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The effect of dredging on the plant community of a Missouri-River floodplain wetland.

Lisa Ann Peterson

THE EFFECT OF DREDGING ON THE PLANT COMMUNITY OF A MISSOURI-RIVER FLOODPLAIN WETLAND

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Lisa A. Peterson

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ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

THESIS ACCEPTANCE

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Committee

Chairperson

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ABSTRACT

A plant community gradient, consisting of Open-water, Bulrush, Grass, and Forest Zones, was evaluated both before (1995) and one-year after (1997) restoration-dredging of a wetland along the Missouri River in east-central Nebraska. Species diversity declined significantly ($P \geq 0.05$) in both the Bulrush and Grass Zones (-24 and -30 species) but not elsewhere. The Open-water Zone, which increased the most with dredging (+40 meters), was dominated by duckweed (*Lemna minor*) (35% canopy cover in 1995 and 45% in 1997) and watermeal (*Wolffia columbiana*) (53% and 61%) both before and after dredging. Coontail (*Ceratophylum demersum*) increased significantly (7% to 25%). The greatest species decline occurred with river bulrush (*Scirpus fluviatilis*) (50% to 28%) both due to a substantial reduction in the areal extent of the Bulrush Zone (-14 m width) and a significant decline in canopy cover of bulrush within the zone (55% in 1995 to 29% in 1997). Reed canary grass (*Phalaris arundinacea*) declined significantly in all terrestrial zones (average decline of 31%). Despite declines in cover in these and other native wetland species, most survived dredging, suggesting that, at least in this one instance, dredging to restore the backwater habitat can be accomplished without a substantive loss of associated plant communities.

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INTRODUCTION

The Missouri River extends 3,767 km from Montana to its mouth north of St. Louis, Missouri and drains one-sixth of the contiguous United States. Historically, the river's floodplain contained multiple braided main channels with numerous islands and sandbars and smaller side channels that provided a wide variety of water depths and flow rates (Faber and Smith, 1999). This complex river system was in a constant state of change, affected by the interaction of floods, bank and bed erosion, and subsequent deposition. Flooding was particularly important to the biological components of the ecosystem, for example, maintaining backwater areas where conditions were particularly suitable for spawning fish, insects, and waterfowl (Hesse, 1996).

The plant communities found along the Missouri River varied considerably, depending on the stage of ecological succession. Among the communities closest to the river were lakes, ponds and marshes (Weaver, 1960). Marshes were often surrounded by extensive stands of prairie cordgrass (*Spartina pectinata*) and reed canary grass (*Phalaris arundinacea*) while swamps were dominated by such species as river bulrush (*Scirpus fluviatilis*), common reed (*Phragmites australis*) and arrowhead (*Sagittaria* spp). The adjacent floodplain forest was dominated by willows (*Salix* spp) and cottonwoods (*Populus* spp).

Today, the Missouri River is manipulated through the "Mainstem Reservoir System," a series of six dams and reservoirs constructed by the U.S. Army Corps of Engineers beginning in the 1930's. Channelization along the "Lower River," from below Sioux City, Iowa to St. Louis, Missouri, was intended to reduce flooding, support barge

traffic, and generate power (Faber and Smith, 1999). In the process of channelization, however, most of the sand bars, islands and side channels were eliminated. The result of this manipulation in the Lower River has been both a marked change in the river dynamics and a loss of wetland and riparian habitat including oxbows and other backwater areas where floodplain wetlands are often concentrated (U.S. Army Corps of Engineers, 1998).

In the absence of historic river dynamics, disconnected oxbows are affected by sedimentation so that only active efforts at wetland restoration, such as through dredging, can maintain their physical character and the plant and animal communities that they support. One such restoration was initiated along the Missouri River in east-central Nebraska in 1995. This study was initiated in order to take advantage of the opportunity to conduct a pre- and post-dredging evaluation of marsh vegetation (1) to assess the response of plant communities to dredging and (2) to provide baseline data for longer-term study on recovery of the marsh from dredging.

MATERIALS AND METHODS

Study Site

The study was conducted at a detached oxbow lake situated within the 526 ha Fontenelle Forest Preserve along the eastern boundary of Nebraska (North 41°10'22" West 95°53'03") (Fig. 1). The study site, referred to as the Great Marsh, but previously known as Heron Lake, Horseshoe Lake or "the marsh," covers approximately 14 ha of

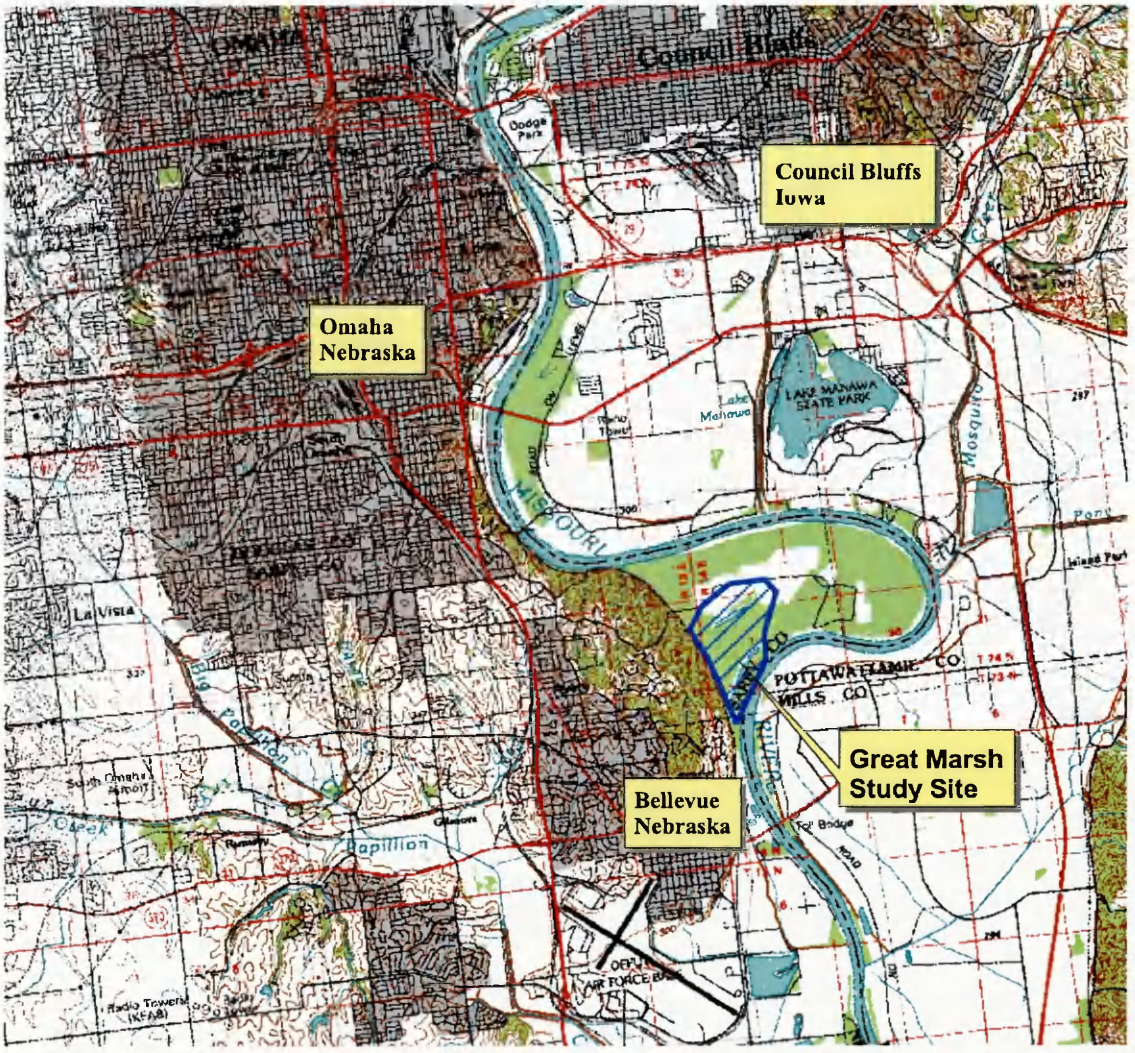

Fig 1. Great Marsh study site

wetland and an adjoining 6 ha of seasonably wet lowland forest (U.S. Army Corps of Engineers, 1995).

Background

Between 1850 and 1900, the Missouri River shifted its channel, leaving behind the oxbow that forms the present Great Marsh. By 1995, siltation had decreased the depth of the marsh to 0.3 - 0.9 meters (Eco-Centrics, 1997).

In 1995, the U.S. Army Corps of Engineers, in consultation with the Fontenelle Forest Nature Center and the Papio-Missouri River Natural Resources District, initiated an effort to deepen the Great Marsh in order to extend its function as a backwater habitat for native biota. Dredging specifically focused on (1) removal of sediment from three arms of the marsh, (2) deepening the marsh to a depth of 0.9 –1.2 meters and (3) grading the marsh's littoral zone to avoid sharp changes in depth along its margin (Eco-Centrics, 1997). Ultimately, 85,680 cubic meters of sediment were removed from Great Marsh, most of which had accumulated as a result of erosion from residential development near Fontenelle Forest over the last 15 years.

Descriptions of the plant communities of the Great Marsh are not known prior to 1900. The earliest plant survey of Fontenelle Forest was conducted in 1959 by the Omaha Botany Club (1959) with a more recent survey conducted by Garabrandt (1988). Neither of these surveys described the Great Marsh specifically, however, based on their plant species lists, it is likely that the open water was dominated by lotus (*Nelumbo lutea*) with the surrounding plant communities dominated by bulrush (*Scirpus* spp) and reed

canary grass (*Phalaris arundincacea*). The adjacent forest would have been dominated by cottonwood (*Poplus deltoides*) with a dogwood (*Cornus spp.*) and poison ivy (*Toxicodendron spp.*) understory.

Field Methods

Plant community sampling was conducted during the fall of 1995 and again in the fall of 1997. The 1995 evaluation was conducted at twelve study stations systematically located around the Great Marsh (Appendix Fig. 1.). Each study station was stratified into four distinct vegetation zones that together encompassed the principal plant community types that surrounded the Great Marsh (Table 1). Each station was geo-referenced using a Global Positioning System (GPS) unit (Appendix Table 7). Data for 1997 were collected from the same study stations used in 1995, although sampling was adjusted so as to be centered in vegetation zones that became established after dredging. Hydraulic dredging continued from May through September of 1996.

Within each vegetation zone, five, 1 x 1-meter quadrats were systematically located at 5-meter intervals along a 25-meter transect aligned parallel to the marsh edge. When zone edges were not clearly defined, the boundary was determined to be the point at which the predominant species from each abutting zone comprised 50% of the plant composition. Within each 1 x 1-meter quadrat, the canopy cover of five plant groupings (Table 2), as well as that of each species, was estimated following procedures modified from Daubenmire (1959). Cover categories used were: 0 = 0%, 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-95%, 7 = 95-99%, 8 = >99%. Botanical

Table 1. Zone descriptions and characteristics.

Zone	Descriptive Term	Characteristics
1	Open-Water Zone	Open water area and adjacent mudflat fringe dominated by floating or submerged vegetation, but including some emergent species.
2	Bulrush Zone	Emergent species. Primarily bulrush (*Scirpus* spp).
3	Grass Zone	Primarily dominated by grasses, such as reed canary grass (*Phalaris arundinacea),* and graminoid species, such as common reed (*Phragmites australis*).
4	Forest Zone	Overstory canopy greater than 5 m.

Table 2. Description of plant categories.

Category	Description
TOTCOV	Total plant cover including overstory trees and submerged aquatic plants.
SUBMUD	Floating unattached plants that move about with winds and currents. Floating attached plants with floating leaves but with roots anchored in the substrate. Submerged plants whose life cycle, with the exception of flowering, is completed beneath the surface of the water. Most are anchored to the substrate, but the vegetative portion either does not reach the surface or the terminal end lies in a horizontal position just beneath the surface.
BULRUSH	Comprised primarily of bulrush (*Scirpus spp.*) and other emergent plants whose roots and basal portion grow beneath the surface of shallow water, but whose leaves and stem are borne primarily above the surface.
GRASS	Comprised principally of graminoid species.
FORBS	Forbs, including non-woody vines.
WOODY	Non-herbaceous plants including canopy trees and shrubs.

nomenclature is based on the Great Plains Flora Association (1986). Species that could not be identified in the field were collected and identified at the University of Nebraska at Omaha Herbarium (OMA).

In addition to plant species composition, the width of each zone was measured in 1995 and estimated in 1997, the latter procedure necessitated by the substantial changes in the marsh edge resulting from dredging. For example, hip waders were required to measure plant canopy cover in the Open-water Zone in 1995, but a canoe was required in 1997.

Analysis

A *t*-test (SAS Institute, 1985) was used to test for significant differences in canopy cover between 1995 and 1997 for those species with a cover value greater than 3% in at least one zone. Between-year differences in species diversity were tested by zone using procedures based on the Shannon Weiner Index (H') as described in Zar (1984). Species Richness (S) of each zone is the total number of species recorded.

RESULTS AND DISCUSSION

Eighty-four plant species were identified in this study (Appendix Table 1). Thirty-eight were found both in 1995 and 1997. Of the remaining forty-six species, thirty, such as swamp milkweed (*Asclepias incarnata*) and path rush (*Juncus tenuis*), were found only in 1995 and sixteen were found only in 1997, including bladderwort

(*Utricularia vulgaris*) and nettle-leaved vervain (*Verbena urticifolia)* (Appendix Tables 3-6). In general, dredging reduced the canopy cover of all plant categories significantly in at least one or more zones with the exception of the submergent category, which increased in the Open-water, Bulrush and Grass Zones (Table 3, Appendix Tables 3-6).

Zone width increased only for the Open-water Zone, the intended consequence of dredging (Table 4). Both the year before and the year after dredging, the dominant herbaceous plants of this zone were duckweed (*Lemna minor*) (35% and 45% mean cover respectively) and watermeal (*Wolffia columbiana*) (53% and 61%). Coontail (*Ceratophyllum demersum*), however, increased significantly from 7% in 1995 to 25% in 1997 (Table 3, Appendix Table 3). The increase in coontail is probably a consequence of the increased water depth of the Open-water Zone. Overall, there were no significant between-year differences in species diversity for this zone (Table 5).

In the Bulrush Zone, river bulrush (*Scirpus fluviatilis*) cover decreased significantly from 47% in 1995 to 27% in 1997 (Fig. 2, Table 3, Appendix Table 4). This decrease in cover within the zone, combined with a substantial decrease in the total amount of the Bulrush Zone (Table 4), resulted in a substantial short-term decline in this species as a consequence of dredging. Reed canary grass was the only other species to occur in relatively high cover in this zone in 1995 (12% cover), although it was eliminated as a consequence of dredging (0% in 1997) (Fig. 3). High cover values for duckweed (8%) and watermeal (6%) in this terrestrial zone before dredging were largely a consequence of these floating plants being deposited on the surface during high water

Table 3. Mean canopy cover by zone and year. Only species averaging > 3% cover in either year are included. S = significant difference between years, NS = no significant difference. tr = < 0.1% cover.

Plant Category and Species by Zone	Year 1995	Year 1997	Statistically Significant Difference (P>0.05)
OPEN-WATER ZONE			
TOTCOV	68.8	96.9	S
SUBMUD	66.4	96.4	S
BULRUSH	0.6	3.0	S
FORBS	1.8	1.4	NS
GRASS	7.0	0	S
WOODY	0	2.6	NS
Wolffia columbiana Karst. (watermeal)	52.6	61.4	NS
Lemna minor L. (duckweed)	35.1	45.5	NS
Ceratophyllum demersum L. (coontail)	7.3	25.4	S
Nelumbo lutea (Willd.) Pers.	6.0	8.3	NS
Echinochloa crusgalli (L). Beauv.	6.1	0	S
Morus alba L.	0	3.1	NS
BULRUSH ZONE			
TOTCOV	82.9	38.3	S
SUBMUD	12.0	28.3	S
BULRUSH	55.3	28.5	S
FORBS	4.6	0.3	S
GRASS	29.9	2.5	S
WOODY	2.0	0.1	NS
Scirpus fluviatilis (Torr.) Gray (river bulrush)	50.0	27.9	S
Phalaris arundinacea L. (reed canary grass)	14.0	0.1	S
Scirpus validus Vahl	9.8	0	S
Lemna minor L. (duckweed)	7.9	22.6	S
Echinochloa crusgalli (L.) Beauv.	6	0	S
Wolffia columbiana Karst. (watermeal)	5.9	13.7	S
Phragmites australis (Cav.) Trin. ex Steud	4.3	0.3	NS
Typha spp	tr	4.3	NS

Table 3. Mean canopy cover by zone and year. Only species averaging > 3% cover in either year are included. S = significant difference between years, NS = no significant difference. tr = < 0.1% cover.

GRASS ZONE			
TOTCOV	86.8	32.3	S
SUBMUD	0.2	12.9	S
BULRUSH	13.6	4.2	S
FORBS	12.0	0.1	S
GRASS	68.3	26.9	S
WOODY	16.9	tr	S
Phalaris arundinacea L. (reed canary grass)	54.0	8.0	S
Scirpus fluviatilis (Torr.) Gray (river bulrush)	12.9	3.2	S
Phragmites australis (Cav.) Trin. Ex Steud (common reed)	11.4	8.8	NS
Morus alba L	8.3	0	S
Salix exigua Nutt.	3.5	0	NS
Lemna minor L.	0.2	8.0	S
Wolffia columbiana Karst.	tr	8.9	S
FOREST ZONE			
TOTCOV	84.0	54.8	S
SUBMUD	0	8.7	S
BULRUSH	8.0	5.8	NS
FORBS	12.2	4.3	S
GRASS	65.8	32.3	S
WOODY	59.1	28.1	S
Phalaris arundinacea L. (reed canary grass)	38.6	4.4	S
Cornus drummondii C.A. Meyer (rough-leaved dogwood)	27.2	7.8	S
Elymus virginicus L. (Virginia wild rye)	12.9	10.9	NS
Morus alba L	7.3	4.4	NS
Fraxinus pennsylvanica Marshall	5.3	1.2	NS
Ulmus americana L	1.1	6.9	NS
Wolffia columbiana Karst.	1.1	5.2	NS
Lemna minor L.	0	5.5	S
Scirpus fluviatilis (Torr.) Gray	7.3	5.5	NS
Spartina pectinata Link	2.9	4.8	NS
Stachys palustris L.	3.4	0	NS

Table 4. Average zone width and changes between 1995 and 1997. See Table 1 for zone descriptions and Appendix Table 2 for individual zone-width measurements.

Zone	Year	Average Zone Width (meters)	Average Change in Zone Width from 1995 to 1997
OPEN-WATER	1995	3	40-m increase
	1997	43	
BULRUSH	1995	20	14-m decrease
	1997	6	
GRASS	1995	19	17-m decrease
	1997	2	
FOREST	1995	13	9-m decrease
	1997	4	

Table 5. Significant differences in species diversity between pre- and post-dredging based on a *t*-test of the Shannon-Weiner diversity indices (H') for each year (Zar 1984). Alpha = 0.05; n = the sum of species occurrences; S = species richness.

Year	Parameter	Zone			
		Open water	Bulrush	Grass	Forest
1995	H_1'	0.8282	1.296	1.338	1.524
	n	165	332	280	320
	S	12	38	44	55
1997	H_2'	0.9403	0.9315	0.995	1.544
	n	324	122	102	224
	S	16	14	14	46
	Differ Significantly	No	Yes	Yes	No

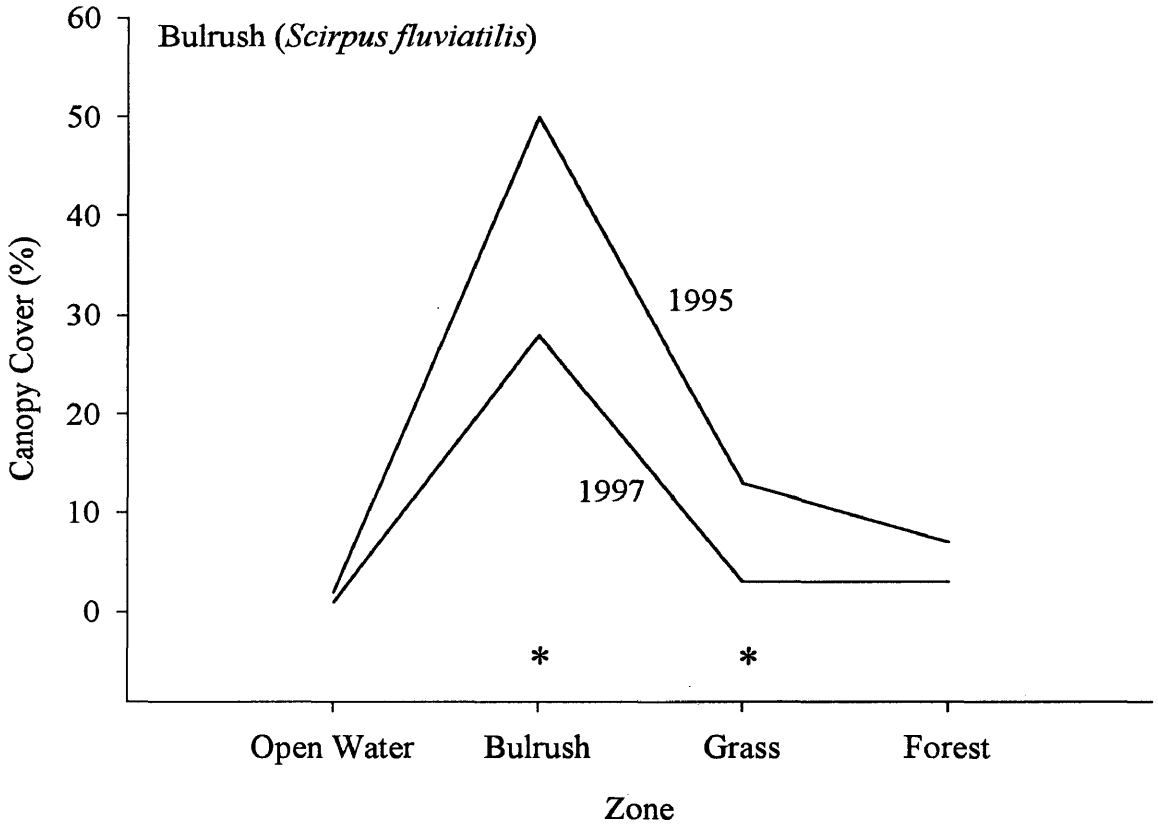

Fig. 2. Mean canopy cover of Bulrush (*Scirpus fluviatilis*) in 1995 and 1997 along an open water-to-forest gradient. * = Significant difference between years ($P \geq 0.05$).

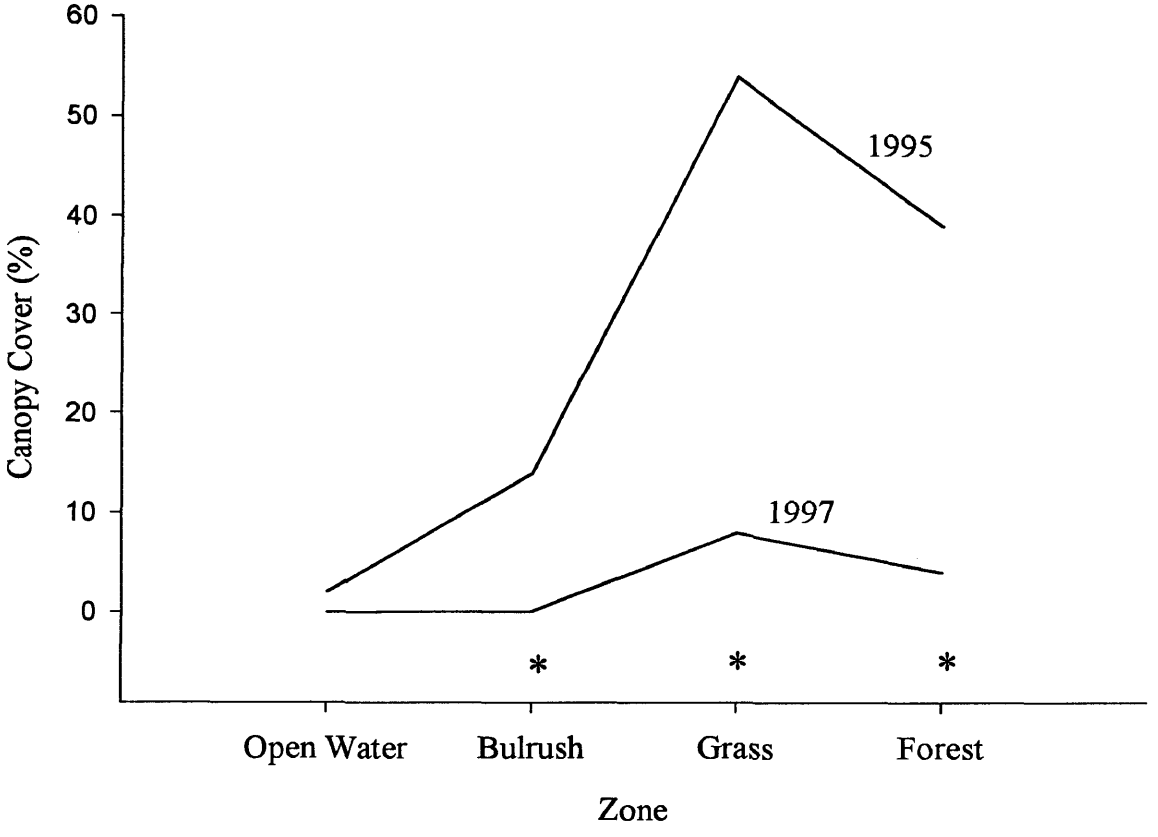

Fig. 3. Mean canopy cover of reed canary grass (*Phalaris arundinacea)* in 1995 and 1997 along an open water-to-forest gradient. * = Significant difference between years ($P \geq 0.05$).

periods that occurred at the marsh shortly before sampling. Overall, there was a significant decline in species diversity for the Bulrush zone from 38 species to 14 species (Table 5). Species lost included bulrush (*Scirpus validus*) and five smartweed species (*Polygonum* spp.).

As with the Bulrush Zone, the decrease in width of the Grass Zone was substantial, and changes in dominant species were significant. For example, reed canary grass dominated before dredging (53% cover), but decreased significantly to 7% cover as a consequence of dredging. Both river bulrush (12% to 3%) and common reed (11% to 8%) also decreased, although only river bulrush declined significantly (Fig. 2, Table 3, Appendix Table 5). These decreases in cover are most likely due to the mechanical removal of portions of the zone (personal observation).

The Forest Zone also declined in extent following dredging, with significant declines in understory grasses and forbs. Reed canary grass, for example, the dominant understory species, declined from 38% to 4%, a response also noted in the Grass Zone and, to a lesser extent, in the Bulrush Zone as well (Fig.3, Table 3, Appendix Table 6). Other species, such as Virginia wild rye (*Elymus virginica*), a native woodland species, persisted irrespective of treatment, although at low levels (12% and 10% cover in 1995 and 1997, respectively). Declines were also noted for woody species cover (59% to 28%) with a significant decline specifically in dogwood (*Cornus drumondii*) (28% to 8%). Species diversity, however, did not decline significantly following dredging (Table 5).

CONCLUSIONS

The Bulrush and Grass Zones were the zones most affected by dredging, each with a significant decline in species richness and a substantial reduction in zone widths (Table 5). Although much of the Bulrush and Grass Zones was replaced by open water, none of the species in those two zones completely disappeared from the marsh. In contrast, the plant diversity of the Open-water Zone was not affected by dredging, although there was a substantial increase in areal extent and in water-depth. The Forest Zone, as with the Open-water zone, was not affected substantially by dredging.

In combination, the results of this study suggest that dredging to restore wetland habitat can successfully deepen and widen the standing-water portion of marsh habitat without eliminating the principal plant communities that immediately surround it, at least not the year immediately following dredging. The significant decline in diversity that accompanied dredging, however, suggests effects that may have a longer-term impact on marsh habitat, although only future study can assess this effect (Table 5). This study provides the base for such long-term assessments. The results of this study should be regarded in the context of a single effort being performed in site-specific conditions. Data from other restoration-dredging efforts would need to be compared with the data from this study in order to suggest generalities about this process as a means of extending the life of marshes where the physical conditions that established them no longer occur.

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APPENDIX

Appendix Table 1. List of species identified in study quadrats at the Great Marsh. Nomenclature follows Great Plains Flora Association. (1986)

Scientific Name	Common Name
Acer seedlings	Maple seedlings
Acer saccharinum L.	Silver maple
Alisma subcordata Raf.	Water plantain
Alliaria petiolata (Bieb.) Cavara & Grande	Garlic mustard
Asclepias incarnata L.	Swamp milkweed
Aster ontarionis Wieg.	Missouri aster
Bidens cernua L.	Nodding beggar-ticks
Bidens frondosa L.	Beggar-ticks
Bidens vulgata Greene	Beggar-ticks
Boehmeria cylindrica (L.) Swartz	False-nettle
Bromus latiglumis (Scribn. ex Shear) Hitchc.	Brome
Bromus pubescens Muhl. ex Willd.	Brome
Bryophyte - Liverwort	
Bryophyte - Moss	
Campanula americana L.	American or tall bellflower
Carex spp.	Sedge
Carex pensylvanica Lam.	GROUP VIII
Celtis occidentalis L.	Hackberry
Ceratophyllum demersum L.	Coontail
Cinna arundinacea L.	Woodreed
Cornus drummondii C.A. Meyer	Rough-leaved dogwood
Cyperus spp.	Umbrella sedge
Cyperus esculentus L.	Umbrella sedge
Echinochloa spp.	Barnyard grass
Echinochloa crusgalli (L.) Beauv.	Barnyard grass
Echinochloa muricata (Beauv.) Fernald	Barnyard grass
Eclipta prostrata (L.)L.	Yerba de Tajo
Elymus canadensis L.	Canada wild rye
Elymus villosus Muhl. ex Willd.	Hairy wild rye
Elymus virginicus L.	Virginia wild rye
Equisetum spp.	Horsetail
Equisetum arvense L.	Field horsetail
Eupatorium serotinum Michx.	Boneset
Fraxinus seedlings	Green Ash seedlings
Fraxinus pennsylvanica Marshall	Green Ash
Galium aparine L.	Catchweed bedstraw
Galium trifidium L.	Small bedstraw
Hemerocallis fulva L.	Daylily
Hystrix patuls Moench.	Bottlebrush grass
Juncus tenuis Willd.	Path rush
Lamiaceae spp.	Mint

Appendix Table 1. List of species identified in study quadrats at the Great Marsh. Nomenclature follows Great Plains Flora Association. (1986)

Scientific Name	Common Name
Leersia oryzoides (L.) Swartz	Rice cutgrass
Leersia virginica Willd.	Whitegrass
Lemna minor L.	Duckweed
Leonurus cardiacea L.	Motherwort
Morus alba L.	White mulberry
Muhlenbergia mexicana (L.) Trin.	Wirestem muhly
Muhlenbergia spp.	Muhly
Nelumbo lutea (Willd.) Pers.	Lotus, Water chinkapin
Oxalis dilleni Jacq.	Gray-green wood sorrel
Panicum dichotomiflorum Michx.	Fall panicum
Phalaris arundinacea L.	Reed canary grass
Phalaris arundinacea L. seedlings	Reed canary grass seedlings
Phragmites australis (Cav.) Trin. ex Steud	Common reed
Pilea pumila (L.) Gray	Clearweed
Platanus occidentalis L.	Sycamore or Plane-tree
Polygonum spp.	Smartweed
Polygonum amphibium L.	Water smartweed
Polygonum hydropiper L.	Waterpepper
Polygonum lapathifolium L.	Pale smartweed
Polygonum pensylvanicum L.	Pennsylvania smartweed
Polygonum persicaria L.	Lady's thumb
Polygonum punctatum Elliott	Water smartweed
Polygonum virginianum L.	Virginia knotweed
Populus deltoides W. Bartram ex Marshall	Cottonwood
Potamogeton nodosus Poir.	Longleaf pondweed
Potamogeton pectinatus L.	Sago pondweed
Ranunculus sceleratus L.	Cursed crowfeet
Rumex crispus L.	Curly dock
Rumex spp.	Dock
Sagittaria latifolia	Arrowhead
Salix spp.	Willow
Salix amygdaloides Anderss.	Peach-leaf willow
Salix eriocephala Michx.	Diamond willow
Salix exigua Nutt.	Sandbar willow
Salix nigra Marshall	Black willow
Sanicula gregaria Bickn.	Black snakeroot
Scirpus spp.	Bulrush
Scirpus acutus Muhl. ex Bigel.	Bulrush
Scirpus fluviatilis (Torr.) Gray	Bulrush
Scirpus validus Vahl	Bulrush
Scutellaria lateriflora L.	Blue skullcap or mad-dog
Smilax hispida Muhl. ex Torr.	Bristly greenbrier

Appendix Table 1. List of species identified in study quadrats at the Great Marsh. Nomenclature follows Great Plains Flora Association. (1986)

Scientific Name	Common Name
Spartina pectinata Link	Prairie cordgrass
Stachys palustris	Hedge-nettle
Toxicodendron radicans (L.) Kuntze	Poison ivy
Tridens flavus (L.) A. Hitchc.	Redtop
Typha spp.	Cattail
Ulmus seedlings	Elm seedlings
Ulmus americana L.	American elm
Ulmus rubra Muhl.	Slippery elm
Unidentified forb spp.	
Unidentified grass spp.	
Unidentified woody spp.	
Urtica dioica L.	Stinging nettle
Utricularia vulgaris L.	Common bladderwort
Verbena urticifolia L.	Nettle-leaved vervain
Viola spp.	Violet
Viola missouriensis Greene	Violet
Vitis riparia Michx.	River-bank grape
Vitis riparia seedlings	River-bank grape seedlings
Vitis spp.	Grape seedlings
Wolffia columbiana Karst.	Watermeal

Appendix Table 2. Zone widths (m) for 1995 and 1997. Direct measurements were made in 1995, but estimated in 1997. See Table 1 for zone descriptions. Study stations numbering is not sequential as numbers 9, 12, and 14 were eliminated during site selection.

	Year and Zones							
	1995				1997			
Study Station	1	2	3	4	1	2	3	4
1	3	18	6	6	27	0	0	6
2	3	8	4	6	16	0	0	6
3	3	4	3	6	11	0	0	6
4	3	9	3	5	14	0	0	6
5	3	21	15	15	46	2	0	6
6	3	20	20	17	52	1	0	6
7	3	57	16	17	85	3	6	0
8	6	53	17	30	102	0	5	0
10	0	0	85	14	50	30	6	12
11	0	18	28	13	59	0	0	0
13	3	21	9	0	34	0	0	0
15	3	11	23	25	15	38	9	0
Sum	33	240	229	154	511	74	26	48
Mean	3	20	19	13	43	6	2	4
Width Change					+40	-14	-17	-9

Appendix Table 3. Mean canopy cover and standard deviation (SD) for the Open-water Zone (Zone 1) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

	Zone 1			
	1995		1997	
Species	Mean	SD	Mean	SD
TOTCOV (*)	68.8	39.0	96.9	8.2
SUBMUD (*)	66.4	40.5	96.4	8.3
BULRUSH (*)	0.6	2.7	3.0	7.7
FORBS	1.8	7.2	1.4	5.5
GRASS (*)	7.0	15.5	0.0	0.0
WOODY	0.0	0.0	2.6	13.5
Alisma subcordata Raf.	0.0	0.0	0.1	0.5
Ceratophyllum demersum L. (*)	7.3	21.7	25.4	25.5
Echinochloa crusgalli (L.) Beauv. (*)	6.1	15.0	0.0	0.0
Fraxinus pennsylvanica Marshall	0.0	0.0	0.1	0.5
Fraxinus seedlings	0.0	0.0	tr	0.1
Lamiaceae spp.	tr	0.3	0.0	0.0
Lemna minor L.	35.1	38.5	45.5	32.9
Morus alba L.	0.0	0.0	3.1	16.6
Nelumbo lutea (Willd.) Pers.	6.0	13.1	8.3	13.6
Phalaris arundinacea L.	1.6	7.0	0.0	0.0
Platanus occidentalis L.	0.0	0.0	0.1	0.5
Polygonum amphibium L.	0.0	0.0	tr	0.1
Polygonum lapathifolium L.	0.1	0.3	0.0	0.0
Polygonum persicaria L.	tr	0.3	0.0	0.0
Potamogeton nodosus Poir.	0.0	0.0	0.4	2.0
Potamogeton pectinatus L. (*)	0.0	0.0	2.0	5.7
Ranunculus sceleratus L.	0.1	0.3	0.0	0.0
Rumex spp.	0.3	1.9	0.0	0.0
Sagittaria latifolia Willd.	0.0	0.0	0.3	1.9
Scirpus acutus Muhl. ex Bigel.	0.0	0.0	tr	0.1
Scirpus fluviatilis (Torr.) Gray	1.7	11.1	1.4	3.3
Utricularia vulgaris L.	0.0	0.0	0.5	2.0
Wolffia columbiana Karst.	52.6	40.8	61.4	29.8

Appendix Table 4. Mean canopy cover and standard deviation (SD) for the Bulrush Zone (Zone 2) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

	Zone 2			
	1995		1997	
Species	Mean	SD	Mean	SD
TOTCOV (*)	82.9	27.2	38.3	46.8
SUBMUD (*)	12.0	22.1	28.3	39.0
BULRUSH (*)	55.3	33.6	28.5	38.4
FORBS (*)	4.6	9.1	0.3	1.9
GRASS (*)	29.9	31.3	2.5	11.4
WOODY	2.0	12.7	0.1	0.3
Alisma subcordata Raf.	0.0	0.0	tr	0.3
Bidens cernua L.	0.3	1.9	0.0	0.0
Bidens vulgata Greene	tr	0.1	0.0	0.0
Boehmeria cylindrica (L.) Swartz	0.1	0.3	0.0	0.0
Bryophyte – Liverwort (*)	0.8	2.7	0.0	0.0
Bryophyte – Moss (*)	2.4	7.3	0.0	0.0
Ceratophyllum demersum L.	0.0	0.0	1.2	5.5
Cyperus esculentus L. (*)	0.1	0.4	0.0	0.0
Echinochloa crusgalli (L.) Beauv. (*)	6.8	23.0	tr	0.1
Echinochloa muricata (Beauv.) Fernald	0.3	1.9	0.0	0.0
Echinochloa spp. (*)	0.2	0.6	0.0	0.0
Eclipta prostrata (L.)L.	0.4	2.0	0.0	0.0
Fraxinus pennsylvanica Marshall	0.0	0.0	tr	0.1
Leersia oryzoides (L.) Swartz (*)	2.1	7.4	0.0	0.0
Lemna minor L. (*)	7.9	19.8	22.6	32.5
Morus alba L.	1.1	8.1	0.0	0.0
Nelumbo lutea (Willd.) Pers. (*)	tr	0.1	0.3	0.6
Panicum dichotomiflorum Michx.	tr	0.1	0.0	0.0
Phalaris arundinacea L. (*)	14.0	23.2	0.1	0.3
Phalaris arundinacea L. seedlings	0.9	5.2	0.0	0.0
Phragmites australis (Cav.) Trin. ex Steud	4.3	15.5	0.3	2.0
Pilea pumila (L.) Gray	0.1	0.5	0.0	0.0
Platanus occidentalis L.	tr	0.1	0.0	0.0
Polygonum amphibium L.	0.7	4.9	0.0	0.0
Polygonum hydropiper L.	tr	0.1	0.0	0.0
Polygonum lapathifolium L. (*)	0.2	0.6	0.0	0.0
Polygonum pensylvanicum L.	0.1	0.5	0.0	0.0
Polygonum persicaria L. (*)	0.2	0.6	0.0	0.0
Polygonum spp.	0.4	2.0	0.0	0.0

Appendix Table 4. Mean canopy cover and standard deviation (SD) for the Bulrush Zone (Zone 2) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

Populus deltoides W. Bartram ex Marshall	0.3	1.9	0.0	0.0
Ranunculus sceleratus L.	tr	0.1	0.0	0.0
Rumex spp.	tr	0.1	0.0	0.0
Salix amygdaloides Anderss.	1.6	12.6	0.0	0.0
Scirpus acutus Muhl. ex Bigel.	1.5	8.5	tr	0.1
Scirpus fluviatilis (Torr.) Gray (*)	50.0	32.7	27.9	37.6
Scirpus validus Vahl (*)	9.8	22.6	0.0	0.0
Scutellaria lateriflora L.	0.8	3.3	0.0	0.0
Spartina pectinata Link (*)	0.0	0.0	0.2	0.6
Typha spp.	tr	0.1	4.3	18.7
Unidentified forbs (*)	0.1	0.5	0.0	0.0
Unidentified grasses	1.4	6.8	0.0	0.0
Unidentified wood spp.	tr	0.1	0.0	0.0
Utricularia vulgaris L.	0.0	0.0	0.1	0.3
Wolffia columbiana Karst. (*)	5.9	14.5	13.7	25.1

Appendix Table 5. Mean canopy cover and standard deviation (SD) for the Grass Zone (Zone 3) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

	Zone 3			
	1995		1997	
Species	Mean	SD	Mean	SD
TOTCOV (*)	86.8	27.2	32.3	46.2
SUBMUD (*)	0.2	0.5	12.9	28.6
BULRUSH (*)	13.6	20.0	4.2	13.7
FORBS (*)	12.0	20.7	0.1	0.5
GRASS (*)	68.3	30.4	26.9	39.6
WOODY (*)	16.9	30.7	tr	0.1
Acer saccharinum L.	tr	0.3	0.0	0.0
Acer seedlings	0.3	1.9	0.0	0.0
Alisma subcordata Raf.	0.0	0.0	tr	0.1
Asclepias incarnata L.	0.5	2.7	0.0	0.0
Boehmeria cylindrica (L.) Swartz	0.1	0.5	0.0	0.0
Bryophyte - Liverwort	0.3	1.9	0.0	0.0
Bryophyte - Moss	1.4	6.8	0.0	0.0
Cornus drummondii C.A. Meyer	0.3	2.0	0.0	0.0
Cyperus spp.	0.3	1.9	0.0	0.0
Echinochloa crusgalli (L.) Beauv.	2.3	12.0	0.1	0.3
Eclipta prostrata (L.)L.	0.3	1.9	0.0	0.0
Elymus virginicus L.	0.1	0.6	0.0	0.0
Equisetum arvense L.	tr	0.3	0.0	0.0
Fraxinus pennsylvanica Marshall	3.0	12.2	tr	0.1
Fraxinus seedlings	0.9	5.2	0.0	0.0
Hemerocallis fulva L.	tr	0.3	0.0	0.0
Lemna minor L. (*)	0.2	0.5	8.0	21.7
Morus alba L. (*)	8.3	23.4	0.0	0.0
Muhlenbergia spp.	tr	0.1	0.0	0.0
Nelumbo lutea (Willd.) Pers. (*)	0.0	0.0	0.1	0.2
Phalaris arundinacea L. (*)	54.0	33.6	8.0	19.5
Phalaris arundinacea L. seedlings	tr	0.3	0.0	0.0
Phragmites australis (Cav.) Trin. ex Steud	11.4	22.3	8.8	23.2
Pilea pumila (L.) Gray	0.1	0.5	0.0	0.0
Platanus occidentalis L.	1.1	8.1	0.0	0.0
Polygonum amphibium L. (*)	2.4	7.6	0.0	0.0
Polygonum hydropiper L.	0.9	5.2	0.0	0.0
Polygonum persicaria L.	0.3	1.9	0.0	0.0
Polygonum punctatum Elliott	0.3	1.9	tr	0.1
Polygonum spp. (*)	2.1	7.4	0.0	0.0

Appendix Table 5. Mean canopy cover and standard deviation (SD) for the Grass Zone (Zone 3) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

Populus deltoides W. Bartram ex Marshall	1.4	8.3	tr	0.3
Salix amygdaloides Anderss.	0.3	2.0	0.0	0.0
Salix eriocephala Michx.	1.1	8.1	0.0	0.0
Salix exigua Nutt.	3.5	16.0	0.0	0.0
Scirpus acutus Muhl. ex Bigel.	0.0	0.0	tr	0.1
Scirpus fluviatilis (Torr.) Gray (*)	12.9	20.2	3.2	11.3
Scirpus spp.	0.6	4.8	0.0	0.0
Scirpus validus Vahl	tr	0.3	0.0	0.0
Scutellaria lateriflora L.	0.7	4.9	0.0	0.0
Smilax hispida Muhl. ex Torr.	tr	0.1	0.0	0.0
Spartina pectinata Link (*)	1.6	5.8	tr	0.1
Stachys palustris L.	tr	0.3	0.0	0.0
Typha spp.	1.6	6.0	1.4	6.8
Ulmus americana L.	1.7	11.1	0.0	0.0
Unidentified forbs (*)	tr	0.1	0.0	0.0
Unidentified wood spp.	0.1	0.3	0.0	0.0
Viola missouriensis Greene	0.1	0.5	0.0	0.0
Vitis riparia Michx.	0.3	1.9	0.0	0.0
Wolffia columbiana Karst. (*)	tr	0.1	8.9	26.1

Appendix Table 6. Mean canopy cover and standard deviation (SD) for the Forest Zone (Zone 4) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

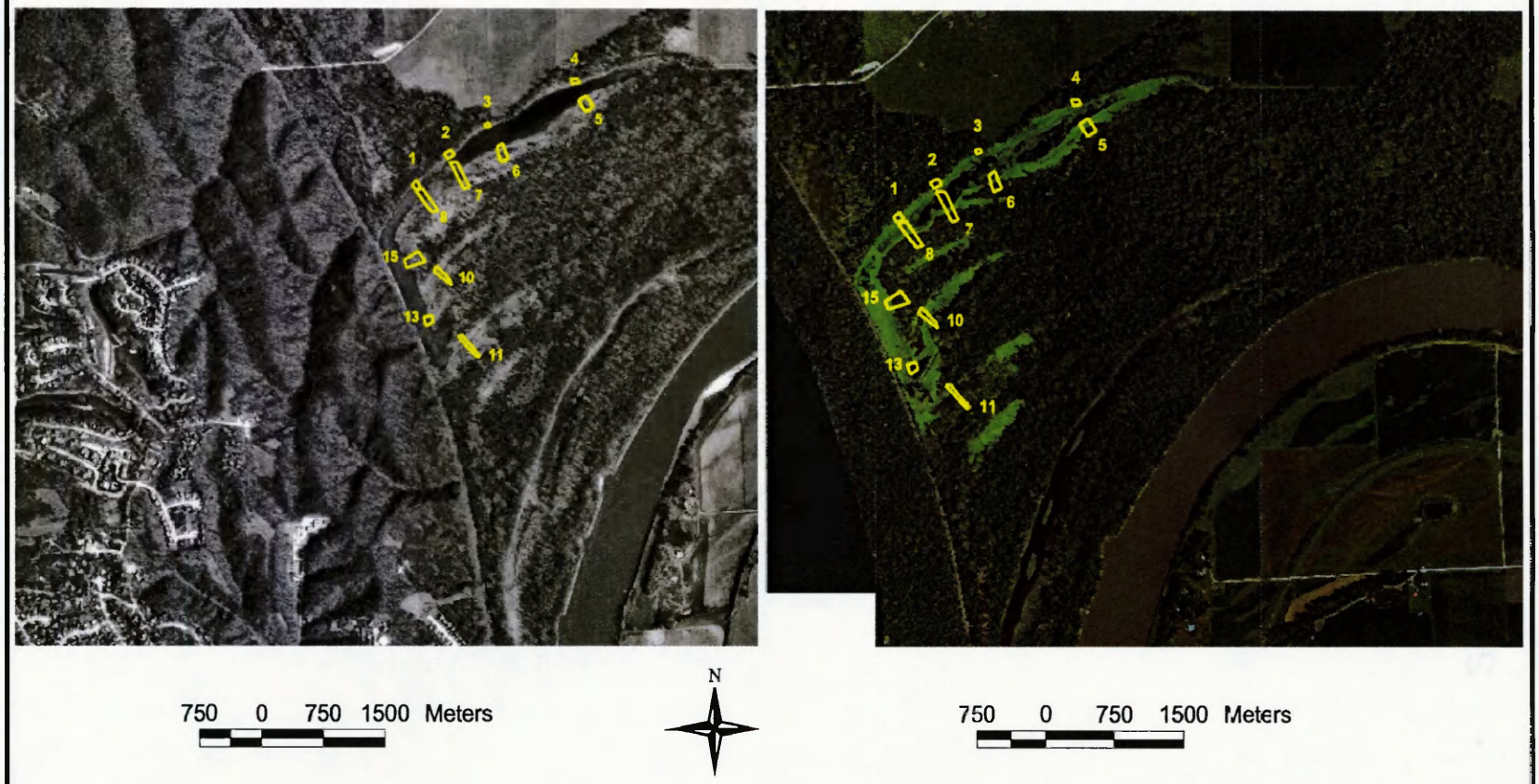
	Zone 4			
	1995		1997	
Species	Mean	SD	Mean	SD
TOTCOV (*)	84.0	27.4	54.8	47.1
SUBMUD (*)	0.0	0.0	8.7	20.7
BULRUSH	8.0	18.3	5.8	14.5
FORBS (*)	12.2	17.4	4.3	9.9
GRASS (*)	65.8	27.8	32.3	36.1
WOODY (*)	59.1	42.0	28.1	37.3
Acer saccharinum L.	tr	0.1	0.1	0.6
Acer seedlings (*)	0.3	0.8	0.0	0.0
Alliaria petiolata (Bieb.) Cavara & Grande	0.0	0.0	0.3	2.0
Asclepias incarnata L.	tr	0.3	0.1	0.3
Aster ontarionis Wieg.	0.0	0.0	tr	0.1
Bidens frondosa L.	0.0	0.0	tr	0.1
Boehmeria cylindrica (L.) Swartz	0.4	2.0	0.0	0.0
Bromus latiglumis (Scribn. ex Shear) Hitchc.	0.0	0.0	0.8	3.3
Bromus pubescens Muhl. ex Willd.	0.3	2.0	0.0	0.0
Campanula americana L.	tr	0.1	0.0	0.0
Carex pensylvanica Lam.	0.8	4.9	0.0	0.0
Carex spp.	0.8	4.9	tr	0.1
Celtis occidentalis L.	1.2	8.1	1.3	8.3
Cinna arundinacea L.	tr	0.1	0.3	2.0
Cornus drummondii C.A. Meyer (*)	27.2	38.6	7.8	21.8
Echinochloa crusgalli (L.) Beauv.	0.0	0.0	0.1	0.3
Elymus canadensis L.	2.3	10.4	0.0	0.0
Elymus villosus Muhl. ex Willd.	1.3	8.3	0.0	0.0
Elymus virginicus L.	12.9	23.5	10.9	23.9
Equisetum arvense L.	0.7	4.8	0.3	1.9
Equisetum spp.	0.1	0.3	0.0	0.0
Eupatorium serotinum Michx.	0.0	0.0	tr	0.1
Fraxinus pennsylvanica Marshall	5.3	15.1	1.2	5.5
Galium aparine L.	0.0	0.0	0.1	0.3
Galium trifidium L.	0.0	0.0	0.1	0.5
Hystrix patuls Moench.	1.7	9.3	2.0	7.4
Juncus tenuis Willd.	0.3	1.9	0.0	0.0
Leersia virginica Willd.	0.0	0.0	0.1	0.3
Lemna minor L. (*)	0.0	0.0	5.5	13.8

Appendix Table 6. Mean canopy cover and standard deviation (SD) for the Forest Zone (Zone 4) for 1995 and 1997. See Table 2 for category descriptions. (*) indicates a significant difference in the mean of that vegetative category or species between 1995 and 1997. tr = < 0.1% cover.

Leonurus cardiacea L.	0.3	2.0	0.1	0.3
Morus alba L.	7.3	23.7	4.4	17.3
Muhlenbergia mexicana (L.) Trin.	0.0	0.0	0.5	2.7
Muhlenbergia spp.	0.1	0.3	0.0	0.0
Oxalis dilleni Jacq.	0.0	0.0	0.1	0.3
Phalaris arundinacea L. (*)	38.6	37.0	4.4	9.3
Phragmites australis (Cav.) Trin. ex Steud	tr	0.1	0.1	0.3
Platanus occidentalis L.	0.0	0.0	0.7	4.9
Polygonum hydropiper L.	0.5	2.7	0.8	4.9
Polygonum lapathifolium L.	0.3	1.9	0.0	0.0
Polygonum punctatum Elliott	0.0	0.0	0.1	0.3
Polygonum spp.	1.4	6.8	0.1	0.5
Polygonum virginianum L.	0.3	2.0	tr	0.1
Populus deltoides W. Bartram ex Marshall	3.1	15.1	0.4	2.0
Rumex crispus L.	tr	0.1	0.0	0.0
Salix amygdaloides Anderss.	0.0	0.0	0.1	0.5
Salix eriocephala Michx.	4.0	15.7	0.0	0.0
Salix exigua Nutt.	1.7	12.6	0.3	1.9
Salix nigra Marshall	1.5	11.0	0.3	2.0
Salix spp. (*)	5.2	19.9	0.0	0.0
Sanicula gregaria Bickn. (*)	0.2	0.7	0.0	0.0
Scirpus fluviatilis (Torr.) Gray	7.3	17.3	5.5	14.5
Scutellaria lateriflora L.	tr	0.3	0.0	0.0
Smilax hispida Muhl. ex Torr.	0.4	2.0	tr	0.1
Spartina pectinata Link	2.9	11.5	4.8	16.7
Stachys palustris L.	3.4	15.5	0.0	0.0
Toxicodendron radicans (L.) Kuntze	1.0	5.2	0.1	0.3
Tridens flavus (L.) A. Hitchc.	0.9	5.2	0.0	0.0
Ulmus americana L.	1.1	8.1	6.9	22.7
Ulmus rubra Muhl.	6.4	21.4	2.8	13.6
Ulmus seedlings	tr	0.1	0.0	0.0
Unidentified forbs	0.4	2.0	0.0	0.0
Unidentified grasses	0.6	4.8	0.6	2.7
Unidentified wood spp.	4.1	18.2	0.0	0.0
Urtica dioica L.	0.3	2.0	0.1	0.3
Verbena urticifolia L.	0.0	0.0	tr	0.1
Viola missouriensis Greene (*)	3.5	10.8	0.1	0.6
Viola spp.	0.0	0.0	0.8	4.9
Vitis riparia Michx.	3.1	12.3	0.0	0.0
Vitis riparia seedlings	tr	0.3	0.0	0.0
Vitis spp.	tr	0.3	0.3	1.9
Wolffia columbiana Karst.	1.1	5.5	5.2	17.4

Appendix Table 7. Latitude and Longitude recordings for the four corners of each study station at the Great Marsh. Study stations numbering is not sequential as numbers 9, 12, and 14 were eliminated during site selection. All GPS points were obtained through a post-process differential-correction of rover data. For relocation purposes, a real-time kinematics unit would be required. All North latitude designations are 41° and all West longitude designations are 95°.

Study Station	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1	10′15.5932″	53′18.7705″	10′15.9619″	53′17.8901″	10′16.7373″	53′18.4826″	10′16.1556″	53′19.3695″
2	10′18.9060″	53′13.3959″	10′19.3688″	53′12.2041″	10′19.9608″	53′12.9063″	10′19.5839″	53′13.9228″
3	10′22.3182″	53′07.0887″	10′22.4846″	53′06.3345″	10′22.8554″	53′06.6132″	10′22.6566″	53′07.3455″
4	10′26.8159″	52′53.0336″	10′26.8297″	52′51.9394″	10′27.3751″	52′52.1232″	10′27.3797″	52′53.3088″
5	10′23.5143″	52′51.2124″	10′24.0894″	52′49.8780″	10′25.3708″	52′50.9845″	10′24.8593″	52′52.2119″
6	10′18.2614″	53′04.9778″	10′18.6220″	53′03.7183″	10′20.3838″	53′04.5914″	10′20.0038″	53′05.4878″
7	10′15.3900″	53′11.0946″	10′15.6456″	53′10.1306″	10′18.5634″	53′11.8675″	10′18.6110″	53′13.1324″
8	10′12.9810″	53′16.3541″	10′13.0847″	53′15.3095″	10′15.7679″	53′17.6585″	10′15.4956″	53′18.7297″
10	10′04.4923″	53′13.7590″	10′05.1268″	53′13.9772″	10′06.7931″	53′16.0007″	10′06.1721″	53′16.4363″
11	09′56.0932″	53′10.2512″	09′56.1676″	53′09.7426″	09′58.7082″	53′12.4831″	09′58.5816″	53′13.0794″
13	09′59.9406″	53′18.0331″	10′00.3930″	53′16.8887″	10′01.1240″	53′17.0121″	10′01.0103″	53′18.4213″
15	10′06.6900″	53′20.7077″	10′07.3009″	53′17.6500″	10′08.5444″	53′18.8058″	10′07.5769″	53′21.0650″



Appendix Figure1. A: Predredge photo (1990) with study stations. B: Postdredge photo (1997) with study stations.