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The effects of a record flood on the aquatic vegetation of the Upper Mississippi River System: some preliminary findings

Andrew Spink[1] & Sara Rogers[2]
[1] *Illinois Natural History Survey, 794 N Schrader Ave, Havana, IL 62644, USA*
Present address: Department of Plant Ecology & Evolutionary Biology, University of Utrecht, P.O. Box 800.84, 3508 TB Utrecht, The Netherlands
[2]*EMTC, 575 Lester Ave, Onalaska, WI 54650, USA*

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Abstract

During 1993 the Upper Mississippi River System experienced floods of exceptional magnitude and duration, especially at its more downstream reaches. The flood had widespread effects on the vegetation. Submerged species such as Potamogeton pectinatus significantly decreased in abundance, especially at sites with more severe flooding. However, many species were able to regenerate in 1994 from seeds or storage organs. Emergent species such as *Scirpus fluviatilis* were similarly affected, but in the upstream reaches were able to regrow in the autumn following the flood and at many sites showed exceptionally high productivity in the following year, probably due to nutrient-rich sediment deposition by the flood. Many tree species were very severely impacted, although *Acer saccharinum* and *Populus deltoides* have shown some seedling regeneration on newly deposited sediment beneath stands of mature trees, which would have out-shaded the seedlings if they had not been killed by the flood.

Introduction

The flood of 1993 had widespread effects on the vegetation of the Mississippi River and its major tributaries. In this paper the results of measurements and observations throughout the Upper Mississippi are brought together and summarized.

The watershed of the Upper Mississippi River System (UMRS: Figure 1) covers 500 000 km^2. It has been altered to support commercial navigation by the construction of locks and dams, wing dikes, and through dredging. This has resulted in dramatic effects to the river ecosystem. The locks and dam, constructed in the 1930s, created relatively stable water levels immediately upstream of the dams and increased water surface areas due to inundation of the floodplain (Chen & Simons, 1986). However, the dams have increased the trapping efficiency of fine sediments in off-channel areas (Peck & Smart, 1986), which can lead to wide-ranging problems for aquatic macrophytes (Sparks et al., 1990). It is predicted that at present sedimentation rates, many backwater areas will become marshes within the next 50 to 100 years (Chen & Simons, 1986). The dams are not managed to store water: during the 1993 their gates were left open to increase water conveyance.

Flooding acts as another stress that can affect macrophytes in a variety of ways depending on the timing, duration and magnitude of the event. Although flood waters may provide additional nutrients via suspended materials to rooted macrophytes (Barko & Smart, 1983), negative consequences can also occur. These include burial or coverage by sediments reduced light availability (Van Dijk, 1992; Tanner et al., 1993), reduced in oxygen supply (when leaves of emergents are submerged: Coutts & Armstrong, 1976, Nielsen, 1993), increased herbicide supply (in agricultural catchments: Goolsby et al., 1994), and uprooting due to high velocities (Spink, 1992) or wind- generated waves because of the increased fetch can also occur.

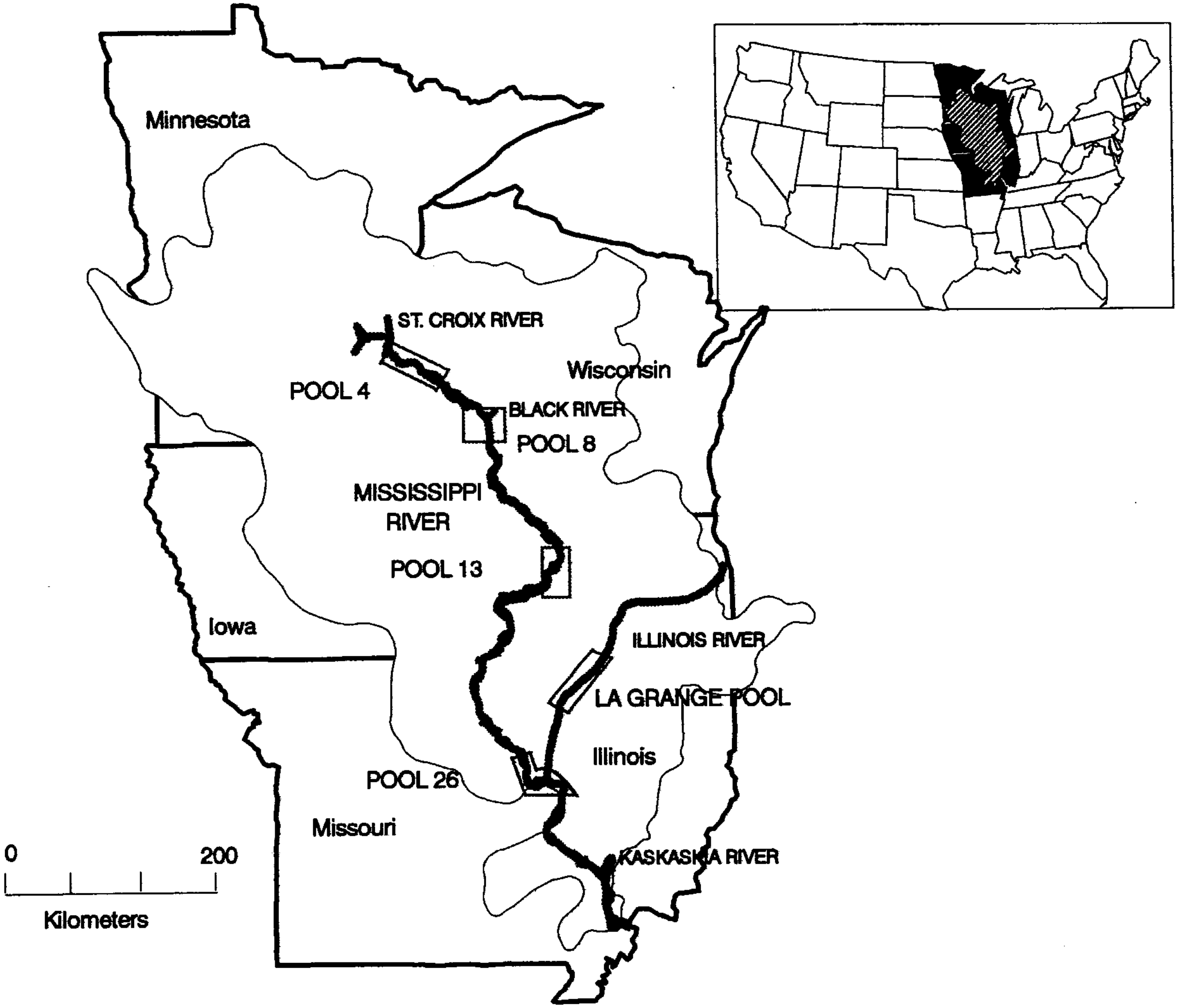

Figure 1. Map of the Upper Mississippi River System (UMRS). Pools are named after the number of the lock and dam at the downstream (southern) end. The UMRS consists of the Illinois River and upper 26 pools of the Mississippi River.

The flood

The flood was caused by a long period of exceptionally high rainfall over much of the upper Mississippi watershed. During June 1993, rainfall was generally twice average: several states had their highest July rainfalls since 1895. In addition to the huge amount of water carried by the 1993 flood, it is suspected that tremendous amounts of sediment were also carried as suspended load and as bed load. In addition to being moved downstream, massive quantities of sediment were deposited onto the floodplain and back channels. Newly created sandbars are evident in most pools, and deposition among the floodplain forest reached several centimeters thick in lower reaches of the river.

The flood of 1993 was notable because of the wide area it affected, large peak discharges, and exceptional duration (Figure 2A). It set new record peaks at nearly every station along the Mississippi. Peak water levels in late June through August were preceded by a period of high river levels that were frequently above flood stage for nearly four months (IFMRC, 1994). Extremely large amounts of agricultural chemicals and sediments were flushed into the Mississippi River and tributaries, including mean atrazine concentrations of 2.2 $\mu g l^{-1}$ (Goolsby et al., 1994).

Not all places along the river were affected equally by the flood; the more downstream sites had higher floods lasting for longer (Figure 2B).

Methods

The data in this paper are taken from three sources;

(a) Vegetation transects of the Long Term Resource Monitoring Program (LTRMP). The LTRMP monitors the biology and chemistry of the UMRS in order to provide information on which to base management decisions. Thirty locations in five of the 26 reaches upstream of a navigation dam are surveyed twice every growing season. Within each location, transects are positioned perpendicular to shore at 50 m intervals. Samples are taken every 15–30 m with a long-handled rake to determine species composition, frequency of occurrence and to estimate relative abundance. In 1993, the timing of the transect sampling coincided with flood events. In all pools, spring/early sampling was completed after early spring high water and just before water levels rose to flood stage in late June. The second sampling began in the upper pools as water levels receded and in Pool 26 while water was still high.

(b) Field observations recorded by LTRMP and other biologists.

(c) Published reports (especially Dieterman, 1993).

Results

Most of the species in the UMRS (e.g. *Elodea canadensis*, *Vallisneria americana*) show a typical increase in density and biomass throughout the season, with a peak biomass towards mid/late summer (Madsen & Adams, 1988). However, the introduced species *Potamogeton crispus* starts turion production followed by senescence at water temperatures around 20 °C, showing an early decline, especially in the more northern pools (Nichols & Shaw, 1986).

In 1993, a different pattern was evident along transect sites between the early sampling period, which occurred between May 15 and June 15, and the second sampling period, which occurred between July 15 and August 30 (Figure 3). In the spring of 1993, before the record flood had started, the vegetation was growing more abundantly than in the previous year. However, as the flood waters rose many of the species were unable to cope with the resultant stresses, and by the summer their cover was significantly (*t*-tests) less than in the previous year. This was particularly marked at sites which had experienced more severe flooding (Figure 2A, 3B): generally more downstream reaches.

Dieterman (1993) found a similar pattern in reaches 3, 5, 5A and 6. He observed declining populations of plants in nearly all backwaters during June–August 1993. In Pool 26 there were no submerged plants observed at all by mid-August 1993, though *Ceratophyllum* demersum was observed in tree branches after the floodwaters began to recede (J. Nelson, in litt.).

Response to flooding (specific species)

Myriophyllum spicatum

M. spicatum apparently became established during the mid 1980s within many of the northern reaches (3 through 13) of the UMRS. Following a widespread drought in 1988, *M. spicatum* appeared in some reaches as large monotypic beds. In backwaters of reaches 7 and 8 many of the plants that were present before the 1993 flood survived when they responded to high water levels by producing stem lengths up to 3.3 m long, reaching the water's surface within two weeks of higher water levels (S. Rogers, pers. obsv.). Once

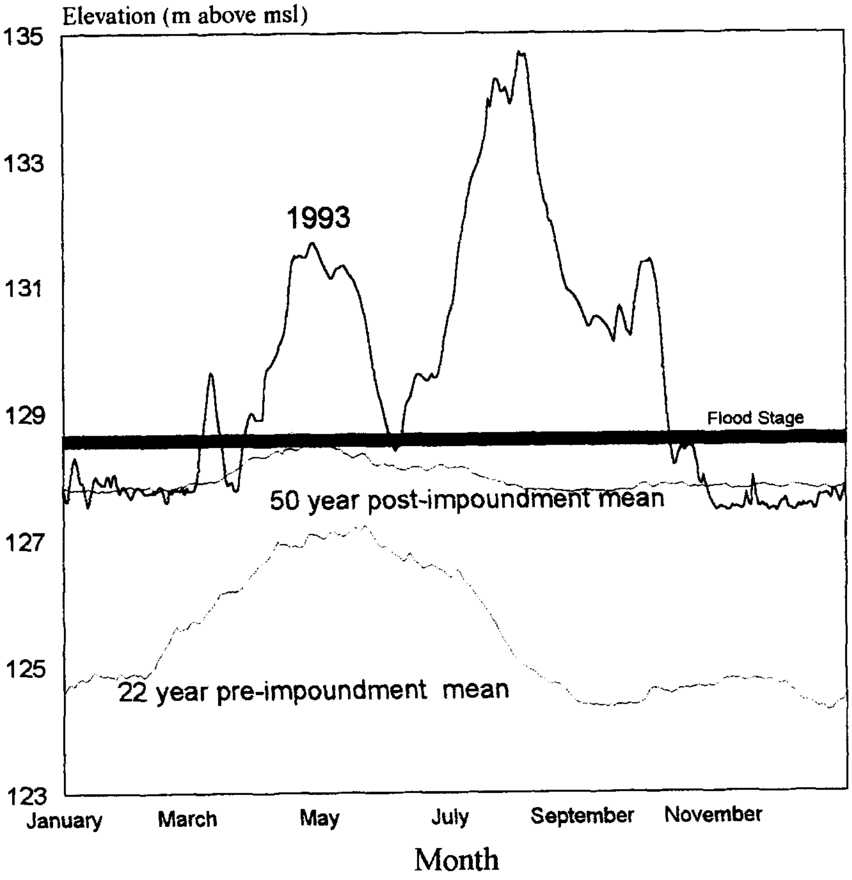

Figure 2a. Hydrograph of 1993 water levels of the Mississippi River at Alton, Illinois (Pool 26), with mean water levels for comparison. Flood stage (128.6 m above mean sea level) is also shown.

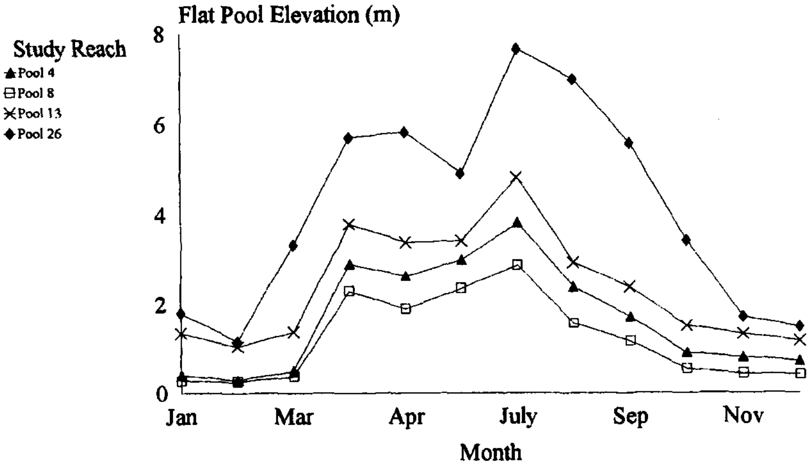

Figure 2b. Monthly averages of daily mean water levels above flat pool elevation (the minimum height maintained for navigation) in the Mississippi River at tailwaters of selected pools during 1993.

water levels fell, thick canopies of *M. spicatum* provided substrate for *Lemna* spp, which collected up to several centimetres thick in *Myriophyllum* beds in Lake Onalaska (Pool 7). In contrast, monotypic beds occurring in the impounded reaches of Pools 8 and 13 (where it was the dominant species in 1991 and 1992), and where velocities and turbidities were probably higher than in backwaters, disappeared by late July. By July 1994, beds of *M. spicatum* in Lake Onalaska persisted in some areas. However, in other portions of the lake, former stands of *M. spicatum* have been partially or completely replaced by *Vallisneria americana* and/or *Zosterella dubia*.

Nelumbo lutea

Initially during the flood, *N. lutea* grew up with the increasing water level, forming stems of at least 4 m in Pool 26 (J. Nelson, in litt.). However, as the water level increased, it was no longer able to keep its leaves above water and suffered severe die-back, especially in the lower pools. Very large beds of *Nelumbo lutea* completely disappeared from the Pools 19 and 26 during the flood event (R. Anderson pers. comm.) as well as other sites including backwaters adjacent to the Illinois River (A. Spink, pers. obsv.). In more upstream pools, where the flooding was less severe, it was able to make a recovery when water levels dropped in July (T. Blackburn, pers. comm.). During 1994 *N. lutea* has been re-establishing from seeds in the sediments deposited during the flood.

Potamogeton pectinatus

During the flood *P. pectinatus* showed a decrease in abundance throughout the UMRS (Figure 3A), and this was more pronounced towards the downstream end of the system, where the flooding was more intense. In the Illinois River it was almost completely eliminated by the 1993 flood. However, during 1994 it has grown again to biomass levels approaching previous years (A. Spink & T. Cook, pers. obsv.), presumably from turions or tubers. This is also the case for more upstream pools, where it has replaced *Myriophyllum spicatum* in some places.

Vallisneria americana

This species was abundant throughout the upper pools until a period of drought in 1988. The drought was associated with periods of low flow (and therefore low nutrient supply) rates as well as higher rates of epiphytic algal growth. During the 1993 flood the remaining *Vallisneria* beds grew well. During 1994 existing beds increased in size, and new beds have appeared in locations where it had been common before 1989. The flooding has also enabled this species to disperse to some areas where it has not been found previously (e.g. backwaters of Reach 26; J. Tucker pers. obsv.), and it is possible this has been the case for some other species as well.

Scirpus fluviatilis

The shoots of this emergent species were completely eliminated during the 1993 flood in many reaches of the lower UMRS. However, its dead stems act as efficient sediment traps, and during 1994 it has shown exceptionally high growth rates at many sites (e.g. a 3 m increase in stem length during a period of one month) (A. Spink, pers. obsv.). In the upper section of the river its growth was decreased during the flood (apparently due to sedimentation), but by mid-September 1993 new growth was appearing and in the summer 1994 the species had shown luxuriant re-growth.

Woody species

Floodplain forest is the most extensive plant cover type in the UMRS and the following summary is intended as a brief overview. Many flood tolerant tree species (e.g. *Salix nigra*, *Acer saccharinum*) have suffered very high mortality rates (especially among saplings) in the lower portion of the UMRS. In the Illinois River most *Salix* survived the flood, but in the spring of 1994 many leafed-out, only to loose their leaves and die within a few weeks. Less tolerant species showed higher mortality, especially during the flood itself. For example, 96% of *Celtis occidentalis* and 100% of *Carya laciniosa* were killed in Pool 26 (J. Nelson & Y. Yin, unpublished data). However, for at least some of these species (e.g. *A. saccharinum*, *Populus deltoides*), the death of shade-forming adult trees and deposition of new sediment has provided the opportunity for extensive seedling regeneration. Further upstream the effects were less severe, with most tree deaths occurring due to uprooting by shoreline erosion.

Discussion and conclusions

The majority of species in the river showed a clear north-south gradient in terms of response to the 1993 flood. The reduction in growth and increase in mortal-

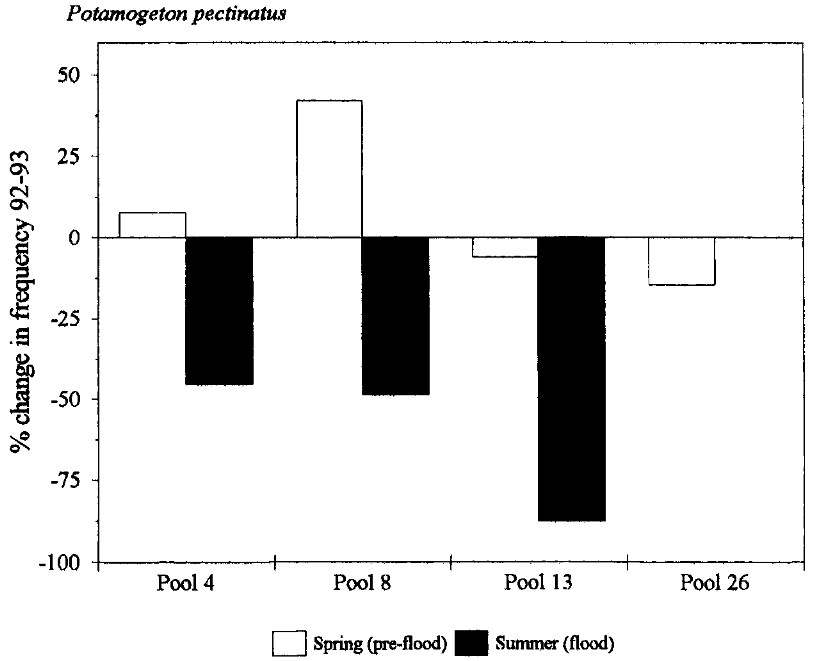

Figure 3a. Comparison of abundance of Potamogeton pectinatus in 1992 and 1993. Bars show % change between 1992 and 1993 in sites with *P. pectinatus* present. Open bars are comparisons between spring sampling (in 1992 before the flood) and summer sites (in 1993 during the flood). There was no *P. pectinatus* in Pool 26 in summer 93.

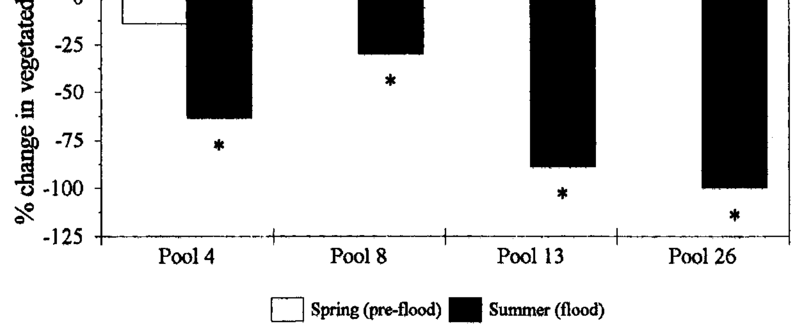

Figure 3b. Change in total submerged vegetation between 1992 and 1993. Bars show % change in the ratio of vegetated to unvegetated sites from 1992 to 1993. Open bars represent spring, closed summer. n.s. = no significant change from 1992-3, * significant change ($p<0.05$).

ity was much greater at the sites further downstream (Figure 3), where flooding was most severe (Figure 2). At the upstream sites many of the indigenous species displayed strategies for flood tolerance by stem etiolation, tolerance of low light levels and a capacity for rapid regrowth. However, at more southerly sites the duration and magnitude of the flood was such that many species suffered mortality. Trees, such as *Salix,* which tolerated limited inundation upstream were unable to cope with their roots being submerged for in excess a year at more severely affected sites. This was probably due to a combination of stresses including prolonged anaerobiosis (causing root death), sediment deposition and an accumulation of toxic agricultural chemicals. Those species which did survive did so by avoidance – *P. pectinatus* re-established from tubers, *N. lutea* from seeds and *S. fluviatilis* from rhizomes. At many of those locations the productivity during 1994 was exceptionally high, probably due to very high nutrient levels (A. Spink & M. Rijks, unpublished data) caused by fresh organic-rich sediment brought in during the flood. However, at sites where dikes broke, floodwaters moved across at high velocities, scouring out both vegetation and sediments, and what deposition did occur was course infertile sand sediment unsuitable either for tree seedling germination or plant growth. High water clarity in the spring of 1994 probably also played a role in the high productivity during the growing season.

The affects of the 1993 flood will influence the vegetation dynamics for many years to come, especially in the downstream reaches, and provides a clear example of how low frequency but high magnitude disturbance events can play a major role in structuring ecosystems.

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