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EFFECTS OF SEDIMENT LOAD ON EMERGENCE OF AQUATIC INVERTEBRATES AND PLANTS FROM WETLAND SOIL EGG AND SEED BANKS

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Abstract: Intensive agricultural activities near prairie wetlands may result in excessive sediment loads, which may bury seed and invertebrate egg banks that are important for maintenance and cycling of biotic communities during wet/dry cycles. We evaluated effects of sediment burial on emergence of plants and invertebrates from seed and invertebrate egg banks. Sediment-load experiments indicated that burial depths of 0.5 cm caused a 91.7% reduction in total seedling emergence and a 99.7% reduction in total invertebrate emergence. Results of our burial experiments corroborated prior research on seedling emergence. However, our study demonstrated that invertebrate emergence is also highly susceptible to the effects of burial. Our research suggests that sediment entering wetlands from agricultural erosion may also hamper successional changes throughout interannual climate cycles. Land-management strategies need to be implemented that will prevent erosion of cropland top soil from entering wetlands.

Key Words: agricultural impacts, egg banks, hydrophytes, prairie potholes, resting eggs, sedimentation, seed banks, siltation, tillage, wetland condition, wetland degradation

INTRODUCTION

Aquatic invertebrate egg and plant seed banks are critical to reestablishment of vegetative and invertebrate communities of wetlands as they alternate between wet and dry phases in the prairie pothole region (PPR) (van der Valk and Davis 1978, van der Valk 1981, Euliss et al. 1999). The PPR undergoes extreme interannual climatic variation, which results in great fluctuations in water levels, hydroperiods, and salt concentrations of wetlands (Euliss et al. 1999). Plants and invertebrates that repopulate wetland basins following dry conditions often are recruited from invertebrate egg and plant seed banks present in wetland sediments. Frequently, relic propagules in drained wetlands facilitate initial recolonization of plant and invertebrate communities in recently restored wetlands (Galatowitsch and van der Valk 1994). However, agricultural practices often degrade wetland invertebrate egg and seed banks. For example, prolonged drainage, cultivation, crushing (e.g., from farm equipment), and/or artificially shortened hydroperiods may reduce or eliminate invertebrate egg and plant seed banks (Wienhold and van der Valk 1989, Galatowitsch and van der Valk 1994, 1996, Hathaway et al. 1996, Euliss and Mushet 1999).

Another disturbance that has great potential to impact invertebrate and plant soil propagules in wetlands is erosion and translocation of upland soil into wetland basins. Sedimentation rates in agricultural wetlands often are orders of magnitude higher than in natural grassland landscapes (Adomaitis et al. 1967, Martin and Hartman 1987, Dieter 1991, Luo et al. 1997, 1999, Gleason and Euliss 1998, Gleason 1996, 2001). Eroded soils from agricultural fields may cover viable seed and egg banks, thus limiting recruitment in reflooded wetlands (Euliss and Mushet 1999). *In vitro* experiments have shown that sediment burial depths of as little as 2.5 mm can reduce species richness, emergence, and germination of hydrophytes (Jurik et al.

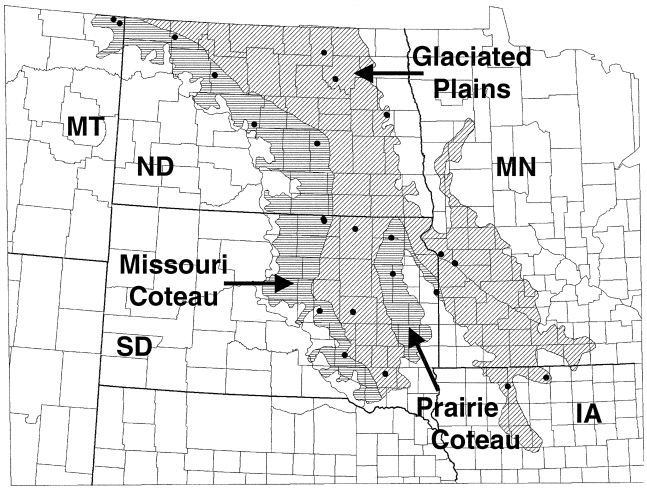

Figure 1. General location of wetlands sampled (n = 46) during 1997 in the United States Prairie Pothole Region. In most cases, because of overlap, a single dot represents the location of two wetlands (i.e., seasonal and semipermanent).

1994, Wang et al. 1994); similar studies have not been conducted on invertebrate egg banks of prairie wetlands. However, Kasahara et al. (1975) and Uye et al. (1979) demonstrated that eggs of marine copepods did not hatch when buried beneath sediments, but these studies did not report the burial depths tested. The goal of our study was to assess effects of sediment burial on emergence of invertebrates from egg banks. Additionally, we examined effects of sediment burial on emergence of plants from seed banks to compare sediment responses of plants and invertebrates.

METHODS AND MATERIALS

Field Methods

During June to September 1997, we collected soil samples (i.e., invertebrate egg and plant seed bank samples) from 46 wetlands in the PPR that included portions of Montana, North Dakota, South Dakota, Minnesota, and Iowa (Figure 1). These sites were used as reference wetlands within a larger overall study to evaluate recovery of seed and invertebrate egg banks in restored wetlands in the PPR (Gleason 2001). We used a systematic sampling design stratified by three physiographic regions (Missouri Coteau, Prairie Coteau, and Glaciated Plains; map based on Kantrud 1993 and Bluemle 1977) to select a representative sample of wetlands in the PPR of the United States. Using a geo-referenced map of the PPR depicting the three major physiographic regions (Figure 1), we drew a line along the medial portions of each physiographic region that follows the long natural orientation (i.e., north-south) of these regions. Along each axis line, we systematically identified nine sampling points in the Missouri Coteau, three in the Prairie Coteau, and twelve in the Glaciated Plains (Figure 1); allocation of sampling points was proportional to the linear length of each physiographic region. Near each sampling point, we selected one seasonal and one semipermanent wetland (Class III and IV wetlands; Stewart and Kantrud 1971) with no history of cultivation in the wetland basin or catchment (i.e., reference wetlands); however, some of the wetland basins (23%) were grazed. The sampling effort resulted in the selection of 46 wetlands. Ideally, our sampling effort would have resulted in the selection of 48 wetlands (24 sampling points $\times$ 2 wetland classes = 48), but certain wetland categories were not readily available near each sampling point.

Of the 46 wetlands selected for study, 24 were seasonal and 22 semipermanent. We collected soil samples from four randomly established transects that radiated from the center of each wetland to the outer edge of the wet-meadow zone (zone classification follows Stewart and Kantrud 1971). From each transect, we collected three cores to a depth of 5 cm in the wet-meadow and shallow-marsh zone using a 7.5-cm-diameter corer. Seed-bank samples were stored at 4°C, and invertebrate egg-bank samples were stored frozen at <0°C until needed for laboratory experiments (Table 1).

Laboratory Methods

Of the 46 wetlands sampled, we randomly selected 37 (17 seasonal and 20 semipermanent) for invertebrate egg-bank experiments and 36 (19 seasonal and 17 semipermanent) for seed-bank experiments because of limitations in greenhouse space and number of aquaria. In the laboratory, we composited the soil samples from each wetland (combined soil samples from wet-meadow and shallow-marsh zones) and mixed and sieved the soils to remove litter, roots, and tubers. We created burial treatments for invertebrate incubation experiments by placing a subsample (380 cm^3) of wetland soil from each wetland composite sample into each of four flats (19.5 $\times$ 19.5 $\times$ 6 cm). This resulted in a soil depth of ca. 1 cm. Soils in flats were then overlain with 0, 0.5, 1, and 2 cm of steam-sterilized upland soil. We prepared flats for seed-bank experiments using similar procedures; however, wetland soils were underlain with 3, 2.5, 2, and 1 cm of steam-sterilized sand for the 0-, 0.5-, 1-, and 2-cm burial treatments, respectively. Additional flats containing only upland soils also were prepared and subjected to experimental conditions to verify that they were free of viable eggs or seeds (33 and 28 control flats for egg- and seed-bank experiments, respectively) (see Table 1). No invertebrates or seedlings emerged from

Table 1. Start dates for invertebrate egg-bank and plant seed-bank experimental trials by wetland class and physiographic region.

Experiment Type	Wetland Class	Physiographic Region	Number of[a] Wetlands	Number of[b] Control Flats	Experiment Start Date
Egg bank	Seasonal	Glaciated Plains	9	5	31 Jan 1998
		Missouri and Prairie Coteau	8	8	4 Apr 1998
	Semipermanent	Glaciated Plains	10	10	10 Jun 1998
		Missouri and Prairie Coteau	10	10	5 Aug 1998
Seed bank	Seasonal	All	12	1	8 Feb 1998
	Semipermanent	All	12	1	9 May 1998

[a] Number of wetlands used during each experimental run (i.e., wetland class-physiographic region combination).
[b] Number of control flats containing only upland soils used to overlay wetland soils.

these control flats. Upland soil used to overlay wetland soils had a silty-clay-loam texture and was sieved through 0.017-mm mesh to concentrate particle sizes similar to erosional sediment (Martin and Hartman 1987). Upland soil was provided by U.S. Department of Agriculture's Northern Grain Insects Research Laboratory, Brookings, South Dakota and was determined to be free of agrochemical residues.

We performed invertebrate incubation experiments in an environmentally controlled room at the U.S. Geological Survey's Northern Prairie Wildlife Research Center, Jamestown, North Dakota. Egg bank burial experiments were conducted in conjunction with other egg-bank studies (Gleason 2001) that required experiments to be stratified by wetland class and physiographic region. We performed experimental trials in the following order: (1) Glaciated Plains seasonal wetlands, (2) Missouri and Prairie Coteau seasonal wetlands, (3) Glaciated Plains semipermanent wetlands, and (4) Missouri and Prairie Coteau semipermanent wetlands. Number of wetlands used for burial experiments during each experimental trial and experimental trial-initiation dates are summarized in Table 1. Procedures used for incubating invertebrates from soil egg-bank samples, including maintenance of photoperiod, water chemistry, and temperature regimes, were similar to those described by Euliss and Mushet (1999). We randomly assigned experimental flats to aquaria (37.8 L) containing well water adjusted (i.e., by adding distilled water) to a specific conductance within the range typical of seasonal (700 μS cm^{-1}) or semipermanent (1400 μS cm^{-1}) wetlands (Stewart and Kantrud 1971). Soil samples were incubated in aquaria for six weeks; temperatures were maintained at 10°C for the first three weeks and then raised to 20°C for the remainder of the experiment. Photoperiod was maintained at 12 h light:12 h dark, and aquaria were aerated. We checked aquaria temperatures daily and added distilled water to maintain water levels and salt concentrations. During the six-week incubation, we harvested invertebrates from aquaria every two weeks by siphoning the water from the aquaria through a 0.1-mm screen to concentrate invertebrates. The siphoned water was then returned to the aquaria. All harvested invertebrates were enumerated and identified following Pennak (1989).

We conducted seedling emergence experiments in an environmentally controlled greenhouse at the U.S. Department of Agriculture's Northern Grain Insects Research Laboratory, Brookings, South Dakota. Seed-bank burial experiments were conducted in conjunction with other seed bank studies (Gleason 2001) that required separate experimental trials for each wetland class. Initiation dates for seasonal and semipermanent wetland seed bank experiments are summarized in Table 1. Flats were placed on a greenhouse bench in a randomized complete block design with wetlands serving as blocks and the four sediment depths (i.e., 0, 0.5, 1, and 2 cm) being treatments. We maintained soils in a saturated state to simulate the drawdown phase of wetlands and to stimulate germination of mudflat annual and perennial emergents (van der Valk and Davis 1978). Greenhouse temperature and photoperiod were increased incrementally during the experiment to simulate environmental conditions from May to July (i.e., temperature range 15–30°C; light range 14–16 hrs). Greenhouse temperatures ranged from 9 to 37°C during seasonal wetland experiments and 11 to 37°C during semipermanent wetland experiments. These environmental conditions provided a range of alternating temperatures and photoperiods that are critical factors in seed germination (Galinato and van der Valk 1986, Baskin and Baskin 1998, Hartleb et al. 1993). Seedlings were counted and removed as they reached an identifiable stage. After three months, all unknown seedlings were transferred to pots and grown to an identifiable stage. Plant species nomenclature follows Great Plains Flora Association (1986).

Statistical Methods

We used analysis of variance (ANOVA) to assess the effects of burial depth on numbers of seedlings and invertebrates that emerged. We conducted ANOVAs

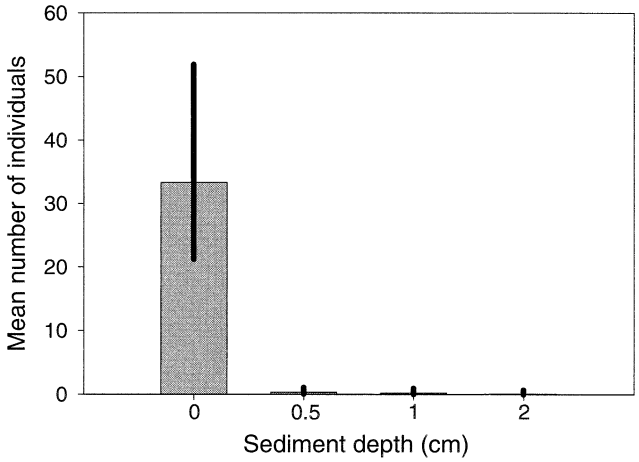

Figure 2. Back-transformed mean number of individuals and 95% confidence intervals of invertebrates incubated from soil egg banks in each sediment-burial treatment.

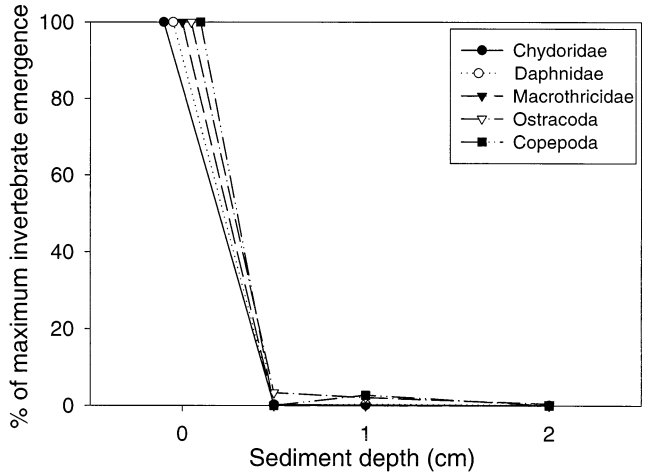

Figure 3. Effect of sediment depth on percent maximum emergence of invertebrate taxa. Percent emergence of invertebrates in the 0.5-, 1-, and 2-cm treatments is relative to maximum emergence of invertebrates in the 0-cm treatment.

using the mixed model procedure (PROC MIXED) of SAS (SAS Institute, Inc. 1997) using a randomized block design; each wetland replicated across the four burial treatments represented a block. The ANOVA model included wetland, which was a random effect, and burial depth, which was a fixed effect. Prior to analysis, transformations (ln[count + 1]) were performed on the data to stabilize variances (Steel and Torrie 1980). Fisher's protected least significant difference tests (LSD) were used to assess individual differences when main effects were significant ($P < 0.05$) (Milliken and Johnson 1984). Here, we report back-transformed means and confidence intervals.

RESULTS

Effects of Sediment Load on Aquatic Invertebrate Emergence

Ostracods, copepods, and three families of cladocerans (Daphnidae, Macrothricidae, and Chydoridae) were the only invertebrate taxa successfully incubated during aquarium experiments. Our lowest level sediment treatment (0.5 cm) nearly eliminated emergence of all aquatic invertebrates from soil egg banks ($F_{3, 108} = 70.0$, $P < 0.001$) (Figure 2). A total of 9,838 invertebrates emerged from the 0-cm sediment depth treatment (i.e., reference), 29 from the 0.5-cm treatment, 21 from the 1-cm treatment, and 5 from the 2-cm treatment. Of the 37 wetland soil samples covered with sediment, 84%, 84%, and 92% failed to hatch invertebrates when covered with 0.5 cm, 1 cm, and 2 cm of sediment, respectively. In contrast, only 14% of the 0-cm sediment cover treatments failed to hatch invertebrates. Our data indicated that 0.5 cm of sediment overburden reduced emergence of all invertebrate taxa present in our samples (Table 2; Figure 3).

Effects of Sediment Load on Seedling Emergence

Covering wetland soils with 0.5, 1, and 2 cm of sediment reduced ($F_{3, 105} = 257$, $P < 0.001$) emergence of seedlings from soil seed banks (Figure 4). A total of 784 seedlings emerged from the 0-cm treat-

Table 2. Back-transformed mean number of individuals and 95% confidence intervals (CI) of invertebrate taxa incubated from soil egg banks in four sediment load treatments. Means within rows with a common letter are not significantly different ($P > 0.05$).

	Sediment Depth (cm)				ANOVA			
Taxa	0 Mean (95% CI)	0.5 Mean (95% CI)	1 Mean (95% CI)	2 Mean (95% CI)	df	*F*	*P*	*n*[a]
Chydoridae	46.2a (27.8–76.4)	0.2b (0.0–0.9)	0.1b (0.0–0.8)	0.1b (0.0–0.8)	3, 75	61.5	<0.0001	26
Ostracoda	4.8a (3.6–6.3)	0.2b (0.0–0.5)	0.1b (0.0–0.4)	<0.0b (0.0–0.3)	3, 75	53.2	<0.0001	26
Daphnidae	10.1a (5.3–18.7)	0.0b (0.0–0.8)	0.1b (0.0–1.0)	<0.0b (0.0–0.9)	3, 42	17.4	<0.0001	15
Copepoda	2.5a (0.9–5.7)	0.0b (0.0–0.9)	0.1b (0.0–1.2)	0.0b (0.0–0.9)	3, 12	5.2	0.0159	5
Macrothricidae	75.8a (3.0–1469.9)	0.0a (0.0–18.2)	0.0a (0.0–18.2)	0.0a (0.0–18.2)	3, 3	5.5	0.0982	2

[a] n = the total number of wetlands out of 37 in which the taxa occurred.

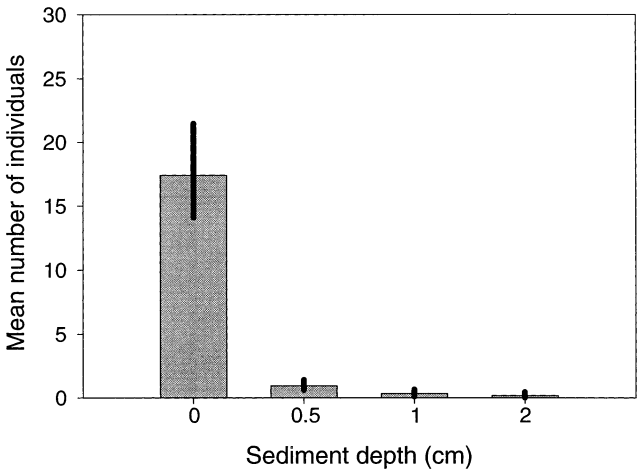

Figure 4. Back-transformed mean abundances and 95% confidence intervals of seedlings emerging from seed banks in each sediment-burial treatment.

ment, 65 from the 0.5-cm treatment, 19 from the 1-cm treatment, and 11 from the 2-cm treatment. At the species level, 0.5 cm of sediment reduced emergence in nearly all cases (Table 3). Of the 40 plant species that emerged from the 0-cm treatment, 11, 7, and 4 emerged from the 0.5, 1, and 2-cm treatments, respectively (Table 3). Seven taxa that emerged from the 1-cm treatment included: *Eleocharis* spp., *Juncus interior*, *Juncus dudleyi*, *Alisma plantago-aquatica*, *Scirpus acutus/validus*, *Sagittaria cuneata*, and *Sparganium eurycarpum*. All of these seven taxa showed decreased emergence when covered with 0.5 cm of sediment (Figure 5). The 2-cm treatment stopped seedling emergence of *Sagittaria cuneata* and *Alisma plantago-aquatica*, whereas seedling emergence of *Scirpus acutus/validus* and *Sparganium eurycarpum* was not completely eliminated by the 2-cm treatment (Figure 5). *Alisma plantago-aquatica*, *Sagittaria cuneata*, *Scirpus acutus/validus*, and *Sparganium eurycarpum* showed more resilience to sediment depth than *Eleocharis* spp., *Juncus interior*, and *Juncus dudleyi* (Figure 5).

DISCUSSION

The lowest sediment load depth of 0.5 cm essentially halted invertebrate and seedling emergence. Our results corroborated earlier findings of the negative impact of sediment burial on emergence of hydrophytes from soil seed banks (Jurik et al. 1994, Wang et al. 1994). Additionally, our results suggest that invertebrate emergence is more sensitive to burial than is seedling emergence (Figure 6).

Studies have suggested that seeds with the largest mass often are least effected by burial (Jurik et al. 1994, Wang et al. 1994, Dittmar and Neely 1999). We did not determine seed mass during our study, but relative seed lengths (as a proxy of mass) from species descriptions (Larson 1993) indicate that a positive relationship between seed size and resilience to burial. *Juncus torreyi* and *Juncus interior* both have smaller seeds (0.3–0.4 mm) than *Eleocharis* spp. (1.4–1.7 mm; based on *E. macrostachya* Britt.), the latter being more resilient to burial (Figure 5). All three of these taxa were less resilient to burial than larger-seeded species (*Scirpus acutus/validus* = 1.5–2.2 mm, *Alisma plantago-aquatica* = 2–2.5 mm, *Sagittaria cuneata* = 2–3 mm, *Sparganium eurycarpum* = 6–8 mm). Three species showed more tolerance to burial (*Sparganium eurycarpum*, *Scirpus acutus/validus*, and *Sagittaria cuneata*). Jurik et al. (1994) also found *Sagittaria* spp. emergence to increase with moderate burial (0.5 cm). In contrast to plant responses that varied by taxa, invertebrate taxa identified in our experiments were all suppressed by burial (Figure 3). Presumably, egg mass does vary among the taxa that emerged during our experiments; however, we did not measure egg mass, and we are aware of no literature to assess this variation. It is possible that, at lower sediment burial depths (i.e., < 0.5 cm), invertebrate taxa may vary in their response to sediment burial.

The effects of sediment on environmental cues necessary for the hatching of invertebrate eggs and germination of seeds was not determined during our study. The presence of sediment likely affected some combination of temperature, light, and oxygen concentration requirements that are known cues for hatching of eggs (Wiggins et al. 1980, Dodson and Frey 1991) and germination of seeds (Baskin and Baskin 1998). Analogous to seed requirements for specific environmental conditions to terminate dormancy (e.g., cold stratification; Baskin and Baskin 1998), resting eggs also need to be exposed to diapause termination conditions (e.g., storage duration, temperature, desiccation, aeration; Wiggins et al. 1980, Dodson and Frey 1991, Moreira dos Santos and Persoone 1998). Storage of seed- and invertebrate egg-bank samples and preparation of experimental flats (i.e., manipulation of soil samples) likely provided some of the conditions necessary to terminate dormancy and diapause. However, the extent to which the covering with sediment inhibited cues needed for termination of diapause or dormancy, or cues for hatching and germination of already activated propagules is not known. The presence of sediment also may have created a physical barrier to emergence. Nevertheless, our burial treatment was associated with sharply decreased emergence of plants and invertebrates.

Our lowest sediment burial treatment (0.5 cm) was within the range of sedimentation rates (0.4–0.8 cm

Table 3. Back-transformed mean number of seedlings and 95% confidence intervals (CI) of plant taxa emerging from seed banks in four sediment load treatments. Means within rows with a common letter are not significantly different ($P > 0.05$).

	Sediment Depth (cm)				ANOVA[a]			
Taxa	0 Mean (95% CI)	0.5 Mean (95% CI)	1 Mean (95% CI)	2 Mean (95% CI)	df	*F*	*P*	*n*[b]
Typha spp.	4.6a (3.6–5.9)	<0.0b (0.0–0.3)	0.0b (0.0–0.2)	0.0b (0.0–0.2)	3, 60	78.6	<0.0001	21
Eleocharis spp.	2.9a (2.2–3.8)	0.6b (0.3–1.0)	0.1b (0.0–0.3)	0.0b (0.0–0.2)	3, 60	52.7	<0.0001	21
Juncus interior Wieg.	4.4a (3.2–5.8)	0.1b (0.0–0.4)	0.1b (0.0–0.3)	0.4b (0.0–0.3)	3, 54	51.9	<0.0001	19
Juncus dudleyi Wieg.	3.0a (1.9–4.5)	0.3b (0.0–0.8)	0.1b (0.0–0.5)	<0.0b (0.0–0.5)	3, 42	16.7	<0.0001	15
Rumex spp.	1.5a (1.3–1.7)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	3, 33	112.5	<0.0001	12
Carex spp.	1.3a (1.1–1.5)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	3, 24	93.7	<0.0001	9
Alisma-plantago aquatica L.	1.2a (0.6–2.0)	0.6ab (0.2–1.2)	0.3bc (0.0–0.7)	0.0c (0.0–0.4)	3, 24	6.1	0.0031	9
Eleocharis acicularis (L.) R. & S.	0.9a (0.7–1.1)	0.1b (0.0–0.2)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	3, 24	29.8	<0.0001	9
Eleocharis obtusa (Willd.) Schult. J. A.	7.1a (4.7–10.4)	0.1b (0.0–0.6)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	3, 15	39.8	<0.0001	6
Scirpus acutus/validus	6.2a (2.6–13.6)	0.6b (0.0–2.2)	0.5b (0.0–2.1)	0.9b (0.0–2.9)	3, 15	8.1	0.0020	6
Potentilla spp.	2.5a (1.0–5.1)	0.0b (0.0–0.8)	0.0b (0.0–0.8)	0.0b (0.0–0.8)	3, 15	5.4	0.0102	6
Sagittaria cuneata Sheld.	1.3a (0.6–2.3)	0.1b (0.0–0.7)	0.3b (0.0–0.9)	0.0b (0.0–0.4)	3, 12	4.6	0.0228	5
Ambrosia artemisiifolia L.	2.1a (1.2–3.5)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	3, 9	12.2	0.0016	4
Sparganium eurycarpum Engelm.	1.7a (0.6–3.8)	0.0a (0.0–0.7)	0.2a (0.0–1.1)	0.2a (0.0–1.1)	3, 9	3.4	0.0652	4
Cyperus acuminatus Torr. & Hook.	1.3a (0.7–2.1)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	3, 9	9.0	0.0045	4
Melilotus spp.	1.2a (1.0–1.5)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	0.0b (0.0–0.1)	3, 9	61.4	<0.0001	4
Ranunculus cymbalaria Pursh	2.7a (0.7–7.0)	0.0a (0.0–1.1)	0.0a (0.0–1.1)	0.0a (0.0–1.1)	3, 6	4.5	0.0569	3
Ammannia robusta Heer & Regel.	1.3a (0.9–1.7)	0.0b (0.0–0.2)	0.0b (0.0–0.2)	0.0b (0.0–0.2)	3, 6	37.6	0.0003	3
Artemisia ludoviciana Nutt.	1.3a (0.9–1.7)	0.0b (0.0–0.2)	0.0b (0.0–0.2)	0.0b (0.0–0.2)	3, 6	37.6	0.0003	3
Beckmannia syzigachne (Steud.) Fern.	2.5a (0.4–7.3)	0.0a (0.0–1.4)	0.0a (0.0–1.4)	0.0a (0.0–1.4)	3, 3	5.1	0.1066	2
Ranunculus sceleratus L.	2.5a (1.8–3.4)	0.0b (0.0–0.3)	0.0b (0.0–0.3)	0.0b (0.0–0.3)	3, 3	74.6	0.0026	2
Juncus torreyi Cov.	1.8a (0.6–3.9)	0.0a (0.0–0.7)	0.0a (0.0–0.7)	0.0a (0.0–0.7)	3, 3	9.0	0.0520	2
Oxalis stricta L.	1.4a (0.8–2.4)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	0.0b (0.0–0.4)	3, 3	19.5	0.0180	2
Scirpus pungens Vahl.	1.0a (0.2–2.5)	0.4a (0.0–1.5)	0.0a (0.0–0.7)	0.0a (0.0–0.7)	3, 3	3.7	0.1571	2
Agrostis hyemalis (Walt.) B. S. P.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Alopecurus aequalis Sobol.	5 (—)	2 (—)	0 (—)	0 (—)	noest	—	—	1
Bacopa rotundifolia (Michx.) Wettst.	2 (—)	1 (—)	0 (—)	0 (—)	noest	—	—	1
Chenopodium rubrum L.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Cirsium arvense (L.) Scop.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Cyperus odoratus L.	15 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Dichanthelium oligosanthes (Schult) Gould	3 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Echinochloa muricata (Beauv.) Fern.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Epilobium spp.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	2
Hordeum jubatum L.	2 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Lactuca serriola L.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Mentha arvensis L.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	2
Medicago spp.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Panicum capillare L.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Polygonum pensylvanicum L.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1
Rorippa palustris (L.) Bess.	1 (—)	0 (—)	0 (—)	0 (—)	noest	—	—	1

[a] noest (no-estimate) = number of wetland replicates that species emerged from was to small to analyze statistically.
[b] n = the total number of wetlands out of 36 in which the species occurred.

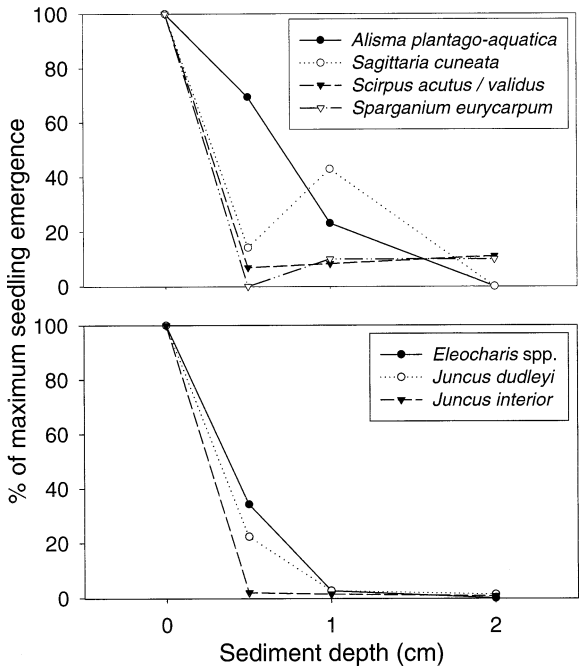

Figure 5. Effect of sediment depth on percent maximum emergence by plant taxa. Percent emergence of seedlings in the 0.5-, 1-, and 2-cm treatments is relative to maximum emergence of seedlings in the 0-cm treatment.

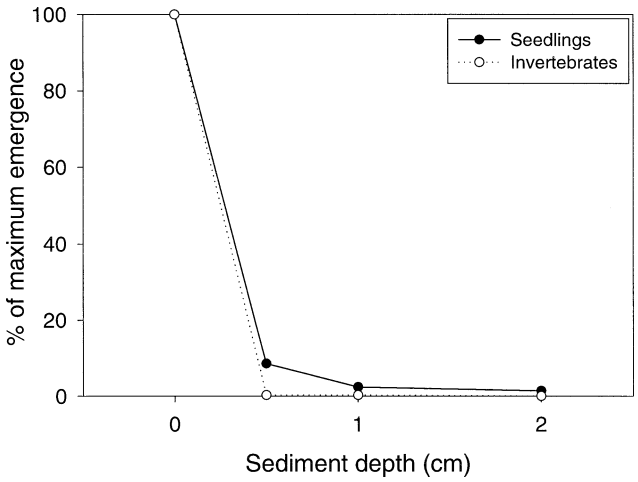

Figure 6. Effect of sediment depth on percent maximum emergence of invertebrates and seedlings. Percent emergence in the 0.5-, 1-, and 2-cm treatments is relative to maximum emergence in the 0-cm treatment.

yr^{-1}) reported for wetlands in cultivated catchments (Martin and Hartman 1987, Gleason 2001). However, severe erosion of cropland soils during heavy precipitation events may lead to substantially greater sedimentation rates (Gleason 1996 and 2001). Consequently, we suggest that wetland sedimentation from agricultural activities may limit reestablishment of plants and invertebrates. However, we did not evaluate potential synergistic and indirect effects of accelerated sedimentation on production of plant and invertebrate propagules. For example, many aquatic invertebrates are collector-gatherers or grazers, consuming periphyton associated with detrital food webs and vegetative substrates. Decreases in primary productivity and loss of standing vegetative structure (Krecker 1939, Rosine 1955, Krull 1970, Euliss and Grodhaus 1987) may reduce invertebrate production. Similarly, suspended sediments associated with sediment inputs (Dieter 1991) decrease light penetration, which can decrease phytoplankton biomass and productivity. Increased suspended sediments and concomitant reduction in phytoplankton concentration have been shown to reduce population growth rates of cladocerans (Arruda et al. 1983, McCabe and O'Brien 1983, Kirk and Gilbert 1990). High concentrations of suspended clay that affects the feeding rate of zooplankton and lowers their assimilation efficiency (Robinson 1957, McCabe and O'Brien 1983) may also reduce energy available for reproduction of resting eggs.

During severe drought, most prairie wetlands are completely dry, and many are cultivated. When wetlands reflood, initial colonization of many invertebrate taxa comes from invertebrate egg banks. Cultivation of dry wetlands, in conjunction with sediment inputs, may severely impact recovery of invertebrate populations during wet periods. Further, in wetlands that dry infrequently, increased suspended sediments may decrease survivorship and fecundity of existing invertebrate populations (Arruda et al. 1983, Kirk and Gilbert 1990). Invertebrates and plants are key components for nearly all ecological functions in wetlands. Invertebrates are important in nutrient cycling (Merritt et al. 1984) and in trophic support for many species of wetland-dependent wildlife, such as waterfowl (Swanson 1985). Similarly, a diversity of vegetation provides important nesting structure for birds, as well as invertebrate habitat. Studies are needed to identify minimally acceptable sediment loads (< 0.5 cm) in order to maximize emergence of invertebrates and plants from their propagules. In addition to controlled laboratory experiments, research on the broad spectrum of agricultural land-use practices (e.g., from no-till to conventional agricultural practices) is needed to elucidate relationships between intensity of cultivation and sedimentation on egg-bank and seed-bank maintenance and viability. Knowledge gained from such studies will provide insight into which agricultural practices should be promoted to enhance productivity and sustain wetlands on agricultural lands.

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