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USDA conservation program and practice effects on wetland ecosystem services in the Prairie Pothole Region

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Abstract. Implementation of the U.S. Department of Agriculture (USDA) Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) has resulted in the restoration of >2 million ha of wetland and grassland habitats in the Prairie Pothole Region (PPR). Restoration of habitats through these programs provides diverse ecosystem services to society, but few investigators have evaluated the environmental benefits achieved by these programs. We describe changes in wetland processes, functions, and ecosystem services that occur when wetlands and adjacent uplands on agricultural lands are restored through Farm Bill conservation programs. At the scale of wetland catchments, projects have had positive impacts on water storage, reduction in sedimentation and nutrient loading, plant biodiversity, carbon sequestration, and wildlife habitat. However, lack of information on the geographic location of restored catchments relative to landscape-level factors (e.g., watershed, proximity to rivers and lakes) limits interpretation of ecosystem services that operate at multiple scales such as floodwater retention, water quality improvement, and wildlife habitat suitability. Considerable opportunity exists for the USDA to incorporate important landscape factors to better target conservation practices and programs to optimize diverse ecosystem services. Restoration of hydrologic processes within wetlands (e.g., hydroperiod, water level dynamics) also requires a better understanding of the influence of conservation cover composition and structure, and management practices that occur in uplands surrounding wetlands. Although conservation programs have enhanced delivery of ecosystem services in the PPR, the use of programs to provide long-term critical ecosystem services is uncertain because when contracts (especially CRP) expire, economic incentives may favor conversion of land to crop production, rather than reenrollment. As demands for agricultural products (food, fiber, biofuel) increase, Farm Bill conservation programs will become increasingly important to ensure provisioning of ecosystem services to society, especially in agriculturally dominated landscapes. Thus, continued development and support for conservation programs legislated through the Farm Bill will require a more comprehensive understanding of wetland ecological services to better evaluate program achievements relative to conservation goals.

Key words: carbon; conservation; ecosystem services; grasslands; prairie potholes; restoration; sedimentation; soil erosion; wetlands; wildlife.

Introduction

The Prairie Pothole Region (PPR) of the northern Great Plains is one of the most productive agricultural regions in the world, accounting for one-third of the nation's annual production of wheat, corn, barley, and soybeans (USDA 2005). Not surprisingly, the agricultural potential of the PPR has caused conversion of native grassland and wetland habitats, which has greatly altered the historic grassland biome. Wetland loss exceeds 50% in most PPR states (Dahl 1990, Dahl and Johnson 1991) and little upland native prairie remains (Mac et al. 1998). Despite significant native habitat loss, the PPR remains one of the most productive and important regions in North America for breeding, nesting, and migrating waterbirds and grassland birds (Smith et al. 1964, Igl and Johnson 1997, Beyersbergen et al. 2004, Niemuth et al. 2006). Additionally, remaining prairie wetlands and grasslands provide other ecosystem services, including maintaining regional and national biodiversity, attenuating floodwater, cycling nutrients, sequestering atmospheric carbon, recharging groundwater, and providing recreational opportunities (Hubbard 1988, Knutsen and Euliss 2001, Gleason et al. 2007, 2008*a*). Recognition of these ecosystem services has stimulated considerable public support for the protection and conservation of these habitats. For example, the importance of the PPR to continental waterfowl populations (Smith et al. 1964) has stimulated the U.S. Fish and Wildlife Service to conserve wetland and grassland habitats through land acquisition (e.g.,

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Waterfowl Production Areas, National Wildlife Refuges) and wetland easements with private landowners (Johnson et al. 1994) since the 1930s.

A major incentive to not drain wetlands occurred in 1985 when Congress passed the Food Security Act (the Act; Public Law 99-198), which included the Swampbuster provision, which made agricultural producers ineligible for certain Farm Bill benefits if they drain or fill wetlands. This provision has been included in subsequent Farm Bills and has protected many small, isolated wetlands that are typical of the PPR (Brady 2005, Reynolds et al. 2006). The 1985 and later Farm Bills also contained other important provisions, such as the Conservation Reserve Program (CRP), which provides financial incentives to farmers who implement practices that protect soils, wildlife habitat, and water quality. The 1990 Farm Bill initiated the Wetlands Reserve Program (WRP) to restore wetland functions, with an emphasis on maximizing wildlife benefits. Since the first Farm Bill, conservation programs have grown and diversified to address a variety of conservation issues on private lands in the PPR. Currently, ~2 200 000 ha in the PPR are enrolled in either the CRP or WRP (Gleason and Laubhan 2008).

In the PPR, >90% of land is in private ownership (Cowardin et al. 1995), and conservation programs such as the CRP and WRP have become extremely important for enhancing diverse ecosystem services at local to global scales. However, only minimal effort has been expended to quantify the effect of Farm Bill programs on ecosystem services. As a result, it is difficult to adapt current policy and management goals of the U.S. Department of Agriculture (USDA) to meet future needs. To remedy these shortcomings, recent mandates (e.g., the President's Budget and Performance Integration Initiative) require that federal programs demonstrate effectiveness by accurately accounting for the expenditure of program dollars and documenting the results achieved. In response to this requirement, the USDA initiated the Conservation Effects Assessment Project (CEAP) in 2003 to scientifically quantify the environmental effects of conservation practices implemented by private landowners participating in conservation programs (Mausbach and Dedrick 2004). In this paper we examine the potential influence of Farm Bill conservation programs and practices on the processes, functions, and ecosystem services of prairie wetlands and associated uplands. Information discussed is intended to assist on-going efforts (e.g., CEAP) to assess the impact of specific conservation practices on ecosystem processes and to develop approaches to quantify environmental products achieved from Farm Bill conservation programs.

The Prairie Pothole Region and Ecosystem Services

The PPR was historically comprised of native prairie interspersed with millions of small depressional wetlands. This region encompasses ~900 000 km^2 (Gleason et al. 2005) and includes portions of Iowa, Minnesota, Montana, North Dakota, and South Dakota in the United States (~300 000 km^2; Fig. 1) and the provinces of Alberta, Saskatchewan, and Manitoba in Canada (~600 000 km^2). Formed largely by glacial processes 9000 to 13 000 years ago (Bluemle 2000), the landscape ranges from rolling plains to hummocky areas of closely spaced hills that are pockmarked with numerous shallow depressional wetlands that are regionally referred to as potholes or sloughs (Stewart and Kantrud 1971). Major physiographic regions that formed from glacial processes in the PPR include the Missouri Coteau, Prairie Coteau, and Glaciated Plains (also known as the drift prairie; Fig. 1). The Missouri and Prairie Coteaus are steep, rugged areas dominated by stagnation and dead-ice moraines, whereas gently rolling ground moraines prevail in the Glaciated Plains. Wetland depressions are most common in areas of end and stagnation moraines (e.g., Missouri Coteau) and can approach densities of $>40 \cdot km^{-2}$ (Kantrud et al. 1989). Most potholes are small (<1 ha), but collectively they represent one of the largest and most hydrologically diverse populations of inland wetlands in North America. According to the National Wetlands Inventory, most wetlands in the PPR are palustrine and lacustrine systems with temporary, seasonal, and semipermanent water regimes. Johnson and Higgins (1997) estimated that of the 932 829 wetlands in the PPR of South Dakota, 55.7% were temporary, 35.9% seasonal, 8.1% semipermanent, and 0.2% permanent. The exact number of prairie potholes is difficult to estimate because inventories do not accurately account for drained wetlands (Gleason et al. 2005). However, presettlement wetlands may have encompassed >20% of the total land area in the U.S. portion of the PPR (Euliss et al. 2006).

Drainage to enhance agricultural production has been the primary cause of wetland loss, with losses of ~89% in Iowa, 42% in Minnesota, 27% in Montana, 49% in North Dakota, and 35% in South Dakota (Dahl 1990). Native grasslands in the PPR have experienced even greater loss (>90%) and degradation (Mac et al. 1998). Since 1830, declines of native prairie grassland exceed those reported for any other ecosystem in North America (Samson and Knopf 1994), and remaining tracts have been degraded by invasion of nonnative species because of fire suppression, changes in herbivory, and introduction of Eurasian species (Johnson et al. 1994). Wetland drainage and grassland loss have been most extensive in the southeast region where climate and landscape factors (e.g., topographic relief, growing season, annual precipitation) are more conducive for agricultural production (Fig. 2). Implementation of national policies to protect wetlands has slowed the rate of wetland drainage in the PPR (Dahl 2006), but ecosystem processes in remaining wetlands continue to be altered and degraded by agricultural practices (Gleason and Euliss 1998).

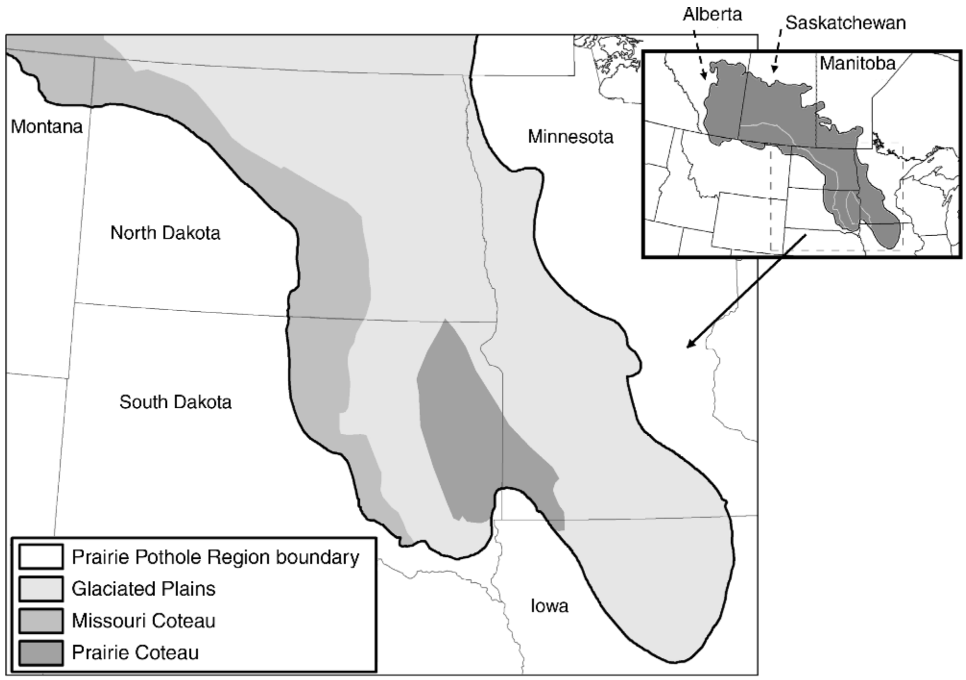

FIG. 1. The Prairie Pothole Region of North America (inset) and extent of the major physiographic regions (Missouri Coteau, Prairie Coteau, and Glaciated Plains) within the United States portion.

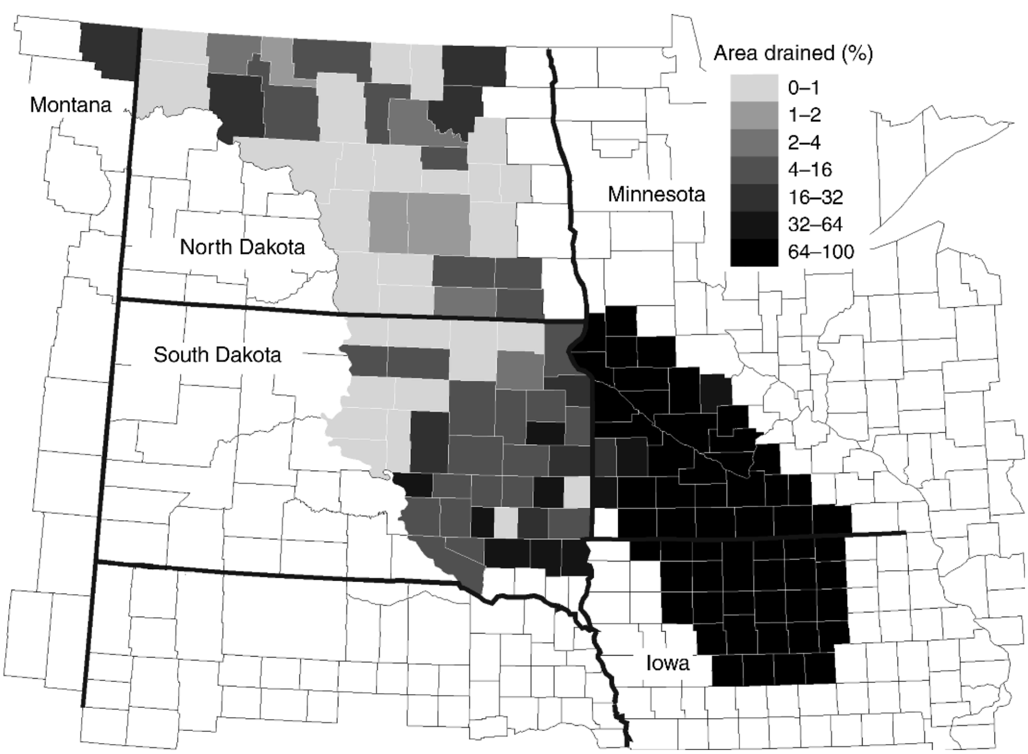

FIG. 2. Percentage of total wetland area drained in counties of the Prairie Pothole Region of the United States (from Gleason et al. 2004).

Tillage of wetland basins and surrounding uplands is the second most significant agricultural activity that alters and degrades natural wetland processes. Potholes tend to occupy topographic depressions and often are focal points of surface runoff that contains agrochemical residues and eroded soils (Grue et al. 1986, Neely and Baker 1989, Euliss and Mushet 1996). Sediment inputs to potholes are several-to-many orders of magnitude greater in agricultural compared to grassland watersheds (Adomaitis et al. 1967, Martin and Hartman 1987, Gleason 1996, 2001). Loss of wetland water depth and storage volume due to anthropogenic sedimentation has important ecological implications. For example, water level fluctuation is an important process affecting dynamic shifts in plant community composition characteristic of prairie wetlands (van der Valk and Davis 1978). As water depths increase during wet periods, pool depths can overtop vegetation and kill the plant community. In contrast, exposure of wetland sediments during drought facilitates germination of seeds and establishes new vegetation on bare mudflats. Dynamic wetland plant communities enhance diversity and the biological integrity of prairie wetlands (Harris and Marshall 1963, Euliss et al. 2004). However, wetlands receiving excess sediment experience decreased water depth, altered hydroperiods, and more static plant communities, all of which contribute to lower wetland productivity. Wetlands that suffer reduced water depths from sedimentation often develop persistent, monotypic stands of vegetation (e.g., *Typha*) that reduce overall ecological value. Sediment also increases water turbidity, which reduces productivity of aquatic plants (e.g., sago pondweed; Kantrud 1990) and invertebrates (Arruda et al. 1983, McCabe and O'Brien 1983, Kirk and Gilbert 1990). Further, invertebrate egg and plant seed banks are negatively impacted when buried with sediment (Jurik et al. 1994, Wang et al. 1994, Dittmar and Neely 1999, Gleason et al. 2003).

The negative impact of many agricultural practices on wildlife habitat is widely recognized (Batt et al. 1989, Igl and Johnson 1997); however, many other ecosystem services are also affected. Erosion and deposition of topsoil from cropland can reduce wetland storage volume, which alters hydrologic services such as water storage and groundwater recharge. Wetland drainage and land use change in the PPR have been linked to increased flood frequency in the Red River Valley of North Dakota (Brun et al. 1981) and the Mississippi River Valley (Miller and Nudds 1996); however, none of these studies considered the influence of reduced storage volumes due to sedimentation. Further, tillage, which enhances decomposition of soil organic carbon, has shifted the function of wetlands and grasslands in the PPR from sinks to net sources of atmospheric carbon (Follett et al. 2001, Euliss et al. 2006).

Application of Conservation Practices in the PPR

Numerous wetland and grassland areas have been enhanced, rehabilitated, or restored through various USDA conservation programs. Besides the CRP and WRP, other notable Farm Bill programs include the Environmental Quality Incentives Program (EQIP), Conservation Reserve Enhancement Program (CREP), and Wildlife Habitat Incentives Program (WHIP). Most conservation practices implemented with these programs are intended to improve wildlife habitat and water quality, reduce erosion and nutrient transport, and control pest species. A fundamental advantage is that they benefit both individual participants by providing technical guidance and monetary incentives for implementing conservation practices and also the American public by enhancing ecosystem services (National Academy of Sciences 2004). Enrollment options vary by program, with most ranging from 5 to 10 years with options for reenrollment; however, certain programs like the WRP offer permanent and 30-year easements. There were 122 specific conservation practices implemented between 2000 and late 2006 on ~1.9 million ha in the PPR (Table 1). Most conservation practices were associated with the EQIP (99 practices), followed by the CRP (76), WHIP (46), WRP (34), and CREP (2). However, only 14 of these practices account for >5% of occurrences or land areas in any one program (Table 2). Restoration and wildlife habitat practices (codes 645, 657, 644, and 643; Table 2) are most relevant to improving wetlands and were most commonly associated with the WRP, WHIP, and CRP. In contrast, practices applied through the EQIP tend to target nutrient management of cropping systems. The number or area of wetlands ultimately affected by these practices is difficult to estimate because USDA databases do not include the spatial data necessary to estimate wetland area on lands enrolled in conservation programs. However, Gleason and Laubhan (2008) estimated that lands enrolled in the CRP and WRP in the PPR may include >168 554 ha of wetlands (Table 3).

Various conservation practices are used to rehabilitate or restore wetlands altered by agricultural practices. For example, implementation of Filter Strip, Conservation Cover, or other nutrient management practices may improve wetland condition by reducing sedimentation and nutrient loading from surrounding agricultural activities. Instead of a single practice (e.g., Filter Strip), programs aimed at restoring wetlands and enhancing wildlife habitat often employ a suite of conservation practices affecting the wetland and surrounding upland areas (Fig. 3). The overall goal of wetland conservation activities is to restore wetland function, habitat diversity, and capacity to approximate pre-disturbance conditions. Techniques or practices used to accomplish this goal typically focus on restoring hydrologic function by plugging surface and subsurface drains (Fig. 3). In some cases, small embankments or water control structures are installed to reduce offsite impacts (e.g., flooding adjacent fields and roads) or facilitate operation and maintenance of water flow. The Wetland Restoration practice also includes guidance for

TABLE 1. Area of lands in the Prairie Pothole Region, USA, enrolled in U.S. Department of Agriculture (USDA) conservation programs from 2000 to late 2006.

	Area enrolled in conservation program (ha)					
State	CRP	WRP	EQIP	CREP	WHIP	Total
North Dakota	149 167	4424	707 888	0	2273	863 752
Minnesota	115 855	10 468	376 038	66	854	503 281
Iowa	113 232	11 122	124 510	0	673	249 537
South Dakota	103 156	6575	77 941	0	6564	194 236
Montana	32 752	0	52 389	0	4834	89 975
Total	514 162	32 589	1 338 766	66	15 198	1 900 781

Note: Abbreviations are: CRP, Conservation Reserve Program; WRP, Wetlands Reserve Program; EQIP, Environmental Quality Incentive Program; CREP, Conservation Reserve Enhancement Program; and WHIP, Wildlife Habitat Incentives Program.

removal of sediments to expose hydric soils (Fig. 3). In most cases, restoration practices rely on native seed banks to reestablish wetland vegetation; however, as native seed banks are likely depauperate due to past land use (Galatowitsch and van der Valk 1994), seeding is recommended. To restore the physical hydrology of contributing areas, all or part of the upland zone surrounding a wetland is planted to perennial vegetation using Conservation Cover or Filter Strip practices (Fig. 3). Following restoration, conservation practices such as pest management, grazing, and burning may be implemented to maintain restored areas.

TABLE 2. USDA conservation practices that accounted for >5% of the total number of contracts or area in each program from 2000 to late 2006.

Conservation program, practice, and code	Occurrence (%)	Area (%)
Conservation Reserve Program (CRP)		
Use Exclusion (472)	21.3	17.6
Conservation Cover (327)	20.2	30.8
Upland Wildlife Habitat Management (645)	13.9	14.9
Filter Strip (393)	7.3	3.3
Pest Management (595)	7.2	7.4
Wetland Restoration (657)	5.9	4.1
Total CRP	75.9	78.1
Wetlands Reserve Program (WRP)		
Wetland Restoration (657)	33.3	21.3
Upland Wildlife Habitat Management (645)	15.0	19.7
Wetland Wildlife Habitat Management (644)	12.6	12.8
Restoration and Management of Rare and Declining Habitats (643)	8.4	7.2
Pest Management (595)	6.4	7.2
Use Exclusion (472)	4.5	8.7
Conservation Cover (327)	4.3	6.8
Prescribed Grazing (528)	2.0	5.3
Total WRP	86.5	89.1
Environmental Quality Incentive Program (EQIP)		
Nutrient Management (590)	23.0	29.6
Residue Management, Mulch Till (392B)	12.9	15.1
Pest Management (595)	11.8	13.0
Residue Management, No-Till/Strip Till (392A)	10.2	10.4
Conservation Crop Rotation (328)	10.1	11.8
Prescribed Grazing (528)	4.4	5.9
Total EQIP	72.4	85.7
Wildlife Habitat Incentives Program (WHIP)		
Upland Wildlife Habitat Management (645)	36.0	33.3
Use Exclusion (472)	11.7	5.7
Pest Management (595)	11.5	12.7
Windbreak/Shelterbelt Establishment (380)	9.5	0.0
Prescribed Grazing (528)	3.0	17.2
Nutrient Management (590)	1.7	5.6
Total WHIP	73.5	74.5
Conservation Reserve Enhancement Program (CREP)		
Use Exclusion (472)	50.0	50.0
Wetland Restoration (657)	50.0	50.0
Total CREP	100.0	100.0

TABLE 3. Total area and estimated wetland area (mean ± SE) on lands enrolled in the Conservation Reserve (CRP) and Wetlands Reserve (WRP) Programs in the Prairie Pothole Region (modified from Gleason and Laubhan [2008]).

	WRP		CRP		CRP and WRP	
State	Total area (ha)	Wetland area (ha)	Total area (ha)	Wetland area (ha)	Total area (ha)	Wetland area (ha)
Iowa	11 376	5076 ± 256	53 183	24 172 ± 1201	64 559	29 248 ± 1457
Minnesota	8633	3168 ± 403	167 349	51 848 ± 8629	175 982	55 016 ± 9032
Montana	...	...	411 127	2996 ± 1690	411 127	2996 ± 1690
North Dakota	3239	199 ± 40	1 099 218	61 669 ± 12 558	1 102 457	61 868 ± 12 598
South Dakota	10 179	539 ± 111	435 172	18 887 ± 4442	445 351	19 426 ± 4553
Total	33 427	8982 ± 810	2 166 049	159 572 ± 28 520	2 199 476	168 554 ± 29 330

Note: Ellipses indicate no data.

EFFECTS OF CONSERVATION PROGRAMS AND PRACTICES ON WETLAND HYDROLOGY AND ECOSYSTEM SERVICES

Hydrology

Hydrological processes are widely recognized as the most important determinants of wetland functions and values (NRC 1995). Long-term studies in the PPR have related wetland hydrology to changes in water chemistry, biodiversity, and productivity (Winter 2003, Euliss et al. 2004). In general, wetland water regimes (e.g., temporary, seasonal, semipermanent) can be related to groundwater hydrologic function (i.e., recharge, discharge, and flow-through). Temporary wetlands generally are recharge sites, seasonal wetlands may be recharge or flow-through areas, and semipermanent and permanent wetlands usually function as groundwater flow-through or discharge sites. Atmospheric water (i.e., precipitation and runoff) drives the water balance of prairie wetlands, but the relationship of wetland basins to groundwater flow paths determines water chemistry, composition of biological communities, and ultimately, diversity of ecosystem services (Euliss et al. 2004).

An understanding of prairie wetland hydrology and the importance of diverse wetland complexes are important for maintaining biodiversity and productivity.

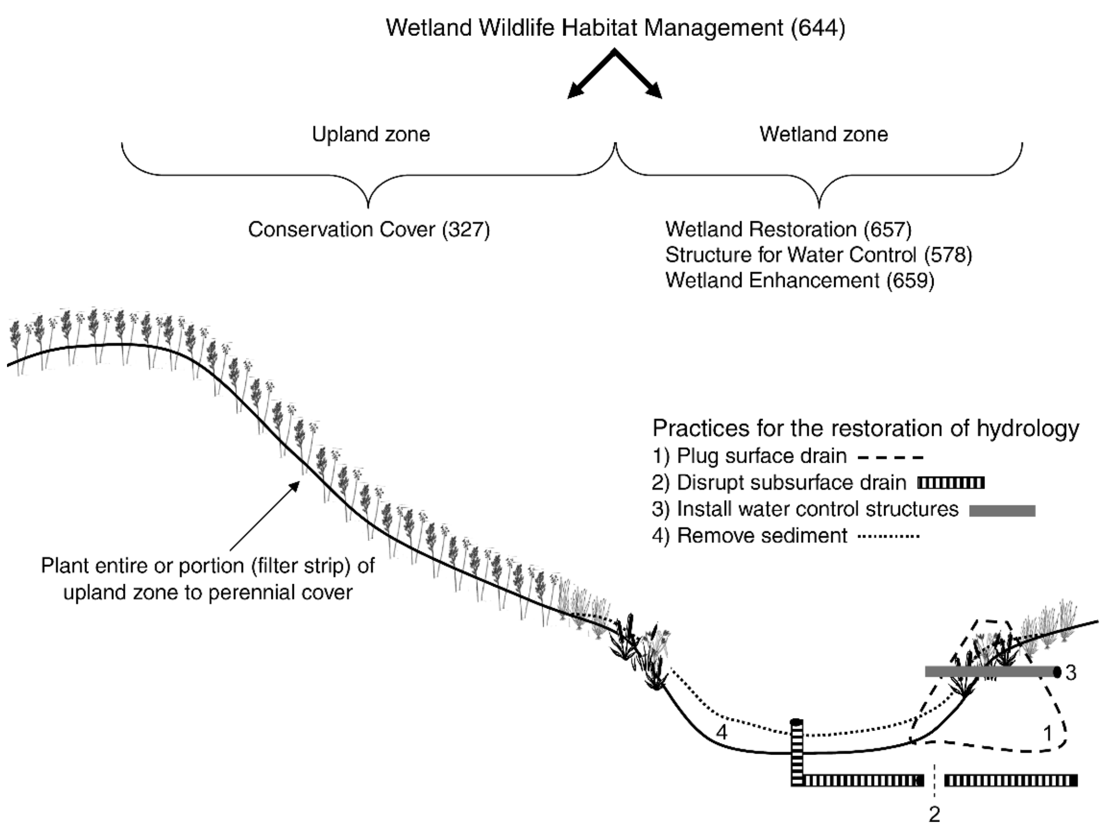

FIG. 3. Wetland catchment depicting application of conservation practices (with code numbers in parentheses) used to restore wetlands.

Eliminating drains and reestablishing vegetation may not restore hydrologic functions to presettlement conditions because agricultural practices have lowered local and regional groundwater tables (Galatowitsch and van der Valk 1994). In areas where the groundwater has been lowered, wetlands that historically functioned as flow-through or discharge sites may now only be capable of functioning as groundwater recharge sites. Hence, restored wetlands often have hydroperiods that are shorter than comparable reference sites (see review by Knutsen and Euliss 2001). Another factor contributing to shortened hydroperiods is the accumulation of sediments that have altered water depth and storage volume. Wetland restoration practices provide recommendations for removal of sediment to restore hydric soils based on the assumption that sediment removal will result in more natural volumes and hydroperiods.

To maximize restoration of hydrologic functions (i.e., groundwater connections) and biodiversity, it is often recommended that wetland restoration occur as part of larger efforts to restore landscapes or wetland complexes rather than restoring isolated wetlands in a drained agricultural landscape (Galatowitsch and van der Valk 1994, Swanson et al. 2003). The importance of wetland complexes to wildlife is recognized, but large-scale restorations are rarely implemented by most conservation programs, and the extent to which wetlands are restored in large blocks or complexes is unquantified in USDA databases. Such information is critical for quantifying all ecosystem services because an isolated restored wetland is not functionally equivalent to a similarly restored wetland within a complex.

Plant composition in upland areas of wetland catchments also has a significant influence on hydroperiod. Van der Kamp et al. (1999) found that wetlands in the PPR of Canada dried completely within a few years after catchments were planted to smooth brome (*Bromus* sp.), while adjacent wetlands in cultivated areas retained water as before. These findings demonstrate that prairie wetland hydrology is highly sensitive to land use in surrounding uplands and suggest that nonnative grasses (i.e., smooth brome) may require more water than native grasses. More recently, Voldseth et al. (2007) simulated the effects of upland vegetation cover and land use practices on water budgets and vegetation dynamics in prairie wetlands. They found that water levels were highest and wetland vegetation was most dynamic in grasslands managed through grazing and prescribed burning, and least dynamic in unmanaged grasslands. These simulations demonstrate the need to consider the effect of upland cover and land management on wetland hydrology when implementing restoration activities. Restoration practices employed by the USDA typically involve the planting of uplands to perennial cover following conservation cover or upland wildlife habitat management practice standards; hence, these practices result in the planting of upland catchments to a mix of species that maximize wildlife habitat (e.g., food, cover, shelter) and are not explicitly designed to restore hydrologic function.

Manipulation of upland vegetation is a key component of the restoration practice, but the impact of cover type and management (e.g., haying, burning, grazing) on wetland hydrology is poorly understood. Currently, USDA conservation practices do not provide adequate guidance for the selection of cover types and management practices to restore and maintain the physical hydrology (surface and shallow subsurface hydrological processes) of wetland catchments. Nor do existing practices explicitly link hydrologic processes in the uplands with wetland hydrology and vegetation dynamics. Development and implementation of upland conservation and management practices that have a hydrologic basis is likely the most effective approach to restore natural wetland functions.

Water storage

Restoration practices typically reduce surface runoff from uplands and enhance water retention in the landscape. Gleason and Tangen (2008) estimated that wetland catchments on lands enrolled in the CRP and WRP in the PPR could potentially intercept precipitation across ~444 574 ha and store ~56 513 hectare-meters (1 ha-m = 10 000 m^3) of water. However, this estimate of total water storage represents a static value that does not account for the effect of wetland conservation practices on numerous hydrologic processes that enhance water retention in the landscape. For example, eliminating drains and removing sediments restores wetland depth and volume, which enhances depression-focused recharge and retention time for evapotranspiration. Reestablishment of permanent vegetation and the associated development of dense root mats and soil organic matter promote greater soil water-holding capacity and infiltration. Additionally, vegetation slows the rate of runoff from upland areas associated with wetlands, thus providing greater opportunities for water infiltration and evapotranspiration. Consequently, when wetland water storage and upland water retention are considered collectively, wetland catchments have the potential to process and store substantial amounts of water that may otherwise contribute to offsite or "downstream" flooding.

Although conservation practices clearly improve water storage, the contribution to reduced offsite flooding has not been directly evaluated. However, at a watershed scale, Ludden et al. (1983) reported that depressional wetlands in the Devils Lake basin of North Dakota could store ~72% and 41% of total runoff volume from a 2-year and 100-year frequency runoff event, respectively, while Vining (2002) reported that wetlands were capable of storing >8000 ha-m in a single subbasin. Additionally, Malcolm (1979) reported that a complex of wetlands retained all local runoff plus 58% of additional inflow, and Gleason et al. (2007) reported that restoring drained and farmed wetlands could increase the water storage of a watershed in Minnesota by 63%. Studies also have related the alteration of wetlands and changes in land use to increases in the frequency and magnitude of flood events along rivers in the PPR (Moore and Larson 1979, Brun et al. 1981, Miller and Frink 1984, Miller and Nudds 1996, Bengtson and Padmanabhan 1999, Manale 2000, Simonovic and Juliano 2001).

Currently, little is known about floodwater storage provided by USDA conservation programs. Such an evaluation will require high-quality spatial data that should include important habitat features (e.g., individual wetlands) and specific management actions (e.g., hydrologic restoration, non-drained restoration, sediment removal) that affect water input rates and storage. Additionally, spatial data are necessary to determine if wetlands are located in contributing or non-contributing areas of drainage basins of lakes and rivers to evaluate the floodwater attenuation service.

Sedimentation and soil erosion reduction

A primary benefit of USDA conservation programs in the PPR is the reduction of soil erosion when perennial vegetation is established on cropland. Specific benefits of reduced soil erosion transport to wetlands include lowered sedimentation rates and decreased inputs of nutrients in runoff from surrounding uplands. Elevated rates of sedimentation can directly or indirectly affect the majority of ecosystem services that wetlands provide by reducing the topographic life of depressional basins (Gleason and Euliss 1998, Gleason 2001). The reduction in depth and water storage volume due to filling, in conjunction with elevated levels of nutrients and suspended materials, can negatively impact various aspects of wetland hydrology, water quality, and productivity. Loss of volume and shortening of wetland hydoperiod affects many ecosystem services, including groundwater recharge, water storage, and wildlife habitat. Similarly, increased nutrients and/or suspended sediments alter wetland biotic communities and may influence overall wetland productivity (Newcombe and MacDonald 1991, Gleason and Euliss 1998).

Studies have shown that implementation of conservation practices can significantly reduce soil erosion and sedimentation of wetlands in the PPR. Tangen and Gleason (2008) estimated that conversion of cultivated cropland to perennial cover might have reduced total soil loss by 1 760 666 Mg/yr on 276 021 ha of uplands surrounding wetlands on CRP and WRP lands in the PPR. For this same area, estimated reduction in nitrogen and phosphorus losses were 5102 Mg/yr and 68 Mg/yr, respectively. Martin and Hartman (1987) reported that sedimentation rates averaged 80 and 43 $mg \cdot cm^{-2} \cdot yr^{-1}$ in cropland and grassland catchments, respectively, and that phosphorus was deposited into cropland wetlands at almost twice the rate of wetlands in grassland. Freeland et al. (1999) found that the wet-meadow zone of wetlands surrounded by cropland had cumulic A horizons >60 cm thick (indicator of accelerated sedimentation), whereas cumulic horizons were absent in native prairie wetlands. Adomaitis et al. (1967) demonstrated that the aeolian mixture of snow and soil ("snirt") in wetlands surrounded by agricultural fields without vegetation accumulated at twice the rate of wetlands surrounded by fields with vegetation. Similar findings have been reported in areas outside the PPR. For example, Luo et al. (1997) reported that the vast majority of playa wetlands with cropland watersheds had completely lost their volume, whereas playas in native grassland had lost only about one-third of their volume.

Conservation practices can significantly reduce soil and nutrient loss from upland zones of wetland catchments, thereby improving sustainability of other ecological services provided by wetlands. Similar to the water storage service, the offsite benefits associated with reduced soil losses have not been comprehensively evaluated; however, reduction in soil erosion and nutrient transport will undoubtedly reduce delivery of sediments and nutrients that impair the water quality of lakes, streams, and rivers.

Plant community biodiversity

Studies of plant communities in restored wetlands have reported mixed results. Some investigators suggest that plant diversity increases rapidly after reflooding (Dornfeld and Warhurst 1988, LaGrange and Dinsmore 1989, Sewell 1989), but these early studies did not use a reference-based approach to facilitate comparisons with similar wetlands within cropland and native grassland. A recent reference-based study on 270 wetlands demonstrated a significant improvement in floristic quality and native-plant diversity relative to cropland wetlands (Laubhan and Gleason 2008), but floristic quality and diversity of restored sites did not attain levels comparable to native prairie sites. Other studies also have shown that plant communities of restored sites are highly variable compared to native prairie sites. For example, Galatowitsch and van der Valk (1996) found that deep marshes and aquatic beds were naturally species poor; hence, restored ecosystems of these types are very similar floristically to natural wetlands. However, edge communities like sedge and wet meadows have complex and diverse communities and are quite dissimilar between restored and natural wetlands.

Most wetlands targeted for restoration have been drained and farmed for extensive periods, which may impede successful plant recolonization (Galatowitsch and van der Valk 1994). For example, seed banks may lose viability due to prolonged drainage and cultivation (Wienhold and van der Valk 1989, Galatowitsch and van der Valk 1994, 1996) or are rendered unavailable due to burial by sediments (Jurik et al. 1994, Wang et al. 1994, Gleason et al. 2003). With the exception of some annuals, seed banks in restored wetlands may contribute little to revegetation (Galatowitsch and van der Valk

1994, 1996), and if species are absent in seed banks, revegetation will depend upon seed dispersal from surrounding wetlands (Galatowitsch and van der Valk 1996). Hence, restored wetlands in landscapes with high wetland densities (e.g., Missouri Coteau, Prairie Coteau) may recover more rapidly than areas like the Glaciated Plains where wetland drainage has been more severe. However, an evaluation of restored wetland seed banks in regions with high densities of prairie wetlands in the landscape indicated that seed banks of restored wetlands were dominated by annual mudflat species (Gleason 2001), whereas those of native prairie wetlands were composed primarily of perennial native seeds (Gleason 2001). Kantrud and Newton (1996) also demonstrated that more perennial, native species were associated with wetlands in grassland watersheds than cropland watersheds. Freeland et al. (1999) demonstrated that agriculture practices elevated phosphorus, nitrogen, and the percentage of silt in wet-meadow zones of wetlands within cropland. Consequently, agricultural land use that has altered soil structure, chemistry, and seed bank composition may prevent native perennial species from becoming established. These altered conditions may also favor invasive plants (e.g., *Phalaris arundinacea*, *Typha* × *glauca*) and preempt establishment of native species (e.g., *Carex* spp.) (Galatowitsch and van der Valk 1994, 1996, Franke 1997, Galatowitsch et al. 1999).

Wetland conservation practices have improved floristic quality and diversity relative to a cropland baseline (i.e., actively farmed catchments). However, current strategies may limit the level of floristic quality and species richness that can be achieved. The primary impediment appears to be the ability to facilitate establishment of plant species with high floristic quality values in both the upland and wetland zones. Many of these species are often absent from seed banks and have specific germination requirements or occupy precise niches (Budelsky and Galatowitsch 1999, van der Valk et al. 1999, Yetka and Galatowitsch 1999) that are difficult to replicate. Initial improvement in native-species richness in restored uplands surrounding wetlands is largely dependent on the mix of species seeded; however, some species may come from existing seed banks. Adding additional species to the seeding mix may increase native-plant diversity; however, selection of the seeding mix often is based on species that are best adapted for the region, rather than specifically tailored for wetland catchments. Depending on size and topographic relief, landscape positions within a catchment (Fig. 4) differ in aspect, soil moisture, and other edaphic factors that result in a range of environmental conditions. Selecting a mix of species best suited for each landscape position within a catchment may enhance establishment of a diversity of vegetation. As indicated earlier (see above, *Hydrology*), vegetation cover and management (e.g., grazing, mowing/haying) in upland zones of catchments influences water balance and vegetation dynamics in wetland zones. This implies that the type of cover and management in uplands may be important to restoring critical hydrological processes necessary for the establishment of diverse vegetation communities within wetlands. Research is needed to better understand the interaction between upland and wetland conservation practices and management activities on recovery of plant species diversity within the entire catchment.

Carbon sequestration

Concern over increasing atmospheric greenhouse gas (GHG) concentrations (e.g., carbon dioxide, nitrous oxide, methane) and associated climate change projections has stimulated interest in the potential of restored wetlands and grasslands to sequester atmospheric carbon (CO_2-C) in soils (Follett et al. 2001, Litynski et al. 2006). The potential amount of carbon sequestered by conservation practices is closely related to losses of soil organic carbon (SOC) that have occurred since agriculture began. For example, conversion of native wetlands and grasslands to cropland has been shown to deplete native SOC stocks by 20% to >50% (Mann 1986, Blank and Fosberg 1989, Anderson 1995, Cihacek and Ulmer 1995, Euliss et al. 2006, Gleason et al. 2008*b*). The difference in SOC between cropland and native prairie is often used as the estimate of potential carbon that could be sequestered through restoration. Using this approach, restoration of cropland wetlands in the PPR of the United States has potential to sequester ~72 Tg of SOC (Gleason et al. 2005, Euliss et al. 2006), and wetland catchments on lands enrolled in the CRP and WRP (444 574 ha) have the potential to sequester 6 662 355 Mg of SOC (Gleason et al. 2008*b*).

While studies indicate that SOC sequestration rates in restored wetlands and grasslands range from 0.1 to >3 $Mg \cdot ha^{-1} \cdot yr^{-1}$ (Gebhart et al. 1994, Conant et al. 2001, Follett et al. 2001, Euliss et al. 2006), there are concerns that this sequestration benefit may be offset by increased emissions of nitrous oxide (N_2O) and methane (CH_4) (Whiting and Chanton 2001, Post et al. 2004, Bedard-Haughn et al. 2006, Bridgham et al. 2006). Though there is limited information on N_2O and CH_4 emissions from wetlands in the PPR, studies suggest that restoration of previously farmed wetlands may reduce emission of these GHGs. Data from a glaciated region in northeastern Germany similar to the North American PPR suggest that enrichment from nitrogen fertilizer and accelerated mineralization of organic matter elevate emissions of N_2O and CH_4 in cropland wetlands (Merbach et al. 2002). More recently, Bedard-Haughn et al. (2006) found that cultivated wetlands in the PPR of Canada had greater total emissions of N_2O than noncultivated wetlands. These findings are consistent with other studies demonstrating that nitrogen fertilization enhances emissions of N_2O (Thornton and Valente 1996, Davidson et al. 2000, Phillips and Beeri 2008). Studies also have shown that conversion of cropland to perennial grassland reduces emissions of CH_4 from upland soils (Keller et al. 1990, Dorr et al. 1993,

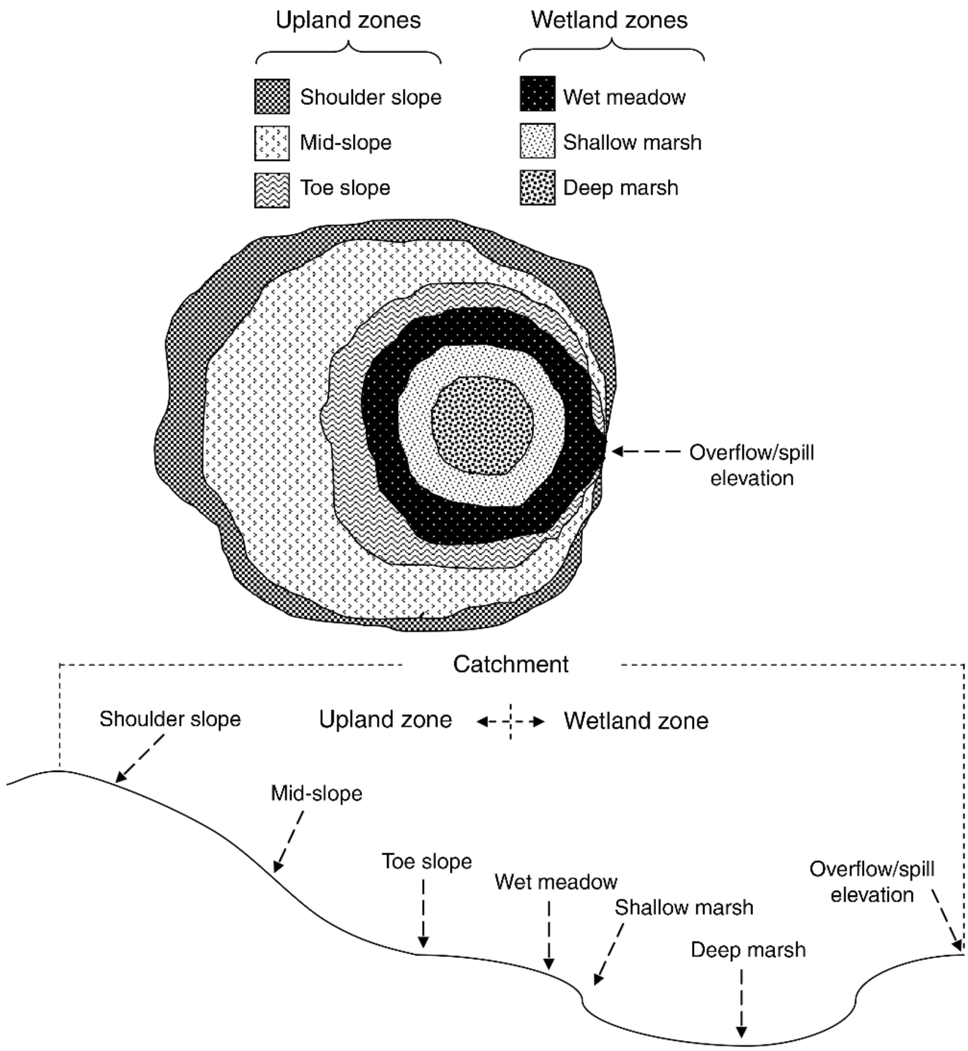

FIG. 4. Generalized depiction of landscape positions/zones within wetland catchments that vary with respect to environmental factors (e.g., relief, aspect, soils, hydrology) that should be considered when implementing conservation practices to reestablish native-plant community diversity (modified from Gleason and Laubhan [2008]).

Parashar et al. 2001). Consequently, converting cultivated cropland to perennial vegetation within restored wetland catchments should reduce nutrient enrichment in restored wetlands and lower emissions of N_2O, and possibly CH_4.

In addition to replenishment of SOC stocks, carbon stored in the aboveground vegetation biomass represents an additional pool of sequestered carbon. Gleason et al. (2008*b*) estimated that >715 000 Mg of carbon may be stored in the vegetation biomass of restored wetland catchments on lands enrolled in the CRP and WRP. Carbon stored or sequestered in the aboveground biomass is often viewed as a non-permanent form of carbon storage because of susceptibility to disturbances such as fire. However, restored grassland and wetland plant communities reestablish quickly following fire; hence, the carbon stored in vegetation biomass represents an almost immediate and rather constant form of carbon storage as long as the area is managed for conservation.

Carbon sequestration is an ancillary benefit because climate change mitigation was not an intended outcome of USDA conservation programs when they were originally implemented. Hence, the importance of restored wetlands to sequester carbon is a recent development, and conservation practices have not been developed or implemented specifically to maximize the carbon sequestration potential of restored wetlands. Much additional information will be required to better understand the role of prairie wetlands in climate change mitigation and to develop or refine conservation practices that optimize potential GHG benefits.

Wildlife habitat

The importance of Farm Bill conservation programs to wildlife is well documented (Heard et al. 2000, Knutsen and Euliss 2001, Haufler 2005, 2007). Research in the PPR has documented the regional-scale positive impacts of the CRP on many species of grassland birds (Johnson 2000, 2005, Haroldson et al. 2006, Veech 2006), waterfowl (Reynolds et al. 2001, Reynolds 2005), and other grassland-dependent wildlife (Knutsen and Euliss 2001). For example, it has been estimated that CRP grasslands in the PPR have contributed to the production of 25.7 million ducks between 1992 and 2003 (Reynolds et al. 2001, Reynolds 2005). Studies conducted at catchment scales also suggest that breeding-bird diversity and abundance in restored wetlands is similar to native prairie wetlands (Knutsen and Euliss 2001, Ratti et al. 2001, Rewa 2007). Restored wetlands may also support similar invertebrate, mammal, and amphibian populations as native prairie wetlands (Knutsen and Euliss 2001, Rewa 2007).

Wildlife response to habitat restoration is a multiscale phenomenon dependent on numerous spatial and structural requisites (Jones-Farrand et al. 2007, Laubhan et al. 2008). Use of CRP lands by various bird species varies by patch size and landscape connectivity to other grassland and wetland communities (Naugle et al. 1999, Johnson 2001, Johnson and Igl 2001, Bakker et al. 2002, Niemuth and Solberg 2003, Horn et al. 2005). Structure and composition of plant communities at the field scale also influences wildlife habitat suitability (Laubhan et al. 2008). Upland habitat vegetation suitability in terms of visual obstruction, height, density, stand age, seral stage, and cover type has been related to nesting grassland birds, shorebirds, and waterfowl (Renken 1983, Hertel 1987, Kantrud and Higgins 1992, Patterson and Best 1996, Scheiman et al. 2003, Fritcher et al. 2004, Bakker et al. 2006, Jones-Farrand et al. 2007). Similarly, temporal changes in wetland vegetation structure and composition, and food resources (i.e., aquatic invertebrates) affect shifts in wildlife use (Swanson and Duebbert 1989, Swanson et al. 2003, Euliss et al. 2004). Many of these studies also emphasize the importance of wetland complexes to meet habitat requirements of breeding waterfowl. For example, waterfowl use temporary and seasonal wetlands for courtship and foraging sites early in the breeding season, whereas semipermanent and permanent wetlands are used for foraging and brood-rearing habitat later in season.

Based on species' habitat requirements, landscape-scale habitat models for grassland birds, waterfowl, and waterbirds have been developed to guide conservation planning and management activities in the PPR (Cowardin et al. 1988, Naugle et al. 2001, Niemuth et al. 2005, Reynolds et al. 2006). The importance of using similar models or approaches to guide delivery of USDA conservation programs in the PPR to maximize wildlife benefits only recently has been considered. For example, Reynolds et al. (2006) developed models to identify areas in the PPR where CRP cover would provide the greatest benefits to duck production. Their analyses showed that 75% of the active CRP contracts in 2005 occurred in areas accessible to high or medium numbers of breeding ducks, whereas 25% occurred in areas of low populations. These findings were instrumental for development of the CRP Duck Nesting Habitat Initiative that specifically aims to restore wetland habitats in areas or landscapes most suitable for nesting waterfowl (USDA 2006). Under this initiative, the Environmental Benefit Index used by the USDA to rank parcels for enrollment, included eligibility criteria tailored to meet the habitat needs of nesting waterfowl. Another USDA initiative, State Acres for Wildlife Enhancement (SAFE; USDA 2007), was adopted to address the habitat needs of endangered, threatened, or high-priority fish and wildlife species. The SAFE initiative also allows conservation practices currently offered under the CRP to be fine-tuned to meet specific state-level wildlife objectives rather than generalized program objectives (Burger 2006). Initiatives like SAFE will likely result in greater reliance in the future on species-specific landscape-level habitat models or concepts to better guide delivery of USDA conservation programs and practices to meet wildlife objectives.

Most experts agree that conserving wildlife resources over the long term will require cooperating with private landowners on agricultural lands (Euliss et al. 2007). The most influential program affecting the quantity and quality of wildlife habitat on private lands is the Farm Bill. Studies have demonstrated that the restoration of wetlands and grasslands under USDA conservation programs has enhanced the distribution and quality of habitat for many wildlife species. However, the preceding review also suggests that greater wildlife benefits may result if species-specific habitat relationships are considered when implementing conservation programs. Many landscape-level habitat models for avian species are available, and significant opportunity exists to incorporate these models along with habitat quality criteria and concepts of wetland complexes to optimize wildlife benefits when targeting lands for conservation programs.

Toward Future Assessments of Ecosystem Services

Recent assessments of USDA conservation programs in the PPR suggest positive environmental benefits, but a comprehensive assessment of all ecosystem services will be required to evaluate overall program performance. Our understanding of environmental benefits provided by conservation programs is limited to relatively few studies conducted on only a few conservation programs (e.g., CRP). These studies were generally conducted at scales that do not allow comprehensive assessments of specific conservation practices or programs on the myriad of ecosystem services. Because of the large number of conservation practices included within existing programs, conducting high-quality assessments would require significant funding. However, detailed spatial data on program lands and practices will be crucial to more fully quantify ecosystem services at watershed scales (e.g., floodwater storage, water quality). Detailed spatial data also are necessary to evaluate potential ecological trade-offs and develop optimization strategies that sustain ecosystem services (Euliss and Laubhan 2005). For example, establishment of grassland strips or wetland buffers adjacent to rivers and lakes may provide significant water quality services; however, establishment of similar habitat in some landscapes may be incompatible with waterfowl production because fragmented or linear habitats often exhibit high depredation rates (Reynolds et al. 2006).

Our current knowledge of ecosystem services provided by USDA conservation programs is largely limited to point-in-time estimates. However, the PPR has a very strong interannual climate that cycles between major drought and deluge. Wetland hydrologic conditions in the PPR are highly sensitive to climate (LaBaugh et al. 1996, Euliss et al. 2004) and extreme variations can result in pronounced changes in wetland processes (e.g., methogenesis, denitrification), water chemistry, and plant, invertebrate, and wildlife diversity. Hence, it is critical to understand how conservation programs and the cumulative effects of conservation practices contribute to ecosystem function throughout the natural interannual climate cycle to provide specific goods and services to society.

Despite the importance of the CRP to waterfowl in the PPR, severe drought lowers the quality of the region for waterfowl. The regional climate also works in synergy with conservation programs to influence all ecosystem services. For example, wetlands fill during extremely wet periods and provide less water storage than in dry years, whereas lowered pool levels maximize storage and buffer the region from extreme precipitation events. Because natural climate variability has such a large impact on ecosystem services, the adaptive management and policy goals of the USDA can only be evaluated when changes in ecosystem services caused by natural weather patterns can be separated from those due to conservation programs in the PPR (Euliss and Laubhan 2005). A recently launched U.S. Geological Survey Science Thrust, the Integrated Landscape Monitoring Initiative in the PPR, is developing a modeling and monitoring framework to quantify change in ecosystem services when conservation practices are implemented. The foundation of this framework is based on the unique climatic drivers in the PPR and models are being developed that will separate change in ecosystem services due to natural factors from those attributable to federal conservation programs (Feng et al. 2009, Euliss et al. 2011). The model is also being developed to incorporate various climate change scenarios to facilitate evaluations of how climate and land use futures may affect provisioning of ecosystem services. Moreover, the modeling framework will facilitate manipulations to explore potential mitigation strategies for diverse ecosystem services from all functional types of wetlands in the PPR.

Conclusions and Future Resource Concerns

Implementation of Farm Bill wetland conservation programs in the PPR has enhanced the provision of various ecosystem services to society. However, the provision of these ecosystem services in the future is uncertain because many contracts (especially CRP) will expire in the near future. Reynolds et al. (2005) reported that nearly 1.01 million ha (2.5 million acres) enrolled in the CRP in the PPR is set to expire in 2007, and by 2010 only ~20% of the land would remain in active contracts. When contracts expire, landowners may reenroll in conservation programs, maintain the restored habitat for grazing, haying, or conservation benefits, or return the land to crop production. Decision criteria used by landowners will include both socioeconomic and conservation considerations (Skaggs et al. 1994, Johnson et al. 1997); hence, crop prices, land values, and demand futures for specialty crops (e.g., biofuels) will likely influence whether conservation lands are returned to crop production. Further, recent improvements in farming techniques and genetically modified crops have increased profit margins and made marginal cropland often targeted by conservation programs more profitable (Herdt 2006, USGAO 2007).

As demands for agricultural products (food, fiber, biofuels) increase, USDA conservation policies will become increasingly important to ensure sustainability, regulation, and provisioning of other ecosystem services to sustain human health and quality-of-life standards (e.g., clean water, wildlife habitat). Program changes will require not only a thorough understanding of the effects of conservation practices on ecosystems services, but also the interaction of all Farm Bill policies and programs that may be working at cross purposes to one another. For example, from 1982 to 1997, 683 943 ha of cropland in South Dakota was enrolled in the CRP, while 736 554 ha of native grassland was converted to cropland; farm program payments are believed to have been an important factor influencing landowner's decisions to convert grasslands to cropland (Stubbs 2007, USGAO 2007).

Environmental and conservation goals have increasingly become key factors in the formulation of USDA policies. Implicit to the development and support for specific conservation policies and programs (e.g., WRP) has been the recognition of important ecosystem services provided by wetlands. Moreover, continued support for these programs will require evaluations of program achievements relative to conservation goals. Overall, recent USDA policies have protected wetlands on agricultural lands from drainage (e.g., the Swampbuster provision) and conservation programs (e.g., WRP) have enhanced the delivery of ecosystem services. However, our understanding of what to expect from wetland conservation programs is still unclear because conservation goals do not include explicit performance measures. For example, conservation goals often are not stated as quantifiable outcomes, such as tons of carbon to be sequestered or a desired percentage of reduction in sediments and nutrients delivered to a lake or river within a specific watershed. Only recently have conservation programs been modified to address region-specific conservation needs. For example, both the CRP Duck Nesting Habitat and SAFE initiatives (see *Wildlife habitat* section) will presumably result in the development of specific performance measures from which to evaluate program achievements. However, development of wetland conservation programs intended to maximize a particular service (e.g., wildlife habitat vs. water quality) may come at a cost to other services. Consequently, future challenges will include developing a better understanding of ecological service trade-offs that may be incurred as conservation programs become more refined to address specific environmental issues (Euliss and Laubhan 2005).

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