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Abstract

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Disciplines

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THE ROLE OF FOUR MACROPHYTE SPECIES IN THE REMOVAL OF NITROGEN AND PHOSPHORUS FROM NUTRIENT-RICH WATER IN A PRAIRIE MARSH, IOWA

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ABSTRACT

Precipitation, runoff, and drainage supplied about 1.5 metric tons of NH_4-N, 4.1 metric tons of NO_3-N, and 0.09 metric tons of PO_4-P to Eagle Lake in 1976. Shoots of *Typha glauca, Carex atherodes, Sparganium eurycarpum,* and *Scirpus validus* had accumulated 18.0 metric tons of N and 1.8 metric tons of P at peak standing crop in late July. During decomposition, shoots of all four species lost organic matter faster than P, and lost P faster than N. *Carex, Typha,* and *Scirpus* litter were more effective in retaining or accumulating N and P than was *Sparganium* litter.

INTRODUCTION

Prairie pothole marshes extend from central Iowa, through southwestern Minnesota and the Dakotas, and into central Canada (Shaw and Fredine 1956), a part of the North American prairie known as the Pothole Region. The landscape is gently undulating glacial till with numerous poorly drained depressions (potholes). When the first settlers traversed the prairie more than a century ago, marshes were abundant. Today, however, most prairie wetlands have been drained. For instance, less than 10% of the presettlement wetland acreage in Iowa remains.

Prairie pothole marshes range in size from less than one to more than 1000 ha and generally are dominated by a mixture of emergent macrophyte species (van der Valk and Davis 1978a). These marshes typically undergo vegetation changes in response to drought cycles of 5- to 20-year duration (Weller and Spatcher 1965; van der Valk and Davis 1976, 1978b, 1979, 1981). There is no indication that they are undergoing succession toward a more mesophytic state.

Because many prairie glacial marshes are in areas now devoted to intensive agriculture, they often receive runoff that is rich in N and P. High levels of these nutrients can be particularly troublesome in streams and lakes, but when agricultural runoff passes through a marsh, water quality often is improved. Phosphorus is precipitated from the water column, and NO_3^- is denitrified in the anaerobic substrate (see

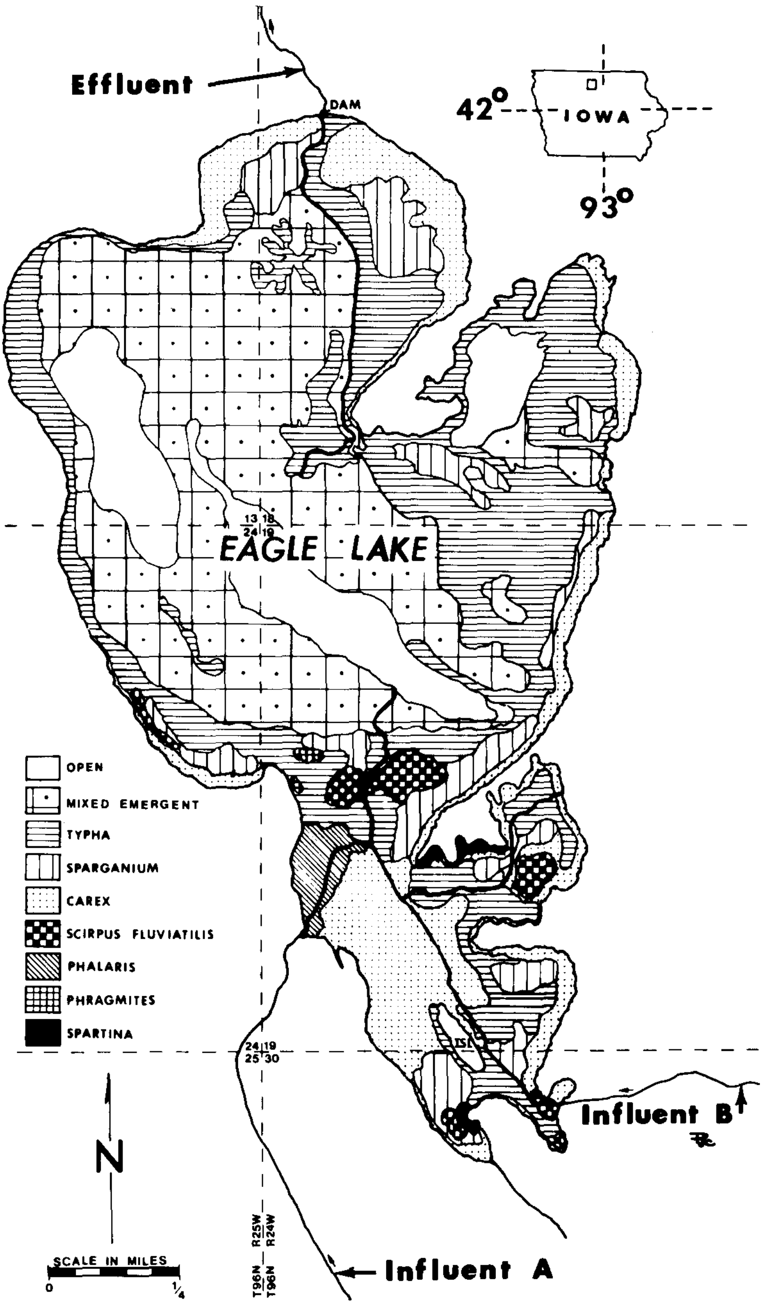

FIG. 1. Influent and effluent points and 1976 vegetation cover at Eagle Lake, Iowa. The Mixed Emergent zone was dominated in 1976 by *Scirpus validus*.

Good et al. 1978, Greeson et al. 1979, for reviews of N and P cycling in freshwater wetlands).

The purpose of this paper is to examine the roles played by *Typha glauca, Sparganium eurycarpum, Carex atherodes,* and *Scirpus validus* in N and P removal from agricultural runoff passing through a large prairie pothole marsh, Eagle Lake.

Study Site

Eagle Lake (Fig. 1) is located in north-central Iowa and is owned and managed by the Iowa Conservation Commission. It has a surface area of 365 ha and receives runoff from a basin of 2562 ha (measured from aerial photographs). Water depth rarely exceeds 1 m and is controlled by a dam at the northern end of the lake.

Surface and drain-tile runoff enters the lake at its southern end and along its eastern shore. A morainal ridge along the western shore limits flow into the marsh from that direction. Flow-weighted averages of influent N and P over a 4-year period (1976 to 1979) were 0.2 ppm NH_4-N, 13.0 ppm NO_3-N, and 0.23 ppm PO_4-P (Davis et al. 1981).

North-central Iowa has a continental climate. Average temperatures in January are $-7°$ to $-9°C$ and in July are 23° to 24°C (Shaw and Waite 1964). Average annual precipitation at Eagle Lake is ca. 802 mm (determined from records at Britt, Iowa, the nearest U.S. Weather Station). Approximately half of this falls in April, May, and June. In 1976, spring precipitation was normal, but a summer drought resulted in decreased water level. By mid-September, the marsh was dry.

The vegetation of Eagle Lake is dominated by the four emergent macrophytes discussed in this study (Fig. 1). Vegetation dynamics have been studied by Currier et al. (1978) and van der Valk and Davis (1978a, 1979, 1981).

Methods

The Eagle Lake basin comprises two drainages, one 992 ha and one 1570 ha. The smaller drainage was monitored for flow and water quality, but the larger basin was monitored for water quality only. Flow from the ungauged drainage was assumed to be proportional to the gauged drainage on an area basis; i.e., $\times 1.58$. This is a reasonable assumption, because the soil type is the same; and topography, cropping practices, and drainage systems are similar in the two watersheds. Because there was no effluent from the lake in 1976, only water quality was monitored in the stagnant water behind the outflow dam.

Water samples were collected at the two influents (Fig. 1) and from the standing water behind the dam every other day during the spring, summer, and fall. During storms, samples were collected every 4 hrs. Samples were collected in polyethylene bottles and frozen until they could be analyzed. A Technicon Autoanalyzer II system was used to analyze for NH_4-N and NO_3-N. The alkaline phenol method was used for NH_4-N analyses, and NO_3-N analyses were done according to the cadmium reduction method. The ascorbic acid reduction method of Murphy and Riley (1962) was used to analyze for PO_4-P. Levels of detection were 0.02 ppm for NH_4-N, 0.05 ppm for NO_3-N, and 0.005 ppm for PO_4-P. The nutrients deposited with precipitation were computed from precipitation data for Britt, Iowa, five miles west of Eagle Lake and from inorganic N and P analyses of precipitation from two other Iowa studies (Tabatabai and Laflen 1976, Baker et al. 1978).

Approximately 300 quadrats (1 m^2) were established in a stratified random pattern and were harvested over a 10-day period in late July and early August of 1976. Shoots were clipped at ground level and separated by species. Samples were returned to the laboratory, oven-dried at 80°C for 48 hrs, and weighed to the nearest gram. Total biomass for each species was calculated by adding the individual quadrat biomass data and extrapolating to the total area of the marsh (Currier et al. 1978).

On 31 July, three shoot samples were collected in homogeneous, monodominant stands of each of the four macrophyte species. Shoots of all ages were removed from an area 50 × 50 cm. These were returned to the laboratory, oven-dried at 80°C for 48 hrs, subsampled, and ground in a 40-mesh Wiley mill. Subsamples of each species were combined and mixed for nutrient analysis which was performed at the WARF Institute, University of Wisconsin–Madison. Total N was determined by semi-microkjeldahl procedures, and P was determined by multispectral analysis (Genson et al. 1976). Absolute quantities of N and P were estimated by multiplying the total biomass of each macrophyte species in late July and early August by the percentage N or P in tissues collected on 31 July.

Changes in biomass and N and P content of decomposing litter were studied by using standard litter bag techniques. Samples of senescent 1975 shoots were collected in November 1975 and oven-dried at 80°C. For each species, subsamples of 20 to 30 g were placed in each of 12 fiberglass mesh bags (1 mm). Three of these bags were selected randomly as controls. The other nine were deployed on the marsh bottom in stands of the same species on 24 November 1975. Three randomly selected bags were retrieved from the marsh on 28 August 1976, 19 September 1977, and 15 September 1979. In the lab the tissues were washed gently in distilled water and extraneous plant and animal tissue was removed. Further sample preparation and nutrient analysis were the same as for shoot tissues.

RESULTS

In 1976, Eagle Lake received 575 mm of precipitation (72% of 10-year average). Inputs of NH_4-N, NO_3-N, and PO_4-P in precipitation and in the two principal influents are illustrated in Fig. 2. Precipitation

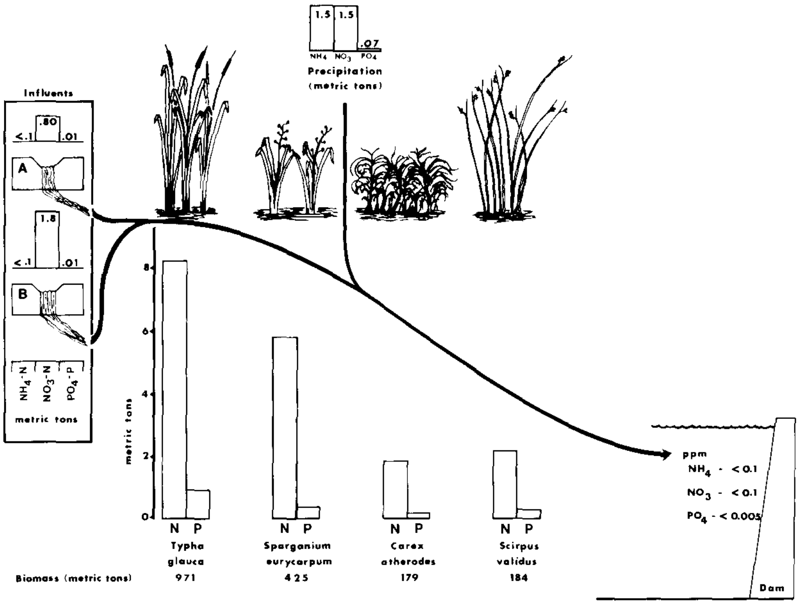

FIG. 2. Water quality and biomass, N, and P content of emergent macrophyte shoots at peak biomass at Eagle Lake in 1976.

contributed 1.5 metric tons of NH_4-N to the marsh, whereas less than 0.1 metric ton entered in each of the influent ditches. Precipitation also contributed 0.07 metric ton of PO_4-P, compared with a combined total of about 0.02 metric ton in the two influents. But the situation with NO_3-N was quite different. Precipitation supplied 1.5 metric tons of NO_3-N, but the two principal influents supplied a total of 2.6 metric tons. Concentrations of NH_4-N and NO_3-N in the stagnant water near the outlet usually were less than 0.1 ppm, and PO_4-P concentration was usually less than 5 ppb.

At peak crop in late July and early August, shoot tissues of the four dominant emergent macrophytes contained 18.4 metric tons of N and 1.8 metric tons of P. Stems of *Typha glauca* contained 8.2, *Sparganium eurycarpum* 5.8, *Scirpus validus* 2.2, and *Carex atherodes* 1.8 metric tons of N; and 0.9, 0.4, 0.3, and 0.2 metric tons of P, respectively. Sampling peak standing crop provides a reasonable estimate of net above-ground primary production in *Typha* and *Sparganium* but underestimates net primary production in *Carex* by 22% and in *Scirpus* by more than 15% (van der Valk and Davis 1978a). Therefore, our estimates of N and P content of *Carex* and *Scirpus* stem tissues are conservative.

TABLE 1. BIOMASS AND NITROGEN AND PHOSPHORUS CONCENTRATIONS OF DECOMPOSING SHOOTS OF FOUR EMERGENT MACROPHYTE SPECIES AT EAGLE LAKE, IOWA. Tissues were enclosed in 1-mm mesh fiberglass litter bags. * Corrected for biomass loss according to Boyd (1970b).

	Biomass (dry weight)		Nitrogen		Phosphorus	
	Grams (SD)	% remaining (SD)	% dw	% remaining*	% dw	% remaining*
Typha glauca						
Nov. 1975 (controls)	30.0	100	0.46	100	0.06	100
Aug. 1976	15.3 (1.1)	51 (3.5)	0.87	96	0.09	77
Sep. 1977	5.4 (1.2)	18 (4.2)	1.64	64	0.11	33
Sep. 1979	3.6 (1.3)	12 (4.0)	1.57	44	0.12	24
Carex atherodes						
Nov. 1975	30.0	100	0.34	100	0.05	100
Aug. 1976	22.5 (4.1)	75 (5.1)	0.34	75	0.09	135
Sep. 1977	15.3 (3.3)	51 (15.3)	0.97	146	0.08	82
Sep. 1979	4.5 (1.3)	15 (4.4)	1.55	68	0.15	45
Sparganium eurycarpum						
Nov. 1975	20.0	100	0.56	100	0.09	100
Aug. 1976	6.8 (2.4)	34 (11.9)	1.60	97	0.24	91
Sep. 1977	2.4 (0.9)	12 (4.7)	1.02	22	0.08	11
Sep. 1979	1.8 (0.9)	9 (4.9)	1.94	31	0.18	18
Scirpus validus						
Nov. 1975	30.0	100	0.36	100	0.06	100
Aug. 1976	7.5 (1.7)	25 (5.7)	1.52	106	0.17	71
Sep. 1977	2.6 (1.5)	9 (4.9)	1.11	28	0.07	11
Sep. 1979	3.1 (1.6)	10 (5.5)	2.62	73	0.19	32

Table 1 compares the biomass, nitrogen, and phosphorus content of stem tissues after 277, 664, and 1391 days of decomposition in mesh bags. After 1391 days, biomass had decreased more than phosphorus, and phosphorus had decreased more than nitrogen in all four species. This pattern was especially pronounced in *Typha, Carex,* and *Scirpus* tissues. After 277 days, *Carex* P content actually had increased by 35%, and after 664 days the *Carex* N content was nearly 50% higher than it had been at the beginning of the study. *Scirpus* tissues were also very effective in retaining or accumulating N and P. Indeed, N levels in these tissues increased by 6% in the first 9 months of decomposition. Following a marked decline in N and P levels after 664 days, these levels recovered substantially. After 1391 days N and P levels in *Scirpus* tissues were 73 and 32% of 1975 levels. Decomposing *Sparganium* tissues were much less efficient at retaining N and P after the first year. By the end of the second year, loss of N was nearly equal to biomass loss, and loss of P exceeded biomass loss. Recovery during the third and fourth years was minimal.

DISCUSSION

In a four-year study of water chemistry at Eagle Lake, Davis et al. (1981) found that this marsh functioned as a major sink for inorganic N and a minor sink for inorganic P. They suggested that the biotic communities in the marsh are important in uptake and release of nutrients in water passing through the marsh; the marsh was far less efficient as a nutrient sink during the cool early spring than it was in the warmer months of the growing season.

Data presented in this paper demonstrate that in 1976 emergent macrophytes (*Typha, Sparganium, Carex,* and *Scirpus*) accumulated a considerable amount of N and P in their shoot tissues during the growing season. Some of this N and P was mobilized from N and P stored in rhizomes; Davis and van der Valk (in press) found that approximately 40% of N and P accumulation in *Typha* shoots was mobilized from N and P reserves in the rhizomes. Even if we subtract 40% from our shoot N and P figures, we still find that these four macrophytes accumulated more than twice the amount of N and 10 times the amount of P that entered the marsh in precipitation, drainage, and runoff combined. But these plants extract N and P primarily from the substrate interstitial water (Bristow and Whitcombe 1971, Valiela and Teal 1974, Klopatek 1978). Therefore, uptake of N and P by emergent macrophytes would not appreciably reduce surface water N and P concentrations.

During the summer, some shoot N and P is translocated to belowground tissues and stored (Bayley and O'Neill 1972, Davis and van der Valk in press), translocated to inflorescences (Boyd 1970a), leached or excreted, or removed by grazing animals, primarily muskrats. In years when precipitation is normal or nearly normal, leaching and grazing would tend to increase N and P in surface water. But, in 1976 leaching and grazing losses were minimal because of the drought. Most of the nontranslocated N and P remained in the shoot tissues until these tissues died in September.

Dead shoot tissues of *Typha, Carex, Scirpus,* and *Sparganium* require several to many years to decompose fully. As decomposition proceeds, tissue N and P are released gradually (Davis and van der Valk 1978a,b; Boyd 1970b) into the water where they may be taken up by plants or microorganisms, precipitated, chemically transformed (i.e., nitrified, denitrified), or flushed from the marsh (van der Valk et al. 1981). Under anaerobic conditions in the substrate, release of tissue N and P via decomposition is probably not total, especially in *Typha* (Davis and van der Valk 1978a,b) and *Carex.* A certain amount of residual shoot tissue N and P will persist after the litter has been converted completely to organic soil.

Decomposing macrophyte litter is colonized by populations of microorganisms that use it as an energy substrate (Mason and Bryant 1975, Mason 1976, Coulson and Butterfield 1978, and others). When N and P concentrations in the litter tissue are too low to support these microorganism populations, the microorganisms extract N and P from the marsh water. Brinson (1977) estimated that litter tissue C:N and C:P ratios of 16 and 200, respectively, are necessary to support microorganism populations and allow for complete decomposition. Davis and van der Valk (in press) found that C:N and C:P ratios for fresh *Typha* litter at Eagle Lake in October 1975 were 132 and 703, respectively. Neely (1982) found that fresh *Sparganium* litter at Eagle Lake had C:N and C:P ratios of 76 and 570, respectively. Although we have no data on C concentrations in fresh *Carex* and *Scirpus* litter, C:N and C:P ratios were undoubtedly higher than 16 and 200, respectively. Therefore, microbial uptake of N and P was largely responsible for the fact that decomposing tissues of all four species lost N and P at a slower rate than they lost biomass. Differences in the C:N and C:P ratios also explain the fact that litter from species with a high content of structural tissue in their shoots (*Typha, Carex, Scirpus*) were more effective in retaining and accumulating N and P than was litter of *Sparganium* which has little structural tissue.

In conclusion, we suggest that because, in most years, conditions within the litter layer support the growth of microorganism populations that extract both N and P from enriched surface water, support the growth of denitrifying bacteria, and retard the mineralization of macrophyte tissue N and P, this compartment is the major sink for N and P at Eagle Lake. By contrast, the macrophyte shoot compartment is at best a minor sink for N and P. The principal contribution of macrophyte production seems to be that it is the source of fresh litter each year.

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