledge of Prairie Pothole Region wetland ecosystems. Analyses of physical, chemical, and biological data are ongoing to develop and refine models to translate ecosystem structure and function into measures of ecosystem services; hence, this study is a work in progress. Although additional work is necessary to objectively evaluate and quantify ecosystem services derived from restoration programs, preliminary information in this report is intended to focus future discussions regarding approaches used to assess environmental benefits derived from restoration programs at a national scale.

Background

The Prairie Pothole Region of the Northern Great Plains covers about 900,000 km^2 (347,490 mi^2) and extends from the north-central United States to south-central Canada (Gleason and others, 2005). Historically, the Prairie Pothole Region was composed primarily of short-, mixed-, and tall-grass prairie interspersed with isolated wetlands and river systems that had tremendous natural resource value; however, the Prairie Pothole Region also is valuable for agricultural production, and activities associated with agriculture have a tremendous impact on native habitats. Drainage to enhance agricultural production has been the primary factor resulting in wetland loss (Dahl, 1990; Dahl and Johnson, 1991). From the 1780s to

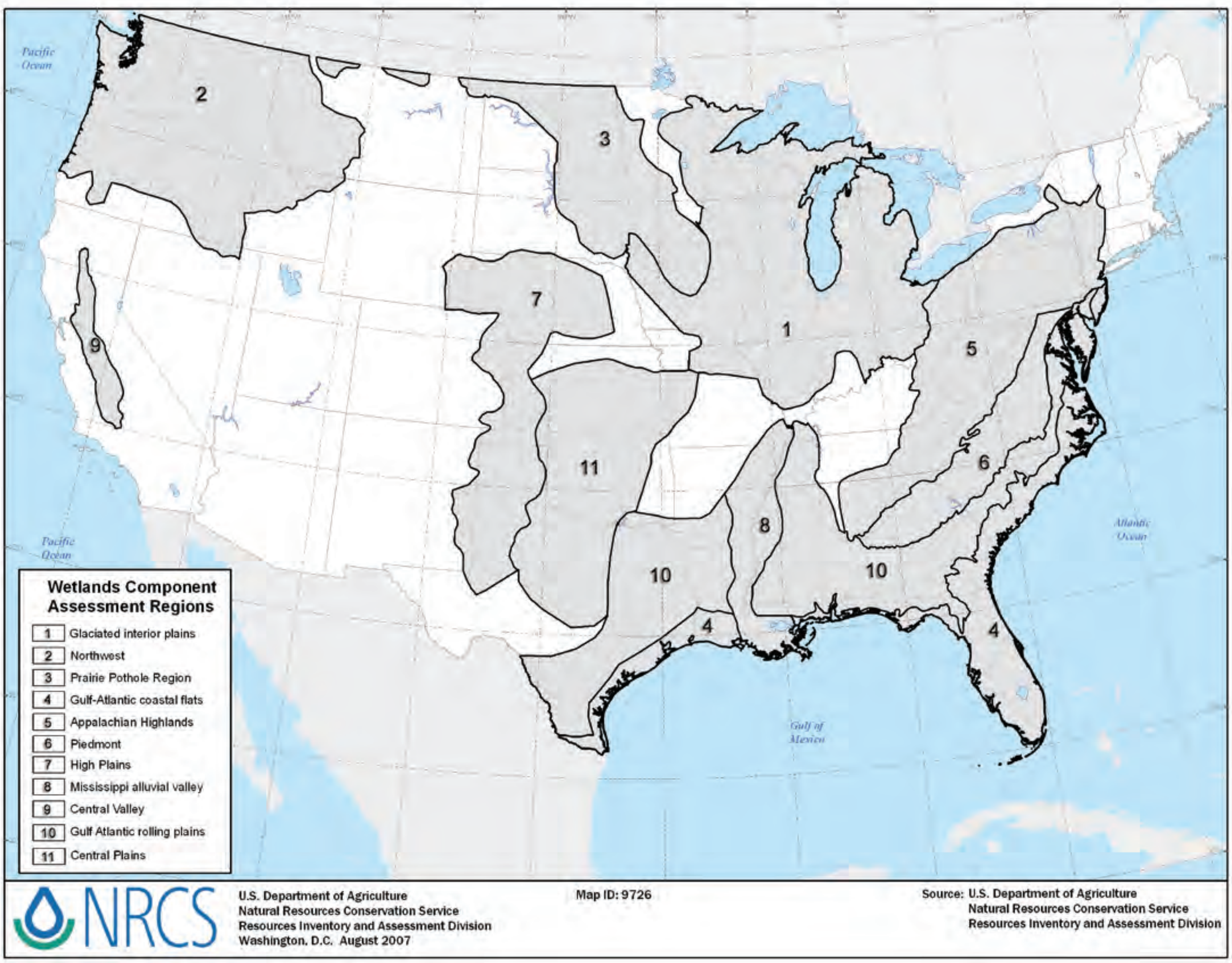

Figure A–1. Conservation Effects Assessment Project (CEAP) Wetland Regional Assessment Areas (*http://www.nrcs.usda.gov/technical/NRI/ceap/wetlands.html*).

the 1980s, wetland loss was approximately 89 percent in Iowa, 42 percent in Minnesota, 27 percent in Montana, 49 percent in North Dakota, and 35 percent in South Dakota (Dahl, 1990). Remaining wetlands continue to be directly and indirectly impacted by numerous agricultural practices that can cause accelerated sedimentation rates (Martin and Hartman, 1987; Gleason and Euliss, 1998; Gleason and others, 2003), addition of agricultural chemicals and nutrients (Grue and others, 1989; Neely and Baker, 1989), unnatural variance in water-level fluctuations (Euliss and Mushet, 1996), and altered vegetative communities (Kantrud and Newton, 1996; Mushet and others, 2002). Uplands in the Prairie Pothole Region have experienced similar loss and degradation. Since 1830, declines of native prairie exceed those reported for any other ecosystem in North America (Samson and Knopf, 1994). In the Prairie Pothole Region, tillage associated with agriculture has resulted in the loss of native prairie and has fragmented remaining grassland tracts (fig. A–2). Remaining tracts of native prairie also have been degraded by invasion of nonnative species, which is due to fire suppression, changes in herbivory, and introduction of Eurasian species (Johnson and others, 1994).

Restoration of wetland and grassland habitats on private lands in the Prairie Pothole Region has been an important activity of the DOI and the USDA. The most notable Federal restoration programs in the Prairie Pothole Region include the CRP and WRP. A 2005 USDA database indicates that there are approximately 2,166,049 ha (5,352,307 acres) of CRP and 33,427 ha (82,598 acres) of WRP lands enrolled in the Prairie Pothole Region (table A–1). Sites restored generally are areas that were previously altered to facilitate production of agricultural crops. Thus, the most common wetland restoration techniques include eliminating unnatural drains to restore hydrology and planting vegetation to restore adjacent uplands.

A fundamental premise used to justify funding Federal conservation programs is the benefit to both program participants and society. For instance, participating landowners receive monetary incentives to alter management practices, which in turn improves various ecological services desired by

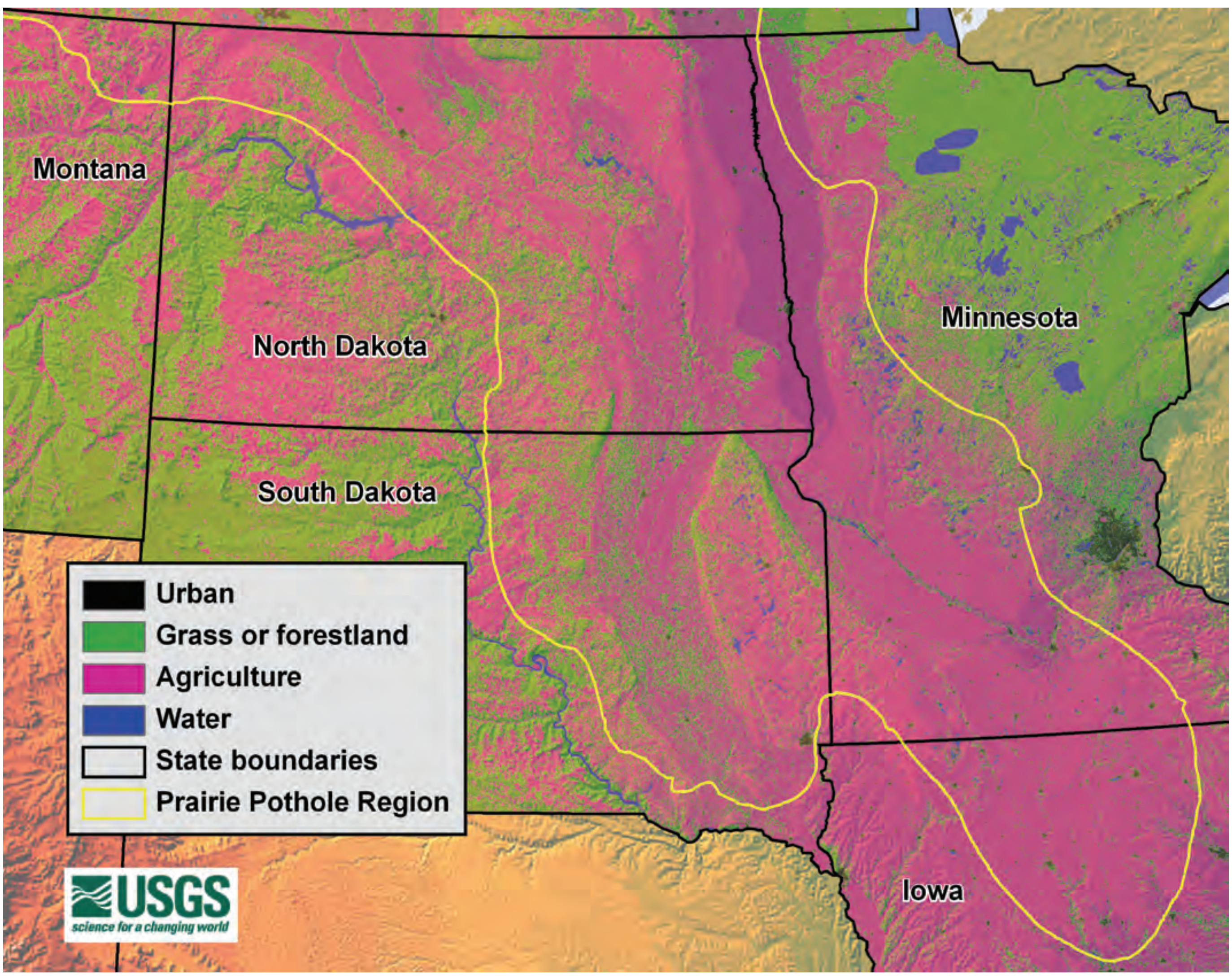

Figure A–2. Land use in the Prairie Pothole Region of the United States.

the American public (National Academy of Sciences, 2004). The most frequently mentioned ecological services include enhancing fish and wildlife habitat, improving water quality, reducing sedimentation and nutrient loading, increasing floodwater retention, recharging ground-water supplies, conserving biological diversity, sequestering carbon, and increasing opportunities for recreation (Knutsen and Euliss, 2001); however, efforts to quantify changes in these ecological services resulting from Federal programs have been minimal. Consequently, developing approaches to quantify the efficacy of conservation programs is especially important, particularly because both the CRP and the WRP are scheduled for program assessment in the near future. The goal of the Prairie Pothole Region Regional Assessment was to address this need by exploring the development and application of approaches that facilitate estimation of ecological services resulting from restoration activities funded by USDA conservation programs.

Methods

Our study was conducted in the United States portion of the Prairie Pothole Region, which encompasses more than 300,000 km^2 (115,830 mi^2) and includes portions of Iowa, Minnesota, Montana, North Dakota, and South Dakota (fig. A–3). Major physiographic regions in the Prairie Pothole Region are of glacial origin and include the Missouri coteau, prairie coteau, and glaciated plains (also known as drift prairie) (fig. A–3). Boundaries of these physiographic regions correspond relatively well with the following nine Major Land Resource Areas (MLRAs) defined by the USDA (U.S. Department of Agriculture, 1981): 53A, 53B, 53C, 55C, 102B, 55A, 55B, 102A, and 103 (fig. A–4). The Missouri and prairie coteaus were formed by stagnant and dead-ice moraines that created a rugged area of closely spaced hills and depressions (Bluemle, 2000). In contrast, the glaciated plains region was formed primarily as a result of ground-moraine processes that created a gently rolling landscape. Climate of the region varies along a northwest-to-southeast gradient, with precipitation and temperature increasing toward the southeast (Visher, 1966). Collectively, these factors influence agricultural production in the Prairie Pothole Region, including spatial and temporal extent of wetland drainage and cropping practices (Galatowitsch and van der Valk, 1994). On the basis of 2005 USDA data, 2,199,476 ha (5,434,905 acres) of land in the Prairie Pothole Region is enrolled in the CRP and WRP (table A–1). Detailed spatial data, such as location and area, of all wetland resources on CRP and WRP lands were not available at the time of this report; however, we estimated lands enrolled in these programs encompassed approximately 168,554 ha (416,497 acres) of wetlands (table A–1).

We designed a comprehensive survey of 204 wetlands in 1997 and of 270 catchments (wetland and surrounding uplands contributing runoff to the wetland) in 2004 (fig. A–3) to gather data necessary for estimating the following ecosystem services: plant community composition, carbon sequestration, floodwater storage, sediment and nutrient reduction, and wildlife habitat. During 1997, a systematic sampling design stratified by physiographic region was used to select

Table A–1. Total area and estimated wetland area on lands enrolled in the Conservation Reserve and Wetlands Reserve Programs in the Prairie Pothole Region.

[CRP, Conservation Reserve Program; WRP, Wetlands Reserve Program; SE, standard error; --, no data]

State	WRP[1]		CRP[1]		CRP and WRP	
	Total area, in hectares (acres)	Wetland area, in hectares ± SE (acres ± SE)	Total area, in hectares (acres)	Wetland area, in hectares ± SE (acres ± SE)	Total area, in hectares (acres)	Wetland area, in hectares ± SE (acres ± SE)
Iowa	11,376 (28,110)	5,076 ± 256 (12,543 ± 633)	53,183 (131,415)	24,172 ± 1,201 (59,729 ± 2,968)	64,559 (159,525)	29,248 ± 1,457 (72,272 ± 3,600)
Minnesota	8,633 (21,332)	3,168 ± 403 (7,828 ± 996)	167,349 (413,519)	51,848 ± 8,629 (128,116 ± 21,332)	175,982 (434,852)	55,016 ± 9,032 (135,945 ± 22,318)
Montana	--	--	411,127 (1,015,895)	2,996 ± 1,690 (7,403 ± 4,176)	411,127 (1,015,895)	2,996 ± 1,690 (7,403 ± 4,176)
North Dakota	3,239 (8,004)	199 ± 40 (492 ± 99)	1,099,218 (2,716,168)	61,669 ± 12,558 (152,384 ± 31,031)	1,102,457 (2,724,171)	61,868 ± 12,598 (152,876 ± 31,130)
South Dakota	10,179 (25,152)	539 ± 111 (1,332 ± 274)	435,172 (1,075,310)	18,887 ± 4,442 (46,670 ± 10,976)	445,351 (1,100,462)	19,426 ± 4,553 (48,002 ± 11,250)
Total	33,427 (82,598)	8,982 ± 810 (22,195 ± 2,002)	2,166,049 (5,352,307)	159,572 ± 28,520 (394,302 ± 70,473)	2,199,476 (5,434,905)	168,554 ± 29,330 (416,497 ± 72,474)

[1] Total area based on the 2005 U.S. Department of Agriculture (USDA) Natural Resources Conservation Service national WRP database and on the 2005 USDA Farm Service Agency national CRP database. Wetland areas in each program were estimated by multiplying total area by the average percentage of wetland area on cropland that was estimated by using the 1997 National Resources Inventory (U.S. Department of Agriculture, 2000).

a representative spatial sample of catchments along the northwest-to-southeast climate and land-use gradients in the Prairie Pothole Region. Along the natural orientation of each physiographic region, we systematically identified 9 sample points in the Missouri coteau, 3 in the prairie coteau, and 12 in the glaciated plains (fig. A–5). Allocation of sample points was proportional to the linear length of each physiographic region. Near each sample point, we located and obtained permission to survey seasonal and semipermanent wetlands (Class III and IV wetlands) (Stewart and Kantrud, 1971) subjected to each of the following land-use treatments:

1. Partially restored drained wetlands: wetlands that had been drained but whose upland zones of catchments were planted to perennial cover as part of USDA or similar restoration programs. The hydrology was altered since the drains were not plugged, and because of active drainage prior to partial restoration, these wetlands were farmed more frequently than nondrained wetlands.
2. Hydrologically restored wetlands in two age classes (restored less than 5 years and more than 5 years): previously drained wetlands that had been restored by plugging drains and planting upland zones of catchments to perennial cover as part of USDA or similar restoration programs. Because of active drainage prior to restoration, these wetlands were farmed more frequently than non-drained wetlands.
3. Nondrained restored wetlands: wetlands that had not been drained but whose upland zones of catchments were restored by planting perennial cover as part of USDA or similar restoration programs. Prior to restoration, these nondrained wetlands were farmed less frequently than actively drained wetlands.
4. Native prairie wetlands: wetlands that had not been drained and whose upland zones of catchments are composed of native prairie vegetation. There was no history of cultivation in the wetland or upland zones of catchments.

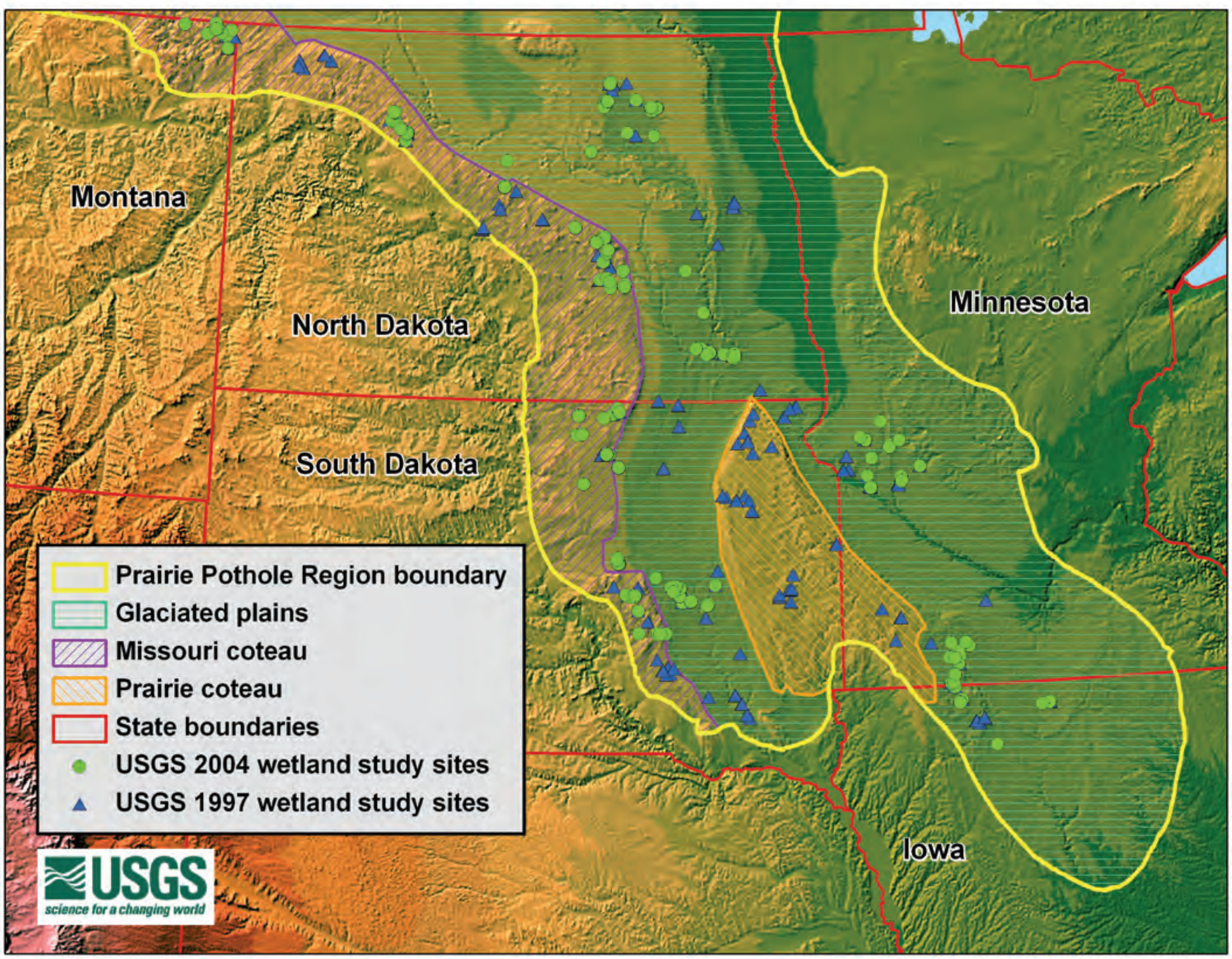

Figure A–3. Extent of the Prairie Pothole Region in the United States, and locations of wetlands sampled by the U.S. Geological Survey (USGS) during 1997 and 2004 in portions of Iowa, Minnesota, Montana, North Dakota, and South Dakota.

Ideally, the 1997 survey should have resulted in selection of 240 wetlands, but not all land-use treatment and wetland type combinations occurred near each sampling point; therefore, the sampling effort resulted in selection of only 204 wetlands (fig. A–3 and table A–2). For the 2004 survey, a subsample of points used during the 1997 survey was used, and data collection was expanded to include entire catchments and a broader spectrum of wetland types. These design changes were implemented to enable comparisons of ecological services provided by restored catchments relative to both cropland and native prairie catchments. Of the original 21 sample points selected during 1997 in the Missouri coteau (n = 9) and glaciated plains (n = 12), 5 points in the Missouri coteau (MC01, MC03, MC05, MC07, MC09) and 5 points in the glaciated plains (GP01, GP03, GP05, GP09, GP11) were selected for sampling in 2004 (fig. A–5). Near each sampling point we attempted to locate a temporary, seasonal, and semipermanent depressional wetland subjected to each of the following land-use treatments:

1. Hydrologically restored wetlands in three age classes (restored less than 5 years, 5–10 years, and more than 10 years): previously drained wetlands that had been restored by plugging drains and planting upland zones of catchments to perennial cover as part of USDA or similar restoration programs. Because of active drainage prior to restoration, these wetlands were farmed more frequently than nondrained wetlands.

2. Nondrained restored wetlands in three age classes (restored less than 5 years, 5–10 years, and more than 10 years): wetlands that had not been drained but whose upland zones of catchments were restored by planting perennial cover as part of USDA or similar restoration programs. Prior to restoration, these nondrained wetlands were farmed less frequently than actively drained wetlands.

3. Drained cropland wetlands: wetlands that had been drained and whose upland zones of catchments were

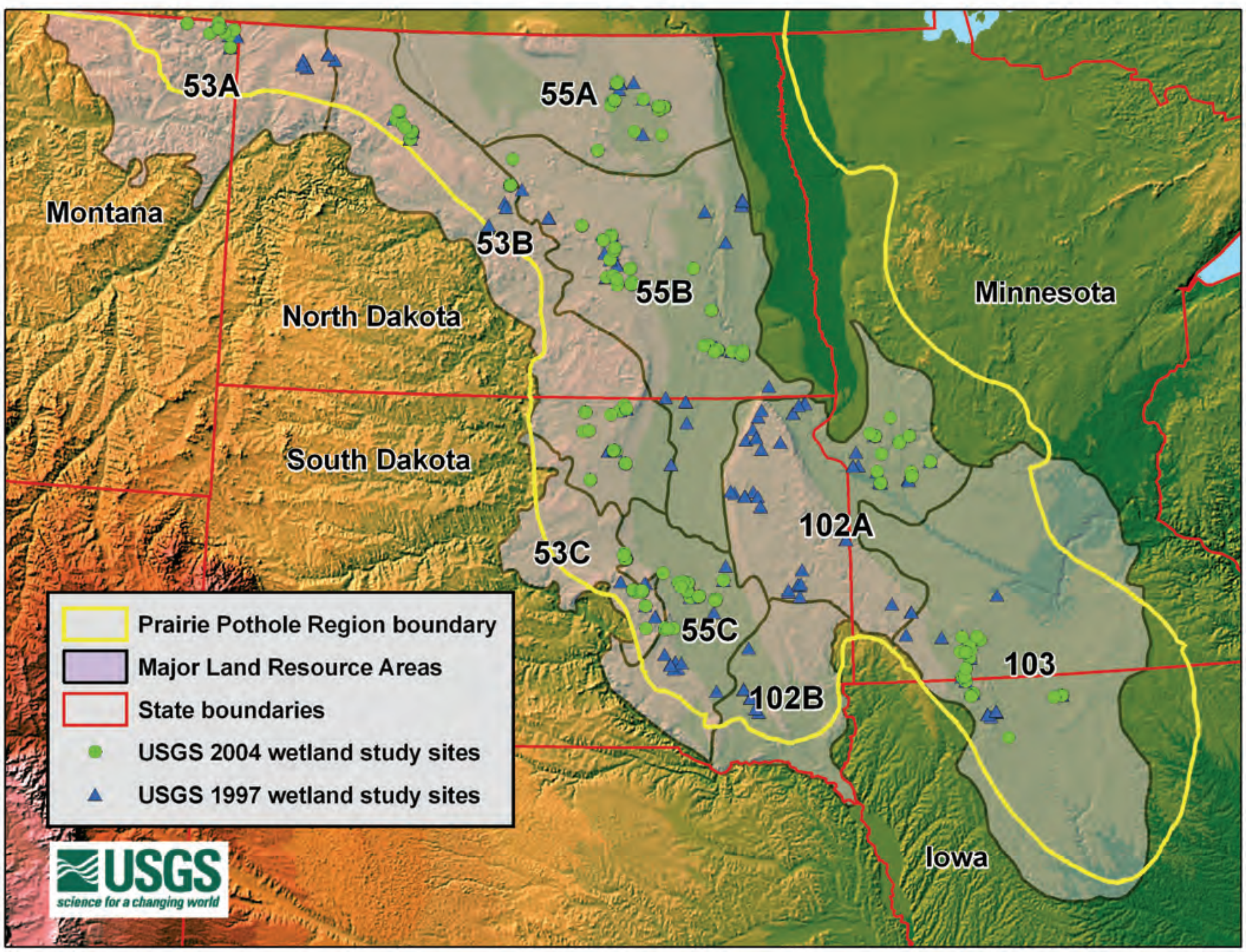

Figure A–4. Major Land Resource Areas defined by the U.S. Department of Agriculture in the Prairie Pothole Region of the United States. Symbols represent locations of wetlands sampled by the U.S. Geological Survey (USGS) during 1997 and 2004.

predominantly cropland. Because of active drainage, wetlands were farmed more frequently than nondrained wetlands.

4. Nondrained cropland wetlands: wetlands that had not been drained and whose upland zones of catchments were predominantly cropland. Wetlands were farmed, but with less frequency than actively drained wetlands.

5. Native prairie wetlands: wetlands that had not been drained and whose upland zones of catchments were composed of native prairie. There was no history of cultivation in the wetland or upland zones of catchments.

The 2004 sampling effort resulted in selection of 270 catchments, of which 52 had been sampled during the 1997 survey (fig. A–3 and table A–3). The 2004 survey differed from the 1997 survey by including upland areas that surround wetlands, adding temporary and cropped wetland catchments as land-use categories, eliminating partially restored wetlands as a land-use category, and separating nondrained restored wetlands into categories on the basis of restoration age.

Data within each catchment were collected along four transects originating in the center of the wetland and extending outward in cardinal directions to the catchment boundary. Along each transect, we identified wetland catchment subzones (wet-meadow, shallow-marsh, and deep-marsh) (Stewart and Kantrud, 1971) and upland catchment subzones (toe-slope, mid-slope, and shoulder-slope) that bisected the transect (fig. A–6). Soil and vegetation data were collected at the midpoint of each subzone. A topographic survey of the entire catchment was completed, and the spatial locations of samples were recorded by using the Global Positioning System. Additional details on data collection methods are described in chapters B–F. During the 1997 survey, only wetland subzones were surveyed, whereas both upland and wetland subzones were

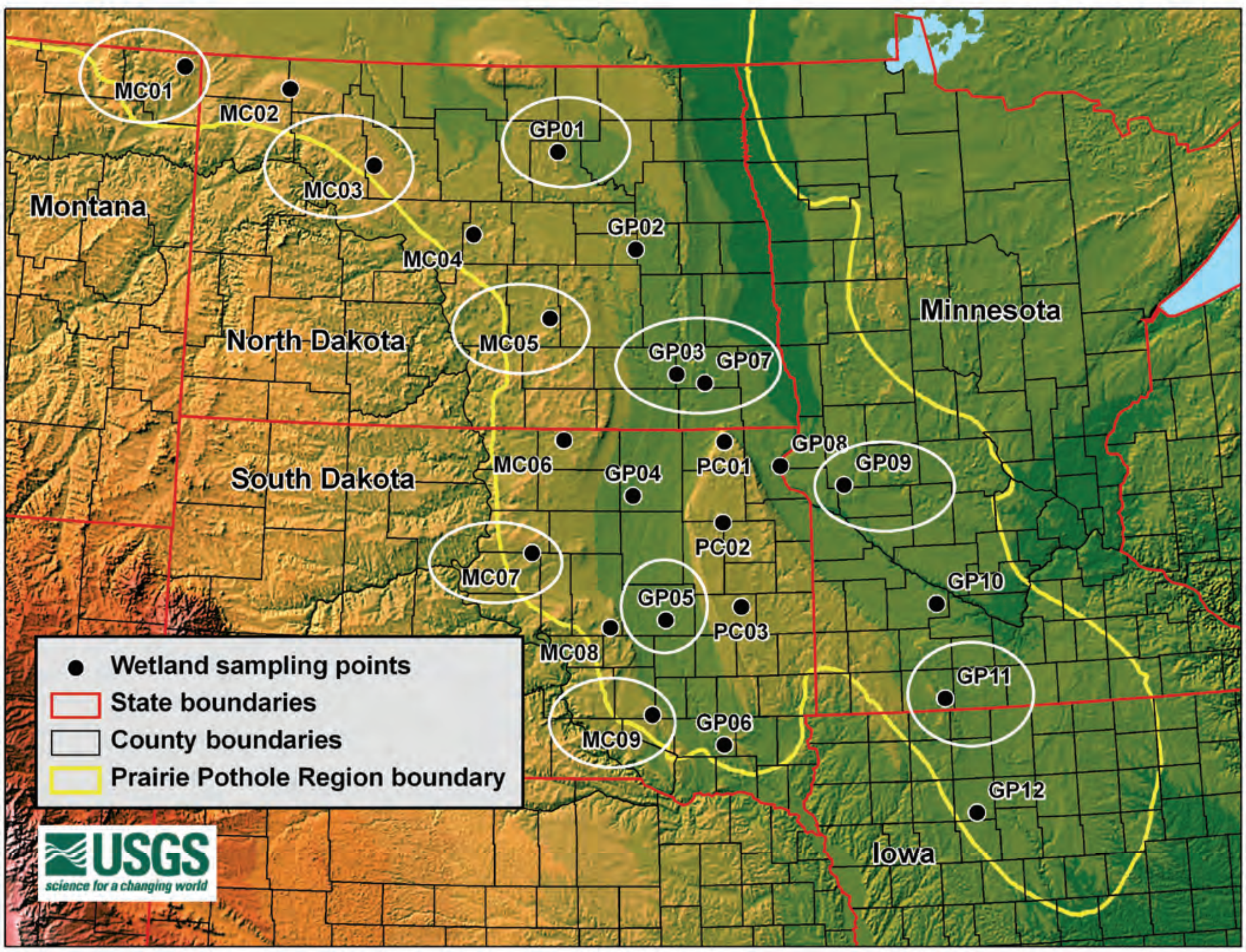

Figure A–5. Location of sample points in the Prairie Pothole Region of the United States in portions of Iowa, Minnesota, Montana, North Dakota, and South Dakota. All glaciated plains (GP01–GP12), Missouri coteau (MC01–MC09), and prairie coteau (PC01–PC03) points were used during the 1997 survey, whereas a subsample (circled points) of points was used during the 2004 survey.

surveyed in 2004. Further, all catchments surveyed contained the three upland subzones, but the number of wetland subzones varied depending on the class of wetland occupying the catchment. Typically, temporary catchments only supported a wet-meadow subzone, seasonal catchments supported a wet-meadow and shallow-marsh subzone, and semipermanent catchments supported a wet-meadow, shallow-marsh, and deep-marsh subzone.

Information collected during both surveys included measurements of soil, vegetation, and morphological variables that are indicators of structure and function and that are useful in estimating various ecosystem services (table A–4). A key element in the sample design is that land-use treatments span an alteration gradient ranging from highly altered (cropland catchments) to minimally altered (native prairie catchments). Therefore, a "reference-based" approach (Smith and others, 1995; Brinson and Rheinhardt, 1996) can be applied to assess how program wetlands (restored catchments) have changed relative to nonprogram wetlands (cropland and native prairie catchments) along the alteration gradient (fig. A–7). Restored

Table A–2. Numbers of wetlands sampled during 1997 in the Prairie Pothole Region by physiographic region, catchment type, and land-use treatment.

Catchment type	Restored lands				Native prairie
	Hydrologic restoration		Nondrained restoration	Partially restored drained	
	Years restored				
	<5 years	>5 years			
Glaciated plains					
Seasonal	11	11	12	12	12
Semipermanent	4	10	9	9	10
Missouri coteau					
Seasonal	5	12	9	7	9
Semipermanent	4	8	8	3	9
Prairie coteau					
Seasonal	3	3	3	3	3
Semipermanent	3	3	3	3	3

Table A–3. Numbers of wetlands sampled during 2004 in the Prairie Pothole Region by physiographic region, catchment type, and land-use treatment.

[Numbers in parentheses represent wetlands that were also sampled during the 1997 survey]

Catchment type	Restored lands[1]						Croplands		Native prairie
	Hydrologic restoration			Nondrained restoration					
	Years restored			Years restored					
	1–5	5–10	>10	1–5	5–10	>10	Drained	Non-drained	
Glaciated plains									
Temporary	6	1	0	5	7	8	4	6	5
Seasonal	9	4 (2)	7 (6)	4	2	7 (2)	5	6	5 (3)
Semipermanent	5	5 (3)	7 (5)	4	4 (1)	5 (1)	3	6	5 (3)
Missouri coteau									
Temporary	5	4	7	4	3	8	5	5	5
Seasonal	4	8 (2)	6 (4)	6	6	8 (5)	7	6	5 (4)
Semipermanent	3	1	5 (3)	3	3	5 (4)	3	5	5 (4)

[1] Of the restored wetlands, 130 were located on lands enrolled in U.S. Department of Agriculture Conservation Reserve Program or Wetlands Reserve Program, and 49 wetlands occurred on sites restored through other, non-USDA programs.

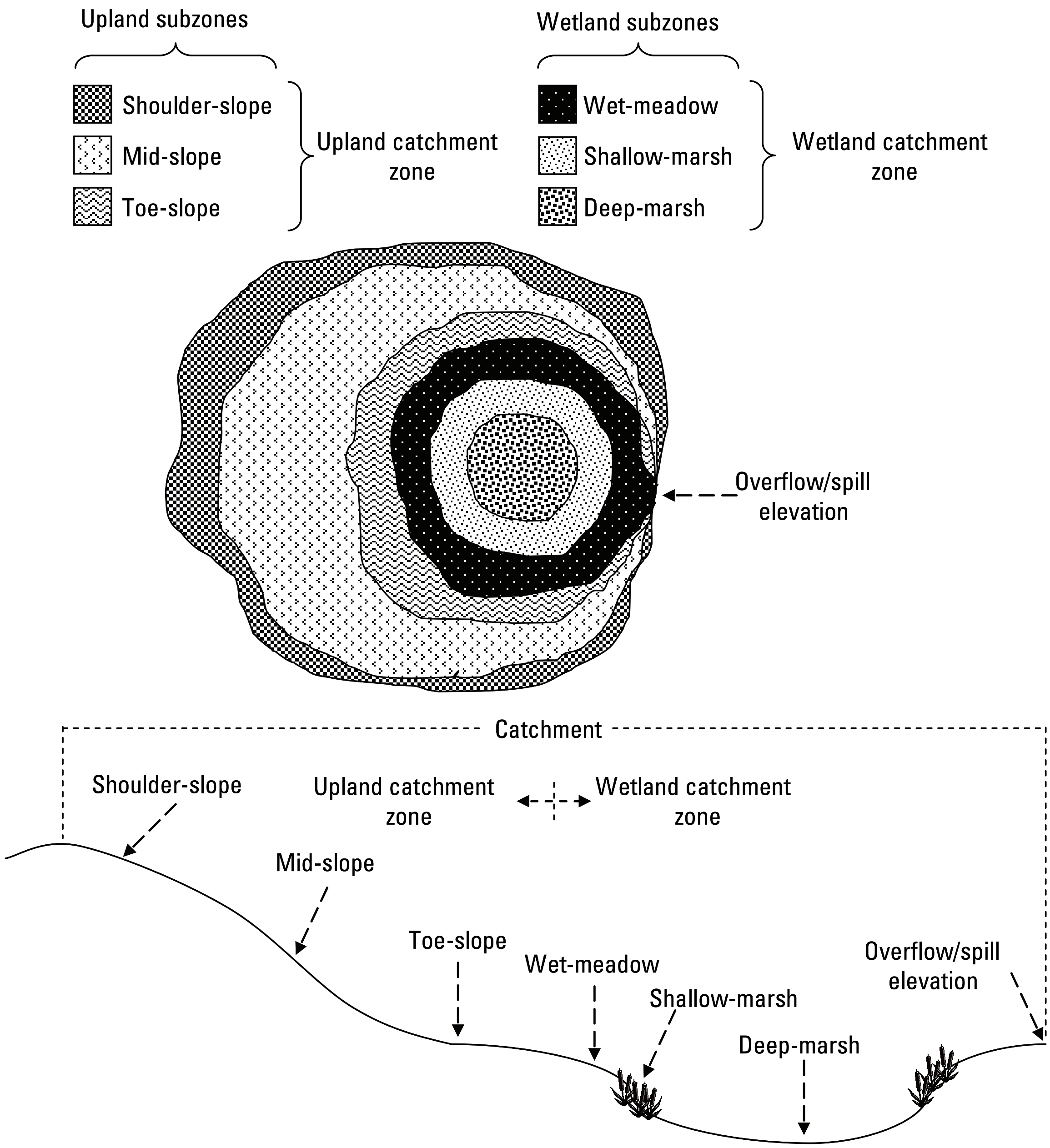

Figure A–6. Plan and profile view of catchment zones. The upland zone is the area contributing surface runoff to the wetland zone and is composed of three subzones based on landscape position: shoulder-slope, mid-slope, and toe-slope. All subzones are present in an upland zone regardless of catchment type (temporary, seasonal, semipermanent). The wetland zone is delineated on the basis of the location of hydrophytes and is composed of one to three subzones depending on catchment type: temporary catchments have a wet-meadow zone, seasonal catchments have wet-meadow and shallow-marsh zones, and semipermanent catchments have wet-meadow, shallow-marsh, and deep-marsh zones. Size and location of wetland zones fluctuate within and among years depending on hydrologic condition (wet/dry periods). The interception area is equivalent to the entire catchment area (both upland and wetland zones).

Table A–4. Soil, vegetation, and morphological variables collected in catchments surveyed in 1997 and 2004 that are indicators of structure and function and that can be used to estimate various ecosystem services.

[C, carbon; P, phosphorus; N, nitrogen]

Variable	Measure
Soils	Nutrients (C, P, N)
	pH
	Electric conductance
	Bulk density
	Texture
	Soil horizon description
	Redox characteristics
	Soil consistency
Vegetation	Composition
	Cover estimates
	Litter depth
	Biomass
	Visual obstruction
	Width of zones
Morphology	Area
	Overflow/spill elevation
	Relief
	Volume

wetlands included in our sample are representative of wetlands restored on CRP and WRP lands. Although the CRP is administered by the FSA, the NRCS establishes technical land eligibility determinations, provides conservation planning, and is involved with practice implementation. Consequently, a similar suite of NRCS practice standards are used on both CRP and WRP lands to restore wetlands and adjacent upland ecosystems. Table A–5 provides the most commonly applied NRCS practice standards in the Prairie Pothole Region. A key element of the phrase "adjacent upland ecosystems" is that the upland zone surrounding a restored wetland is planted to perennial cover by using various conservation practices (table A–5). Consequently, for many of the ecosystem functions and services considered in this report, it is not appropriate to delineate spatial boundaries between the wetland and the adjacent upland ecosystem (National Academy of Sciences, 2004). Likewise, attempting to quantify ecosystems services for each "program practice" applied would not be possible or appropriate since wetland functions and processes are intimately linked to the surrounding upland ecosystem.

Report Format

The objective of this report is to present preliminary findings on existing ecosystem services provided by Prairie Pothole Region wetland catchments subjected to different land-use treatments. Chapter A (this section) describes the impetus for the report and provides general information on the study area, overall study design, and sampling approach used during the 1997 and 2004 surveys. Chapters B–F contain information on individual ecosystem services as follows: plant community quality and richness (chap. B), carbon sequestration (chap. C), floodwater storage (chap. D), reduction of sedimentation and nutrient loading (chap. E), and wildlife habitat (chap. F). Each chapter includes a synopsis and methods, results, discussion, and references cited sections. The methods section in each chapter identifies which survey data (1997, 2004) were used and how data were collected and analyzed to quantify the ecosystem service. To reduce redundancy of methods among chapters, information regarding sampling design and terminology used in the report is presented only in chapter A.

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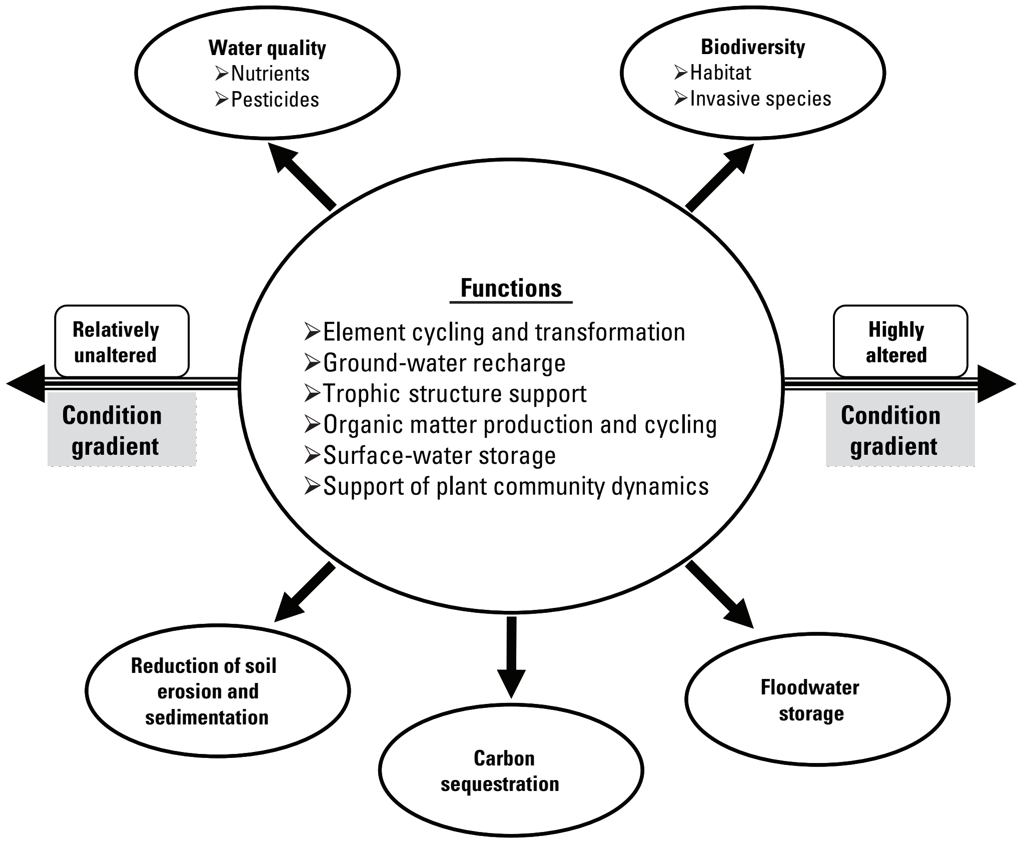

Figure A–7. Wetland functions and ecological services expected to change along a condition gradient ranging from highly altered wetlands to relatively unaltered wetlands.

Table A–5. Natural Resources Conservation Service and Farm Service Agency practices and standards commonly applied to Conservation Reserve Program and Wetlands Reserve Program lands in the Prairie Pothole Region.

[FSA, Farm Service Agency; CRP, Conservation Reserve Program; NRCS, Natural Resources Conservation Service; CP, conservation practice]

NRCS practice standards (code-practice: purpose)	FSA CRP conservation practices		
	CP1-Establishment of permanent introduced grasses and legumes	CP2-Establishment of permanent native grasses	CP23-Wetland restoration
327-Conservation Cover: To reduce soil erosion and sedimentation, improve water quality, and enhance wildlife habitat.	X	X	
644-Wetland Wildlife Habitat Management: To maintain, develop, or improve habitat for waterfowl, furbearers, or other wetland associated flora and fauna.	X	X	X
657-Wetland Restoration: To restore hydric soil, hydrologic conditions, hydrophytic plant communities, and wetland functions that occurred on disturbed wetland sites prior to modification to the extent practicable.			X
659-Wetland Enhancement: To modify the hydrologic condition, hydrophytic plant communities, and/or other biological habitat components of wetlands to favor specific wetland functions or values.			X
587-Structure for Water Control: To control the stage, discharge, distribution, delivery, or direction of water flow.			X

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Chapter B: Plant Community Quality and Richness

By Murray K. Laubhan and Robert A. Gleason

Synopsis

One of the most observable effects following restoration activities is the rapid development of plant communities. Plants are the foundation of natural ecosystems because they capture solar energy through photosynthesis and store it as chemical energy in plant biomass that can be transferred to other trophic levels in the ecosystem. For example, photosynthetic energy is converted to animal biomass when plant material is ingested by primary consumers, such as herbivores, and atmospheric carbon captured through photosynthesis and stored in aboveground and belowground biomass results in carbon sequestration benefits (see chap. C). Decomposition of root systems facilitates development of soil organic matter that improves soil fertility, structure, aggregation, and water-holding capacity, whereas aboveground plant cover reduces the velocity and amount of surface water runoff, soil erosion, and sedimentation of wetland basins (see chaps. D and E). Plant community composition also determines the diversity of foods and cover types available for wildlife (see chap. F). Hence, a diversity of vegetation is the underpinning of most ecological services derived from restoration programs.

The objective of this chapter is to evaluate the impacts of conservation programs on vegetation composition. We compared floristic quality and species richness of temporary, seasonal, and semipermanent catchments in cropped, restored, and native prairie treatments in the glaciated plains and Missouri coteau physiographic regions of the Prairie Pothole Region of the United States. We selected floristic quality and richness because these measures not only characterize plant community composition but also directly and indirectly influence numerous other ecological services. Cropped treatments included catchments that were actively farmed, whereas native prairie treatments included catchments with no prior history of disturbance related to crop production. Restored treatments included wetlands that had been restored by plugging drains (if present) to restore hydrology and planting uplands surrounding wetlands to perennial cover.

In general, floristic quality of the upland and wetland zones of restored catchments was significantly greater than that of the cropland baseline but lower than that of native prairie catchments in both the glaciated plains and Missouri coteau. The only exception to this trend was similar floristic quality in the wetland zones of restored and native prairie catchments in the glaciated plains. Catchment type also influenced floristic quality independent of treatment. Factors contributing to observed differences among treatments were not investigated; however, planting native vegetation rather than agricultural crops and differences in the number of nonnative species influenced upland floristic quality. Further, direct and indirect changes in hydrology from hydrologic and nonhydrologic restorations and establishment of native species with different coefficients of conservatism influenced wetlands floristic quality. Although the restoration strategies evaluated in this study improved floristic quality as compared to cropland baselines, full recovery to native conditions likely will require additional time and/or manipulations to reduce nonnative species and stimulate recruitment of additional native grasses and forbs from the seed bank.

Methods

The floristic quality index (FQI) method and species richness of native and nonnative species were used to assess the impact of land-use treatment on plant community quality and composition. The FQI method is based on the concept that plants respond rapidly to both improvement and degradation of systems (Northern Great Plains Floristic Quality Assessment Panel, 2001; Ervin and others, 2005) because individual species display varying degrees of fidelity to specific habitats and differ in the ability to tolerate disturbance (Swink and Wilhelm, 1979, 1994). Each native species in a region is assigned a score (coefficient of conservatism [C]) of 0–10, with species exhibiting low tolerance to disturbance and high fidelity to a specific habitat receiving higher scores. Therefore, FQI provides a standardized approach that enables comparisons among different sites and different habitat management and restoration efforts (Northern Great Plains Floristic Quality Assessment Panel, 2001). The equation used to calculate FQI is as follows:

$$\text{FQI} = \overline{C} \times \sqrt{N} \quad ,$$

where

$$\overline{C} = \frac{\sum C}{N} \text{, and}$$

N = number of native plants.

This formula does not incorporate nonnative species—these species evolved disjunct from the native regional flora and cannot be used in natural area assessments (Swink and Wilhelm, 1979, 1994)—however, excluding nonnative species may result in overestimation of ecological integrity because the presence of even one exotic species may have significant impacts on wetland health (Ervin and others, 2005). This concept is particularly relevant because we evaluated catchments across a broad disturbance gradient that included highly disturbed environments, such as drained cropland, that potentially could support numerous nonnative species and, in some cases, no native species. Therefore, we used the following modified

FQI equation that incorporates total species richness and the proportional richness of native to nonnative species:

$$\mathrm{FQI} = \frac{\sum C}{\sqrt{S}} \times \frac{N}{S},$$

where
S = total number of all species encountered.

This equation originally was proposed for use with wetness coefficients rather than *C* values (Ervin and others, 2005), but we retained the use of *C* values assigned to species in North and South Dakota and adjacent grasslands (Northern Great Plains Floristic Quality Assessment Panel, 2001).

We used only 2004 survey data in this analysis because upland vegetation was not collected during the 1997 survey (fig. A–3). Vegetation data was collected on four transects that radiated from the center of the wetland and extended in cardinal directions to the catchment boundary. Along each transect, we located a 1-m^2 (10.8-ft^2) quadrat at the midpoint of each catchment subzone (fig. A–6). Within each quadrat, we recorded all plant species, vegetation cover of each taxon by ocular estimation (Daubenmire, 1959), and litter depth (cm). Portions of a quadrat devoid of vegetation were categorized as either bare or open water. Of 270 catchments surveyed in 2004 (table A–3 and fig. A–3), 263 catchments were included in the analysis (table B–1) (7 catchments were excluded because they were restored prior to implementation of the CRP and WRP). We calculated FQI separately for upland and wetland zones of each catchment by combining data from the three highest (shoulder-slope, mid-slope, toe-slope) and three lowest (wet-meadow, shallow-marsh, deep-marsh) topographic zones, respectively (fig. A–6). All catchments contained the three upland zones, but the number of wetland zones varied depending on wetland class within the catchment. In general, one wetland zone (wet-meadow) occurred in temporary catchments, two zones (wet-meadow and shallow-marsh) occurred in seasonal catchments, and three zones (wet-meadow, shallow-marsh, and deep-marsh) occurred in semipermanent catchments.

Although the equation used to calculate FQI incorporates nonnative species, a separate analysis of species richness was conducted to compare native and nonnative taxa among land-use treatments in each catchment type. This information provides additional insight into plant community composition and interpretation of the FQI (Kantrud and Newton, 1996). Each plant species was classified as native or nonnative on the basis of information published by the Northern Great Plains Floristic Quality Assessment Panel (2001) to maintain consistency between the two analyses. Each catchment was divided into an upland zone and wetland zone as described in the previous paragraph, and the mean richness of native and nonnative taxa was calculated separately for each zone.

Analysis of variance (ANOVA) was used to assess the influence of land-use treatment on FQI and species richness. Sample points used as focal areas to originally select catchments were included as a blocking factor (fig. A–5). The model for both FQI and species richness included physiographic region (Missouri coteau, glaciated plains), catchment type (temporary, seasonal, semipermanent), catchment zone (upland, wetland), land-use treatment (drained and nondrained cropland, nondrained and hydrologically restored, and native prairie), and all possible interactions as independent variables. For significant main effects and interaction terms, we tested for differences among the following categories: (1) cropped (drained and nondrained cropped categories), (2) restored (hydrologically restored and nondrained restored categories of all ages), and (3) native (native prairie category). The two cropped treatments were combined because differences were primarily temporal: both drained and nondrained cropland catchments were tilled and planted in drier years. Thus, the only difference was the frequency and extent of cropping in the wetland zone of these catchments (for example, drained wetland zones are farmed more frequently than are nondrained). Although intensity and frequency of cropping can have important impacts on vegetation community quality and composition, records of past activities were not of sufficient detail to reliably separate catchments on the basis of temporal patterns of agriculture. Similarly, most hydrologically restored and all nondrained restored catchments were planted to perennial cover. In addition, neither restoration strategy involved planting wetland vegetation. Given similar planting regimens and the large variation in antecedent conditions of hydrologically restored wetlands (see chap. C), we decided to combine the restored treatments because assessing the overall value of restoration activities relative to cropland and native prairie sites was of most interest. We used univariate ANOVA and contrast statements with inferences that applied only to the observed levels of the random effects to test for differences in FQI and species richness among the cropped, restored, and native prairie treatments. All analyses were conducted by using PROC MIXED of SAS version 8.2 (SAS Institute, Inc., 1999) and considered a $P \leq 0.05$ as the level of statistical significance for all tests.

Results

According to the Northern Great Plains Floristic Quality Assessment Panel (2001), there are 1,584 plant taxa in the Dakotas and surrounding grasslands. We documented 349 (22.0 percent) of these species in catchments surveyed, including 231 (66.2 percent) forbs, 67 (19.2 percent) grasses, 24 (6.9 percent) sedges, 16 (4.6 percent) shrubs, and 5 (1.4 percent) trees (table B–2). The majority of species ($n = 248$; 71.1 percent) were perennials, followed by annuals ($n = 87$; 24.9 percent) and biennials ($n = 14$; 4.0 percent). Seasonal catchments supported 209 species compared to 200 and 158 species in semipermanent and temporary catchments, respectively.

Native plant species made up 76.8 percent ($n = 268$) of all plants identified in catchments compared to 23.2 percent (n = 81) nonnative species. Native species composition was dominated by forb (n = 178; 66.4 percent) and grass (n = 41; 15.3 percent) species, followed by sedge (n = 24; 8.9 percent), shrub (n = 15; 5.6 percent), and tree (n = 5; 1.9 percent) species (table B–2). Forb (n = 53) and grass (n = 26) species accounted for 65.4 percent and 32.1 percent of nonnative plants, respectively, with the remaining 2.5 percent of nonnative species being accounted for by one shrub and one tree species.

Floristic Quality Index

Regardless of treatment, floristic quality differed among catchment types ($F_{2,100}$ = 5.85, P < 0.004) with semipermanent catchments exhibiting greater quality than temporary catchments ($F_{1,100}$ = 11.70, P < 0.0009) (fig. B–1). In contrast, the floristic quality of seasonal catchments was intermediate and similar to that of both semipermanent ($F_{1,100}$ = 3.59, P < 0.06) and temporary catchments ($F_{1,100}$ = 2.83, P < 0.10). The interaction of catchment type and zone also influenced floristic quality ($F_{2,108}$ = 3.91, P < 0.02); however, further analysis indicated that the only difference was lower floristic quality in the upland compared to the wetland zone in semipermanent catchments ($F_{1,108}$ = 5.07, P < 0.026) (fig. B–2). Floristic quality did not vary by physiographic region ($F_{1,8}$ = 2.43, P < 0.16) or zone ($F_{1,8}$ = 0.09, P < 0.76), but it was affected by treatment ($F_{4,100}$ = 60.18, P < 0.0001) and the interaction of treatment with physiographic region and zone ($F_{4,108}$ = 3.07, P < 0.02) (fig. B–3). The upland zone FQI of restored catchments was greater relative to the cropland baseline (glaciated plains, $F_{1,108}$ = 14.65, P = 0.0002; Missouri coteau, $F_{1,108}$ = 14.20, P < 0.0003), but it was lower relative to native prairie reference catchments in both physiographic regions (glaciated plains, $F_{1,108}$ = 42.08, P < 0.0001; Missouri coteau, $F_{1,108}$ = 282.12, P < 0.0001) (fig. B–3). In the Missouri coteau, the wetland zone FQI exhibited trends similar to the upland zone FQI with restored catchments having a greater FQI than cropped catchments ($F_{1,108}$ = 13.59, P < 0.0004) but a lower FQI than native prairie catchments ($F_{1,108}$ = 14.39, P < 0.0002). In the glaciated plains, the wetland zone FQI of restored catchments also was greater than that of cropped catchments ($F_{1,108}$ = 8.73, P < 0.0001), but there was no difference between restored and native prairie catchments ($F_{1,108}$ = 0.44, P < 0.51).

Species Richness

Native species richness differed among catchment types ($F_{2,100}$ = 16.86, P < 0.0001) and zones within catchment types ($F_{2,108}$ = 8.37, P < 0.0004), regardless of treatment. Semipermanent catchments supported a greater native richness than did seasonal catchments ($F_{1,100}$ = 7.11, P < 0.009), and seasonal catchments were richer in native species than were temporary catchments ($F_{1,100}$ = 11.57, P < 0.001) (fig. B–1). In semipermanent catchments, native richness was greater in the wetland zone than in the upland zone ($F_{1,108}$ = 4.99, P < 0.028), whereas in temporary catchments the upland zone supported more native species than the wetland zone ($F_{1,108}$ = 12.16, P < 0.0007) (fig. B–2). In seasonal wetlands, the richness of native species in the upland and wetland zones was similar ($F_{1,108}$ = 0.05, P < 0.82).

Physiographic region ($F_{1,8}$ = 9.22, P = 0.02), treatment ($F_{4,100}$ = 25.97, P < 0.0001), and the interaction of physiographic region, zone, and treatment ($F_{4,108}$ = 2.68, P < 0.04) also influenced native species richness. Upland native species richness of restored catchments in both the glaciated plains and Missouri coteau was greater than that of cropped catchments (glaciated plains, $F_{1,108}$ = 8.41, P = 0.005; Missouri coteau, $F_{1,108}$ = 18.32, P < 0.0001), but it was lower than that of native prairie catchments (glaciated plains, $F_{1,108}$ = 20.68, P <0.0001; Missouri coteau, $F_{1,108}$ = 118.97, P < 0.0001) (fig. B–4). In contrast, the richness of native wetland plants in restored catchments was similar to that of both cropped ($F_{1,108}$ = 1.98, P < 0.16) and native prairie ($F_{1,108}$ = 0.01, P < 0.92) catchments in the glaciated plains, whereas in the Missouri coteau the richness of native wetland plants in restored catchments was similar to that of native prairie catchments ($F_{1,108}$ = 1.10, P < 0.30) and greater than that of cropped catchments ($F_{1,108}$ = 7.22, P = 0.008).

Table B–1. Distribution of 263 wetland catchments based on land-use treatment, catchment type, and physiographic region (glaciated plains, Missouri coteau) that were evaluated in the Prairie Pothole Region.

	Catchment type					
	Semipermanent		Seasonal		Temporary	
Land-use treatment	Glaciated plains	Missouri coteau	Glaciated plains	Missouri coteau	Glaciated plains	Missouri coteau
Cropland	9	8	11	13	10	10
Restored	28	20	30	38	25	31
Native prairie	5	5	5	5	5	5

Nonnative species richness was greater in the Missouri coteau ($\overline{x} = 5.22 \pm 0.22$) than in the glaciated plains ($\overline{x} = 3.99 \pm 0.22$) regardless of treatment ($F_{1,8} = 15.46$, $P = 0.004$). Differences in nonnative richness also occurred among catchment types ($F_{2,100} = 6.68$, $P = 0.002$) and zones within catchment type ($F_{2,108} = 4.69$, $P = 0.01$) in the absence of treatment. The nonnative richness of semipermanent and seasonal catchments was similar ($F_{1,100} = 1.75$, $P < 0.19$), but both semipermanent ($F_{1,100} = 12.73$, $P = 0.0006$) and seasonal ($F_{1,100} = 5.99$, $P = 0.02$) catchments exhibited greater nonnative richness than did temporary catchments (fig. B–1). In contrast, the upland zone had a richer nonnative plant community than did the wetland zone in all three catchment types (semipermanent, $F_{1,108} = 13.08$, $P = 0.0005$; seasonal, $F_{1,108} = 13.61$, $P = 0.0004$; temporary, $F_{1,108} = 53.82$, $P < 0.0001$) (fig. B–2). Treatment ($F_{4,100} = 6.38$, $P = 0.0001$) and the interaction of treatment and zone ($F_{4,108} = 5.66$, $P = 0.0004$) also influenced nonnative richness. In the upland zone, restored catchments had a richer nonnative plant community than both cropped ($F_{1,108} = 39.42$, $P < 0.0001$) and native prairie ($F_{1,108} = 11.55$, $P = 0.001$) catchments. In the wetland zone, non-native plant richness in restored catchments was similar to both cropped ($F_{1,108} = 2.35$, $P = 0.13$) and native prairie ($F_{1,108} = 0.61$, $P = 0.44$) (fig. B–5) treatments.

Discussion

Our study was conducted to evaluate changes in floristic quality and plant species composition resulting from Federal restoration programs. The best approach for accomplishing this goal is to assess the outcomes of restoration activities in relation to current and future potential landscape scenarios. In the Prairie Pothole Region, agricultural activities largely are responsible for the loss and degradation of both terrestrial and aquatic vegetation communities. In addition, agriculture is, and likely will remain, the predominant land use in this region (Samson and Knopf, 1994). Thus, we selected cropped catchments as our baseline reference for use in assessing improvements on the landscape. At the other extreme, determining if restoration programs are performing at their greatest potential requires comparison to some desired condition. We selected native prairie catchments as the upper benchmark because they are floristically rich and represent the potential upper bound of what could be accomplished with regard to natural vegetation restoration in the Prairie Pothole Region; however, the use of native vegetation conditions as a benchmark does not necessarily equate with the goals of Federal restoration programs, which are diverse and tend to vary depending on specific conservation practices and programs considered.

Table B–2. Number and percent of native and nonnative plant species recorded in 263 catchments in the glaciated plains and Missouri coteau physiographic regions, 2004.

	Native		Nonnative		Total	
Physiognomy	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Cryptogam	4	1.5	0	0.0	4	1.1
Forb						
Annual	44	16.4	22	27.2	66	18.9
Biennial	9	3.4	5	6.2	14	4.0
Perennial	125	46.6	26	32.1	151	43.3
Grass						
Annual	3	1.1	15	18.5	18	5.2
Perennial	38	14.2	11	13.6	49	14.0
Sedge						
Annual	3	1.1	0	0.0	3	0.9
Perennial	21	7.8	0	0.0	21	6.0
Shrub	15	5.6	1	1.2	16	4.6
Tree	5	1.9	0	0.0	5	1.4
Vine	1	0.4	1	1.2	2	0.6
Total	268	100.0	81	100.0	349	100.0

Within this construct, the average upland zone FQI of restored catchments we evaluated was higher than that of cropped catchments but lower than that of native prairie catchments. This trend occurred regardless of catchment type in both the glaciated plains and Missouri coteau. The observed differences between treatments likely were due to a combination of factors, but we suspect that a shift in the type and number of species planted and differences in nonnative species richness were among the most important. Agricultural species are not assigned a *C* value because they are not native to the Prairie Pothole Region, whereas some native species planted as part of conservation programs have moderate *C* values. For example, the *C* values for big bluestem (*Andropogon gerardii*) and little bluestem (*Andropogon scoparius*) are 5 and 6, respectively. Further, agricultural species are favored in cropped catchments owing to cultivation and chemical application, which are designed to eliminate all other species, whereas the intensity and frequency of disturbance are much less on restored lands. Collectively, these changes act to immediately improve FQI of restored upland zones.

Only about four to eight native grass species are typically seeded as part of restoration activities, whereas native prairie upland zones typically support a more diverse flora. Consequently, planting a limited number of native species cannot increase the floristic quality of restored catchments to levels comparable to native prairie conditions. Another factor that may have lowered upland floristic quality in restored catchments relative to native prairie catchments was the presence of more nonnative species. Many terrestrial nonnatives are annual forbs and grasses (Northern Great Plains Floristic Quality Assessment Panel, 2001), many of which are adapted for germination on disturbed soils. Thus, restored upland zones in our study may be more vulnerable, at least initially, to invasion by nonnative species because the process of restoring agricultural lands often includes a period when soils are disturbed and plant cover is minimal. In contrast, native prairie uplands in our study had no previous history of large-scale soil disturbance from farming; thus, the temporal frequency and spatial extent of exposed, disturbed soils has been lower. These results indicate further increases in FQI will require establishment of additional native species, many of which exhibit high site fidelity and are intolerant of disturbance.

In the Missouri coteau, wetland floristic quality exhibited the same general trend as upland floristic quality, with the FQI of restored treatments being intermediate between cropped and native prairie treatments. In the glaciated plains, wetland floristic quality of restored treatments also was greater compared to cropped treatments, but it was similar to native prairie treatments. Unlike upland restoration, wetland restoration techniques evaluated in this study did not include planting

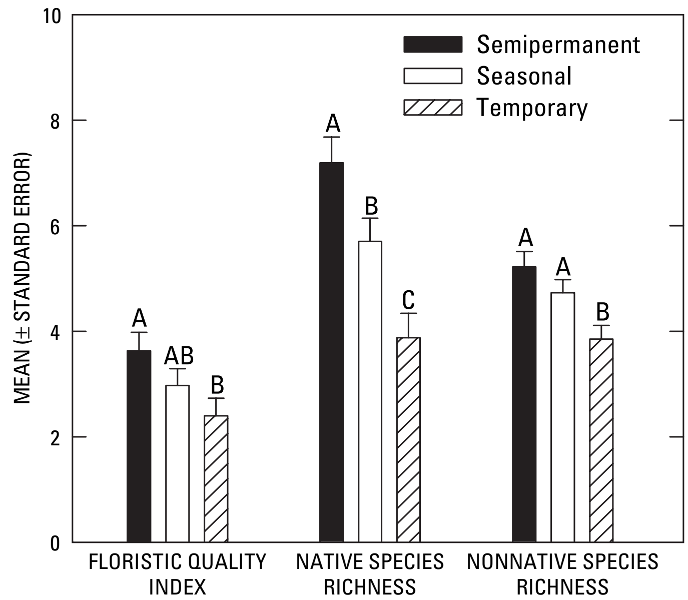

Figure B–1. Differences in floristic quality, native species richness, and nonnative species richness among catchment types (semipermanent, seasonal, temporary). Bars with letters in common within a group are not significantly different (P > 0.05).

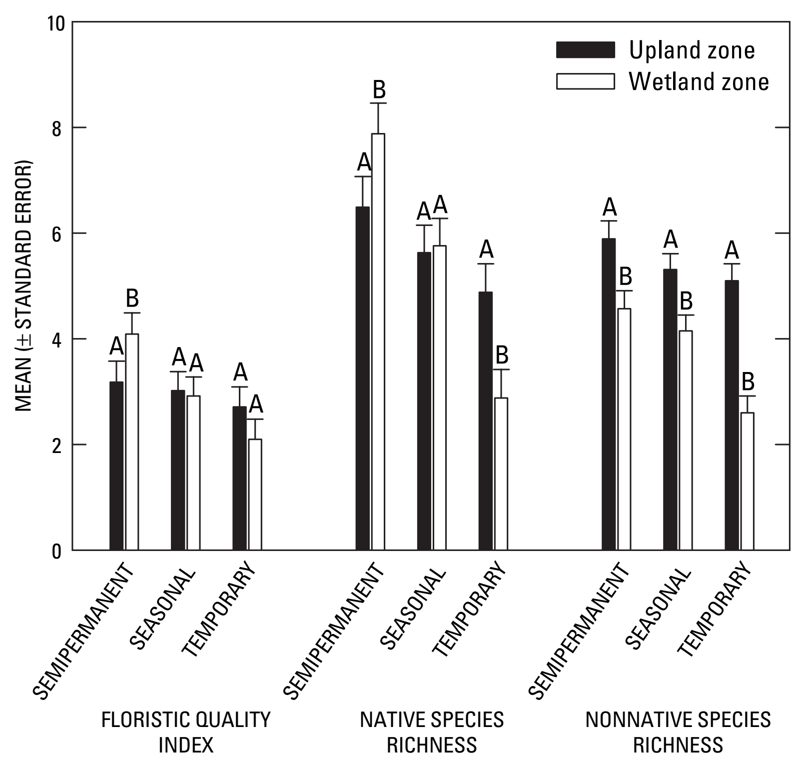

Figure B–2. Differences in floristic quality, native species richness, and nonnative species richness between the upland and wetland zones within a catchment type (semipermanent, seasonal, temporary). Bars with letters in common within a catchment type and group are not significantly different (P > 0.05).

vegetation. Therefore, differences in wetland floristic quality likely were associated with changes in land-use treatments relative to natural wetland processes and extant seed banks. Although many abiotic factors are important in determining floristic quality of wetland zones, hydrologic cycles are among the most important. The frequency, timing, and duration of flooding directly and indirectly influence the primary factors (moisture, temperature, chemistry, and oxygen concentration of the soil) controlling seed germination (Stewart and Kantrud, 1971; Simpson and others, 1989; Cronk and Fennessy, 2001). In native prairie catchments, dynamic hydrologic cycles result in constantly changing environmental conditions that facilitate germination of diverse plant species; hence, floristic quality can change intra-annually and inter-annually. In cropped catchments, however, hydrologic cycles are often curtailed and less variable because modern techniques enable many wetlands to be drained completely and planted to nonnative crops even in wet years. Reduced hydroperiod variability, coupled with planting crops in all or a portion of the wetland, likely contributed to the low floristic quality we observed in wetland zones of cropped catchments. Conversely, improvements in wetland floristic quality likely occurred following either hydrologic restoration or elimination of agriculture in the surrounding lands, such as nondrained restored catchments, because both strategies return hydroperiods to a more natural state. Although we did not examine causal factors, hydrologic restoration strategies would eliminate or reduce discharge of water from ditches; and planting the surrounding catchment to perennial cover can reduce sedimentation rates (see chap. E), lower inputs of agrichemicals and nutrients from surrounding uplands, and attenuate unnatural surface water input to the basin (Neely and Baker, 1989; Euliss and Mushet, 1996; Gleason and Euliss, 1998; chap. D, this report). Our results suggest that the extent to which these restoration techniques are successful depends on physiographic region. Greater $\overline{C}$ values and similar species richness in native prairie treatments compared to restored treatments indicate that greater $\overline{C}$ values are related more to the uniqueness of the plant communities in native prairie treatments than to the number of species per catchment (fig. B–3).

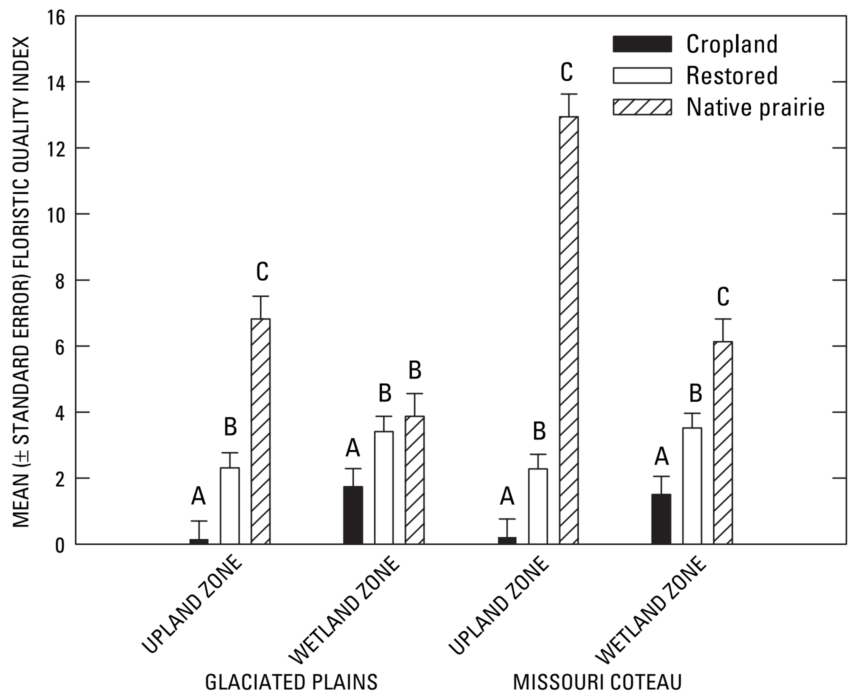

Figure B–3. Floristic quality among land-use treatments (cropland, restored, native prairie) in the upland and wetland zones of surveyed catchments in the glaciated plains and Missouri coteau physiographic regions. Bars with letters in common within a catchment zone and physiographic region are not significantly different (P > 0.05).

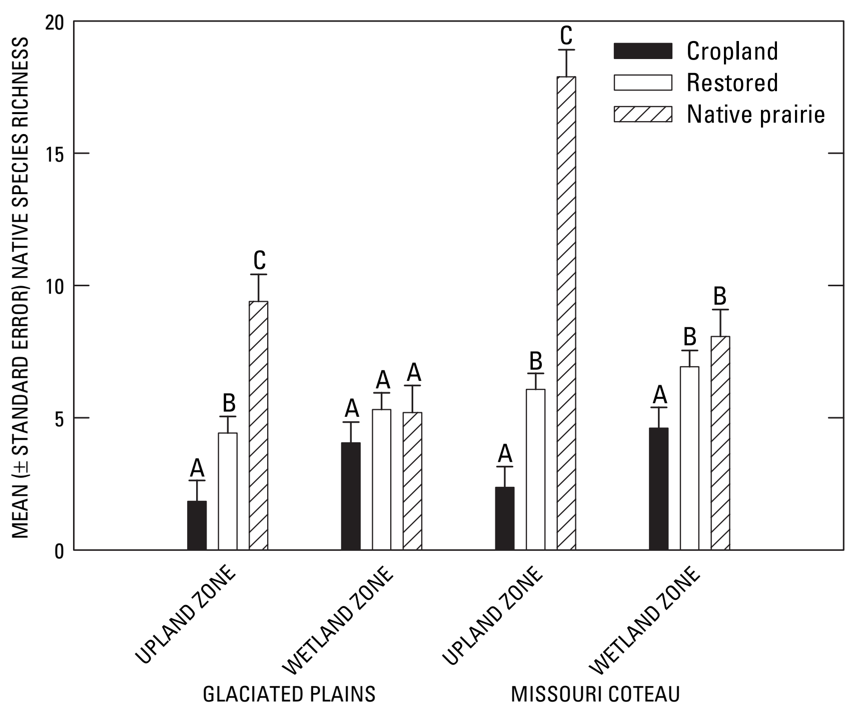

Figure B–4. Native species richness among land-use treatments (cropland, restored, native prairie) in the upland and wetland zones of surveyed catchments in the glaciated plains and Missouri coteau physiographic regions. Bars with letters in common within a catchment zone and physiographic region are not significantly different (P > 0.05).

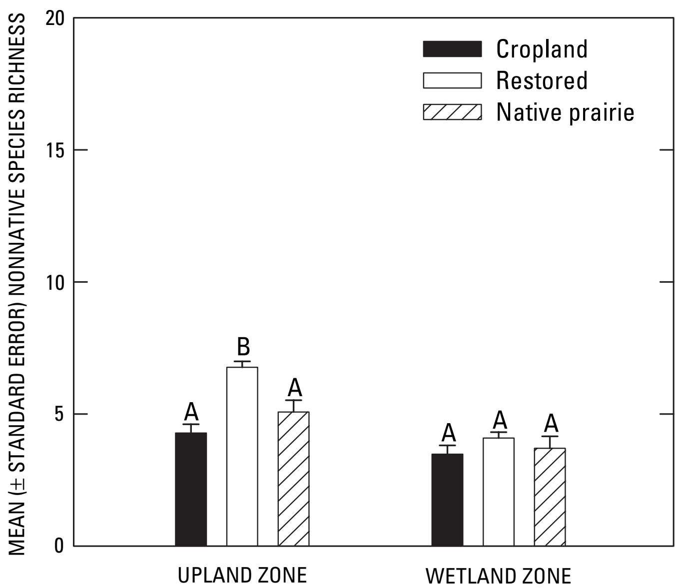

Figure B–5. Mean nonnative species richness among land-use treatments (cropland, restored, native prairie) in the upland and wetland zones of surveyed catchments. Bars with letters in common within a catchment zone are not significantly different ($P > 0.05$).

The lack of interaction between treatment and catchment type suggests that the restoration approaches evaluated in this study are viable regardless of the wetland class that occurs within a catchment; however, our analysis suggests that differences in floristic quality and composition occurred among catchment types because the extent of plant community recovery following restoration may vary by wetland class. Semipermanent catchments exhibited greater floristic quality, native richness, and nonnative richness than did temporary catchments. In contrast, the floristic quality of seasonal catchments was similar to that of both semipermanent and temporary catchments, native species richness was intermediate between that of semipermanent and temporary catchments, and nonnative species richness was similar to that of semipermanent catchments. Causal factors were not examined as part of this study; however, one possible explanation for these differences may be related to abiotic factors (soils, hydrology, topography) that influence the frequency or extent of cropping in catchments supporting different wetland types. Both duration of drainage and cultivation have been demonstrated to reduce species richness and abundance of wetland seed banks that play a critical role in reestablishment of wetland vegetation (Erlandson, 1987; Wienhold and van der Valk, 1989). Catchments supporting temporary wetlands typically can be cropped more frequently and extensively because these wetlands are shallow, typically express surface water only several weeks annually, and can be rapidly drained in most years. In contrast, many semipermanent wetlands are difficult to drain completely because they contain large volumes of water, are connected to groundwater, and often occupy lower topographic position of catchments. Therefore, cropping may change the area of wetland vegetation, but complete tillage of semipermanent catchments is rare, and wetland floristic quality may not be as severely altered because refugia for native plants exist in most years. This conclusion is supported to some extent by differences between the wetland and upland zones of each catchment type. Floristic quality and native species richness were greater in the wetland zone than in the upland zone of semipermanent catchments, whereas this trend was reversed for temporary catchments, although the difference in floristic quality was not significant. The upland and wetland zones of catchments supporting seasonal wetlands, which have hydroperiods intermediate of semipermanent and temporary wetlands, were similar in floristic quality and native species richness.

In summary, our study indicates that the approaches being used to restore catchments in the Prairie Pothole Region are effective in improving floristic quality and native species richness. In general, restoration activities improved floristic quality of both the upland and wetland zones relative to the baseline reference of cropped catchments, but floristic quality did not approach full site potential as defined by native prairie catchments, with the exception of restored wetland catchments in the glaciated plains. The magnitude and significance of change varied depending on wetland class that occupied the catchment (catchment type), physiographic region, and catchment zone. Causal factors for these relationships were not examined, but differences among catchment types occurred independent of treatment effects and may be related to the frequency and extensiveness of cropping that can occur in catchments with different wetland classes. In addition, differences in the floristic quality of upland zones between cropped and restored treatments likely result from conversion of planting agricultural crops to planting a limited mixture of native species, whereas the difference between the restored and native prairie treatment may be due to a combination of higher native species richness and the presence of more species with high site fidelity in the native prairie treatment. Differences in wetland floristic quality among treatments likely were related to hydroperiod and the time since cessation of agricultural planting. The low floristic quality of cropped wetlands likely resulted from a combination of shortened hydroperiods and the planting of agricultural crops. In contrast, the improved floristic quality of restored treatments can be partially explained by the absence of cropping in the wetland and either the direct restoration of hydrology by plugging ditches or, in the case of nondrained wetlands, indirect restoration of hydroperiods by planting uplands to perennial cover. These activities resulted in wetland floristic quality improvements that were similar to native prairie conditions in the glaciated plains, but they achieved only 50 percent of the native prairie wetland floristic quality in the Missouri coteau.

Although our results indicate that restoration activities improved floristic quality, current strategies may be limited in attaining the level of floristic quality and native species richness of native prairie catchments. The primary impediment appears to be the ability to facilitate establishment of plant species with high site fidelity in both the upland and wetland zones. Many of these species tend to have specific germination requirements or occupy precise niches. Therefore, further improvement in floristic quality and native species richness may require refinement of existing restoration techniques to more fully restore critical ecosystem processes, such as hydrology, fire, and grazing; implementing intensive management actions for several years following restoration; or a combination of both activities. Ultimately, determining the adequacy of restoration techniques solely on the basis of floristic quality and richness is ill advised because plant community composition can change rapidly in response to natural variation in abiotic factors and processes as well as in response to human-induced restoration and management activities.

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Chapter C: Carbon Sequestration

By Robert A. Gleason, Brian A. Tangen, and Murray K. Laubhan

Synopsis

In response to concerns over global climate change, many countries are developing strategies to reduce emission of greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). One such strategy is to sequester atmospheric carbon by implementing conservation practices on agricultural lands to enhance soil organic carbon (SOC) sinks (Lal and others, 1998). Policies promoting wetland conservation and restoration, such as the U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP), have led to the restoration of approximately 2.2 million ha (5.4 million acres) of wetland and grassland habitats in the Prairie Pothole Region of the United States. Restoration of grassland and wetland habitats (including wetland catchments) via the CRP or WRP is most often recognized for improving soil and water quality, reducing soil erosion, enhancing flood storage, and creating wildlife habitat (Knutsen and Euliss, 2001); however, these restorations also have had an influence on carbon sequestration and greenhouse gas emissions in the United States. Research suggests that wetlands and grasslands in the Prairie Pothole Region historically were sinks of atmospheric carbon, but cultivation, the current principal land use, shifted their function to net sources of atmospheric carbon (Follett and others, 2001; Euliss and others, 2006). Studies have shown that shifting land use from cultivation to a more natural state often results in replenishment of SOC stocks and the capture and storage of atmospheric carbon. A recent inventory of greenhouse gas emissions and sinks for the United States (U.S. Environmental Protection Agency, 2003) identified restored wetlands and grasslands on lands enrolled in the CRP and WRP as carbon sinks.

Our objective was to evaluate the impact of conservation programs on carbon sequestration in the soils and vegetation communities of restored wetland catchments on program lands. During 2004, a survey of 270 catchments in the Prairie Pothole Region was conducted to evaluate how SOC and vegetation organic carbon (VOC) stocks of restored catchments on program lands vary in relation to cropland and native prairie catchment baselines. Our results demonstrated that catchments with a cultivation history, including those that have been restored and those with cropland, had 12 to 26 percent less SOC in the soil surface (0–15 cm [0–6 in]) than native prairie catchments, depending on physiographic region (Missouri coteau, glaciated plains) and catchment zone (upland, wetland). These results are consistent with the published literature indicating that cultivation reduces native prairie carbon stocks. On the basis of the average difference in SOC (15 $Mg \cdot ha^{-1}$ [6.7 $tons \cdot acre^{-1}$]) between restored and native prairie catchments, we estimated that catchments (444,574 ha [1,098,542 acres]) on program lands in the Prairie Pothole Region have a total of 6,662,355 Mg (7,341,915 tons) less SOC than an equivalent area of native prairie catchments. This estimate of total SOC loss represents the potential amount of SOC that could be replenished by the capture and storage of atmospheric carbon (sequestration) on catchments located on program lands. We were not able to detect a significant increase in SOC stocks in restored catchments relative to cropland baselines, nor were we able to detect a relationship between the time since restoration and carbon content. Consequently, we were unable to calculate a SOC sequestration rate for restored catchments that we could use to estimate the amount of SOC sequestered on program lands; however, on the basis of a published SOC sequestration rate of 0.5 $Mg \cdot ha^{-1} \cdot yr^{-1}$ (0.2 $tons \cdot acre^{-1} \cdot yr^{-1}$) for CRP lands (Follett and others, 2001), catchments on program lands possibly sequester 222,287 $Mg \cdot yr^{-1}$ (244,960 $tons \cdot yr^{-1}$) of SOC. Considering the cumulative annual carbon sequestration since lands have been enrolled in these conservation programs, we estimated a total SOC sequestration of 2,712,714 Mg (2,989,411 tons) for catchment areas on program lands in the Prairie Pothole Region. Further, on the basis of our survey, an additional 715,094 Mg (788,034 tons) of VOC could be stored in the plant biomass in catchment areas. Explanations for our inability to detect changes in restored catchment SOC stocks are discussed and include difficulties inherent to paired-sampling designs and the influence of climatic variations that alter SOC sequestration processes and baselines.

Sequestration of atmospheric carbon in soils and plants following restoration was not an intended outcome when the CRP and WRP were originally implemented. Hence, this benefit is considered an additional ecological service that may contribute to offsetting greenhouse gas emissions. In addition to sequestering carbon, restored catchments also may result in reduction of other greenhouse gas emissions, such as N_2O and CH_4, according to studies conducted outside the Prairie Pothole Region that have demonstrated that nutrient enrichment from agricultural runoff can enhance emissions of greenhouse gases (Merbach and others, 2002). Consequently, converting cultivated cropland to permanent grassland within restored catchments should reduce nutrient enrichment in restored wetlands (see chap. E) and lower emission of N_2O, and possibly CH_4, relative to a cropland baseline.

Methods

Data Collection

During 2004, we collected SOC and VOC samples from 270 wetland catchments in the Prairie Pothole Region (fig. A–3 and table A–3). This sample included catchments containing temporary, seasonal, and semipermanent wetlands in hydrologically restored and nondrained restored catchments on program lands; drained and non-drained catchments on croplands; and native prairie catchments (table A–3). We collected samples along four transects that radiated from the center of the wetland and extended in cardinal directions to the catchment boundary. Along each transect we collected SOC samples to a depth of 30 cm (12 in) in each catchment subzone (shoulder-slope, mid-slope, toe-slope, wet-meadow, shallow-marsh, and deep-marsh) (fig. A–6). Previous work (Euliss and others, 2006) demonstrated that most differences in SOC between farmed and non-farmed wetlands occur within the upper 15 cm (6 in); however, we sampled to a depth of 30 cm (12 in) to ensure compatibility with current and future carbon sink and source inventories for the United States (for example, U.S. Environmental Protection Agency, 2003). A separate soil sample from each subzone was collected for determination of bulk density (total mass per unit volume) to facilitate conversion of nutrient concentrations to mass per unit area. The four SOC samples from each subzone were composited by 0–15 cm (0–6 in) and 15–30 cm (6–12 in) depth increments for determination of physical (particle size) and chemical (extractable phosphorus [P], total and inorganic carbon [C], total and extractable nitrate [NO_3^-], and ammonium [NH_4^+]) attributes by using standard methods (Page and others, 1982; Klute, 1986). In contrast to SOC samples, VOC samples were collected from subzones on only one of the four transects by clipping all aboveground biomass (live and dead) within a 0.25-m^2 (2.7-ft^2) quadrat. For VOC samples, we determined total dry mass, total carbon, total nitrogen, and total phosphorus by following standard methods (Page and others, 1982; Klute, 1986).

Data Analyses

We calculated SOC and VOC content separately for upland and wetland zones in each of the 270 catchments surveyed during 2004. Upland zone estimates included carbon estimates collected from three upland subzones (toe-slope, mid-slope, and shoulder-slope) that occurred in every catchment. In contrast, wetland zone estimates consisted of a combination of three subzones that varied by catchment type (temporary, seasonal, semipermanent) (fig. A–6); in general, one subzone (wet-meadow) occurred in temporary catchments, two subzones (wet-meadow and shallow-marsh) occurred in seasonal catchments, and three subzones (wet-meadow, shallow-marsh, and deep-marsh) occurred in semipermanent catchments.

We used analysis of variance (ANOVA) to test for differences in SOC and VOC among land-use treatments. Sample points used as focal areas from which to select catchments across the climate and land-use gradient of the Prairie Pothole Region were included as a blocking factor (fig. A–5), and our model included physiographic region (Missouri coteau and glaciated plains), catchment type (temporary, seasonal, semipermanent), catchment zone (upland and wetland), land-use treatment (drained and nondrained cropland, hydrologically and nondrained restored, and native prairie), and all possible interactions as independent variables. For significant main effects and interaction terms, we constructed specific ANOVA tests by developing contrast statements with inferences that applied only to the observed levels of random effects to test for differences in carbon among main effects. We constructed treatment-weighted contrasts to test for differences among the following categories: (1) cropland (drained and nondrained cropland categories), (2) restored (hydrologically and nondrained restored categories of all ages), and (3) native (native prairie category). We selected 263 of the 270 catchments sampled (table A–3), of which 128 and 135 occurred in the glaciated plains and Missouri coteau, respectively (7 wetlands were excluded from the analysis because they were restored prior to implementation of the CRP and WRP). We used PROC MIXED of SAS version 8.2 (SAS Institute, Inc., 1999) to conduct all analyses and considered $P \leq 0.05$ as the level of statistical significance for all tests. We used simple linear regression (PROC REG; SAS Institute, Inc., 1999) to examine the relationship of SOC to restoration age (in years).

Results

Soil Organic Carbon

Soil organic carbon in the surface 15 cm (6 in) was affected by treatment ($F_{4,100} = 18.48$, $P < 0.0001$) and the interaction of treatment with physiographic region and catchment zone ($F_{4,108} = 2.82$, $P = 0.0285$) (fig. C–1). Most comparisons of SOC among treatments within physiographic regions indicated that SOC in both the upland and wetland zones was significantly higher in native prairie catchments than in restored and cropland catchments (fig. C–1). The one exception to this trend occurred in the glaciated plains, where SOC in the wetland zone of cropland catchments was not significantly lower than that of native prairie catchments ($F_{1,108} = 2.94$, $P = 0.0891$) (fig. C–1). In the Missouri coteau, SOC in both the upland and wetland zones of restored catchments was lower than that of cropland catchments. In contrast, SOC in the upland and wetland zones of restored catchments in the glaciated plains was similar to that of cropland catchment zones (fig. C–1).

Soil organic carbon at the 15–30-cm depth (6–12-in) was affected by the interaction of treatment with physiographic region and catchment type ($F_{8,100} = 2.48$, $P = 0.0170$). In the Missouri coteau, SOC below 15 cm (6 in) was greater in native prairie semipermanent catchments ($\overline{x}$ = 53.14 ± 4.52 Mg·ha^{-1} [23.70 ± 2.02 tons·acre^{-1}]) than in restored catchments ($\overline{x}$ = 37.26 ± 3.49 Mg·ha^{-1} [16.62 ± 1.56 tons·acre^{-1}]; $F_{1,100}$ = 21.58, P < 0.0001) and cropland catchments ($\overline{x}$ = 41.52 ± 4.16 Mg·ha^{-1} [18.52 ± 1.86 tons·acre^{-1}]; $F_{1,100}$ = 7.47, P = 0.0074). All other comparisons among treatments within physiographic regions and catchment types were not significantly different. Soil organic carbon below 15 cm (6 in) also was affected by the interaction of treatment and catchment zone ($F_{4,108}$ = 2.56, P = 0.0426) (fig. C–2). Carbon below 15 cm (6 in) in the upland zone of restored catchments was lower than that in native prairie catchments ($F_{1,108}$ = 5.20, P = 0.0246) but was similar to that in cropland catchments ($F_{1,108}$ = 0.25, P = 0.6170), whereas SOC in the wetland zone of restored catchments was lower than that in cropland catchments ($F_{1,108}$ = 4.25, P = 0.0417) but similar to that in native prairie catchments ($F_{1,108}$ = 0.09, P = 0.7613). Soil organic carbon in both the upland and wetland zones of cropland catchments was similar ($F_{1,108}$ = 2.95-3.26, P = 0.0738-0.0889) to that in native prairie catchments (fig. C–2). Regression analyses indicated that SOC in restored wetlands did not significantly (P > 0.05) vary with restoration age (fig. C–3).

Vegetation Organic Carbon

Amounts of VOC in standing crops varied significantly among treatments ($F_{4,99}$ = 56.67, P < 0.0001), with greater VOC in restored catchments ($\overline{x}$ = 1.85 ± 0.08 Mg·ha^{-1} [0.83 ± 0.04 tons·acre^{-1}]) compared to native prairie catchments ($\overline{x}$ = 1.47 ± 0.14 Mg·ha^{-1} [0.66 ± 0.06 tons·acre^{-1}]; $F_{1,99}$ = 7.52, P = 0.0073) and cropland catchments ($\overline{x}$ = 0.24 ± 0.011 Mg·ha^{-1} [0.11 ± 0.005 tons·acre^{-1}]; $F_{1,99}$ = 225.8, P < 0.0001). Native prairie catchments had significantly greater ($F_{1,99}$ = 60.79, P < 0.0001) VOC stores than did cropland. Based on differences in average VOC stores among restored and cropland catchments, we estimated that restoration of catchments (444,574 ha [1,098,542 acres]) on program lands has resulted in a net VOC storage gain of 715,094 ± 60,412 Mg (788,034 ± 66,574 tons) (table C–1).

Discussion

We conducted a regional assessment of SOC stocks in the Prairie Pothole Region to evaluate how carbon in restored wetlands varied in relation to cropland and native prairie catchment baselines. Our results indicate that SOC stocks in the surface soil (0–15 cm [0–6 in]) of wetland and upland zones in both physiographic regions was significantly lower in restored catchments than in native prairie catchments (fig. C–1). In nearly all cases cropland catchments also had significantly lower SOC stocks than native prairie catchments; however, for one comparison in the glaciated plains, SOC in the wetland zone of cropland catchments ($\overline{x}$ = 52.88 ± 3.29 Mg·ha^{-1} [23.58 ± 1.47 tons·acre^{-1}]) was not significantly ($F_{1,108}$ = 2.94, P = 0.0891) lower than that in native prairie catchments ($\overline{x}$ = 58.78 ± 3.77 Mg·ha^{-1} [26.22 ± 1.68 tons·acre^{-1}]). Collectively, our results suggest that catchments with a cultivation history have lost SOC relative to a native prairie baseline. Overall, previously farmed catchments in the glaciated plains had 12 and 26 percent less SOC in the upland and wetland zones, respectively, than did native prairie catchments. Similarly, previously farmed catchments in the Missouri coteau had 20 and 26 percent less SOC in the upland and wetland zones, respectively, than did native prairie catchments. Our findings are consistent with other studies demonstrating that conversion of native prairie to cultivated agricultural land often reduces carbon stocks by 20 to 50 percent or more (Mann, 1986; Anderson, 1995; Cihacek and Ulmer, 1995).

Presumably, the lowered SOC in previously farmed wetlands represents carbon losses from oxidation by cultivated agriculture. On average, restored catchments had 15 Mg·ha^{-1} (6.69 tons·acre^{-1}) less SOC in the upper 15 cm (6 in) than did native prairie catchments. On the basis of this estimate, the 444,574 ha (1,098,542 acres) of catchments on program lands in the Prairie Pothole Region would have a total of 6,662,355 Mg (7,341,915 tons) less SOC than would an equivalent area of native prairie catchments.

The above estimate of total SOC loss represents the potential amount of SOC that could be replenished through carbon sequestration on program lands, but it does not address the rate of SOC replenishment. When grasses and forbs are reestablished in the upland zone of croplands, SOC stocks generally increase as a result of carbon sequestration by plants. Though estimates are highly variable, studies have demonstrated that conversion of cropland to grassland on CRP lands results in carbon sequestration rates of approximately 0.5–1.0 Mg·ha^{-1}·yr^{-1} (0.22–0.45 tons·acre^{-1}·yr^{-1}; for example, Follett and others, 2001). A commonly applied approach to estimate carbon sequestration rates is to compare SOC stocks on restored lands to cropped sites that are as similar as possible with respect to edaphic and climatic factors. In our study we used a similar approach to estimate carbon sequestration rates; however, we were unable to detect a significant increase in SOC of restored catchments relative to a cropland baseline. Rather, we found that carbon stocks were significantly higher in cropland than in restored catchments in the Missouri coteau, whereas carbon stocks were statistically similar between restored and cropland catchments in the glaciated plains (fig. C–1). Further, we were unable to detect a linear increase in carbon with restoration age (fig. C–3). Therefore, we were unable to estimate carbon sequestration rates by using a paired-sampling design for restored and cropland catchments, nor were we able to estimate rates by using a relationship between carbon stocks and restoration age. In contrast, a previous study in the Prairie Pothole Region did show a positive relationship between wetland zone SOC and restoration age for semipermanent catchments but not for seasonal catchments (Euliss and others, 2006). Upland zones were not examined by Euliss and others (2006).

The rate at which SOC stocks change is likely a function of climate, cropping history, type of plants seeded, landscape position, hydrology, soil characteristics, and time. Ideally, all of these factors are considered when pairing restored catchments to cropped catchments. In reality, however, the pairing of restored catchments to cropland catchments is extremely difficult because a given catchment often is not uniform with respect to abiotic features. For example, most catchments in our study included two to three soil mapping units. Further, the position of catchments in the landscape influences surface-water and ground-water hydrology which in turn are affected by inter-annual and intra-annual climatic conditions. Such variation in hydrology influences plant communities that develop following restoration. Even when soil factors and catchment types (temporary, seasonal, and semi-permanent) are relatively well matched, restored and cropland catchments often have very different cropping histories, such as tillage practices, crop type, and crop rotations, that greatly influence SOC stocks. Collectively, the difficulties associated with paired-sampling designs likely contributed to wide variation in SOC values and our inability to detect measurable increases in SOC on restored lands. Other studies that have used paired-sampling designs also have observed variable SOC sequestration rates, including SOC estimates for cropland sites that exceed those for restored grassland sites on CRP lands (for example, Follett and others, 2001).

Conducting studies to estimate carbon sequestration rates of restored catchments may require long-term monitoring, including SOC measurements before and after restoration, rather than paired-sampling designs. Future studies also should consider how carbon sequestration rates and SOC baselines vary in relation to climatic variation. We believe that some of the observed variation in SOC estimates within and between different restoration age classes (fig. C–3) may be related more to climatic conditions before, during, and after a site is restored rather than to restoration age. For example, wet and dry cycles in the Prairie Pothole Region greatly influence the intensity and frequency that catchments are cultivated and the cycling of vegetation within wetland catchments. Farmable wetlands often are cultivated during dry periods, which contribute to oxidation and loss of SOC. In contrast, these wetlands are not cultivated during wet periods, which results in increased carbon sequestration by the plant communities that typically develop. Hence, wet and dry conditions prior to restoration may explain why some recently restored wetlands had higher carbon stocks than did wetlands restored for longer periods (fig. C–3). This potential climatic effect might also explain some of the variation in SOC within restoration age class and why cropland catchments had similar or higher SOC than did some restored wetlands (fig. C–1).

Once wetlands are restored, wet and dry cycles also are expected to greatly influence carbon sequestration rates and processes (belowground primary production and sedimentation). In general, wetland vegetation communities exhibit the following four phases in response to water-level fluctuations during wet and dry cycles: dry marsh, regenerating marsh, degenerating marsh, and lake marsh (van der Valk and Davis, 1978). The first two phases, dry marsh and regenerating

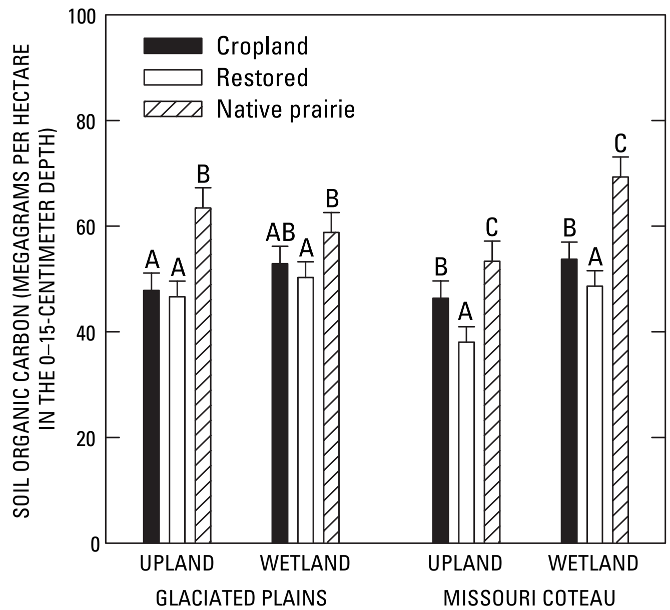

Figure C–1. Soil organic carbon in the surface soil (0–15 cm [0–6 in]) among land-use treatments (cropland, restored, native prairie) in the upland and wetland zones of surveyed catchments in the glaciated plains and Missouri coteau physiographic regions. Bars with letters in common within a catchment zone and physiographic region are not significantly different (P > 0.05).

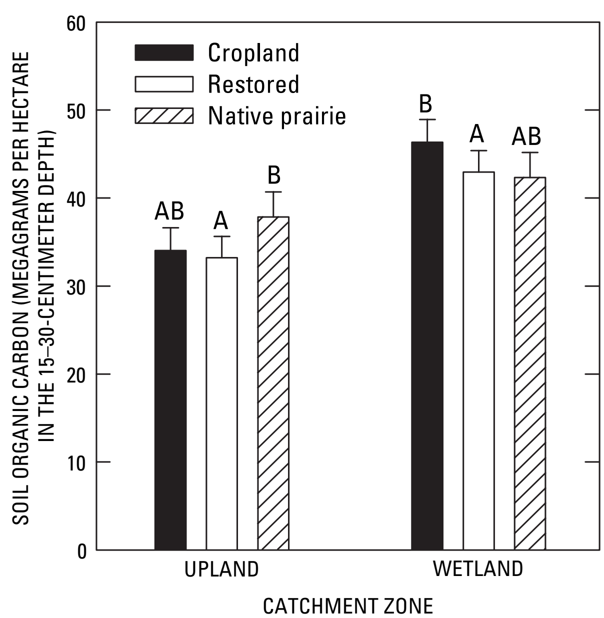

Figure C–2. Soil organic carbon at soil depths between 15 and 30 cm (6 and 12 in) among land-use treatments (cropland, restored, native prairie) in the upland and wetland zones. Bars with letters in common within a catchment zone are not significantly different (P > 0.05).

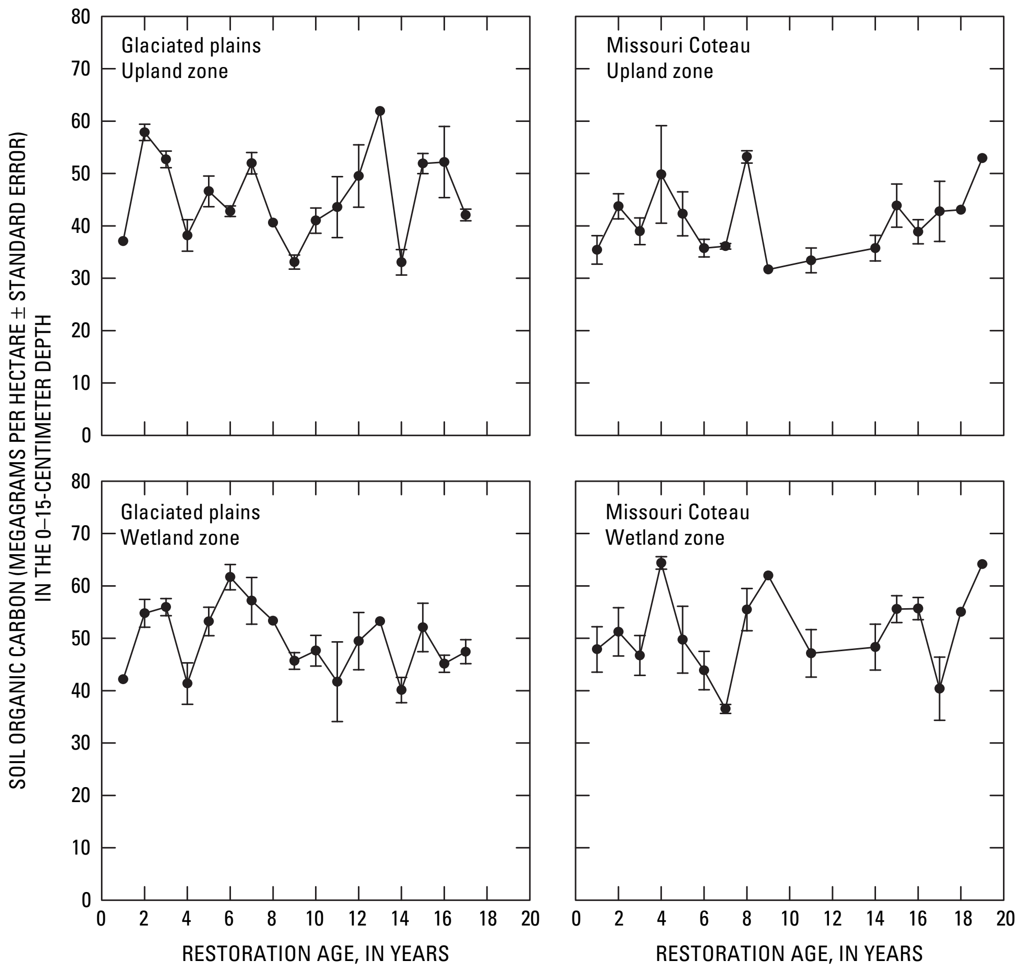

Figure C–3. Relationship of soil organic carbon content in the 0–15 cm (0–6 in) soil depth to age of restored catchments by catchment zone (upland and wetland) and physiographic region (glaciated plains and Missouri coteau).

marsh, generally occur during dry to moderately wet conditions, respectively. During these phases, production of belowground biomass by emergent vegetation typically develops rapidly and likely is the primary process that contributes to development of soil organic matter and sequestration of carbon. The latter two phases (degenerating marsh and lake marsh) occur during prolonged wet periods, and high water levels typically result in the death of emergent vegetation and development of floating aquatic plants that contribute to carbon sequestration. During the degenerating marsh and lake phases, death of emergent plants and floating aquatic vegetation results in the sedimentary accumulation of organic matter. Burial of this organic matter through sedimentary processes in prairie wetlands has been estimated to be approximately 0.83 $Mg{\cdot}ha^{-1}{\cdot}yr^{-1}$ (0.37 $tons{\cdot}acre^{-1}{\cdot}yr^{-1}$) (Euliss and others, 2006). On the basis of this information, two assumptions about SOC can be made regarding variability in carbon sequestration processes relative to wetland phases: (1) the greatest contribution to SOC would occur during the dry marsh and regenerating marsh phases, when primary production of belowground biomass is highest, and (2) direct contributions to SOC would be expected to be lower during the degenerating marsh and lake phases, when rooted emergent plants are replaced by floating aquatic vegetation communities, whereas sedimentary carbon sequestration may be higher. Given this construct, restoration age would influence the rate of carbon sequestration less than would the dominant phases expressed by a restored wetland.

Our study included sites that had been restored over a 19-year period (1986–2004), a timespan that included one of the most extreme dry and wet cycles recorded during the last 100 years in the Prairie Pothole Region. This cycle likely influenced SOC baselines and carbon-sequestration rates and processes in catchments. Considering the importance of climatic variation on vegetation community phases and carbon sequestration processes and baselines, we examined how climatic conditions varied from 1986 to 2004 in relation to restoration age and SOC of restored wetlands. We plotted the Palmer Drought Severity Index (PDSI) with SOC of restored wetlands and their restoration age (fig. C–4). The PDSI is a measure of dryness, with zero indicative of normal conditions, positive numbers indicative of wet conditions, and negative numbers indicative of drought conditions. Variation in the PDSI over the past 19 years indicates two pronounced climate phases. The first phase (1986–96) included a period of extreme drought (1986–92) followed by an extreme wet period (1993–96). The second phase (1997–2004) showed a transition from extreme wetness to less moist conditions (fig. C–4). The relationship between the SOC content of restored wetlands to climatic variation as indicated by the PDSI cannot be quantified with the available data; however, the extreme variation in climatic conditions does provide a platform from which to discuss how cropland and restored SOC baselines may have varied over the past 19 years. As indicated earlier, we have frequently observed that many farmable catchments are only cultivated during dry periods. In contrast, with the exception of well-drained wetlands, catchments are infrequently cultivated during pronounced wet periods (for example, 1993–2001) (fig. C–4) and robust emergent vegetation often develops. Essentially, during wet periods, farmable catchments may sequester carbon at rates similar to those of restored catchments. Given this scenario, we would expect a restored wetland to have SOC stocks similar to those of a cropland wetland that, because of wet conditions, had not been cultivated and was flooded like a restored wetland. Consequently, the amount of SOC in cropland catchments likely oscillates over wet and dry cycles that influence intensity and frequency of cultivation activities. The prevalence of above normal moisture conditions over the past decade likely resulted in cropland catchments having higher SOC stocks than would have occurred during dryer periods. Likewise, SOC baselines in recently restored catchments would vary depending on the intensity and frequency of cultivation activities prior to restoration. It has only been in the last few years that farmers have been able to reclaim and cultivate farmable catchments. Reclaiming these catchments usually results in tillage that

Table C–1. Net carbon gain stored in plant biomass (vegetation organic carbon [VOC]) when cultivated cropland is planted to perennial cover as part of the Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) in the Prairie Pothole Region. Net gain is the difference between CRP/WRP and cropland estimates.

[CRP, Conservation Reserve Program; WRP, Wetland Reserve Program; ha, hectare; Mg, megagram; SE, standard error]

			CRP/WRP	Cropland	Net gain
State	Program	Area, ha (acre)	Mg carbon ± SE (tons ± SE)	Mg carbon ± SE (tons ± SE)	Mg carbon ± SE (tons ± SE)
Iowa	CRP	53,182 (131,413)	98,387 ± 4,255 (108,422 ± 4,689)	12,764 ± 5,850 (14,066 ± 6,447)	85,623 ± 7,234 (94,357 ± 7,972)
	WRP	11,184 (27,636)	20,690 ± 895 (22,800 ± 986)	2,684 ± 1,230 (2,958 ± 1,355)	18,006 ± 1,521 (19,843 ± 1,676)
Minnesota	CRP	134,873 (333,271)	249,291 ± 10,780 (274,719 ± 11,880)	32,340 ± 14,823 (35,639 ± 16,335)	216,951 ± 18,328 (239,080 ± 20,197)
	WRP	7,934 (19,605)	14,672 ± 634 (16,169 ± 699)	1,903 ± 872 (2,097 ± 961)	12,769 ± 1,079 (14,071 ± 1,189)
Montana	CRP	8,869 (21,915)	16,408 ± 710 (18,082 ± 782)	2,129 ± 976 (2,346 ± 1,076)	14,279 ± 1 ,206 (15,735 ± 1,329)
North Dakota	CRP	171,767 (424,436)	317,231 ± 13,718 (349,589 ± 15,117)	41,154 ± 18,862 (45,352 ± 20,786)	276,077 ± 23,323 (304,237 ± 25,702)
	WRP	553 (1,366)	1,021 ± 44 (1,125 ± 48)	132 ± 61 (145 ± 67)	889 ± 75 (980 ± 83)
South Dakota	CRP	54,685 (135,127)	101,167 ± 4,375 (111,486 ± 4,821)	13,124 ± 6,015 (14,463 ± 6,629)	88,043 ± 7,438 (97,023 ± 8,197)
	WRP	1,527 (3,773)	2,823 ± 122 (3,111 ± 134)	366 ± 168 (403 ± 185)	2,457 ± 208 (2,708 ± 229)
Total CRP		423,376 (1,046,162)	782,484 ± 33,838 (862,297 ± 37,289)	101,511 ± 46,526 (111,865 ± 51,272)	680,973 ± 57,529 (750,432 ± 63,397)
Total WRP		21,198 (52,380)	39,206 ± 1,695 (43,205 ± 1,868)	5,085 ± 2,331 (5,604 ± 2,569)	34,121 ± 2,883 (37,601 ± 3,177)
Total Prairie Pothole Region		444,574 (1,098,542)	821,690 ± 35,533 (905,502 ± 39,157)	106,596 ± 48,857 (117,469 ± 53,840)	715,094 ± 60,412 (788,034 ± 66,574)

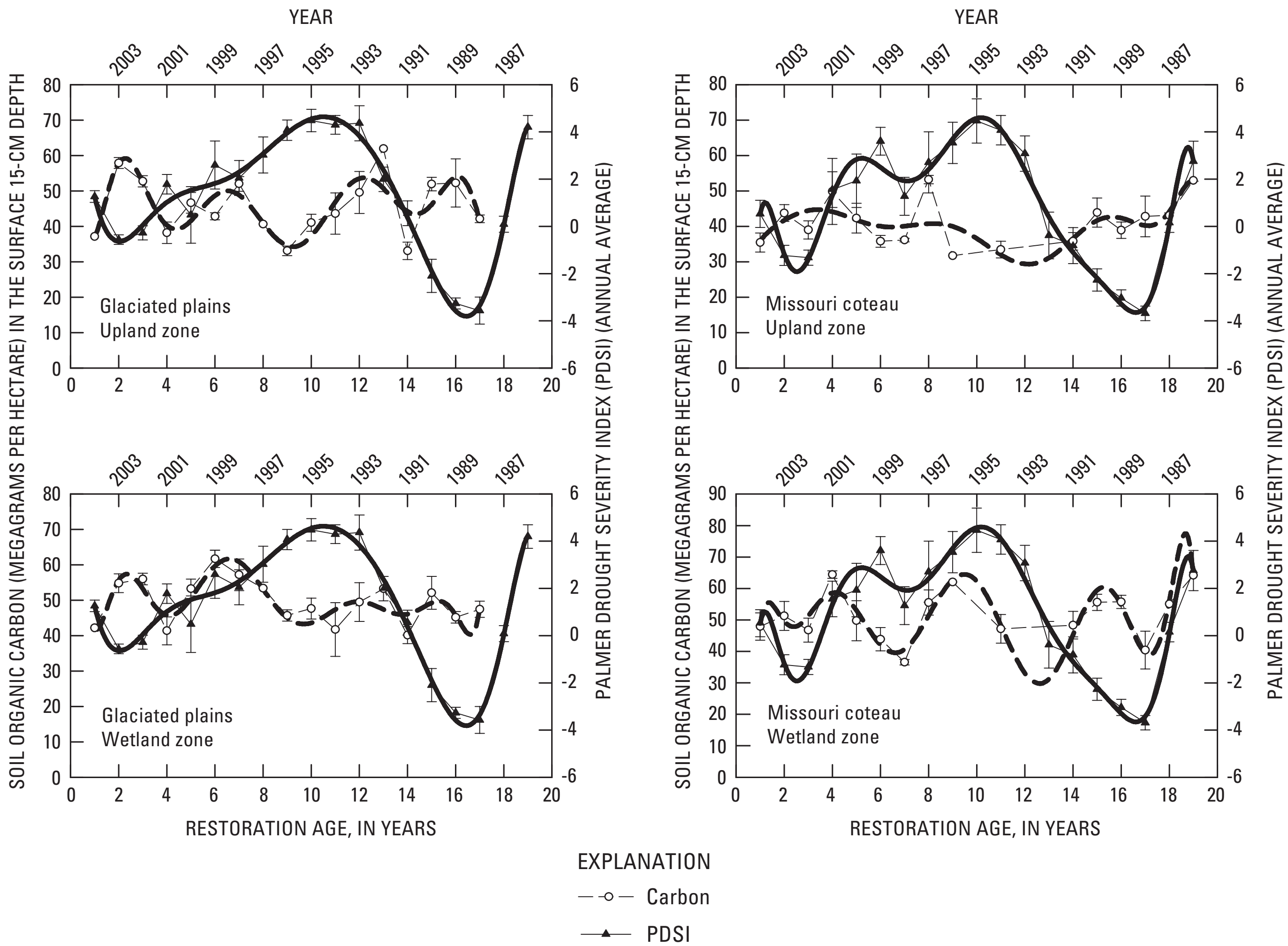

Figure C–4. Relationship of soil organic carbon content of restored catchments to restoration age and the Palmer Drought Severity Index (PDSI) (bold lines represent a smoothing function).

incorporates any robust emergent vegetation that developed into the soil. Incorporation of this vegetative biomass would increase SOC and may explain why wetland zones of cropland catchments had higher SOC than did restored catchments (figs. C–1 and C–2); however, with continued dry conditions that would facilitate repeated cultivation, we expect that much of the SOC from incorporation of emergent vegetation would ultimately be oxidized and lost to the atmosphere.

The previous examples depict how SOC baselines can oscillate in response to climatic conditions. Understanding how SOC varies in relation to climate is critical to allow meaningful comparisons of SOC of restored catchments to cropland catchments or to compare SOC within and between restoration ages. The question still remains, however, "How much carbon has been sequestered on program lands?" We were unable to estimate a SOC sequestration rate for restored catchments that we could use to estimate how much SOC has been sequestered on the 444,574 ha (1,098,542 acres) of restored catchments on program lands in the Prairie Pothole Region. Published literature, however, indicates that conversion of cropland to grassland on CRP lands results in carbon sequestration rates of 0.5–1 $Mg \cdot ha^{-1} \cdot yr^{-1}$ (0.22–0.45 $tons \cdot acre^{-1} \cdot yr^{-1}$) (for example, Follett and others, 2001), and Euliss and others (2006) estimated that restored wetland catchments have potential to sequester up to 3 $Mg \cdot ha^{-1} \cdot yr^{-1}$ (1.34 $tons \cdot acre^{-1} \cdot yr^{-1}$). Using the most conservative of the published sequestration rates (0.5 $Mg \cdot ha^{-1} \cdot yr^{-1}$ [0.22 $tons \cdot acre^{-1} \cdot yr^{-1}$]), we estimated that 222,287 $Mg \cdot yr^{-1}$ (244,960 $tons \cdot yr^{-1}$) could be sequestered on program lands. When considering the cumulative annual carbon sequestration since lands have been enrolled in conservation programs, we estimated a total SOC sequestration of 2,712,714 Mg (2,989,411 tons).

In addition to replenishment of SOC stocks, the vegetative community that rapidly develops in restored catchments represents an additional pool of sequestered carbon. We estimated that an additional 715,094 Mg (788,034 tons) of VOC could be stored on program lands (table C–1), which equates to approximately 1.6 $Mg \cdot ha^{-1}$ (0.71 $tons \cdot acre^{-1}$) of restored catchment. On the basis of these projections, it appears that substantial atmospheric carbon can be stored in the emergent vegetation of restored wetlands. Though carbon stored in vegetation often is viewed as being susceptible to loss from disturbances, such as fire, vegetative communities often quickly reestablish. Given the resilient nature of plant communities, carbon storage in vegetation is an almost immediate and rather constant form of carbon storage.

In summary, SOC sequestration is considered an ancillary benefit of USDA conservation programs because climate change mitigation was not an intended outcome when the CRP and WRP were originally implemented. Hence, it is considered an additional ecological service that may contribute to offsetting greenhouse gas emissions. As demonstrated by our work, more research is necessary to quantify rates of atmospheric carbon sequestration and its storage in the soil and vegetation on program lands. In addition to sequestering carbon, conservation programs also may influence emission of other greenhouse gases such as N_2O and CH_4. Though there is little information on N_2O and CH_4 emissions from prairie wetlands, studies outside the Prairie Pothole Region have demonstrated that nutrient enrichment from agricultural runoff can influence emission of these greenhouse gases (Merbach and others, 2002). Consequently, converting cultivated cropland to perennial grassland within restored catchments should reduce nutrient enrichment in restored wetlands (see chap. E) and could lower emission of N_2O and CH_4 relative to a cropland baseline. Any reduction in emissions of CH_4 and N_2O that results from restorations relative to a cropland baseline would represent an additional greenhouse gas reduction benefit.

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Chapter D: Floodwater Storage

By Robert A. Gleason and Brian A. Tangen

Synopsis

Traditionally wetlands in the Prairie Pothole Region have been considered valuable resources for attenuating and storing water that would otherwise contribute to offsite or "downstream" flooding, but the current status of floodwater storage potential of wetlands in the Prairie Pothole Region is vague. Wetland drainage for agricultural use has significantly decreased wetland storage volume (Dahl, 1990; Dahl and Johnson, 1991), and this reduction has been linked to increased frequency of flooding in the Prairie Pothole Region (Brun and others, 1981; Miller and Frink, 1984; Miller and Nudds, 1996; Manale, 2000). In an effort to mitigate wetland losses, numerous wetlands have been restored through various Federal, State, and private programs. For example, during the past 19 years, enrollment in the U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) has resulted in the restoration of approximately 168,554 ha (416,497 acres) of wetlands on 2,199,476 ha (5,434,905 acres) of program lands in the Prairie Pothole Region (table A–1). Aside from wildlife benefits (see chap. F), floodwater attenuation is one of the most widely recognized ecosystem services provided by restored wetlands, even though estimates of storage potential are lacking.

The objective of this chapter is to quantify the water-storage potential of wetlands on program lands in the Prairie Pothole Region. To address this goal we used morphometry data collected on 497 wetlands in the Prairie Pothole Region to develop models that define relationships between wetland surface area, wetland volume, and upland zone area. These models were used to estimate maximum water-storage capacity and interception area of wetlands on program lands. We estimated that wetland catchments on program lands in the Prairie Pothole Region could intercept precipitation across approximately 444,574 ha (1,098,542 acres) and store approximately 56,513 ha-m (458,151 acre-ft) of water if filled to maximum capacity, which equates to an average storage volume of 0.34 ha-m·ha^{-1} (1.1 acre-ft·acre^{-1}) of wetland. Water-storage estimates presented in this paper are believed to provide a reasonable first approximation of flood-storage benefits derived from USDA conservation programs in the Prairie Pothole Region, but estimates likely are conservative because databases used to estimate total wetland area tend to underestimate wetland areas on lands in the Prairie Pothole Region. Further, our static estimates of maximum wetland water storage do not account for dynamic hydrologic processes, such as evapotranspiration, ground-water recharge, and infiltration, that slow the rates that wetlands fill. Consequently, the flood-storage service provided by wetlands is greater than the maximum total water-storage potential reported in this study. Essential to future development and application of methods to quantify flood-storage benefits is the availability of quality spatial data that can be used to determine important habitat features, such as individual wetlands, and specific management actions, such as hydrologic restoration, nondrained restoration, seeded areas, nonseeded areas, that affect water input rates and amounts of water storage. Availability of such data will facilitate application of models to better quantify dynamic floodwater-storage benefits at both site-specific and watershed scales.

Methods

Topographic Surveys

We used morphometry data collected on 497 depressional wetland catchments, including 386 catchments sampled during the 1997 and 2004 surveys (tables A–2, A–3, and fig. A–3) and 111 catchments surveyed as part of other U.S. Geological Survey studies (Gleason and others, 2007). Morphometry of each catchment was surveyed by using a Nikon model DTM 750 total station during 1997 and a Trimble 5700 GPS system during 2004. Features surveyed included drainage plugs, tile drains, surface outlets and inlets, and surface water elevation. We used the software program ForeSight (Tripod Data Systems, 1997) to compute the surface area and volume of the wetland zone and the surface area of the upland zone (fig. A–6). The maximum area of the wetland zone was based on the elevation at which surface water would flow out of the wetland (fig. A–6). Wetland volume was determined by specifying the maximum elevation of the wetland in ForeSight and calculating the fill volume for each wetland polygon. The upland zone is defined as the area that contributes surface runoff to a wetland and was defined by interpreting contour maps and digital elevation models constructed by using the survey data. Upland areas sloping toward a wetland basin were considered part of the catchment, whereas areas sloping away from the wetland basin were considered outside of the catchment.

Model Development

We used linear regression analysis (SAS Institute, Inc., 2003) to determine the relationship of wetland zone area to wetland volume and upland zone area. For all regression models, areas and volumes were transformed by using the natural logarithm. Initial results indicated that relationships among variables differed among each of the physiographic regions of the Prairie Pothole Region, which vary in topographic relief (fig. A–3). Therefore, we developed unique models for each physiographic region to improve estimates. Coefficients of determination (r^2) for wetland volume regression models varied from 0.91 to 0.94 and for upland zone models ranged from 0.49 to 0.65 (table D–1). Across a range of wetland surface areas (1–10 ha [2.47–24.7 acres]) typical of the Prairie Pothole Region, our models predicted greater storage volumes and upland zone areas for catchments in the prairie coteau, followed by the Missouri coteau and glaciated plains (fig. D–1).

Estimating Water Storage, Upland Zones of Catchments, and Interception Areas

The regression models we developed generally are applied to surface areas of individual depressional wetlands, but this information was not available for wetlands on program lands. Since data on individual wetlands were not available as inputs for models presented in table D–1, we calculated a mean wetland area for seasonal and semipermanent wetlands surveyed in 2004 (table A–3). This mean wetland surface area of 1.6 ± 0.1 ha (4.0 ± 0.2 acres) was input into our region-specific models (table D–1) to estimate an average storage volume and upland zone area per hectare of wetland. The region-specific estimates were applied to the total area of wetlands on program lands (table A–1) within each State/Major Land Resource Area (MLRA) combination (fig. A–4). For State-MLRA combinations that occurred in more than one physiographic region, we assigned estimates from the physiographic region that encompassed the most land area. Application of this approach assumes that the average surface area of seasonal and semipermanent wetlands entered into models is representative of wetland sizes on program lands. Seasonal and semipermanent wetlands were chosen because they are the most common catchment types restored on program lands. More precise estimates could be calculated if surface areas of individual wetlands on program lands were available.

Wetland and upland zone areas were combined to estimate the area of the entire catchment, which is also called the interception area of the wetland (fig. A–6). The interception area represents an area that intercepts precipitation and does not route surface water “downstream” in a watershed unless the wetland fills to capacity and overflows. Estimates of the upland zone and entire catchment areas were constrained by the area of land enrolled in conservation programs: the area of wetland catchments could not be greater than the area of land enrolled in conservation programs. This situation frequently occurs when wetlands are located in small tracts of conservation program lands that contain wetland zone areas but not the entire area of upland zones.

Results

We estimated that wetlands on program lands in the Prairie Pothole Region have a maximum water-storage capacity of 56,513 ha-m (458,151 acre-ft), with 53,680 ha-m (435,184 acre-ft) occurring on CRP lands and 2,833 ha-m (22,967 acre-ft) on WRP lands (table D–2). This estimate translates to an average storage volume of 0.34 ha-m·ha^{-1} (1.1 acre-ft·acre^{-1}) of wetland. Total area of upland zones associated with wetlands was estimated to be 276,021 ha (682,048 acres) (table D–3) or approximately 1.6 ha (4.0 acres) of upland zone per hectare of wetland. Estimated catchment area was 444,574 ha (1,098,542 acres), which accounts for 20 percent of the total land area (2,199,476 ha [5,434,905 acres]) enrolled in the CRP and WRP in the Prairie Pothole Region.

Discussion

Attempts to estimate water-storage potential of program and nonprogram wetlands in the Prairie Pothole Region are constrained by lack of information on wetland volumes and catchment areas. The primary constraint is inadequate resolution of available databases, such as topographic and digital elevation maps, to determine the bathymetry of individual depressional wetlands. Given this constraint, we developed models that defined relationships between wetland surface area, wetland volume, and upland zone area (table D–1). For all models developed, wetland surface area was strongly correlated to wetland volume (r^2 = 0.91–0.94) and upland zone area (r^2 = 0.49–0.65) (table D–1). Many other studies have used similar approaches to estimate wetland volumes from surface area estimates (Haan and Johnson, 1967; Best, 1978; Best and Moore, 1979; Hubbard, 1982; Bell and others, 1999; Bengtson and Padmanabhan, 1999; Hayashi and van der Kamp, 2000; Wiens, 2001; Gleason and others, 2007). Ideally, input data for these models would include the area of individual wetland basins, which often can be acquired from available spatial databases such as the National Wetlands Inventory (NWI). At the time of our study, however, information on areas of individual wetland basins on program lands was not available. Therefore, we used the mean size of wetlands surveyed for this study as a model input to estimate wetland storage volumes and upland areas per hectare of wetland. These estimates were applied to estimates of total wetland areas on program lands to calculate volumes and upland zone areas. Using this approach, we estimated an average storage volume of 0.34 ha-m·ha^{-1} (1.1 acre-ft·acre^{-1}) of wetland and an average upland zone area of 1.6 ha (4.0 acres) per hectare of wetland, which are within the range of values found in other studies (Haan and Johnson, 1967; Best, 1978; Best and Moore, 1979; Hubbard, 1982; Arndt and Richardson, 1988; Bell and others, 1999; Bengtson and Padmanabhan, 1999; Hayashi and van der Kamp, 2000; Wiens, 2001).

We believe that our estimates provide a reasonable first approximation of the potential flood-storage benefit derived from USDA programs. The greatest source of uncertainty associated with our storage estimate is the estimate of total wetland area on program lands. The availability of quality spatial data that can be used to differentiate habitat features of interest, such as individual wetlands, and specific management actions, such as hydrologic restoration, nondrained restoration, seeded areas, and nonseeded areas, is critical to future development and application of methods to estimate any ecological service derived from conservation programs. Existing databases, such as the NWI, can be used to identify some wetlands on program lands, but many drained wetlands that are subsequently restored often are not mapped by NWI (Gleason and others, 2007). Consequently, development of a spatial database of wetlands on program lands likely will require the use of existing spatial databases in conjunction with input from field personnel responsible for implementing USDA conservation practices.

We estimated that wetland catchments on program lands in the Prairie Pothole Region could intercept precipitation across approximately 444,574 ha (1,098,542 acres) and could store approximately 56,513 ha-m (458,151 acre-ft) of water if filled to maximum capacity. These estimates suggest that wetlands on program lands have significant potential to intercept and store precipitation that otherwise might contribute to "downstream" flooding. The potential of program lands to reduce flooding offsite was not addressed in this study, but other studies in the Prairie Pothole Region have demonstrated the benefits of wetlands at a watershed scale to intercept and store water. Ludden and others (1983) reported that depressional wetlands in the Devils Lake basin of North Dakota could store approximately 72 and 41 percent of the total runoff volume from a 2-year and 100-year frequency runoff event, respectively. Vining (2002) reported that pothole wetlands in the Starkweather Coulee subbasin (more than 80,000 ha [197,680 acres]) in the watershed of Devils Lake were capable of storing more than 8,000 ha-m (64,856 acre-ft) of water. Additionally, Malcolm (1979) reported that a complex of wetlands retained all local runoff plus 58 percent of additional inflow, and Gleason and others (2007) reported restoring drained and farmed wetlands could increase the water retention capacity of a watershed in the Prairie Pothole Region of Minnesota by up to 63 percent.

The water-storage benefit of wetlands on program or non-program lands is much more complex than simply estimating a "static" maximum water-storage potential. Such estimates only represent a gross storage volume and do not account for how wetlands process and store precipitation. The capacity of wetland catchments to intercept, process, and store water is influenced by many factors, including timing and amount of precipitation, land use, vegetation, topographic relief, soil type, evapotranspiration, temperature, and type of ground-water connection. For example, studies have demonstrated that wetlands surrounded by croplands generally receive greater surface water inputs than do wetlands surrounded by grasslands (Euliss and Mushet, 1996; Gleason, 1996). This difference is due, in part, to the ability of plants to slow runoff and increase the infiltration capacity of the soil. Consequently, conversion of cultivated cropland to grassland cover as part of conservation programs results in a reduction in surface water runoff and, ultimately, reduces the rate at which a basin fills and overflows. Wetland catchments also remove large quantities of water via transpiration and evaporation (Shjeflo, 1968; Millar, 1971; Winter, 1989; Parkhurst and others, 1998). Although it is a relatively slow process, wetlands also recharge ground-water supplies through infiltration (Shjeflo, 1968; Winter and Rosenberry, 1995). Hence, there are many hydrologic processes, such as water gains and losses, occurring within wetland catchments that need to be considered to improve the accuracy and precision of flood-storage estimates. These factors must be incorporated into existing models to provide a better understanding of the capacity of wetlands to attenuate and store water over time (Gleason and others, 2007).

Another often overlooked water-storage benefit of USDA conservation programs is that planting of catchments to perennial cover extends the topographic life of basins by reducing the inflow of sediments from the uplands as a result of erosion, thus maintaining storage volumes (Gleason and Euliss, 1998; Gleason, 2001). Gleason (2001) projected that, after 200 years of cultivation, 35 percent of his study wetlands (n = 77) would no longer be able to attain water depths great enough to overtop and kill tall, robust, emergent plants, such as cattails (*Typha* sp.), thus altering natural vegetation communities. Additionally, 17 and 21 percent of wetlands from the 1997 and 2004 surveys, respectively, had soil horizons buried to depths

Table D–1. Models developed to estimate wetland volume and upland zone area by physiographic region in the Prairie Pothole Region.

[Size refers to wetland area for volume models and to upland zone area for upland zone area models. V, predicted wetland volume, in hectare meters; UA, predicted upland zone area, in hectares; A, maximum wetland area, in hectares, from ground survey or spatial data, such as the National Wetlands Inventory]

Predicted variable	Physiographic region	Number	Size, in hectares: Mean	Size, in hectares: Range	Model (volume or area)	Coefficient of determination (r^2)
Wetland volume	Glaciated plains	288	0.92	0.002–9.25	$V = 0.25A^{1.4742}$	0.91
Wetland volume	Missouri coteau	186	1.28	0.01–11.29	$V = 0.398A^{1.542}$	0.91
Wetland volume	Prairie coteau	23	2.22	0.24–7.08	$V = 0.458A^{1.5611}$	0.94
Upland zone area	Glaciated plains	288	2.19	0.06–12.99	$UA = 2.24A^{0.4647}$	0.49
Upland zone area	Missouri coteau	186	2.70	0.07–18.56	$UA = 2.42A^{0.5172}$	0.62
Upland zone area	Prairie coteau	23	3.85	0.62–9.03	$UA = 2.27A^{0.6603}$	0.65

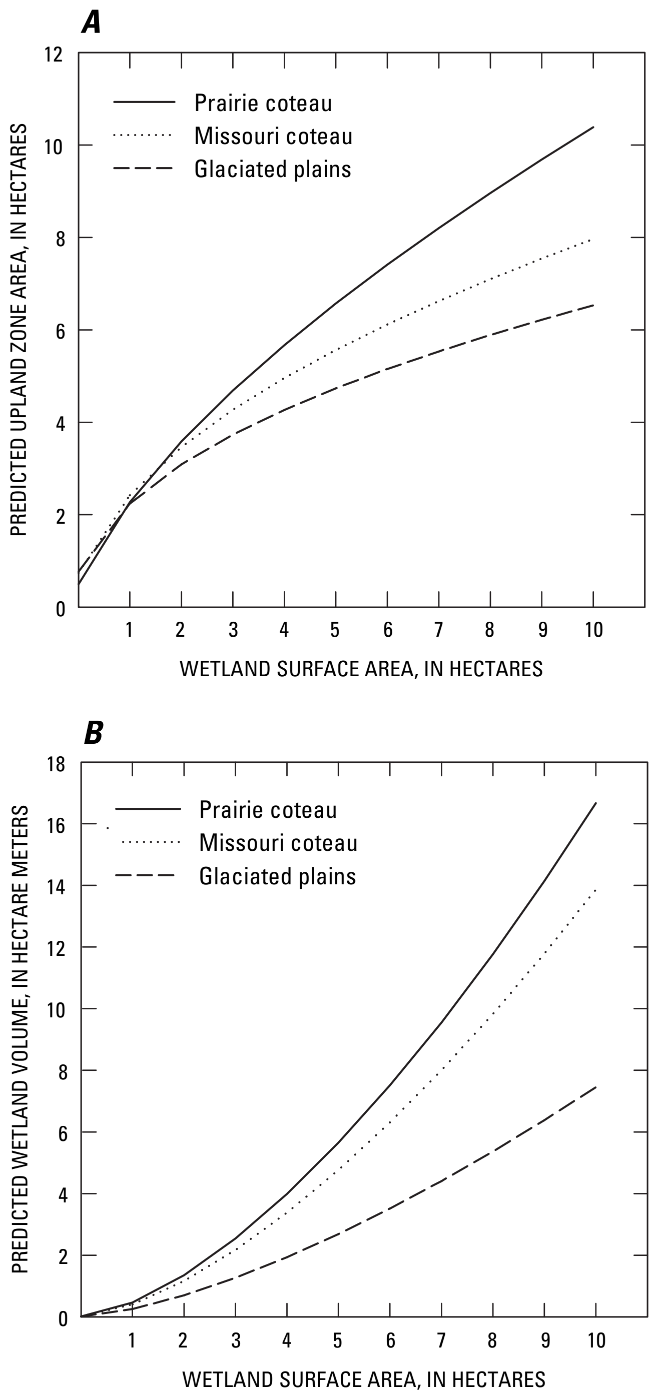

Figure D–1. Models developed to predict upland zone areas (*A*) and wetland volumes (*B*) for the primary physiographic regions of the Prairie Pothole Region. For each predicted variable, the models generally depict greater values for the prairie coteau, followed by the Missouri coteau and glaciated plains.

ranging from 9 to 116 cm (3.5 to 45.7 in), indicating considerable losses in water-storage volumes (see chap. C).

In summary, we developed models to estimate water-storage capacity and upland zone areas of wetlands on program lands. Application of these models was limited by the uncertainty associated with estimates of wetland areas on program lands; however, water-storage estimates presented in this paper are believed to provide a reasonable and conservative first approximation of flood-storage benefits derived from USDA conservation programs in the Prairie Pothole Region. Water-storage estimates are likely conservative because the databases used to estimate total wetland areas on program lands tend to underestimate wetland area (Gleason and others, 2005, 2007). Further, our static estimates of maximum wetland water storage do not account for dynamic hydrologic processes that attenuate the rate at which wetlands fill and overflow. Consequently, the flood-storage service provided by wetlands is greater than the maximum water-storage potential reported in this study.

Essential to future development and application of methods to quantify all ecological services, including flood-storage benefits, is the availability of quality spatial data that can be used to identify important habitat features, such as individual wetlands, and specific management actions, such as hydrologic restoration, nondrained restoration, seeded areas, and nonseeded areas. Availability of such data will facilitate application of models to better quantify dynamic floodwater-storage benefits at both site-specific and watershed scales.

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Table D–2. Wetland areas (table A–1) and estimated maximum water storage volumes of wetlands enrolled in U.S. Department of Agriculture conservation programs in the Prairie Pothole Region. The ranges of maximum volumes are based on the mean (± standard error) wetland area of surveyed seasonal and semipermanent wetlands (see “Methods,” this chapter).

[ft, feet; CRP, Conservation Reserve Program; WRP, Wetlands Reserve Program; --, no data]

State	Wetland area, in hectares (acres)		Maximum volume, in hectare meters (acre-ft)	
	CRP	WRP	CRP	WRP
Iowa	24,172 (59,729)	5,076 (12,543)	7,251–7,735 (58,784–62,708)	1,523–1,624 (12,347–13,166)
Minnesota	51,848 (128,116)	3,168 (7,828)	15,554–16,591 (126,096–134,503)	950–1,014 (7,702–8,220)
Montana	2,996 (7,403)	-- --	1,468–1,558 (11,901–12,631)	-- --
North Dakota	61,669 (152,384)	199 (492)	19,154–20,422 (155,281–165,561)	60–64 (486–519)
South Dakota	18,887 (46,670)	539 (1,332)	8,496–9,130 (68,877–74,017)	207–223 (1,678–1,808)
Prairie Pothole Region totals	159,572 (394,302)	8,982 (22,195)	51,923–55,436 (420,940–449,420)	2,740–2,925 (22,213–23,713)

Table D–3. Wetland zone areas (table A–1) and estimated upland zone and catchment areas of wetlands enrolled in U.S. Department of Agriculture conservation programs in the Prairie Pothole Region. The areas are based on the mean (± standard error) wetland area of surveyed seasonal and semipermanent wetlands (see “Methods,” this chapter).

[CRP, Conservation Reserve Program; WRP, Wetlands Reserve Program; --, no data]

State	Wetland zone area, in hectares (acres)		Upland zone area, in hectares (acres)		Catchment area, in hectares (acres)	
	CRP	WRP	CRP	WRP	CRP	WRP
Iowa	24,172 (59,729)	5,076 (12,543)	[1]29,011 (71,686)	6,106–6,110 (15,088–15,098)	[1]53,182 (131,413)	11,182–11,186 (27,631–27,641)
Minnesota	51,848 (128,116)	3,168 (7,828)	81,465–84,584 (201,300–209,007)	4,732–4,800 (11,693–11,861)	133,313–136,432 (329,416–337,123)	7,900–7,968 (19,521–19,689)
Montana	2,996 (7,403)	-- --	5,693–6,053 (14,067–14,957)	-- --	8,690–9,049 (21,473–22,360)	-- --
North Dakota	61,669 (152,384)	199 (492)	106,107–114,089 (262,190–281,914)	341–367 (843–907)	167,776–175,758 (414,575–434,298)	540–566 (1,334–1,399)
South Dakota	18,887 (46,670)	539 (1,332)	34,731–36,864 (85,820–91,091)	957–1,020 (2,365–2,520)	53,618–55,751 (132,490–137,761)	1,496–1,559 (3,697–3,852)
Prairie Pothole Region totals	159,572 (394,302)	8,982 (22,195)	257,007–270,601 (635,064–668,655)	12,136–12,297 (29,988–30,386)	416,579–430,172 (1,029,367–1,062,955)	21,118–21,279 (52,183–52,580)

[1] Range is not presented; the high and low estimates were the same as a result of constraining the estimates by the area of conservation program lands (see “Methods,” this chapter).

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Chapter E: Reduction of Sedimentation and Nutrient Loading

By Brian A. Tangen and Robert A. Gleason

Synopsis

In terms of quantity, sediment is the largest pollutant of wetlands, lakes, estuaries, and reservoirs in the United States (Baker, 1992; U.S. Environmental Protection Agency, 1995). Though soil erosion and sedimentation occur naturally, agricultural activities often accelerate soil erosion above natural baselines and result in excessive sedimentation of aquatic habitats. This process is especially true of depressional wetlands in the Prairie Pothole Region, where most native grasslands that once mitigated soil erosion and surface runoff have been converted to cropland. Consequently, prairie wetlands in cultivated catchments often receive soils eroded from upland zones that contribute to accelerated sedimentation or filling of wetland depressions. Studies have demonstrated that prairie wetlands within cropland catchments have greater sediment inputs than do wetlands in grasslands (Adomaitis and others, 1967; Martin and Hartman, 1987; Gleason, 1996; Gleason and Euliss, 1998, Gleason 2001). These sediment inputs can directly or indirectly affect wetland functions, such as floodwater storage and wildlife habitat, by reducing the topographic life of depressional basins and altering biotic communities and overall wetland productivity. A primary benefit of U.S. Department of Agriculture (USDA) conservation programs is the reduction of wind and water soil erosion when grassland is reestablished on erosive or environmentally sensitive cropland as part of the Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP). More than 2.2 million ha (5.4 million acres) of grassland and wetland habitats have been restored in the Prairie Pothole Region through these programs; however, the potential of these programs to reduce sedimentation and nutrient loading of prairie wetlands has not been quantified.

The objective of this chapter is to quantify the potential of the CRP and the WRP to reduce upland soil losses and potential nutrient loading and sedimentation of wetland basins in the Prairie Pothole Region. We used the Revised Universal Soil Loss Equation (RUSLE) to estimate the change in soil erosion rates on upland zones of catchments when tillage was replaced with perennial cover as part of the CRP and WRP. We estimated that conversion of cultivated cropland to perennial cover reduced total soil loss by 1,760,666 $Mg \cdot yr^{-1}$ (1,940,254 $tons \cdot yr^{-1}$) on 276,021 ha (682,048 acres) of upland zones on Prairie Pothole Region lands enrolled in the CRP and WRP. For this same area, we estimated that nitrogen and phosphorus losses would be reduced by 5,102 $Mg \cdot yr^{-1}$ (5,622 $tons \cdot yr^{-1}$) and 68 $Mg \cdot yr^{-1}$ (75 $tons \cdot yr^{-1}$), respectively. Assuming that reduction in annual losses remains static, we estimated a cumulative soil loss reduction of 21,156,125 Mg (23,314,050 tons) and a cumulative reduction in nitrogen and phosphorus losses of 60,772 Mg (66,971 tons) and 798 Mg (879 tons), respectively, since lands have been enrolled in conservation programs. Our results indicate that conservation practices can significantly reduce soil and nutrient losses from upland zones of catchments, thereby improving the sustainability of other ecological services, such as wildlife habitat and floodwater storage, provided by wetlands through lowering unnatural deposition rates of these substances in the wetland zone of catchments.

Methods

We used the RUSLE to estimate pre- and post-program soil erosion rates of catchments on CRP and WRP lands. The RUSLE is defined as follows:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P,$$

where

- A is the estimated average annual soil loss per unit area caused by rainfall,
- R is the climatic erosivity factor (the erosion force of rainfall as determined by kinetic energy and 30-minute intensity),
- K is the soil erodibility factor (the susceptibility of soil to erosion and rate of runoff),
- L and S are the slope length and steepness factors,
- C is the cover and management factor (the effect of plants, soil cover, soil biomass, and soil-disturbance activities relative to erosion), and
- P is the supporting practice factor (the impact of support practices on erosion rate [for example, contouring or stripcropping relative to row farming parallel to slope, on erosion rate]).

We calculated average values for R, K, and C by using data obtained from the 1997 National Resources Inventory (NRI) database (U.S. Department of Agriculture, 2000) for soil series common to both cultivated croplands and program lands within each Major Land Resource Area (MLRA) in the Prairie Pothole Region (table E–1 and fig. A–4). The NRI does not include information for lands enrolled in the WRP. Therefore, we assumed that soil data obtained from NRI for CRP lands were representative of WRP lands because lands and restoration methods are often comparable among these two programs. The P value was set at 1 for all soil-loss estimates because specific cropping practices are unknown and a P value of 1 does not have an effect on the RUSLE estimates. An average topographic factor LS (table E–1), which replaces the individual L and S factors in RUSLE (Renard and others, 1997), was estimated by using morphometry data (*L* and *S* values) collected from 270 catchments surveyed during 2004 (table A–3 and fig. A–3). Morphometry of each catchment was surveyed by using a Trimble 5700 GPS system. The software program ForeSight (Tripod Data Systems, 1997) was used to compute the average grade (*S*) and length (*L*) of slopes in the upland zone (fig. A–6). Average RUSLE values (table E–1) were then used to calculate an annual soil-loss estimate for cropland and program lands within each MLRA (table E–2). Cropland and program land soil-loss estimates were then multiplied by the total area estimates of upland zones of catchments on program lands (table D–3) within each MLRA. Methods used to estimate upland zone areas on program lands are described in chapter D. Potential reduction in soil losses attributable to program lands was calculated as the difference between soil loss estimated for cropped lands and that for program lands.

To estimate nutrient loading associated with estimates of soil erosion, we multiplied soil-loss estimates by the mean total phosphorus and nitrogen concentrations in the soils of the upland zones of cropland and restored catchments. Nutrient data were from the 2004 survey of 270 catchments in the Prairie Pothole Region, which included 56 cropland catchments and 179 catchments on program lands. Soil samples for nutrient determinations were collected along four transects that radiated from the center of the wetland zone and extended in cardinal directions to the catchment boundary. Along each transect, we collected soil samples to a depth of 15 cm (6 in) in each upland subzone (toe-slope, mid-slope, and shoulder-slope; fig. A–6) for determination of total nitrogen and phosphorus using standard methods (Page and others, 1982; Klute, 1986). The three upland subzone estimates within each catchment were combined to provide an average estimate of total nitrogen and phosphorus concentrations. These estimates were then used to estimate nitrogen and phosphorus losses due to soil erosion.

Results

We estimated that conversion of cultivated cropland to perennial cover as part of USDA conservation programs would reduce soil erosion rates by an average of 6.36 $Mg{\cdot}ha^{-1}{\cdot}yr^{-1}$ (2.84 $tons{\cdot}acre^{-1}{\cdot}yr^{-1}$) (table E–2), which is equivalent to a 94 percent reduction in soil loss. Across the entire Prairie Pothole Region, our results suggest that total soil losses would be reduced by 1,760,666 $Mg{\cdot}yr^{-1}$ (1,940,254 $tons{\cdot}yr^{-1}$) on the estimated 276,021 ha (682,048 acres) of upland zones of catchments on program lands (table E–3). When considering the cumulative annual reduction in soil loss since lands have been enrolled in conservation programs, we estimated a total reduction of 21,156,125 Mg (23,314,050 tons) (table E–3). Similarly, average nitrogen losses were reduced by 0.02 $Mg{\cdot}ha^{-1}{\cdot}yr^{-1}$ (0.009 $tons{\cdot}acre^{-1}{\cdot}yr^{-1}$) and average phosphorus losses were reduced by 0.0002 $Mg{\cdot}ha^{-1}{\cdot}yr^{-1}$ (0.00009 $tons{\cdot}acre^{-1}{\cdot}yr^{-1}$). Estimated total reductions in nitrogen and phosphorus loss are 5,102 $Mg{\cdot}yr^{-1}$ (5,622 $tons{\cdot}yr^{-1}$)

Table E–1. Revised Universal Soil Loss Equation (RUSLE) factor values used to estimate average annual soil losses for cultivated croplands and conservation program lands.

[CRP, Conservation Reserve Program; MLRA, Major Land Resource Area; RUSLE, Revised Universal Soil Loss Equation; WRP, Wetlands Reserve Program]

MLRA	Common soil series (number)	RUSLE[1] factor values: Climate erosivity (*R*)[2]	Soil erodibility (*K*)[2]	Slope length (*L*)[3]	Steepness (*S*)[3]	Practice factor (*P*)	Cover management (*C*)[2]: Cropland	CRP/WRP	*LS*[4]: Cropland	CRP/WRP
102A	64	104.21	0.28	33.82	0.02	1	0.24	0.015	0.33	0.32
102B	27	120.48	0.30	65.97	0.02	1	0.25	0.014	0.40	0.36
103	74	144.06	0.25	51.63	0.04	1	0.26	0.020	0.52	0.47
53A	29	42.53	0.32	56.20	0.07	1	0.30	0.016	1.17	1.02
53B	48	57.45	0.28	47.44	0.07	1	0.21	0.020	1.10	0.98
53C	18	71.42	0.31	55.00	0.02	1	0.15	0.010	0.30	0.28
55A	36	52.51	0.27	40.22	0.03	1	0.21	0.022	0.35	0.33
55B	66	68.29	0.27	43.05	0.05	1	0.23	0.015	0.76	0.68
55C	23	95.96	0.30	49.04	0.03	1	0.22	0.010	0.44	0.40

[1] RUSLE equation: $A = R{\cdot}K{\cdot}L{\cdot}S{\cdot}C{\cdot}P$, where *A* = average annual soil loss per unit area caused by rainfall.

[2] Values from 1997 National Resources Inventory data for soil series common to cultivated cropland and CRP lands.

[3] Values based on mean upland zone slope length and steepness (percent) obtained from 2004 topographic surveys (for MLRA 102B, values were calculated from the 1997 National Resources Inventory because of the lack of survey data).

[4] *LS* values calculated by using tables from Renard and others (1997).

and 68 $Mg \cdot yr^{-1}$ (75 $tons \cdot yr^{-1}$), respectively, with cumulative reductions in nitrogen and phosphorus of 60,772 Mg (66,971 tons) and 798 Mg (879 tons), respectively (table E–4).

Table E–2. Mean soil-loss values calculated by using the Revised Universal Soil Loss Equation (RUSLE); factor input values are presented in table E–1. Mean reduction in soil loss is defined as the mean soil loss for conservation program lands subtracted from the mean soil loss for croplands. In all cases, estimates for croplands are considerably higher than those for conservation program lands. The overall mean reduction values are 6.36 $Mg \cdot ha^{-1} \cdot yr^{-1}$ (2.84 $tons \cdot acre^{-1} \cdot yr^{-1}$) and 94 percent.

[Mg, megagrams; ha, hectares; CRP, Conservation Reserve Program; MLRA, Major Land Resource Area; WRP, Wetlands Reserve Program]

	Mean soil loss $Mg \cdot ha^{-1} \cdot yr^{-1}$ ($tons \cdot acre^{-1} \cdot yr^{-1}$)		Mean reduction in soil loss	
MLRA	Croplands	CRP/WRP	$Mg \cdot ha^{-1} \cdot yr^{-1}$ ($tons \cdot acre^{-1} \cdot yr^{-1}$)	Percent
102A	5.26 (2.35)	0.31 (0.14)	4.95 (2.21)	94.11
102B	8.04 (3.59)	0.40 (0.18)	7.64 (3.41)	95.02
103	10.76 (4.80)	0.75 (0.33)	10.01 (4.46)	93.03
53A	10.67 (4.76)	0.51 (0.23)	10.17 (4.54)	95.31
53B	8.20 (3.66)	0.71 (0.32)	7.48 (3.34)	91.22
53C	2.29 (1.02)	0.13 (0.06)	2.16 (0.96)	94.32
55A	2.37 (1.06)	0.23 (0.10)	2.15 (0.96)	90.72
55B	7.24 (3.23)	0.44 (0.20)	6.80 (3.03)	93.92
55C	6.11 (2.73)	0.25 (0.11)	5.86 (2.61)	95.91

Discussion

The RUSLE is an erosion model intended to estimate long-term average annual soil losses that result from surface runoff from individual field slopes with specific cropping and management systems (Renard and others, 1997). Since site-specific data typically are not available at large spatial scales, we applied mean factor values to the RUSLE to estimate soil losses for catchments on conservation program lands across the Prairie Pothole Region. This approach allowed us to evaluate USDA conservation programs by making broad generalizations that do not require detailed information about catchment areas and soil types on program lands; however, this approach assumes that RUSLE factors obtained from the NRI database and those calculated from our survey of catchments are representative of program lands (table E–1). Consequently, more precise estimates of reduction in soil loss could be calculated if areas of individual wetlands on program lands were available.

Our results suggest that significant differences in average annual soil-loss estimates exist between cultivated croplands and restored program lands for soil series from all MLRAs (table E–2). On the basis of our calculations, estimated average annual soil losses can be reduced, on average, by approximately 94 percent (table E–2) as a result of converting cultivated croplands to grasslands. More specifically, restored catchments in the Prairie Pothole Region have the potential to reduce soil losses by approximately 1,760,666 $Mg \cdot yr^{-1}$ (1,940,254 $tons \cdot yr^{-1}$) (table E–3), but this estimate is conservative because wetland catchments represent only 20 percent of the total land (approximately 2.2 million ha [5.4 million acres]) enrolled in conservation programs throughout the Prairie Pothole Region. Assuming that annual reductions remain static every year that lands are enrolled, reductions are even more significant because they would accrue throughout the duration of the contract. For example, a catchment enrolled in the WRP for 10 years that reduced soil loss by 10 $Mg \cdot yr^{-1}$ (11 $tons \cdot yr^{-1}$) would have the potential to reduce soil losses by 100 Mg (110 tons) over the enrollment term. By factoring in contract length, the potential reduction in soil losses is more than 21 million Mg (23 million tons) (table E–3).

The RUSLE was developed to assess onsite soil losses but not offsite sediment accumulation (Mutchler and others, 1994). Thus, we cannot quantify the benefits of reducing soil and nutrient loss to areas downstream from a wetland or other areas outside of catchments. Similarly, we are unable to determine the fate of soils transported within a catchment or the amount of soil that is actually delivered to a wetland; however, in a cropped catchment containing a wetland we can assume that some portion of the soil lost to erosion in the upland zone would move downslope and into a wetland basin over time. In contrast, much less soil would be expected to move into a wetland basin when the upland zone is dominated by perennial cover. For example, Gleason (1996) reported significantly lower sedimentation rates among wetlands surrounded by grasslands than in wetlands surrounded by summer fallow,

Table E–3. Potential reduction in total soil loss when upland zone catchment areas (table D–3) are converted to perennial cover as part of the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs in the Prairie Pothole Region. Soil-loss estimates were calculated by using the Revised Universal Soil Loss Equation (RUSLE). Reduction is defined as soil-loss estimates for conservation program lands subtracted from estimates from cultivated croplands.

[Mg, megagrams; yr, year; CRP, Conservation Reserve Program; WRP, Wetlands Reserve Program]

State	Program	Total area of upland zones of catchments, in hectares (acres)	Total soil loss, in $Mg \cdot yr^{-1}$ ($tons \cdot yr^{-1}$)		Total reduction, in $Mg \cdot yr^{-1}$ ($tons \cdot yr^{-1}$)	Total reduction × restoration age[1], in Mg (tons)
			Cropland	CRP/WRP		
Iowa	CRP	[2]29,011 (71,686)	[2]312,172 (344,014)	[2]21,877 (24,108)	[2]290,295 (319,905)	[2]3,269,927 (3,603,460)
	WRP	6,106–6,110 (15,088–15,098)	65,579–65,607 (72,268–72,299)	4,588–4,589 (5,056–5,057)	60,991–61,018 (67,212–67,242)	545,088–545,374 (600,687–601,002)
Minnesota	CRP	81,465–84,584 (201,300–209,007)	650,962–667,370 (717,360–735,442)	43,079–44,036 (47,473–48,528)	607,883–623,334 (669,887–686,914)	7,531,854–7,731,751 (8,300,103–8,520,390)
	WRP	4,732–4,800 (11,693–11,861)	46,063–46,416 (50,761–51,150)	3,173–3,194 (3,497–3,520)	42,890–43,222 (47,265–47,631)	320,053–321,587 (352,698–354,389)
Montana	CRP	5,693–6,053 (14,067–14,957)	60,773–64,611 (66,972–71,201)	2,887–3,069 (3,181–3,382)	57,886–61,542 (63,790–67,819)	799,960–850,484 (881,556–937,233)
North Dakota	CRP	106,107–114,089 (262,190–281,914)	510,748–548,853 (562,844–604,836)	36,731–39,467 (40,478–43,493)	474,017–509,386 (522,367–561,343)	6,127,173–6,583,770 (6,752,145–7,255,315)
	WRP	341–367 (843–907)	1,846–1,986 (2,034–2,189)	123–132 (136–145)	1,723–1,854 (1,899–2,043)	8,676–9,334 (9,561–10,286)
South Dakota	CRP	34,731–36,864 (85,820–91,091)	197,042–209,449 (217,140–230,813)	11,609–12,329 (12,793–13,587)	185,433–197,120 (204,347–217,226)	2,085,485–2,216,245 (2,298,204–2,442,302)
	WRP	957–1,020 (2,365–2,520)	6,337–6,769 (6,983–7,459)	321–343 (354–378)	6,016–6,426 (6,630–7,081)	46,225–49,337 (50,940–54,369)
Total CRP		257,007–270,601 (635,064–668,655)	1,731,697–1,802,455 (1,908,330–1,986,305)	116,183–120,778 (128,034–133,097)	1,615,514–1,681,677 (1,780,296–1,853,208)	19,814,399–20,652,177 (21,835,468–22,758,699)
Total WRP		12,136–12,297 (29,988–30,386)	119,825–120,778 (132,047–133,097)	8,205–8,258 (9,042–9,100)	111,620–112,520 (123,005–123,997)	920,042–925,632 (1,013,886–1,020,046)
Total Prairie Pothole Region		269,143–282,898 (665,052–699,041)	1,851,522–1,923,233 (2,040,377–2,119,403)	124,388–129,036 (137,076–142,198)	1,727,134–1,794,197 (1,903,302–1,977,205)	20,734,441–21,577,809 (22,849,354–23,778,746)

[1] Total reduction multiplied by the number of years that the lands have been enrolled in restoration program.

[2] Range is not presented; the high and low estimates were the same as a result of constraining the estimates by the area of conservation program lands (see "Methods," this chapter).

Table E–4. Estimated potential reduction in nitrogen and phosphorous loss when upland zone catchment areas (table D–3) are converted to perennial cover as part of the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs in the Prairie Pothole Region. Reduction is defines as nutrient-loss estimates for conservation program lands subtracted from estimates from cultivated croplands.

[N, nitrogen; Mg, megagrams; yr, year; P, phosphorus; CRP, Conservation Reserve Program; WRP, Wetlands Reserve Program]

		Total N loss, in $Mg \cdot yr^{-1}$ ($tons \cdot yr^{-1}$)		Total P loss, in $Mg \cdot yr^{-1}$ ($tons \cdot yr^{-1}$)		Total reduction, in $Mg \cdot yr^{-1}$ ($tons \cdot yr^{-1}$)		Total reduction × restoration age[1], in Mg (tons)	
State	**Program**	**Croplands**	**CRP/WRP**	**Croplands**	**CRP/WRP**	**N**	**P**	**N**	**P**
Iowa	CRP	[2]1,004 (1,106)	[2]48 (53)	[2]15 (17)	[2]0.4 (0.44)	[2]956 (1054)	[2]14.6 (16.1)	[2]10,772 (11,871)	[2]161 (177)
	WRP	[3]211 (233)	[3]10 (11)	[3]3 (3.3)	[3]0.09 (0.099)	[3]201 (222)	[3]2.9 (3.2)	[3]1,795 (1,978)	[3]27 (30)
Minnesota	CRP	2,048–2,097 (2,257–2,311)	108–111 (119–122)	[3]28 (31)	[3]0.8 (0.88)	1,940–1,986 (2,138–2,189)	[3]27.2 (30.0)	23,999–24,595 (26,447–27,104)	329–336 (363–370)
	WRP	147–148 (162–163)	[3]7 (7.7)	[3]2 (2.2)	[3]0.06 (0.066)	140–141 (154–155)	[3]1.9 (2.1)	1,048–1,053 (1,155–1,160)	15–16 (17–18)
Montana	CRP	114–121 (126–133)	[3]5 (5.5)	[3]1 (1.1)	[3]0.03 (0.033)	109–116 (120–128)	[3]1.0 (1.1)	1,504–1,599 (1,657–1,762)	16–17 (18–19)
North Dakota	CRP	1,246–1,339 (1,373–1,476)	94–101 (104–111)	15–16 (16.5–17.6)	[3]0.6 (0.66)	1,152–1,238 (1,270–1,364)	14.4–15.4 (15.9–17.0)	14,864–15,976 (16,380–17,606)	178–191 (196–210)
	WRP	[3]5 (5.5)	[3]0.3 (0.33)	[3]0.06 (0.066)	[3]0.002 (0.0022)	4.7 (5.2)	[3]0.058 (0.064)	21–23 (23–25)	[3]0.3 (0.33)
South Dakota	CRP	528–561 (582–618)	32–34 (35–37)	5–6 (5.5–6.6)	[3]0.19 (0.209)	496–527 (547–581)	4.8–5.8 (5.3–6.4)	5,554–5,899 (6,121–6,501)	58–61 (64–67)
	WRP	18–19 (20–21)	[3]1 (1.1)	[3]0.2 (0.22)	[3]0.006 (0.0066)	17–18 (19–20)	[3]0.19 (0.21)	133–142 (147–156)	1–2 (1.1–2.2)
Total CRP		4,940–5,122 (5,444–5,644)	287–299 (316–329)	64–66 (71–73)	[3]2 (2.2)	4,653–4,823 (5,128–5,315)	62–64 (68–71)	56,693–58,841 (62,476–64,843)	742–766 (818–844)
Total WRP		381–383 (420–422)	[3]18 (20)	5 (5.5)	[3]0.16 (0.176)	363–365 (400–402)	[3]5 (5.5)	2,997–3,013 (3,303–3,320)	43–45 (47–50)
Total Prairie Pothole Region		5,321–5,505 (5,864–6,067)	305–317 (336–349)	69–71 (76–78)	[3]2 (2.2)	5,016–5,188 (5,528–5,717)	67–69 (74–76)	59,690–61,854 (65,778–68,163)	785–811 (865–894)

[1] Total reduction multiplied by the number of years that the lands have been enrolled in restoration program.

[2] Range is not presented; the high and low estimates were the same as a result of constraining the estimates by the area of conservation program lands (see "Methods," this chapter).

[3] Range is less than 1.

and Euliss and Mushet (1996) documented that water-level fluctuations of wetlands in cropped catchments were more extreme than in grassland catchments because of alterations in surface water flow, indicating an increased potential for sediment transport in cropped catchments. Furthermore, 17 and 21 percent of catchments with a cultivation history, including those that have been restored and those with cropland, from the 1997 and 2004 surveys, respectively, had buried A or O soil horizons with average burial depths of 35 cm (14 in; range 12–98 cm [5–39 in]) in 1997 and 56 cm (22 in; range 9–116 cm [4–46 in]) in 2004, indicating considerable sediment accumulation in cropland catchments.

Increased sedimentation rates in prairie wetlands can have a significant effect on many wetland functions and values, such as water storage, plant and invertebrate communities, and wildlife habitat. Increased sediment inputs can partially or completely fill depressional wetlands, drastically altering water depths and storage volumes (Gleason and Euliss, 1998; Gleason, 2001). Amplified inputs of sediments and nutrients can also influence plant and invertebrate communities (Jurik and others, 1994; Wang and others, 1994; Gleason and Euliss, 1998; Gleason and others, 2003) that are essential sources of food and habitat for waterfowl and other wildlife.

In summary, we applied a relatively simple approach to estimate potential reduction in soil loss when uplands surrounding wetlands are converted from cultivated agriculture to perennial cover as part of USDA conservation programs. We estimated an annual reduction in soil loss of 1,760,666 $Mg \cdot yr^{-1}$ (1,940,254 $tons \cdot yr^{-1}$) and a cumulative reduction of more than 21 million Mg (more than 23 million tons). The primary benefit of reduced soil erosion is maintenance of the full range of water depths and storage volumes of wetland depressions, which are critical to sustaining all ecosystem services derived from wetlands. For example, maintenance of depressional volume is key to floodwater-storage potential and cycling of vegetation during wet and dry cycles (Gleason and Euliss, 1998; Gleason, 2001). Reducing sediment inputs prevents the burial of persistent seed and invertebrate egg banks that are critical for establishment of wetland flora and fauna that provide wildlife habitat and food-chain support. Additionally, reducing inputs of nitrogen to wetlands potentially reduces emissions of nitrous oxide, a potent greenhouse gas (Gleason and others, 2005).

In this study we did not address offsite benefits associated with the reduction of soil loss; however, reduction in soil erosion will undoubtedly reduce delivery of sediments and nutrients that impair water quality to lakes, streams, and rivers. Sediments from agricultural lands have long been recognized as a primary pollutant of our Nation's waters. To better quantify the benefits associated with reduction in soil erosion at site-specific and watershed scales will require detailed spatial data not only on program lands but also on all land areas within watersheds of interest.

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Chapter F: Proposed Approach to Assess Potential Wildlife Habitat Suitability on Program Lands

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Synopsis

The social and economic values of fish and wildlife as an ecosystem service often are not fully appreciated even though an estimated 82 million United States residents annually spend $108 billion to fish, hunt, or observe wildlife (Cordell and Herbert, 2002; U.S. Department of the Interior, 2002). Although difficult to quantify, concurrent benefits of lands managed for wildlife also include improvement of water quality, reduction in flood risk, and enhancement of carbon sequestration (Knutsen and Euliss, 2001; Euliss and others, 2007; Gleason and others, 2007). Currently, the most influential Government programs affecting the quantity and quality of wildlife habitat on private lands are the U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) authorized by the Conservation Title of the 1985 Food Security Act. The CRP and WRP have resulted in the restoration and enhancement of approximately 2,200,000 ha (5,436,200 acres) of wetlands and grasslands in the Prairie Pothole Region of the United States (table A–1). Because of the expanse of the area enrolled, program lands (lands enrolled in the CRP and the WRP) have much potential to improve habitat conditions for many wildlife species. For example, research on CRP lands has documented positive impacts on select wildlife guilds or species, including increased production or survival of ducks, ring-necked pheasants, and grassland-dependent birds (Haufler, 2005). Although information documenting wildlife use of WRP sites largely is lacking, research on wildlife response to wetland restoration activities similar to those implemented in the WRP suggests positive impacts for many species (Rewa, 2005). In many cases, species that benefit include those of economic or recreational value, as well as those considered to be of conservation concern because of habitat loss or declining populations.

Although program lands have inherent value as wildlife habitat, survival and reproduction of many species depend on specific spatial and structural requisites, such as type and size of habitats, juxtaposition of habitat types, structural features of vegetation, or floristic composition. Because of the fragmented spatial distribution of remaining native grasslands and wetlands, the value of a particular tract of program land may vary depending not only on conditions within the tract but also on conditions in the surrounding landscape (Knopf and Samson, 1995). Further, biological systems are dynamic and composed of complex, interacting factors that function as drivers of community composition and size (Pickett and White, 1985). Changes in climate or land-use practices surrounding the tract also may cause wildlife use to change over time (Hobbs and Norton, 2004). Therefore, the value of program lands as wildlife habitat cannot be considered in isolation, nor can particular wildlife values typically be attributed to the same tract in every year. Hence, the most objective means of assessing the importance of program lands to wildlife is to evaluate habitat quality over time. Developing approaches to document and report the myriad of wildlife values provided by program lands, although difficult, is important, considering directives to quantify the outcomes of program activities in terms of quality rather than simply the amount of area restored.

This chapter provides an overview of one approach that facilitates periodic assessment of multiple ecosystem services, including wildlife, provided by conservation programs. Outcomes are measured in terms of potential habitat suitability for select species based on relationships between the life requisites of selected species and measures of various spatial and structural habitat features. In an analysis of a single example township, the CRP resulted in the conversion of 1,792 ha (4,428 acres) of cropland to grassland between 1987 and 2005. Within this area, 313 ha (773 acres) of wetlands (500 seasonal, 234 temporary, and 18 semipermanent) shifted from cropland to grassland catchments. These changes resulted in an increased number of grassland polygons (contiguous areas of grassland) that exceeded published area requirements for all five area-sensitive grassland birds considered in our evaluation (table F–1). In a separate evaluation based on the interquartile range (25–75 percent) of upland vegetation obstruction measurements, our analysis indicated that restored seasonal catchments potentially provide suitable nesting habitat for all nine avian species we evaluated, whereas restored temporary and restored semipermanent catchments provide potential nesting habitat for seven and eight of the nine species evaluated, respectively (table F–2). These results suggest that restored catchments, regardless of wetland type, provide at least some resources that are required by a diversity of bird species but are not provided in cropland catchments. The justification of this approach is based on the assumptions that habitat conditions are a primary determinant of wildlife community composition and the variables used to assess change are the most appropriate and provide acceptable results. Therefore, the number and types of variables included (measurement methods used to estimate variables, spatial scale considered, and the relative importance of different wildlife-habitat relationships) are examples of critical factors that must be considered to make the approach applicable. Further, estimates resulting from this approach are limited to community composition because population size varies inter-annually and intra-annually depending on numerous spatial and temporal factors operating at regional, national, or international scales. The utility of this method is the capability to efficiently estimate potential wildlife species richness over time, which complements population estimates provided by traditional wildlife surveys.

Methods

The approach we developed to estimate potential habitat suitability can be applied to any wildlife species given that sufficient information is available to define key habitat requirements. In this example, we restricted evaluation to the impact of CRP lands on a select suite of migratory birds that use the Prairie Pothole Region as breeding or migration habitat. Birds are an excellent group for this type of approach because they are well known, disperse widely, and are highly visible (Knopf and Samson, 1995). Prior to measuring vegetation and abiotic variables, we recorded bird species using each of the 270 catchments surveyed in 2004 and compiled a list of all species detected. Species were documented opportunistically during a single survey that was not constrained by unfavorable time or weather conditions. Thus, only some portion of the avian species using these catchments likely was observed, and no inferences can be made regarding overall avian richness or abundance. We selected 10 species from this list on the basis of availability of habitat requirement information in the literature that matched the variables we collected during surveys. We also attempted to select species that defined a broad spectrum of spatial and structural vegetation habitat requirements and also are considered to be of conservation concern or recreational value. Species selected may not be the most appropriate for a full-scale evaluation, but they are adequate for demonstrating the approach. We identified two important parameters—minimum area requirements and visual obstruction of vegetation at nest sites—that were determinants of habitat suitability and searched the scientific literature for quantitative information on these parameters. Species differ in habitat requirements; thus, both parameters were not applicable to all species selected. Initially, we restricted our search to studies conducted in the northern Prairie Pothole Region, but sufficient information was not available, so we expanded our search to include studies completed in other regions. The use of the information developed in areas outside the Prairie Pothole Region may not be directly applicable to the Prairie Pothole Region. For example, area requirements developed in one area for grassland birds may not be applicable in other areas because of differences in location relative to the range of the species or landscape conditions (Johnson and Igl, 2001);

Table F–1. Change in the number of suitable grassland patches for five grassland-dependent bird species in a Prairie Pothole Region township.

[CRP, Conservation Reserve Program; >, greater than; Mo., Missouri; <, less than; Nebr., Nebraska; Ill., Illinois; %, percent; N. Dak., North Dakota. Scientific names of species are given in table F–3]

Species	Spatial metric	Requirement of bird, in hectares (acres)	State	Citation	Number of patches Pre-CRP	Number of patches Post-CRP	Number of patches Change
Upland sandpiper	Minimum area	>10 (25)	Mo.	Samson, 1980	26	34	+8
		>70 (173)	Mo.	Winter, 1998	4	13	+9
	Perimeter: area	<0.008 (0.02)	Nebr.	Helzer and Jelinski, 1999	6	21	+15
Savannah sparrow	Minimum area	>75 (185)	Ill.	Walk and Warner, 1999	4	13	+9
	50% incidence	>40 (99)	Ill.	Herkert, 1994	10	21	+11
	Territory	>15 (37)	Ill.	O'Leary and Nyberg, 2000	21	30	+9
Vesper sparrow	Minimum area	>10 (25)	Mo.	Samson, 1980	26	34	+8
	50% incidence	>20 (49)	Maine	Vickery and others, 1994	18	27	+9
Grasshopper sparrow	Minimum area	>12 (30)	Ill.	Walk and Warner, 1999	22	32	+10
	50% incidence	>30 (74)	Ill.	Herkert, 1994	15	25	+10
		>70 (173)	Iowa	Horn, 2000	4	13	+9
	Perimeter: area	<0.018 (0.04)	Nebr.	Helzer and Jelinski, 1999	28	36	+8
		<0.023 (0.06)	Nebr.	Helzer and Jelinski, 1999	32	38	+6
	Territory	>15 (37)	Ill.	O'Leary and Nyberg, 2000	21	30	+9
Bobolink	50% incidence	>50 (124)	Ill.	Herkert, 1994	8	20	+12
		>80 (198)	N. Dak.	Horn, 2000	3	13	+10
	Perimeter: area	<0.018 (0.04)	Nebr.	Helzer and Jelinski, 1999	28	36	+8

Table F–2. Range (50 percent of observations) of visual obstruction measurements in the upland zone of 54 catchments sampled in the vicinity of the example township in the glaciated plains, and the range of visual obstruction estimates at nest sites of nine bird species reported in the literature.

[Species that could occur in each land-use treatment/catchment type combination based on visual obstruction measurements are denoted with an “X.” Scientific names for species are given in table F–3]

Catchment type	Interquartile range of upland vegetation obstruction, in centimeters (inches)	Bird species, and range of reported visual obstruction,[1] in centimeters (inches)								
		Mallard[2] 14.7–42.0 (5.8–16.5)	Sharp–tailed grouse[3] 15.0–30.0 (5.9–11.8)	Northern harrier[4] 10.0–48.0 (3.9–18.9)	Willet[5] 0.0–20.0 (0.0–7.9)	Upland sandpiper[5] 0.0–40.0 (0.0–15.7)	Clay–colored sparrow[6] 16.0–46.3 (6.3–18.2)	Grasshopper sparrow[7] 13.0–33.6 (5.1–13.2)	Dickcissel[8] 17.0–67.0 (6.7–26.4)	Bobolink[9] 19.2–22.0 (7.6–8.7)
Cropland										
Temporary (n=4)	0.0–2.5 (0.0–1.0)				X	X				
Seasonal (n=4)	0.0–0.0 (0.0–0.0)				X	X				
Semipermanent (n=4)	0.0–0.0 (0.0–0.0)				X	X				
Restored										
Temporary (n=12)	22.5–40.6 (8.9–16.0)	X	X	X		X	X	X	X	
Seasonal (n=12)	20.0–40.0 (7.9–15.7)	X	X	X	X	X	X	X	X	X
Semipermanent (n=12)	21.3–36.3 (8.4–14.3)	X	X	X		X	X	X	X	X
Native prairie										
Temporary (n=2)	18.8–32.5 (7.4–12.8)	X	X	X	X	X	X	X	X	X
Seasonal (n=2)	31.3–41.3 (12.3–16.3)	X	X	X		X	X	X	X	
Semipermanent (n=2)	17.5–25.0 (6.9–9.8)	X	X	X	X	X	X	X	X	X

[1] Values obtained for each species are based on broadest possible range and include minimum, maximum, and mean measurements reported at nest sites.

[2] Minimum (Montana, Holm, 1984); maximum (North Dakota, Hertel, 1987).

[3] Minimum (North Dakota, Kantrud and Higgins, 1992); maximum (North Dakota, Kohn, 1982).

[4] Minimum (North Dakota, Kantrud and Higgins, 1992); maximum (North Dakota, Sedivec, 1994).

[5] Minimum (North Dakota, Kantrud and Higgins, 1992); maximum (North Dakota, Kantrud and Higgins, 1992).

[6] Minimum (North Dakota, Renken, 1983); maximum (North Dakota, Nenneman, 2003).

[7] Minimum (Montana, Dieni and Jones, 2003); maximum (Kansas, Winter and others, 2003).

[8] Minimum (South Dakota, Fritcher and others, 2004); maximum (Iowa, Patterson and Best, 1996).

[9] Minimum (North Dakota, Hertel, 1987); maximum (North Dakota, Scheiman and others, 2003).

however, we considered this information to be more reliable and defensible in our example than relying on subjective determinations.

Assessing the impact of USDA programs on the suite of 10 bird species was accomplished by using a combination of digital land-use covers and vegetation data collected as part of the extensive 2004 survey. To illustrate this approach, we selected a single township (93.2 km^2 [36.0 mi^2]) in the glaciated plains of the Prairie Pothole Region for analysis. The township was near two of the sample points originally established for other portions of this study, and vegetation data from 54 catchments within or near the township were available for estimation of structural conditions of vegetation.

We constructed two land-use covers of the township representing conditions before and after the USDA implemented the CRP. A base land cover was created by reclassifying the 1992 digital National Land Cover Data (NLCD) into cropland, grassland, tree/shrubland, wetland, and urban categories; by replacing areas classified as wetland or urban with surrounding land uses; and by smoothing the edge and transition zones. This process resulted in a base land cover composed of three land-use classes: cropland, grassland, and tree/shrubland. For the pre-CRP land cover, the 2005 CRP spatial data were categorized as cropland and added to update the base land cover and to check for CRP tracts implemented prior to 1992, which we deduced from signup dates. For the pre-CRP land cover, this check resulted in four tracts being reclassified from cropland back to grassland following the base land cover for the tract because CRP was implemented after 1992 or sign-up dates were not present in the database so the tracts were treated as existing grassland. Thus, the pre-CRP cover approximates terrestrial land-use conditions present in 1987 (first year of CRP), and existing grassland tracts were assumed to be native tracts subjected to different types and intensities of human activities, such as idle, grazing, or haying. Some tracts, however, were possibly agricultural lands enrolled in earlier conservation programs, such as Soil Bank. For the post-CRP land cover, we assumed that all grassland tracts in the 2005 CRP spatial cover were CRP lands even though some potentially originated from other Government programs. To estimate changes in the area and number of wetlands relative to catchment land use, we intersected the pre- and post-CRP land-cover maps with wetland type and location data obtained from the National Wetlands Inventory (NWI). Finally, previous research indicates that roads cause fragmentation by removing habitat and creating high-contrast edges (Miller and others, 1996) that can result in declines in species that are area-sensitive or exhibit limited dispersal capabilities (Saunders and others, 1991). Therefore, we intersected the pre- and post-CRP covers with a layer of primary and secondary roads obtained from the North Dakota Department of Transportation via an online geographic information system hub (*http://www.nd.gov/gis*, accessed February 2006). We buffered the road data to a total width of 7 meters (23 feet), which closely approximated the observed road width based on photographic analysis, and intersected the pre- and post-CRP covers with the buffered road data, resulting in the addition of the urban land-use class to the base land cover. When roads bisected a land-use category, we used the road to create separate polygons with unique identities. We used Arc-Info (ESRI, Redlands, Calif.), Patch Analyst (*http://flash.lakeheadu.ca/~rrempel/patch/*, accessed February 2006), and SAS (SAS Institute, Inc., 2003) to calculate several landscape metrics for both covers to describe general changes in land use during the 19-year period. We also calculated the area of each grassland polygon in both covers and constructed a frequency table of the number of polygons that exceeded the reported area requirements (minimum area, perimeter:area ratio, territory size) of selected area-dependent grassland bird species.

In a separate evaluation, we used data collected from 54 catchments within or near the township to evaluate the influence of upland vegetation obstruction on avian habitat suitability. Catchments were classified on the basis of wetland type (semipermanent, seasonal, temporary) and land-use treatment (cropped, restored, native prairie), which resulted in nine catchment types. In each catchment, vegetation obstruction was estimated from four directions at one location in each of the three upland subzones (shoulder-slope, mid-slope, and toe-slope; fig. A–6). We calculated a mean visual obstruction for each subzone by averaging the four measurements collected at each sample location and used these estimates to compute an interquartile range (25–75 percent) of upland vegetation obstruction across all land-use/catchment type combinations; number of catchments in each combination ranged from 2–12 (table F–2). This range was compared with reported visual obstruction readings collected at breeding sites of each bird species selected for evaluation to assess potential habitat availability provided by each land-use treatment.

Results

Seventy-seven avian species were recorded during the 2004 survey of 263 catchments (table F–3). Thirty-eight taxa were recorded in native prairie catchments compared to 40 and 65 taxa in cropped and restored catchments, respectively. At least one bird species was observed in 24 (82.8 percent) of 29 native prairie catchments, 149 (84.2 percent) of 177 restored catchments, and 20 (64.9 percent) of 37 cropped catchments. No species were observed in 5 native prairie, 28 restored, and 20 cropped catchments. In contrast, the maximum number of species observed in a single catchment was 8 in native prairie catchments, 9 in cropped catchments, and 15 in restored catchments. These results indicate that all catchment types were used by at least some avian species; however, no inferences can be made regarding avian richness or abundance because we did not use standardized techniques. Of these species, 10 were selected for evaluation, including 6 that are considered to be of conservation concern at various spatial scales according to the "Birds of Conservation Concern 2002" (U.S. Fish and Wildlife Service, 2002), 2 that are considered species of concern by the Northern Plains and Prairie

Table F–3. Bird species recorded by observation from vantage points and one walking survey conducted prior to measuring vegetation and abiotic variables in 263 catchments in the Prairie Pothole Region in 2004.

[No., number; %, percent]

		Land-use treatment					
		Cropped		Restored		Native prairie	
Common name	Scientific name	No.	%[1]	No.	%[1]	No.	%[1]
American bittern	*Botaurus lentiginosus*	2	3.5	5	2.8	1	3.5
American coot	*Fulica americana*	2	3.5	6	3.4	2	6.9
American goldfinch	*Carduelis tristis*	1	1.8	4	2.3	1	3.5
American robin	*Turdus migratorius*	1	1.8	2	1.1	0	0.0
American white pelican	*Pelecanus erythrorhynchos*	1	1.8	1	0.6	0	0.0
American wigeon	*Anas americana*	0	0.0	0	0.0	1	3.5
Barn swallow	*Hirundo rustica*	6	10.5	10	5.7	2	6.9
Black tern	*Chlidonias niger*	3	5.3	10	5.7	0	0.0
Black-crowned night-heron	*Nycticorax nycticorax*	1	1.8	5	2.8	0	0.0
Blue-winged teal	*Anas discors*	3	5.3	40	22.6	5	17.2
Bobolink	*Dolichonyx oryzivorus*	0	0.0	36	20.3	6	20.7
Brewer’s blackbird	*Euphagus cyanocephalus*	0	0.0	2	1.1	0	0.0
Brown-headed cowbird	*Molothrus ater*	0	0.0	5	2.8	0	0.0
Canada goose	*Branta canadensis*	1	1.8	0	0.0	0	0.0
Canvasback	*Aythya valisineria*	0	0.0	0	0.0	1	3.5
Chipping sparrow	*Spizella passerina*	0	0.0	15	8.5	2	6.9
Clay-colored sparrow	*Spizella pallida*	1	1.8	18	10.2	0	0.0
Cliff swallow	*Petrochelidon pyrrhonota*	0	0.0	1	0.6	0	0.0
Common grackle	*Quiscalus quiscula*	1	1.8	2	1.1	1	3.5
Common tern	*Sterna hirundo*	1	1.8	0	0.0	0	0.0
Common yellowthroat	*Geothlypis trichas*	2	3.5	31	17.5	2	6.9
Downy woodpecker	*Picoides pubescens*	0	0.0	2	1.1	0	0.0
Eastern kingbird	*Tyrannus tyrannus*	1	1.8	8	4.5	2	6.9
Field sparrow	*Spizella pusilla*	1	1.8	5	2.8	0	0.0
Forster’s tern	*Sterna forsteri*	0	0.0	1	0.6	0	0.0
Franklin’s gull	*Larus pipixcan*	2	3.5	0	0.0	0	0.0
Gadwall	*Anas strepera*	1	1.8	6	3.4	3	10.3
Grasshopper sparrow	*Ammodramus savannarum*	4	7.0	26	14.7	2	6.9
Gray partridge	*Perdix perdix*	0	0.0	1	0.6	0	0.0
Great blue heron	*Ardea herodias*	0	0.0	3	1.7	0	0.0
Great egret	*Ardea alba*	0	0.0	1	0.6	0	0.0
Greater yellowlegs	*Tringa melanoleuca*	2	3.5	1	0.6	0	0.0
Hooded merganser	*Lophodytes cucullatus*	0	0.0	0	0.0	1	3.5
Horned grebe	*Podiceps auritus*	0	0.0	1	0.6	0	0.0
Killdeer	*Charadrius vociferus*	18	31.6	8	4.5	2	6.9
Lark sparrow	*Chondestes grammacus*	0	0.0	9	5.1	0	0.0
Le conte’s sparrow	*Ammodramus leconteii*	0	0.0	1	0.6	0	0.0
Least sandpiper	*Calidris minutilla*	0	0.0	1	0.6	0	0.0
Least tern	*Sterna antillarum*	0	0.0	0	0.0	1	3.5
Lesser yellowlegs	*Tringa flavipes*	0	0.0	0	0.0	1	3.5

Table F–3. Bird species recorded by observation from vantage points and one walking survey conducted prior to measuring vegetation and abiotic variables in 263 catchments in the Prairie Pothole Region in 2004.—Continued

[No., number; %, percent]

		Land-use treatment					
		Cropped		Restored		Native prairie	
Common name	Scientific name	No.	%[1]	No.	%[1]	No.	%[1]
Long-eared owl	*Asio otus*	0	0.0	0	0.0	1	3.5
Mallard	*Anas platyrhynchos*	4	7.0	38	21.5	5	17.2
Marsh wren	*Cistothorus palustris*	3	5.3	39	22.0	6	20.7
Mourning dove	*Zenaida macroura*	1	1.8	5	2.8	0	0.0
Northern harrier	*Circus cyaneus*	0	0.0	3	1.7	3	10.3
Northern pintail	*Anas acuta*	0	0.0	1	0.6	0	0.0
Northern shoveler	*Anas clypeata*	1	1.8	5	2.8	0	0.0
Orchard oriole	*Icterus spurius*	0	0.0	0	0.0	1	3.5
Pied-billed grebe	*Podilymbus podiceps*	0	0.0	2	1.1	0	0.0
Red-tailed hawk	*Buteo jamaicensis*	1	1.8	1	0.6	0	0.0
Red-winged blackbird	*Agelaius phoeniceus*	14	24.6	72	40.7	5	17.2
Redhead	*Aythya americana*	0	0.0	1	0.6	1	3.5
Ring-billed gull	*Larus delawarensis*	1	1.8	1	0.6	0	0.0
Ring-necked pheasant	*Phasianus colchicus*	1	1.8	27	15.3	1	3.5
Ruddy duck	*Oxyura jamaicensis*	1	1.8	2	1.1	0	0.0
Savannah sparrow	*Passerculus sandwichensis*	3	5.3	17	9.6	0	0.0
Sedge wren	*Cistothorus platensis*	0	0.0	14	7.9	0	0.0
Semipalmated sandpiper	*Calidris pusilla*	0	0.0	0	0.0	1	3.5
Sharp-tailed grouse	*Tympanuchus phasianellus*	1	1.8	1	0.6	1	3.5
Short-eared owl	*Asio flammeus*	0	0.0	2	1.1	0	0.0
Song sparrow	*Melospiza melodia*	1	1.8	5	2.8	1	3.5
Sora	*Porzana carolina*	0	0.0	6	3.4	1	3.5
Spotted sandpiper	*Actitis macularia*	0	0.0	2	1.1	0	0.0
Swainson's hawk	*Buteo swainsoni*	0	0.0	1	0.6	1	3.5
Tree swallow	*Tachycineta bicolor*	1	1.8	8	4.5	0	0.0
Upland sandpiper	*Bartramia longicauda*	1	1.8	0	0.0	1	3.5
Vesper sparrow	*Pooecetes gramineus*	0	0.0	4	2.3	1	3.5
Virginia rail	*Rallus limicola*	0	0.0	6	3.4	0	0.0
Western kingbird	*Tyrannus verticalis*	2	3.5	3	1.7	0	0.0
Western meadowlark	*Sturnella neglecta*	2	3.5	10	5.7	0	0.0
Willet	*Catoptrophorus semipalmatus*	0	0.0	1	0.6	1	3.5
Wilson's phalarope	*Phalaropus tricolor*	0	0.0	0	0.0	1	3.5
Wilson's snipe	*Gallinago delicata*	1	1.8	2	1.1	0	0.0
Wood duck	*Aix sponsa*	0	0.0	3	1.7	1	3.5
Yellow warbler	*Dendroica petechia*	0	0.0	2	1.1	0	0.0
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	6	10.5	32	18.1	5	17.2
Yellow-rumped warbler	*Dendroica coronata*	0	0.0	1	0.6	0	0.0

[1] Percent occurrence in cropland (n = 57), restored (n = 177), and native prairie (n = 29) catchments.

Pothole Region shorebird plan (Skagen and Thompson, 2003), and 3 that are included on the Stewardship or Watch List in the "Partners in Flight North American Landbird Conservation Plan" (Rich and others, 2004) (table F–4).

Prior to implementation of the CRP, land use within the township was composed of 54 cropland polygons that constituted 85.5 percent of the township, 134 grassland (assumed to be native prairie) polygons that accounted for 13.9 percent of the township, and 63 polygons of tree and shrubland that occupied 0.6 percent of the township (fig. F–1*A* and table F–5). Within these land-use classes were 3,616 wetlands, of which 2,771 (76.6 percent) were in cropland, 378 (10.5 percent) were in grassland, 7 (0.2 percent) were in tree/shrubland, and 460 (12.7 percent) were in catchments with more than one land-use category. Wetland area made up 14.9 percent (1,376 ha [3,400 acres]) of the township and included 1,131 ha (2,795 acres) in cropland, 227 ha (561 acres) in grassland, and 18 ha (44.5 acres) in tree/shrubland (fig. F–1*A*).

In contrast, following implementation of the CRP, cropland area declined 19.4 percent to encompass only 66.2 percent of the township, grassland increased 19.4 percent to encompass 33.3 percent of the township, wetland area in cropland catchments decreased 22.7 percent, and tree/shrubland did not change (fig. F–1*B* and table F–5). This shift resulted from conversion of 1,792 ha (4,428 acres) of cropland to grassland between 1987 and 2005. In addition, the number of grassland polygons decreased from 134 in 1987 to 114 in 2005, whereas cropland patches increased from 54 to 87 during the same period. The increase in grassland area, coupled with a decrease in number of grassland polygons, indicates that CRP grasslands connected some preexisting grassland polygons and resulted in larger grassland polygons than would have occurred solely as a result of implementing the CRP. To determine the extent that CRP tracts connected pre-existing grassland area, we calculated the amount of grassland area (core area) more than 100 m (328 ft) from an edge. This analysis revealed that core area increased by approximately 1,078 ha (2,664 acres) from 1987 (442 ha [1,092 acres]) to 2005 (1,520 ha [3,756 acres]). Total wetland area (1,376 ha [3,400 acres]) remained the same between 1987 and 2005 because we used the same NWI digital data coverage; however, 22.7 percent (313 ha [773 acres]) of wetland area shifted from cropland to grassland catchments. The most dramatic shifts occurred in seasonal and temporary wetlands; 500 seasonal and 234 temporary wetlands in cropland catchments during 1987 were in grassland catchments in 2005 (table F–5). In addition, 18 semipermanent wetlands in cropland catchments in 1987 were completely within grassland catchments in 2005, whereas the number of wetlands within tree/shrubland remained unchanged.

Information on spatial habitat requirements of breeding areas was available for five grassland-dependent species (bobolink [*Dolichonyx oryzivorus*], grasshopper sparrow [*Ammodramus savannarum*], savannah sparrow [*Passerculus sandwichensis*], upland sandpiper [*Bartramia longicauda*], and vesper sparrow [*Pooecetes gramineus*]) that we selected for evaluation, four of which are considered to be of conservation concern by regional and national plans (table F–4). Area requirements in the published literature vary among and within species depending on the type of metric considered. For example, minimum area requirements for the upland sandpiper ranged from more than 10 ha (25 acres; Samson, 1980) to more than 70 ha (173 acres; Winter, 1998). Differences in reported requirements likely are related to studies being conducted in different landscapes, the use of different analyses, a focus on different dependent variables, such as territory size or nesting area, or a combination of these factors. Regardless of the metric considered, implementing the CRP resulted in an increased number of grassland polygons that exceeded breeding area requirements for each species evaluated. The magnitude of change varied from an increase of 6 suitable polygons for the grasshopper sparrow to 15 suitable polygons for the upland sandpiper (table F–1).

Visual obstruction caused by upland vegetation in cropped treatments exhibited low variability. All obstruction estimates in the upland zone of seasonal and semipermanent cropped catchments were 0.0 cm (0.0 in), whereas the interquartile range of observations in cropped temporary catchments was 0.0–2.5 cm (0.0–1.0 in), and the largest estimate was 5.0 cm (2.0 in) (fig. F–2). In contrast, the interquartile range of vegetation obstruction estimates was 22.5–40.6 cm (8.9–16.0 in) in restored temporary catchments, 20.0–40.0 cm (7.9–15.7 in) in restored seasonal catchments, and 21.3–36.3 cm (8.4–14.3 in) in restored semipermanent catchments. Native prairie catchments also supported upland vegetation that had a wider range of visual obstruction compared to cropped catchments, but ranges appeared similar to those in restored catchments (fig. F–2). The interquartile range of vegetation obstruction estimates in native prairie temporary catchments was 18.8–32.5 cm (7.4–12.8 in), whereas in native prairie seasonal and native prairie semipermanent catchments the interquartile range was 31.3–41.3 cm (12.3–16.3 in) and 17.5–25.0 cm (6.9–9.8 in), respectively (table F–2).

Visual obstruction values at nest sites were determined for 9 (bobolink, clay-colored sparrow [*Spizella pallida*], dickcissel [*Spiza americana*], grasshopper sparrow, mallard [*Anas platyrhynchos*], northern harrier [*Circus cyaneus*], sharp-tailed grouse [*Tympanuchus phasianellus*], upland sandpiper, and willet [*Catoptrophorus semipalmatus*]) of the 10 species evaluated. Comparisons of these values with the interquartile range of upland vegetation obstruction in surveyed catchments indicate that cropped catchments (regardless of wetland type) potentially provide suitable nesting habitat for only two (willet and upland sandpiper) of the nine species for which information was available (table F–2). In contrast, restored seasonal, native prairie temporary, and native prairie semipermanent catchment types potentially provide suitable nesting habitat for all nine species. Restored temporary and native prairie seasonal catchments provide potential nesting habitat for all species except the willet and bobolink, whereas restored semipermanent catchments provide suitable nesting habitat for all species except the willet. Overall, these comparisons

Table F–4. Conservation status of avian species selected for evaluation.

[Species listed in “Birds of Conservation Concern 2002” are denoted with an “X.” Species listed in the “Partners in Flight North American Landbird Conservation Plan” as Stewardship or Watch List species in the Prairie Avifaunal Biome are denoted with an “R,” and species of continental importance are denoted with an “N.” Designations listed in the shorebird plan are as follows: C = species of concern; B, M = region is highly important to population for breeding and migrating, respectively. “North American Waterfowl Management Plan” represents objectives for the midcontinent region. For scientific names of the species, see table F–3. BCR, Bird Conservation Region]

	Birds of Conservation Concern 2002[1]			North American Landbird Conservation Plan[2]		Northern Plains Prairie Potholes Regional Shorebird Conservation Plan[3]	North American Waterfowl Management Plan[4]
Species	BCR 11	Region 6	National	Watch	Steward		
Mallard							8.2 million
Sharp-tailed grouse					R, N		
Northern harrier	X	X	X				
Willet	X					B, M	
Upland sandpiper	X	X	X			C, B, M	
Clay-colored sparrow							
Vesper sparrow							
Grasshopper sparrow	X	X	X		R, N		
Dickcissel		X	X	R, N			
Bobolink		X					

[1] U.S. Fish and Wildlife Service, 2002.

[2] Rich and others, 2004.

[3] Skagen and Thompson, 2003.

[4] U.S. Fish and Wildlife Service and others, 1999.

indicate that program lands increase vegetation structure and provide suitable nesting habitat for more species than cropland; however, this assessment is based on a limited number of samples and only one structural variable. Finally, these results should not be misconstrued to imply that a single catchment type provides all necessary requisites for completion of a species breeding cycle; rather, each catchment type considered suitable potentially provides some of the necessary resources required by that species.

Discussion

Our example, although limited to a single township and one structural variable, illustrates the influence of program lands on wildlife in the Prairie Pothole Region, including species considered to be of conservation concern. Our analysis also indicates that these habitat benefits can be enhanced for some area-sensitive species if program lands were placed strategically on the landscape to take advantage of existing favorable land uses (Johnson and Igl, 2001). For example, enrolling cropland tracts that split existing grassland tracts can expand grassland areas beyond the area enrolled. In addition, such a strategy also may increase variability of vegetation structure because larger areas often exhibit more heterogeneous topography, slope, and aspect than smaller areas.

We did not statistically compare vegetation obstruction between restored and native prairie catchments, but the range of vegetation obstruction values we measured indicate that CRP grasslands overlap with native prairie grasslands, at least in that portion of the Prairie Pothole Region that is composed of mixed-grass prairie (fig. F–2). As a result, the number of species potentially supported is similar between these two land-use treatments for the species we evaluated. In contrast, vegetation obstruction of both restored and native prairie grasslands differed markedly from cropland, and this difference restricts the suitability of habitat for a number of bird species that use the Prairie Pothole Region. Vegetation obstruction was the only habitat variable we evaluated, however, and this relationship may not be true for other habitat parameters.

The approach we used indicates conservation programs are of value to wildlife. However, for most species, the most objective means of evaluating effectiveness of conservation programs is to determine if habitat for a large diversity of wildlife species is provided over temporal scales that encompass the full range of natural climatic variability. Thus, much additional work will be required if this approach is used to report the temporal variability in wildlife values across a broad geographic area. First, spatial data for the entire Prairie Pothole Region must be processed to identify and delineate past and current land-use treatments. We used a combination

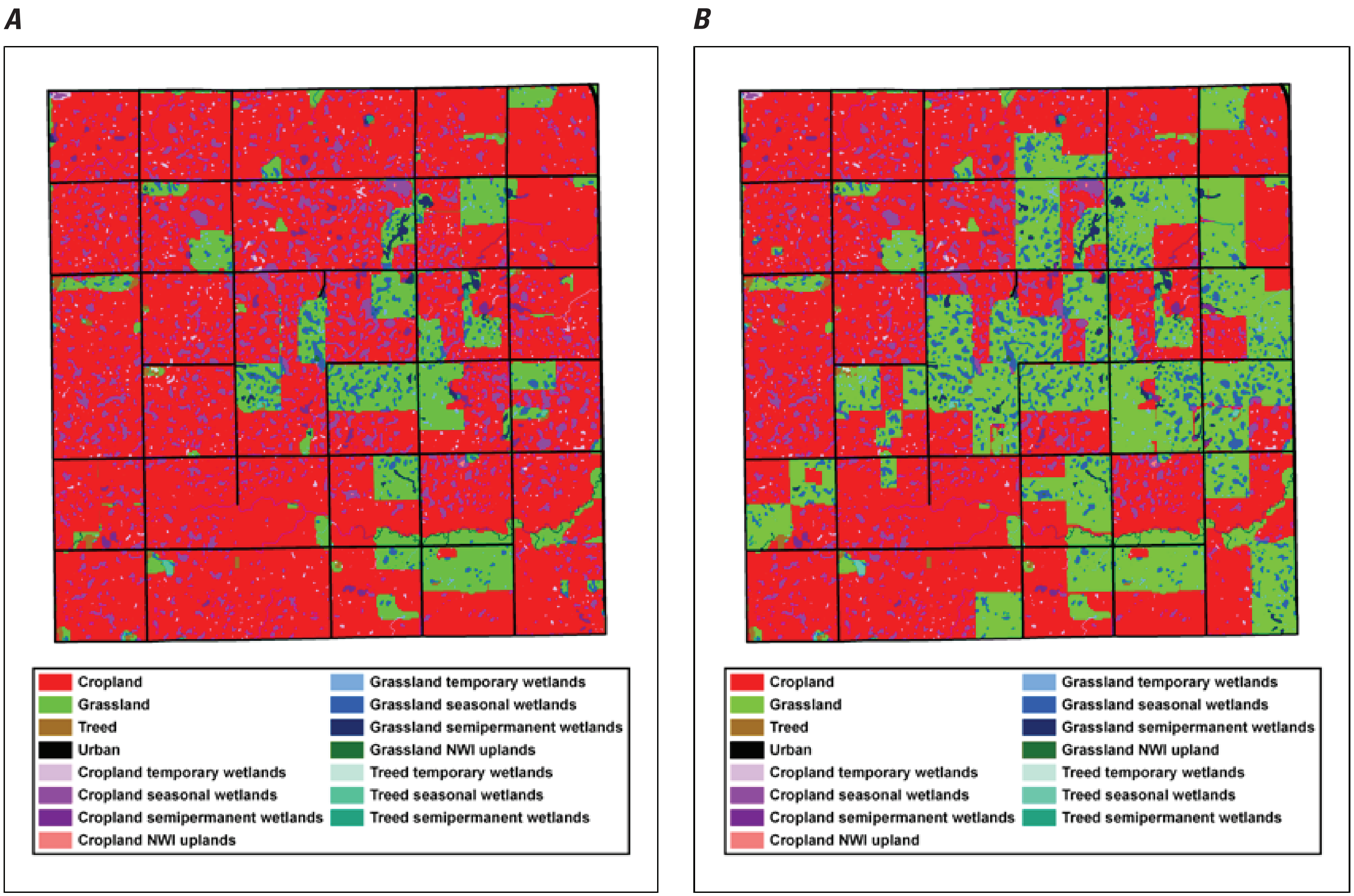

Figure F–1. Land-use treatments (*A*) prior to and (*B*) following implementation of the Conservation Reserve Program in a single township (93.0 km^2 [36.0 mi^2]) in the glaciated plains of the Prairie Pothole Region (NWI, National Wetlands Inventory).

Table F–5. Change in number of polygons and area of land-use classes prior to and following implementation of the Conservation Reserve Program in a single township in the glaciated plains of the Prairie Pothole Region.

[CRP, Conservation Reserve Program; --, no data]

Land-use class	Number of patches			Area, in hectares (acres)		
	Pre-CRP	Post-CRP	Change	Pre-CRP	Post-CRP	Change
Cropland/wetland complex						
Upland	54	87	+33	6,752.07 (16,684.36)	5,272.99 (13,029.56)	-1,479.08 (-3,654.81)
Temporary wetlands	926	692	-234	99.80 (246.61)	75.04 (185.42)	-24.76 (-61.18)
Seasonal wetlands	1,803	1,303	-500	790.32 (1,952.88)	531.06 (1,312.25)	-259.26 (-640.63)
Semipermanent wetlands	42	24	-18	37.91 (93.68)	22.64 (55.94)	-15.27 (-37.73)
Partial wetlands[1]	--	--	--	202.80 (501.12)	188.98 (466.97)	-13.82 (-34.15)
All wetlands	2,771	2,019	-752	1,130.83 (2,794.28)	817.72 (2,020.59)	-313.11 (-773.69)
Total	2,825	2,106	-719	7,882.90 (19,478.65)	6,090.71 (15,050.14)	-1,792.19 (-4,428.50)
Grassland/wetland complex						
Upland	134	114	-20	1,055.32 (2,607.70)	2,534.40 (6,262.50)	+1,479.08 (+3,654.81)
Temporary wetlands	157	388	+231	17.68 (43.69)	42.06 (103.93)	+24.38 (60.24)
Seasonal wetlands	210	668	+458	81.45 (201.26)	280.93 (694.18)	+199.48 (+492.92)
Semipermanent wetlands	11	31	+20	7.19 (17.77)	23.05 (56.96)	+15.86 (+39.19)
Partial wetlands	--	--	--	120.46 (297.66)	193.85 (479.00)	+73.39 (+181.35)
All wetlands	378	1,087	+709	226.78 (560.37)	539.89 (1,334.07)	+313.11 (+773.69)
Total	512	1,201	+689	1,282.10 (3,168.07)	3,074.29 (7,596.57)	+1,792.19 (+4,428.50)
Tree/shrub wetland complex						
Upland	63	63	0	40.39 (99.80)	40.39 (99.80)	0 (0)
Temporary wetlands	3	3	0	0.92 (2.27)	0.92 (2.27)	0 (0)
Seasonal wetlands	4	4	0	0.42 (1.04)	0.42 (1.04)	0 (0)
Semipermanent wetlands	0	0	0	0.0 (0.0)	0.0 (0.0)	0 (0)
Partial wetlands	--	--	--	16.74 (41.36)	16.74 (41.36)	0 (0)
All wetlands	7	7	0	18.08 (44.68)	18.08 (44.68)	0 (0)
Total	70	70	0	58.47 (144.48)	58.47 (144.48)	0 (0)

[1] Wetlands with upland catchments composed of more than one land-use class.

of NLCD, NWI, and CRP land data in our township to identify land-use treatments because they were available nationally; however, spatial resolution of this data did not allow accurate assignment of wetlands and grassland tracts. Therefore, in some cases we assumed that grassland present prior to 1987 was native prairie and that all additional grassland occurring after 1987 resulted from enrollment in the CRP. These assumptions, however, may not be valid at all spatial scales because factors other than the CRP obviously influences cropland conversion. For example, several Federal and State programs, such as Soil Bank and U.S. Fish and Wildlife Service Waterfowl Production Areas, facilitated establishment of grasslands in the Prairie Pothole Region prior to the CRP. Increased classification accuracy is possible, however, with existing spatial technology and data (Skidmore, 2002; Ustin, 2004). For example, land-cover data from the National Aeronautics and Space Administration's (NASA) GeoCover2000 (14.5 m [47.6 ft] resolution) are available for the Prairie Pothole Region, and the NLCD 2001 is in various stages of completion. More advanced imagery also can be acquired from other sources, including NASA and the U.S. Geological Survey Center for Earth Resources Observation and Science. These types of data could facilitate separating land uses into more distinct subcategories (for example, hayed grassland, burned grassland) that would improve the ability to assess suitability of habitats for wildlife.

Second, additional wildlife species and associated habitat parameters must be incorporated to more broadly assess wildlife benefits of conservation programs. Selection of species should be based on the range of habitat conditions that support all fauna of interest. For example, spatial requirements of grassland-dependent birds provide useful criteria for judging program success relative to area; however, other spatial criteria, such as corridors, interwetland distances, and wetland density, would be required to determine area suitability for other taxonomic groups. Developing this species list may seem overwhelming, but it is possible to select a species pool composed of relatively few species. For example, although 330 bird species occur on the Great Plains (Johnsgard, 1979), protecting avian diversity may require that only 32 species receive priority for conservation (Knopf and Samson, 1995).

Third, following identification of a full complement of species to evaluate, a search of the published information must be conducted to compile quantitative measures that define habitat quality for each species. Habitat conditions vary throughout the year; thus, multiple parameters will be required. For example, breeding sites require adequate foraging, brood, and pair habitat in addition to suitable nesting habitat. Similarly, upland vegetation structure is extremely important during the breeding cycle for ground-nesting waterfowl, but it is less important during migration. Unfortunately, detailed knowledge of exact features that influence habitat suitability in the

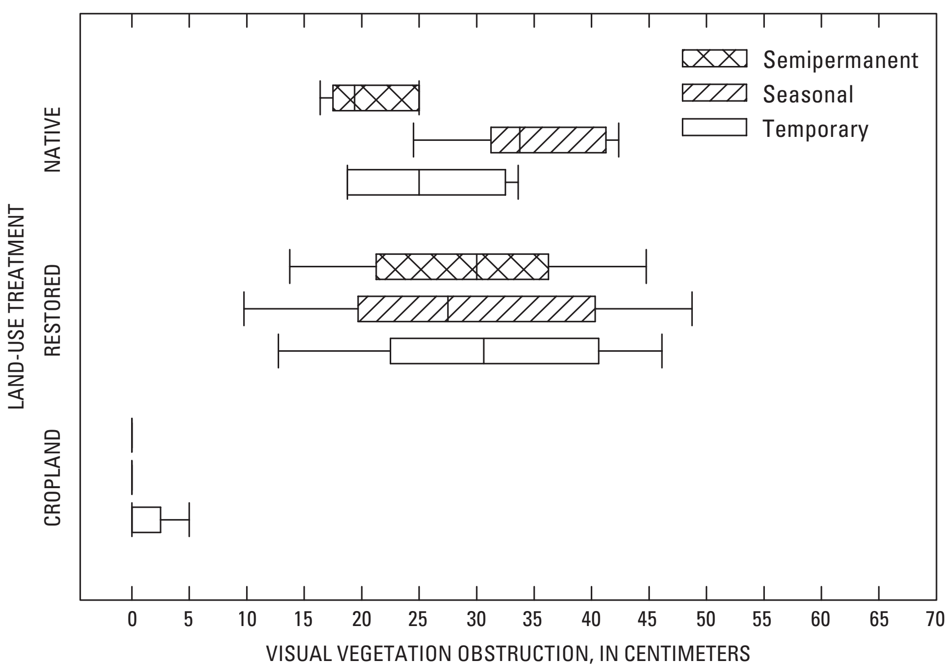

Figure F–2. Median (|), interquartile (25–75 percent) range (box), and 10–90 quantile (10–90 percent) range (stems) of vegetation obstruction measurements for nine land-use treatment/catchment type (temporary, seasonal, semipermanent) combinations in the vicinity of the Prairie Pothole Region township that was used as an example to illustrate a habitat-based approach for determining wildlife habitat suitability.

Prairie Pothole Region is lacking (Johnson and Igl, 2001). Thus, information for some parameters likely will not be available or, if available, may be of uncertain applicability because it was developed in areas different from the Prairie Pothole Region. In these cases, information will have to be obtained and verified through monitoring or research. In other cases, some information already has been compiled in various bibliographies and databases, but it must still be synthesized and electronically linked to spatial land-cover data to facilitate processing and evaluation. For example, in our analysis we used vegetation obstruction information developed outside the Prairie Pothole Region to determine bird habitat requirements. In addition, we were unable to assign vegetation obstruction values to each tract because of limited data. Consequently, it was not possible to determine if grassland tracts of suitable area also provided appropriate vegetation obstruction. To resolve this issue, each habitat variable considered must be evaluated relative to its importance in defining habitat suitability, as well as to the ease and rapidity that the variable can be measured at the spatial scale of interest. Technology exists to develop many habitat estimates either directly or by using surrogate measures, but additional research involving remote sensing likely will be required to develop reliable estimators.

Finally, the fully developed approach must undergo scientific scrutiny to determine applicability, including veracity evaluation, sensitivity analysis, and cost:benefit analysis. Veracity evaluation and sensitivity analysis will require conducting or obtaining results of wildlife surveys to determine if precision and accuracy of the approach are adequate to meet the needs of the USDA. If the results of these analyses indicate that the approach is inadequate, then additional evaluation will be required to determine if inclusion of more or different habitat variables would resolve the problem. A cost:benefit analysis also will be required to determine if implementing the approach periodically to ascertain temporal changes in wildlife values is cost effective. The intent is not to replace existing wildlife surveys, as surveys provide population estimates and other data that can not be obtained from the habitat-based approach recommended here; however, the capability to periodically document population changes in numerous species simultaneously by using wildlife survey methods would require substantial funds, involve extensive coordination, and require much time to enter and analyze data. In contrast, the cost of using habitat conditions as a surrogate measure for assessing wildlife values is theoretically lower, particularly if existing methods are available or if methods could be developed to remotely acquire information necessary to predict habitat suitability. Thus, conducting wildlife surveys periodically would complement a habitat-based approach by providing values not estimated by the habitat approach. In concert, these surveys could be used to evaluate and improve the predictive capability of a habitat-based approach.

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