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SEDIMENTATION OF PRAIRIE WETLANDS

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Abstract: *Many wetlands in the prairie pothole region are embedded within an agricultural landscape where they are subject to varying degrees of siltation. Cultivation of wetland catchment areas has exacerbated soil erosion; wetlands in agricultural fields receive more sediment from upland areas than wetlands in grassland landscapes and hence are subject to premature filling (i.e., they have shorter topographic lives). Associated impacts from increased turbidity, sediment deposition, and increased surface water input likely have impaired natural wetland functions. Although trapping of sediments by wetlands is often cited as a water quality benefit, sediment input from agricultural fields has potential to completely fill wetlands and shorten their effective life-span. Thus, the value placed on wetlands to trap sediments is in conflict with maximizing the effective topographic life of wetlands. Herein, we provide an overview of sedimentation, identify associated impacts on wetlands, and suggest remedial management strategies. We also highlight the need to evaluate the impact of agricultural practices on wetland functions from an interdisciplinary approach to facilitate development of best management practices that benefit both wetland and agricultural interests.*

The prairie pothole region (PPR) occurs in a topographic, hydrologic, and land use setting that exacerbates the accumulation and retention of sediments in wetlands. Sediment retention by wetlands is often described as a water quality benefit (e.g., Botto and Patrick 1978; Kuenzler 1990). However, excessive sediment input from erosion of agricultural soils has potential to severely impact PPR wetlands; sediment is the major pollutant of wetlands, lakes, rivers, and estuaries in the United States (Baker 1992; USEPA 1995). Wetlands in the PPR are embedded within an agricultural landscape where cultivation of wetland catchment areas (i.e., the area that contributes surface runoff to the wetland basin) has greatly altered surface runoff dynamics and hydrologic inputs to groundwater. Grasslands that once protected prairie soils from erosion and moderated surface runoff have been converted to cropland. Consequently, wetlands in agricultural fields receive significantly more surface runoff containing sediment than occurred prior to agricultural conversion (Grue et al. 1986; Neely and Baker 1989; Euliss and Mushet 1996; Gleason 1996).

The impact of suspended sediment and sedimentation on fish and aquatic life has been investigated in riverine systems (Newcombe and MacDonald 1991; Waters 1995), but few studies have addressed impacts of sedimentation in wetland ecosystems. Sedimentation impacts include increased turbidity that reduces the depth of the photic zone and increases sediment fallout which may cover primary producers and invertebrates. Excessive sediment input thus potentially alters aquatic food webs as well as basic wetland functions related to water quality improvement, nutrient cycling, and other biogenic processes that transform and sequester pollutants. Moreover, erosional sediment can fill wetlands either as a single catastrophic event or gradually; basins totally filled with sediment provide no natural wetland functions of benefit to society.

The primary source of sediments in prairie wetlands is wind and water erosion from agricultural fields (Gleason 1996). Agricultural research is replete with information on soil erosion and the detrimental effects of soil loss on agricultural production (e.g., Wischmeier and Smith 1978; Bills and Heimlich 1984; Lane and Nearing 1989; Moldenhauer and Black 1994). Agricultural research also has been instrumental in developing and implementing conservation practices on private lands that reduce soil erosion, maintain productivity of croplands, and improve soil and water quality (Cook 1988; Moldenhauer and Black 1994). However, the benefits of such practices are generally evaluated from an agricultural perspective and the consequences of implementing those conservation practices on most wetland functions have not been evaluated. Future research needs to examine the impact of sedimentation from an interdisciplinary platform. Integration of agricultural and wetland interests and expertise is critical to the development of such research programs (Gleason and Euliss 1997).

This manuscript is a review of sedimentation in PPR wetlands. Its purpose is to (1) present an overview of sedimentation and identify potential impacts on wetland functions, (2) identify management strategies that reduce sediment inputs, and (3) highlight research needs of prairie wetlands relative to soil conservation issues.

Erosion and Sedimentation

Most wetlands in the PPR are surficially closed basins that lack integrated drainage networks (Richardson et al. 1994). Thus, wetland sediment inputs are derived primarily from wind and water erosion of upland soils in catchment and adjacent areas. Tillage has greatly altered the surface hydrologic dynamics of wetland catchments; conventional tillage increases erosion rates and surface runoff relative to grassland landscapes (Gleason 1996; Euliss and Mushet 1996). However, few studies have examined the impact of sedimentation on the majority of functions that prairie wetlands are known to perform. Adomaitis et al. (1967), demonstrated that the aeolian mixture of snow and soil ("snirt") in wetlands surrounded by fields without vegetation accumulated at twice the rate as in wetlands surrounded by fields with vegetation. Similarly, Martin and Hartman (1987) found that the flux of inorganic sediments into wetlands with cultivated catchments occurred at nearly twice the rate of wetlands with native grassland catchments. Organic matter also occurs at significantly greater concentrations in wetland sediments in wetlands with native grassland catchments than in wetlands with cultivated catchments. Dieter (1991) demonstrated that turbidity was highest in tilled (i.e., wetland and catchment areas tilled) than in untilled and partially tilled (i.e., portions of the basin tilled with a buffer strip of vegetation separating the basin and catchment area) wetlands. Similarly, Gleason (1996) and Gleason and Euliss (1996) found that sedimentation rates and the inorganic fraction of sediment entering wetlands were significantly higher in wetlands with cultivated catchments than in wetlands with grassland catchments. There also was more aeolian deposited sediment in wetlands in cultivated catchments than in wetlands with grassland catchments (Gleason and Euliss unpublished data). In the playa wetlands of Texas, Luo et al. (1997) found that wetlands in cultivated watersheds had lost nearly all of their original volume due to filling by sediment, whereas comparable sites in rangeland watersheds lost only about a third of their original volume. Additionally, hydroperiods of playa wetlands in cultivated watersheds have been drastically altered by sedimentation over the past six decades. A conclusion common to all these studies is that wetlands in agricultural landscapes have shorter topographical lives than wetlands in grassland landscapes.

Effects of Sedimentation on Wetland Function and Values

While natural processes may fill wetlands with sediment, anthropogenic influences have great potential to accelerate erosion, prematurely fill wetlands, and degrade wetland functions. The most severe impact occurs when wetlands fill with so much sediment that they no longer pond water; such wetlands have lost their capacity to perform most natural wetland functions. While the loss of wetland functions when basins totally fill with sediment is intuitive, the relationship of functional loss and degradation to gradual but chronic filling is less well appreciated and understood. In the following discussion, we examine impacts of sedimentation on primary production, aquatic invertebrates, wildlife habitat, and on hydrologic and water quality issues.

Effects on Primary Production

The production of aquatic macrophytes and algae is an important component of prairie wetland food chains. Aquatic macrophytes provide structural habitat for invertebrate and vertebrate life and also provide substrates for colonization by epiphytic algae and microbes that are important foods of aquatic invertebrates (Murkin 1989). Once macrophytes senescence, they contribute litter for colonization by microbes which provide additional food resources for aquatic invertebrates (Mann 1988). In addition to epiphytic algae, phytoplankton and epibenthic algae are also major sources of carbon in prairie wetlands and are important food resources of aquatic invertebrates (Murkin 1989; Neill and Cornwell 1992). Anthropogenic sedimentation has potential to suppress primary production and alter natural food chain interactions. Increased sediment in the water column generally reduces the depth of the photic zone and hence reduces the light available for primary production by aquatic macrophytes and algae (Ellis 1936; Robel 1961; Dieter 1991). As sediment falls out of suspension, deposition may be adequate to bury epibenthic algae, macrophytic photosynthetic substrates, and seed banks (Rybicki and Carter 1986; Hartleb et al. 1993; Jurik et al. 1994; Wang et al. 1994). Jurik et al. (1994) and Wang et al. (1994) demonstrated that sediment depths of 0.25 cm can significantly reduce species richness, emergence, and germination of wetland macrophytes. Jurik et al. (1994) also found that the greatest decreases in germination occurred for species with the smallest seeds. Hartleb et al. (1993) showed that seed germination of water milfoil (*Myriophyllum spicatum* L.) was significantly reduced when buried by more than 2 cm of sediment, and Rybicki and Carter (1986) found that survival of water-celery (*Vallisneria americana* MICHX) tubers declined 90% when buried by 10 cm, and by 100% when buried by 25 cm of sediment. Although, these studies demonstrated the relationship between sedimentation and germination, the causative agent that inhibits germination or survival is poorly understood. For example, covering of seeds with varying depths of sediment may alter light and/or redox conditions that inhibit seed germination or the sediment may create a physical barrier to emergence.

The magnitude and timing of anthropogenically enhanced sedimentation may influence structure and recolonization of plant communities in prairie wetlands. Under natural conditions, plant communities in prairie wetlands are dynamic and undergo cyclic changes in response to short- and long-term water-level fluctuations and salinity. Four prairie wetland cyclic conditions were identified by van der Valk and Davis (1976): dry marsh, regenerating marsh, degenerating marsh, and lake. During the dry marsh or drawdown phase, sediments and seed banks are exposed and mudflat annuals and emergent plant species germinate and recolonize the wetland (van der Valk and Davis 1976). Since recolonization is dependent on viable seed banks, the covering of seed banks with sediment has potential to impede the recolonization process (Jurik et al. 1994). Additionally, the loss of wetland volume from accelerated sedimentation makes wetlands shallower, which allows monodominant stands of cattails, normally restricted to water depths <60 cm (Bellrose and Brown 1941) to expand. Such stands of vegetation contribute little to biological diversity and exacerbate problems with agricultural interests because they provide roost sites for blackbirds that depredate cereal crops (Linz et al. 1996).

Effects on Aquatic Invertebrates

Any suppression of primary production from sedimentation would be expected to negatively impact wetland invertebrates. The loss of standing vegetative structure generally makes wetlands less productive of invertebrates (Krecker 1939; Krull 1970; Euliss and Grodhaus 1987). Recent studies stressing the nutritional value of algae to invertebrates (Neill and Cornwell 1992) suggest that loss of algal biomass especially periphyton and phytoplankton, also would make wetlands less productive of invertebrates. Direct impacts of turbidity and sedimentation may include covering of invertebrates eggs, the clogging of filtering apparatuses, and the covering of organic substrates important in aquatic food chains (Swanson and Duebbert 1989). High levels of suspended silt and clay have been shown to be toxic and to reduce zooplankton feeding rates and assimilation (Robinson 1957; McCabe and O'Brien 1983; Newcombe and MacDonald 1991). Further, impacts of sediment on aquatic invertebrates and plants may be exacerbated in the presence of other stressors such as agrichemicals when sorbed to sediments (Hartman and Martin 1984, 1985). For example, the acute toxicity of the agricultural herbicide glyphosate is increased for water fleas (*Daphnia pulex*), but suppressed for duck weed (*Lemna minor*) when adsorbed to suspended sediment (Hartman and Martin 1985). Glyphosate adsorbed on suspended sediment was apparently ingested by water fleas (*Daphnia pulex*) and thus provided a direct route of exposure, whereas adsorption of glyphosate on sediment rendered it unavailable to duck weed (*Lemna minor*).

Effects on Wildlife

An important function of wetlands is to provide wildlife habitat. Alteration of vegetative cover and aquatic invertebrate communities has a direct impact on all wetland wildlife. Aquatic invertebrates are important dietary items of waterfowl (Krapu 1974a, 1974b; Swanson et al. 1974, 1985; Euliss and Harris 1987; Miller 1987; Euliss et al. 1991) and other wetland-dependent birds (Reeder 1951; Fritzell et al. 1979). Protein-rich invertebrate foods are needed to meet the physiological demands of egg-laying for hens during the breeding season (Krapu 1979) and they provide essential amino acids for other seasonal changes such as feather molt (Heitmeyer 1988). The impact of sedimentation on wetland wildlife is likely indirect, involving habitat changes in response to siltation events.

Effects on Hydrologic Functions

The effects of wetland sediments on groundwater hydrology is unknown, but the alteration of the ratio of surface water to ground water hydrology in prairie wetlands is obvious. As the native prairie landscape was converted to cropland, the runoff dynamics of the entire landscape was changed. Surface runoff from snowmelt and storms during presettlement times was moderated by native vegetation, dampening the effect of runoff and increasing the time available for infiltration. Conversion of native prairie grassland to cropland has likely increased the intensity of runoff events and decreased the time available for infiltration. The unusually high variance in water level fluctuations in PPR wetlands in agricultural landscapes found by Euliss and Mushet (1996) was attributed to higher runoff potential of cropland versus grassland. Further, modifications to presettlement surface runoff dynamics result from an extensive road system in the PPR, with roads occurring in both north-south and east-west orientation at roughly 1.61 km (1 mile) intervals. Most of these roads are elevated and many lack adequate culvert systems to pass water through traditional paths of conveyance. As a result, the sheet flow dynamics have been severely altered since settlement of the PPR and the importance of surface flow has greatly increased in recent times. Increased surface flow can exacerbate flooding as was noted by Miller and Nudds (1996) who related intensity of floods in the Mississippi River Valley to landscape changes involving conversion of grassland to cropland in the prairies.

Aside from altering the natural ratio of ground to surface water input into wetlands, wetland sedimentation may have altered local groundwater flow patterns. Precipitation that was once lost through evapotranspiration or infiltration to groundwater before entering wetlands in grassland catchments, may now enter wetlands via spates of surface runoff from tilled catchments. These surface runoff spates may transport sediments, nutrients, and other pollutants into wetlands (see Goldsborough and Crumpton 1998). In addition to the alteration of hydrologic inputs, the loss of basin volume from siltation reduces the water storage capacity and flood attenuation benefits of wetlands (Brun et al. 1981; Ludden et al. 1983).

Effects on Water Quality Functions

The water quality functions wetlands provide are dependent upon interactions between vegetation, substrates, and microbial populations (Hemond and Benoit 1988; Hammer 1992). Wetland soils are the primary media wherein microbial mediated transformation of nutrients and storage of pollutants occur. The most active sites of chemical transformations are the thin aerated zones at the soil-water interface, and the thin aerobic zone surrounding the roots of vascular plants (Hammer 1992; Mitsch and Gosselink 1993). For agrichemicals that require biological or chemical transformation for solubilization and subsequent removal, there is some potential for sediment burial to decrease the release of bound nutrients (Neely and Baker 1989). However, we generally have a poor understanding of the impact of sedimentation on specific processes involved with improving water quality in prairie wetlands (Hemond and Benoit 1988; Adamus and Brandt 1990).

Although incomplete, we have a better understanding of the indirect impact sediment exerts on water quality through its influence on hydrophytes, organic exchange substrates, and microbial populations. Reduction of light available for photosynthesis due to turbidity and the burial of macrophyte seed banks are obviously negative impacts of excessive sediment entering wetlands from adjacent fields. Aquatic macrophytes and algae are important in the uptake, short-term storage, and cycling of nutrients in wetlands; negative impacts on plants from sediments may alter water quality functions. Increased input of allochthonous inorganic matter to wetlands (Martin and Hartman 1987; Gleason 1996) would reduce the availability of organic exchange surfaces important for sorption of contaminants, especially on the thin aerobic zone at the soil-water interface. While the impact of sedimentation on microbes has not been studied (Adamus and Brandt 1990), sediment fallout may cover microbes, or organic matter needed for microbial processes, or alter redox profiles important in the performance of water quality processes. Finally, the ability of wetlands to remove and retain sediments is a basic concept of improved water quality, but many PPR wetlands are closed systems that can totally fill with sediments and hence lose their capacity to function properly. The trade off between the importance of sediment removal as a water quality benefit and maintaining the topographic life of wetland basins clearly needs to be integrated into management strategies of wetlands.

Research Needs

Reduction of Sediment Inputs

1) Evaluate the effectiveness of alternative agricultural practices to reduce erosion from cropland and sedimentation of wetlands. Studies need to simultaneously consider the benefits to both agricultural and conservation communities; scientists from both communities <u>must</u> provide input to make realistic and informed decisions about the management of wetlands within agricultural landscapes. Ideally, studies should be interdisciplinary and have active participants from both agricultural and wetland disciplines to provide a forum for evaluation of agricultural conservation practices. The potential for sedimentation to degrade wetlands is great and the most obvious research need is to evaluate land-use practices that reduce surface runoff and erosion of valuable topsoil. Concerns over soil erosion and its effects on agricultural productivity has resulted in a great body of knowledge on watershed factors (e.g., slope, soils, cover, land-use) that influence erosion and the input of sediment, phosphorus, nitrogen, and agrichemical runoff associated with conventional and conservation tillage practices (Bills and Heimlich 1984; Neely and Baker 1989; Isenee and Sadeghi 1993; Fawcett et al. 1994). These conservation practices certainly reduce soil erosion and runoff, however they have generally been evaluated from an agricultural perspective. Research is now needed to evaluate the effectiveness of the various conservation practices to reduce sediment input and thereby maximize the topo-

graphic lives of wetlands within the agriculturally-dominated ecosystem of the PPR. Economic incentives may be an important tool to facilitate landowner acceptance and implementation of conservation practices that target goals of sustained agricultural production and long-term wetland management. Additionally, monitoring programs should be developed to foster the continual improvement of soil conserving practices and ones that enhance the performance or longevity of wetland functions.

2) Evaluate control measures and siting criteria to reduce sediment input in wetlands. Vegetative buffer strips are frequently used and have been shown to be effective at reducing nonpoint source pollutants, including sediment, from adjacent habitats (Dillaha et al. 1989; Magette et al. 1989; Castelle et al. 1992). However, little research has been conducted on the benefits they may provide to prairie wetlands. The semi-arid PPR undergoes long periods of drought followed by long periods of abundant rainfall. These wet/dry cycles can persist for 10 to 20 years (Duvick and Blasing 1981; Karl and Kascielny 1982; Karl and Riebsame 1984; Diaz 1983, 1986). During periods of severe drought, most wetlands go dry during summer and many remain dry throughout the drought years. Buffer strips established to protect wetands during a dry cycle may become submerged and ineffective in reducing sediment input in wetlands during the wet cycle (Gleason 1996). Thus, research is needed to identify effective buffer strip widths for wetlands with different catchment morphometries, soil types, and surrounding agricultural practices. Although substantial amounts of land has been planted to perennial cover as part of the Conservation Reserve Program, studies have not been conducted to evaluate which cover types are most effective in reducing soil erosion under various land use and topographic scenarios.

Effects on Wetland Functions

3) Evaluate the impacts of increased surface runoff and sedimentation on all wetland functions (e.g., wildlife habitat, groundwater recharge, nutrient cycling, water quality improvement, production). The impact of sediment on all wetland functions has been inadequately studied (Adamus and Brandt 1990). The point at which sediment inputs overload the assimilative capacity of wetlands needs to be identified and management guidelines developed that are based on sound remedial practices that simultaneously consider various interests and needs. Due to the paucity of information, major research gaps exist but a current emphasis seems to be on wildlife and water

quality issues. Given the dynamic nature of prairie wetlands, research on sediment impact on wetland functions needs to be conducted and interpreted within a conceptual framework that considers natural hydrologic, chemical, and climatic events that characterize the region.

Wetland Restoration

5) Evaluation of methods to restore pool depth in silted-in wetlands. Methods to restore drained or nondrained wetlands that are silted in and have lost their original wetland volume need to be evaluated within the context of economics and their postrestoration potential to provide targeted functions. Excavation of sediments and/or increasing the water depth with water control structures may have the same effect of restoring water depth but the economic cost versus gain in wetland functions are not known.

Conclusions

Most prairie wetlands are embedded in agricultural landscapes and tillage of their catchment areas facilitates increased surface runoff and sediment inputs relative to a grassland condition. Erosional sediment from anthropogenic sources greatly shortens the topographic life of prairie wetlands. Obviously, a filled basin has lost its capacity to provide natural wetland functions of value to society; however, less intuitive is the impact of altered hydrology and spates of sediment inputs on wetland functions. Often wetlands are highlighted as providing numerous functions and values, including improving water quality. A fundamental property of wetlands to improve water quality is that they filter and retain sediments, and through physical, chemical and biological processes they transform and sequester pollutants; however, there is a trade off between the importance of sediment removal as a water quality benefit and maintaining the topographic life of wetland basins. Obviously, wetlands play an important role in improving environmental quality, especially controlling the offsite impacts of agricultural runoff on rivers, lakes, and reservoirs. However, wetlands should only be used to remove sediments and other agricultural pollutants after agricultural best management practices have been implemented (Kuenzler 1990). Consequently, research is needed to evaluate the effectiveness of the various conservation practices that reduce sediment input and maximize the effective period of time wetlands can provide critical functions within the agriculturally dominated ecosystem of the PPR.

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