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The role of emergent macrophytes in nutrient cycling in Lake Niepruszewskie (western Poland)

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Key words: littoral zone, emergent macrophytes, distribution, biomass production, nutrient concentrations

Abstract

The role of emergent macrophytes in nutrient cycling was investigated in the littoral zone of Lake Niepruszewskie, which is dominated by this type of vegetation. The lake is characterized by an advanced stage of eutrophication as is evident in the frequent blooms that cause low transparency and high concentrations of chlorophyll *a* and seston. The shoot biomass of *Phragmites australis* and *Typha angustifolia* is the major component of the plant cover with respect to nutrient accumulation. Other plants play a marginal role in the nutrient turnover of the studied lake.

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INTRODUCTION

Emergent macrophytes play an important role in regulating the biogeochemistry of lake ecosystems, particularly through nutrient uptake, storage, and release. In particular, plants with potentially high annual primary production can extract large amounts of nutrients from their environment and store them in biomass and litter (Grace 1988, Verhoeven and Van der Toorn 1990). They also affect environmental conditions (oxygen, pH, conductivity), reduce the current rate of water flow, which in turn effects phosphorus, nitrogen and potassium cycling (Toet et al. 2003). Variation in macrophyte development can strongly affect nutrient cycles in lakes. Therefore, the proper management of the littoral zone can improve the quality of water bodies. Specifically, considerable amounts of nutrients can be removed by harvesting the aboveground parts of emergent macrophytes (Verhoeven and Van der Toorn 1990).

The main questions addressed in this study were:

1) whether emergent macrophytes in the littoral zone differ considerably in nutrient concentration and nutrient uptake at the peak standing stock and with regard to location in the littoral zone;
2) whether harvesting the aboveground parts of emergent macrophytes results in significant N and P removal from the lake.

SITE DESCRIPTION

Lake Niepruszewskie is located 25 km west of the city of Poznań (western Poland). It is a shallow, freshwater lake with average and maximum depths of 3.5 m and 4.8 m, respectively (IRŚ 1961). It is the first one of a series of lakes interconnected by the Samica Stęszewska River, regulated at the outlet by a weir. The water level was regulated for irrigation purposes from 1974 to 2002 with an average amplitude of 0.8 m (Ławniczak and Zbierska 2006). During this period, the lake surface varied from 260 ha, at minimum water level (76.50 m a.s.l.), to 281 ha, at maximum water level (77.25 m a.s.l.). Natural water level fluctuations cause a dramatic decline of submerged plants and increase the area of the littoral zone, which has been mostly created by emergent macrophytes (Ławniczak 2006).

The lake has been contaminated by irregular discharge of sewage and wastewaters from villages in the vicinity of the lake, but also by angler bait and percolating waters from the surrounding farms and arable land. The catchment is mostly agricultural (74% of the total catchment area), with 68.4% used as arable land and 5.4% used as grassland, orchards, and gardens. Forests cover only 12% of the total catchment area. One disadvantage of this situation is the

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high degree of landscape homogeneity and the domination of cereal fields, which cover almost 79.4% of the arable land (Ławniczak and Zbierska 2006).

All these factors have an impact on water quality in the lake. The advanced stage of eutrophication is evident due to frequent blooms causing low transparency and high concentrations of chlorophyll *a* and seston.

MATERIALS AND METHODS

The study was carried out in the littoral zone of Lake Niepruszewskie during the growing seasons in 1999-2001. Six permanent transects, perpendicular to the shoreline, were chosen in an area of abundant vegetation. Each transect was based on two sampling sites: one located at 1/3 and the other at 2/3 the width of the littoral zone. Three replicate plots (1 m × 1 m) per site were selected. All plots were marked permanently with plastic sticks. The biomass assessments were timed at maximal shoot growth in August 1999-2001. In 2001, additional sites were selected. The density of plants was then determined in situ every year and the plants were harvested in 0.5 m × 0.5 m squares at ground level. The plants were carefully washed in tap water to clean them of periphyton. The samples were sorted into living and dead fractions, dried for two days at 70°C, and then weighed. The shoot biomass of six emergent macrophyte species (*Phragmites australis*, *Typha angustifolia*, *Glyceria maxima*, *Carex acutiformis*, *C. acuta*, *C. riparia*) was pooled, ground, and analyzed for total nitrogen, phosphorus, and potassium content. Total nitrogen (N) was measured by using Kjeldahl digestion followed by determination with automated colorimetry. Phosphorus (P) and potassium (K) extractable in 0.5 M ammonium acetate/acetic acid buffer were determined by ascorbic acid/molybdenum blue automated colorimetry and flame photometry, respectively (Chemical-Agricultural Station in Poznań). The nutrient standing stock was quantified, basing on the shoot biomass, area covered by particular species, and nutrient data.

All statistical analyses were performed by using Statistica 7.1. Data were log-transformed to assess the homogeneity of variance. One-way and two-way interactions of sampling date, species, locations on shoot biomass, N, P and K concentration, and N and P standing stocks of selected plants were tested with analyses of variance (ANOVA). In all cases, *a posteriori* Bonferroni tests were performed.

RESULTS AND DISCUSSION

Composition of emergent vegetation

The emergent macrophytes of Lake Niepruszewskie are a dominant component of the littoral zone and are characterized by zonal distribution due to water level fluctuations (Ławniczak 2006). *Phragmites australis* and *Typha angustifolia* are predominant species, which cover 23.3 and 10.0 ha (51% and 22% of the total littoral zone area), respectively. The patchy distribution of plant communities is found only in some sections, were water is present seasonally. The largest area is covered by patches dominated by *Carex acutiformis* (3.78 ha, 8.4% of the littoral zone). Other plant species, such as *Glyceria maxima*, *C. acuta*, and *C. riparia*, jointly cover approximately 2 ha, with 0.5-m annual amplitude of water level fluctuations.

Shoot biomass

In late August, shoot biomass produced average peak values of 2063 g m^{-2} for *Phragmites* stands and 2377 g m^{-2} for *Typha* stands (Table 1, Fig. 1). Shoot length reached its maximum with an average of 3.0 m and 3.5 m for *Phragmites* and *Typha*, respectively. Shoot biomass was always significantly higher in *Phragmites* and *Typha* than in the other species (Table 1, Fig. 1). The productivity of *Carex acutiformis* and *Glyceria maxima* was relatively high, as

Table 1

Area covered and shoot biomass production of emergent macrophytes at peak standing stock in the littoral zone of Lake Niepruszewskie

Species	Area (ha)	Shoot biomass of macrophytes at peak standing stock*	
		g m^{-2} ±SD	tons in the littoral zone
Phragmites australis	23.23	2063 ±488	479.2
Typha angustifolia	10.01	2377 ±305	238.3
Carex acutiformis	3.78	745 ±98	28.2
Carex riparia	1.27	1785 ±148	22.7
Glyceria maxima	0.35	889 ±154	3.11
Carex acuta	0.01	1045 ±155	0.10

*average (1999-2001)

compared to other studies (Verhoeven et al. 1983, Wassen et al. 2002), while *C. riparia* showed the highest shoot biomass, ranging between 899.3 and 1265.0 g dry mater m^{-2} y^{-1}. Shoot biomass was in the middle of the range of peak shoot biomass observed in *P. australis* in eutrophic, natural, or constructed

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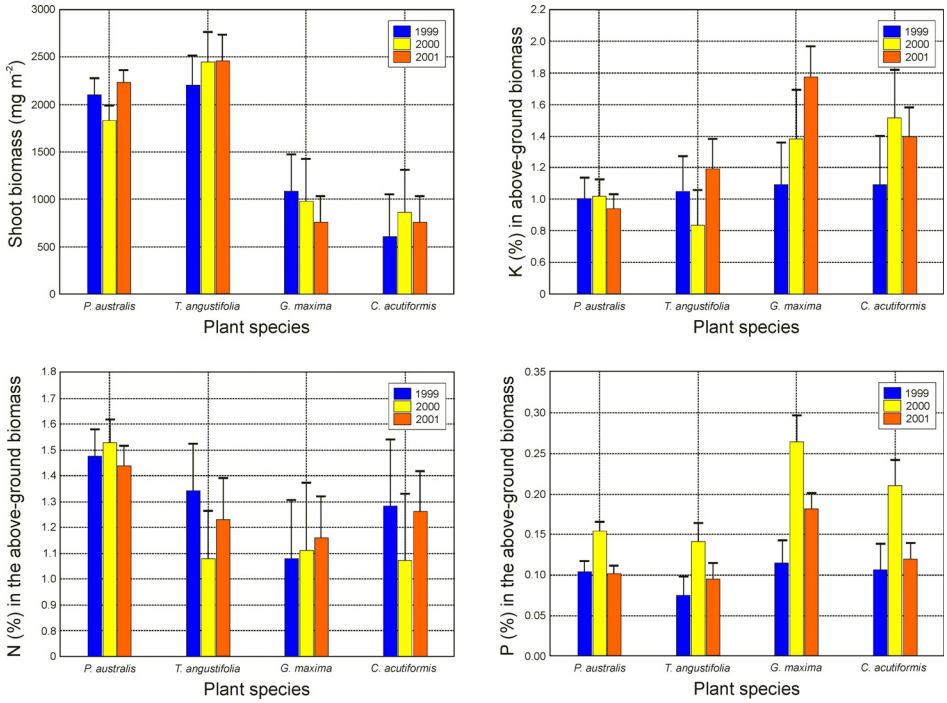


Fig. 1. Shoot biomass, N, P, and K concentrations of emergent macrophytes in the littoral zone of Lake Niepruszewskie in 1999-2001.

wetlands and treatment wetlands in temperate climates (600–4995 g m^{-2}, Dykyjová and Květ 1978, Meuleman et al. 2002, Toet 2003). However, the shoot biomass of *T. angustifolia* was higher than the productivity observed in other ecosystems (Table 1, Fig.1, Dykyjová and Květ 1978, Whigham et al. 1989). This was related to the high shoot density of *Typha* spp., which is characteristic of nutrient-rich sites (Grace 1988).

Among the studied plant species, only the shoot biomass of *G. maxima* varied significantly between years (Table 1, Fig.1, $P<0.005$). The vitality of this species probably decreased due to the removal of the shoot biomass in control plots. This relationship was not observed in the other species. However, in short-term experiments the removal of shoots of this species does not always caused a reduction of aboveground biomass (Güsewell 2003). The high water level at the beginning of the growing season might have suppressed its growth.

Location in the littoral zone had a significant effect on shoot biomass and a slight one on nitrogen standing stock (Table 2). However, these differences caused the domination of highly productive species in the study sites located

Table 2

Results of two-way ANOVAs of shoot biomass, shoot N, P and K concentration, and aboveground N, P and K standing stocks influenced by sampling date, plant species and location in the littoral zone section (bold values indicate statistically significant differences)

Source	df	Biomass g m^{-2}	N %	P %	K %	N st. stock g m^{-2} N	P st. stock g m^{-2} P	K st. stock g m^{-2} K
Species	5	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**
Location	1	**0.007**	0.171	0.390	0.442	**0.031**	0.564	0.307
Year	2	0.431	0.184	**0.000**	**0.003**	0.416	**0.000**	0.131
Species x Year	6	**0.022**	**0.029**	**0.005**	**0.000**	0.818	0.205	0.288
Location x Year	2	**0.000**	**0.000**	**0.000**	0.295	**0.012**	0.157	0.085

closer to open water (at 2/3 width of the littoral zone), than those located closer to the shoreline (at 1/3 width of the littoral zone), where mostly *Carex* spp. and *G. maxima* dominated. Differences in shoot biomass of *Phragmites* between the two zones were not significant statistically (P>0.05). Therefore, the flooding gradient had a direct effect on the occurrence of the differential flooding tolerance of plant species, which determined the zonation of the littoral vegetation but had no effect on shoot production within species.

Nutrient concentration and standing stock

Large differences were found in accumulated nutrients between plant species (Table 2, Fig. 1). Compared to other abundant species in the littoral zone, *P. australis*, had assimilated a higher fraction of nutrients from the shoot biomass by the end of August (Fig. 1). The highest N concentration was found in *P. australis* (1.47%) and *C. acuta* (1.42%). However, shoot N concentration and N standing stock in the *Phragmites* and *Typha* stands were often significantly higher than those in *Carex* stands. P and K concentrations also differed significantly among species. *Glyceria maxima* accumulated the highest amount of P and K (0.18% and 1.51% of tissue dry weight, respectively) but covered only a small area of the littoral zone (Fig. 1, Table 3). Nutrient concentrations in its tissues indicated that *G. maxima* occurred in sites with high nutrient availability. This is consistent with the preferences of these species (Hroudová and Zákravský 1995) but not exactly with the position of ecological optima of *Carex* spp., *P. australis*, and *G. maxima* in relation to the trophic level presented by Hager (2003). The strong eutrophication of Lake Niepruszewskie favored *P. australis* more strongly than *G. maxima*.

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Table 3

Nutrient (N, P, K) standing stocks in the littoral zone of Lake Niepruszewskie

Species	N standing stock (g m^{-2})	N standing stock in the littoral zone* (kg N)	P standing stock (g m^{-2})	P standing stock in the littoral zone* (kg P)	K standing stock (g m^{-2})	K standing stock in the littoral zone* (kg K)
Phragmites australis	29.72 (7.99)	690.40	2.38 (0.87)	55.29	19.99 (6.68)	464.37
Typha angustifolia	29.24 (7.52)	292.69	2.50 (1.00)	25.03	26.06 (16.22)	260.86
Carex acutiformis	9.06 (1.00)	0.09	1.04 (0.43)	0.01	10.17 (2.77)	0.10
Carex riparia	19.99 (1.65)	7.00	1.82 (0.15)	0.64	20.89 (1.73)	7.31
Glyceria maxima	9.97 (1.90)	37.69	1.57 (0.54)	5.93	13.00 (1.23)	49.14
Carex acuta	14.84 (2.21)	18.85	1.29 (0.19)	1.64	12.75 (1.90)	16.19
Total		1046.72		88.54		797.97

*estimated value

The shoots of *P. australis* were recognized as the major component of plant cover with respect to nutrient accumulation (Table 3), although the highest shoot biomass per square meter was produced by *T. angustifolia*. The relatively small area covered by this species, compared to pure stands of reed, caused a two-fold lower nutrient concentration in the total standing stock. Other plants play a marginal role in the nutrient turnover of Lake Niepruszewskie (Table 3).

An appropriate management regime in the littoral zone can help to diminish the effect of eutrophication in the lake. Mowing the shoot biomass of pure patches of *P. australis* and *T. angustifolia* can reduce the excess of nutrients in the lake. This could also reduce the vitality of these common species and in the long run could increase the biodiversity of the littoral zone.

CONCLUSIONS

1. Shoots of *Phragmites australis* are the major component of plant cover with respect to nutrient accumulation in Lake Niepruszewskie. The highest shoot biomass per square meter is produced by *Typha angustifolia*, but it covers a relatively a small area. Other plants play a marginal role in the nutrient turnover of this lake.
2. Location in the littoral zone of Lake Niepruszewskie had a significant effect on shoot plant biomass and slightly on nitrogen standing stock. However, differences in water level caused the domination of highly productive

species in the study sites located closer to open water (2/3 width of the littoral zone). At sites located closer to the shoreline (1/3 width of the littoral zone), mostly *Carex* spp. and *Glyceria maxima* dominated.

3. The highest N concentration was found in *P. australis* (1.47%) and *C. acuta* (1.42%). Shoot N concentration and N standing stock in *P. australis* and *T. angustifolia* stands were often significantly higher than those in the *Carex* spp.
4. P and K concentrations also differ significantly among species. *Glyceria maxima* accumulated the highest amount of P and K (0.18% and 1.51% of tissue dry weight, respectively) but covered only a small area of the littoral zone. Nutrient concentrations in *G. maxima* indicated that it occurred in sites with a high nutrient availability.
5. Mowing the shoot biomass of pure patches of *P. australis* and *T. angustifolia* can reduce the excess of nutrients in the lake. This could also increase the biodiversity of the littoral zone in the long run.

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REFERENCES

Dykyjová D., Květ J. (Eds.), 1978, *Pond Littoral Ecosystems. Structure and Functioning*, Ecological Studies, No. 28, Springer-Verlag, Berlin, Heidelberg, pp. 460

Grace J.B., 1988, *The effects of nutrient additions on mixtures of Typha latifolia and Typha domingensis along a water-depth gradient*, Aquatic Botany, 31:83-92

Güsewell S., 2003, *Management of Phragmites australis in Swiss fen meadows by mowing in early summer,* Wetlands Ecology Management, 11: 443-445

Hager H.A., 2003, *Invasion dynamics of Lythrum salicaria L*, PhD thesis, University of Regina, Saskatchewan, Canada

Hroudová Z., Zákravský P., 1995, *Vegetation dynamics in a fishpond littoral related to human impact,* Hydrobiologia, 415: 139–145

IRŚ, 1961, *Bathymetric plan and morphometric map of Lake Niepruszewskie,* Olsztyn

Ławniczak A.E., 2006, *Floristic diversity of the littoral zone communities in Lake Niepruszewskie,* PTPN, Poznań, (in Polish with English summary), 100: 113-121

Ławniczak A.E., Zbierska J., 2006, *Effect of water level lowering on the water quality in Lake Niepruszewskie,* PTPN, Poznań, (in Polish with English summary), 100: 105-112

Meuleman A.F.M., Beekman J.P., Verhoeven J.T.A., 2002, *Nutrient retention and nutrient-use efficiency in Phragmites australis stands after wasterwater application,* Wetlands, 22 (4): 712-721

Toet S., 2003, *A treatment wetland used for polishing tertiary effluent from a sewage treatment plant: performance and processes*, PhD thesis, Utrecht University, The Netherlands, pp. 201

Verhoeven J.T.A., Beltman B., De Caluwe H., 1983, *Changes in plant biomass in fens in the vechtplassen area, as related to nutrient enrichment,* Aquatic Ecology, 30: 227-237

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Verhoeven J.T.A., Van der Toorn J., 1990, *Wetland management: Marsh eutrophication and wastewater treatment*, [in]: Patten, B.C. (eds.), *Wetlands and shallow continental water bodies*, Vol. 1. SPB Academic Publishing, The Hague, pp. 571-586

Wassen M.J., Peeters W.,H.M., Olde Venterink H., 2002, *Patterns in vegetation, hydrology, and nutrient availability undisturbed river floodplain in Poland.* Plant Ecology 165: 27–43

Whigham D. F., Jordan T. E., Miklas J., 1989, *Biomass and resource allocation of Typha angustifolia L. (Typhaceae): The effect of within and between year variations in salinity, Bulletin of the Torrey Botanical Club*, Vol. 116, No. 4, pp. 364-370