Restoration with the Forest Herbicide Hexazinone. Ph.D. Dissertation. University of Florida, Gainesville, FL, 147 pp.
Wunderlin, R.P., 1982. Guide to the Vascular Plants of Central Florida. University Press of Florida, Tampa, FL, 472 pp.
Zutter, B.R. and S.M. Zedaker, 1988. Short-term effects of hexazinone applications on woody species diversity in young loblolly pine (*Pinus taeda*) plantations. For. Ecol. Manage., 24: 183–189.
Zutter, B.R., D.H. Gjerstad, A.L. Webb and G.R. Glover, 1988. Response of a young loblolly pine (*Pinus taeda*) plantation to herbicide release treatments using hexazinone. For. Ecol. Manage., 25: 91–104.

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Elsevier Science Publishers B.V., Amsterdam

Nutrient removal capacity in submersed macrophyte pond systems in a temperate climate

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ABSTRACT

The natural capacity of submersed plants to reduce the phosphorus and nitrogen content of polluted waters was investigated in a full-scale experiment with *Elodea canadensis* and *Cladophora glomerata*, grown in eutrophied stream water in 16 parallel canals in Southern Sweden. Between September 1988 and June 1991 the weekly mean reduction was 32% of nitrogen and 62% of phosphorus, equivalent to specific mean reductions of 0.5 g N m^{-2} d^{-1} and 0.04 g P m^{-2} d^{-1}. Harvested biomass contained approximately 10% of removed nitrogen and 20% of removed phosphorus.

Sediment nutrient content and regression analysis showing that nitrogen removal was strongly dependent on temperature and nitrogen load suggest that denitrification was the major nitrogen removal process. Sediment burial was the most important phosphorus removal mechanism. Variations in phosphorus removal were largely explained by insolation, supporting the hypothesis that biomass uptake is important for phosphorus removal. Both nitrogen and phosphorus removal were correlated to detention time.

INTRODUCTION

Aquatic macrophytes have a very high growth capacity, which has led to the idea of using aquatic plants in water treatment (Reed et al., 1988). A widespread concept in tropical and subtropical climate is aquatic systems using water hyacinth (*Eichhornia crassipes*) and other thermophile free-floating species (Reddy and DeBusk, 1987). In temperate zones more

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cold-tolerant species are necessary. This has led to the development of reed-beds (root-zones) planted with emergent macrophytes (Gumbricht, 1992) and the use of submersed macrophytes (Brix and Schierup, 1989; Hammer, 1989; Cooper and Findlater, 1990). Investigations of the potential of submersed macrophytes have been limited (Gumbricht, 1993). Apart from plant uptake followed by subsequent harvest, many other processes contribute to the removal efficiency of nitrogen and phosphorus in aquatic macrophyte ponds (Reddy and DeBusk, 1987; Tchobanoglous, 1987; Reed et al., 1988; Brix and Schierup, 1989). (See Gumbricht, (1993) for an extended discussion on these removal processes).

The objective of this study was to evaluate the potential of using submersed macrophytes for nutrient removal in a temperate climate. Results on the full-scale experiment are reported, and the importance of different removal mechanisms are discussed. Statistical regression analysis was used to interpret the results and to evaluate potential nutrient removal capacity.

MATERIALS AND METHODS

Inspired by a Danish idea to use the naturally growing marine macrophyte *Ulva lactuca* in Odense Bay as tertiary treatment of the effluents from Odense wastewater treatment plant (Frederiksen, 1987), K-Konsult, a Swedish consulting firm, started research on using submersed plants as tertiary treatment. After several years of laboratory studies, a full-scale pond at Snogeröd in Scania, southern Sweden (Fig. 1) was built, and put into operation in September 1988.

The submersed macrophyte plant at Snogeröd consists of 16 parallel canals, surrounded by 4 ditches with similar construction (Fig. 1). The canals and ditches are dug (fine till soil) and are not sealed or cemented. Each canal is approximately 200 m long and 2 m wide at the bottom, with a water depth of about 0.6 m. Total water surface is 1.2 ha (1.5 including ditches) and the total water volume is approximately 6000 m^3 (including ditches). The plant is fed by water from Snogerödsbäcken, the most polluted tributary of Lake Ringsjön. Entering water volume is controlled by a simple weir.

The construction made it possible to connect the canals in four series with four canals in each (4 × 4) or with all sixteen canals connected with parallel flow (16 × 1) (Fig. 1). During winter, with higher flow, the connection was parallel (16 × 1), whereas during summer the canals were connected in series (4 × 4) to allow every drop of water to pass four canals before re-entering the stream. There was no mixing of water in the plant, and, in theory, water travelled through the plant as plug flow. However, no tracer study was conducted.

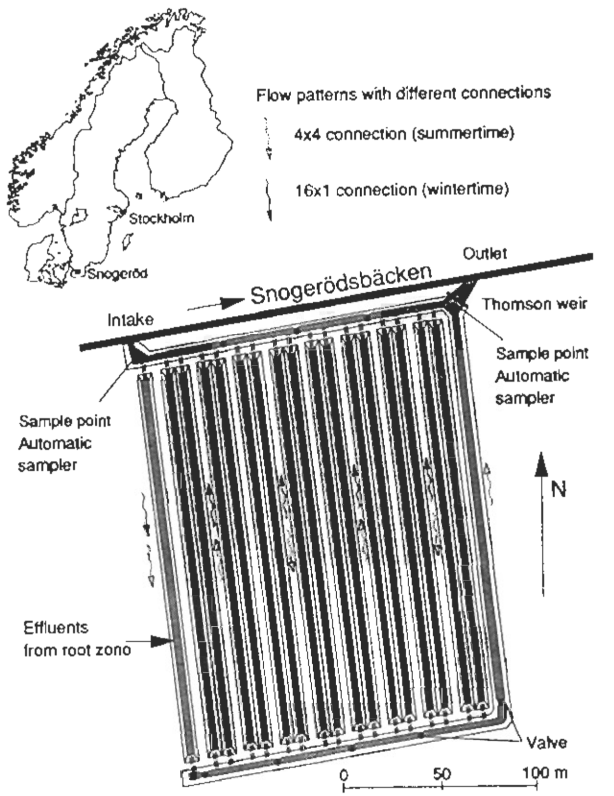

Fig. 1. Principal arrangement and location of the submersed macrophyte pond at Snogeröd, Sweden.

The flow through the plant was measured via a Thomson weir at the outflow. Apart from the inflowing water from the stream, the plant was also fed by the effluent from a nearby reed-bed (Fig. 1). The inflow from the reed-bed was separately measured, and the inflow from the stream was estimated as the difference between outflow and inflow from the reed-bed. In the following, flow has been converted to theoretical detention time by assuming plug flow and a constant water volume. Precipitation or evapotranspiration were not included in the water budget. A water balance calculation revealed they only affected water balance by 1% in the most extreme situations. During the summers of the test period Snogerödsbäcken carried very little water, and approximately 10 l s^{-1} were pumped from

Lake Ringsjön. Measuring total inflow and outflow during this period made it clear that approximately 2 l s^{-1} were infiltratated from the pond system into the clayey till soil in which it was dug. No regard has been taken to this loss in the following calculations. The lake water had a lower and much more stable N/P ratio (mass ratio around 7) than did the stream water, where N/P ratios fluctuated from 2 to 180.

During the period September 1988 to June 1991 the concentration of unfiltered total nitrogen and total phosphorus were measured at the inflows and the outflow. Water was collected by continuous, constant samplers, and samples taken out on weekly intervals, when also water temperature was measured. Representative samples are missing for a few weeks. Determination of total phosphorus was performed using digestion with peroxodisulphate (Koroleff, 1976) as given in Swedish standards SS 02 81 27 (Standardiseringskommissionen i Sverige – SIS, 1992; Miljöstandard vatten, Stockholm, 2nd edition). Determination of total nitrogen was carried out using oxidation with peroxodisulphate (Koroleff, 1970) as given in SS 02 81 31 (2nd edition). Phosphate, nitrate and ammonia were measured on 20 occasions as unfiltered point samples. Phosphate was determined by molybdate binding (Koroleff, 1976) as given in SS 02 81 26 (2nd edition), nitrate by cadmium–copper reduction (Grasshoff, 1983) as given in SS 02 81 33 (2nd edition), and ammonia by the phenolhypochlorite method (Solórzano, 1969) as given in SS 02 81 34. Reduction was calculated from the difference in concentration in incoming and outgoing water, assuming that inflow and outflow were the same and that samples for one particular week represented the same water volume.

The species used were a planted submersed phanerogam, *Elodea canadensis*, and the alga *Cladophora glomerata* which invaded the pond spontaneously. From May to September macrophytes were harvested biweekly by cutting with a double knife mounted on a forest tractor and collected separately after each cutting. The harvested biomass was piled together, drained and its weight estimated by volumetric measurement. The wet weight, dry weight and content of nitrogen (Kjeldahl method-Techator AN 30/87) and phosphorus (KLK, 1966) were analysed on 7 different occasions.

Mean annual air temperature at Lund (20 km SW of Snogeröd) is 8°C, and the mean temperature of the coldest (February) and warmest (July) months are −1°C and 17°C respectively. Mean annual precipitation is about 720 mm and mean annual evapotranspiration about 550 mm.

RESULTS

Incoming and outgoing concentrations together with reduction, expressed both in percentage and in kg d^{-1} are shown in Table 1. Reductions and outgoing concentrations are also shown in Fig. 2. For the 34-month period September 1988 to June 1991, weekly mean reduction was 32% of nitrogen and 62% of phosphorus, equivalent to annual mean reductions of 0.5 g N m^{-2} d^{-1} and 0.04 g P m^{-2} d^{-1}. On average total nitrogen decreased from 9.8 to 7.5 mg l^{-1}, and total phosphorus from 0.26 to 0.07 mg l^{-1}. Both changes were statistically significant ($P < 0.05$).

TABLE 1

Average weekly nitrogen and phosphorus concentration and reduction for the submersed macrophyte pond at Snogeröd for the period September 1988–June 1991

Parameter		*n*	Mean	95%-confidence level
Incoming tot-N	(mg l^{-1})	135	9.8	9.0 –10.6
Outgoing tot-N	(mg l^{-1})	138	7.5	6.7 – 8.3
Reduction	(%)	135	32	26 –37
Reduction	(kg d^{-1})	135	6.2	3.5 – 8.9
Incoming tot-P	(mg l^{-1})	136	0.26	0.23– 0.29
Outgoing tot-P	(mg l^{-1})	138	0.07	0.06– 0.08
Reduction	(%)	136	62	57 –68
Reduction	(kg d^{-1})	136	0.45	0.35– 0.55

During summer (defined as the period with water temperatures > 10°C) the weekly reduction averaged 62% for nitrogen and 86% for phosphorus, which was significantly ($P < 0.05$) higher than removal during winter, 12% for nitrogen and 48% for phosphorus. As flow and thus the load of nutrients was higher during winter, the mass nitrogen removed averaged 4.3 kg N d^{-1} during summer and 7.3 kg N d^{-1} during winter; the difference however was not statistically significant ($P > 0.05$). The same holds for phosphorus, except that the summer reduction of 0.31 kg P d^{-1} was significantly lower ($P < 0.05$) than the winter redution of 0.54 kg P d^{-1}. The length of the summer and winter periods are shown in Fig. 2b.

Nitrate averaged 9.6 mg l^{-1} in incoming and 7.8 mg l^{-1} in outgoing water, thus making up more than 90% of the nitrogen fraction. Incoming ammonia was about 1%, or 0.12 mg l^{-1}, which is slightly higher than the average outgoing concentration of 0.07 mg l^{-1}. Phosphate was the dominating fraction in both incoming (0.12 mg l^{-1}) and outgoing water (0.08 mg l^{-1}), which was approximately equivalent to 70% of total phosphorus content at the 20 measurement occasions.

Mass balances for total nitrogen and phosphorus for the test period are shown in Table 2. In October 1990 the sediment contents of nitrogen and phosphorus were measured from sediment concentrations and thicknesses. Sediment thickness decreased from canal inlets to outlets, and sediment

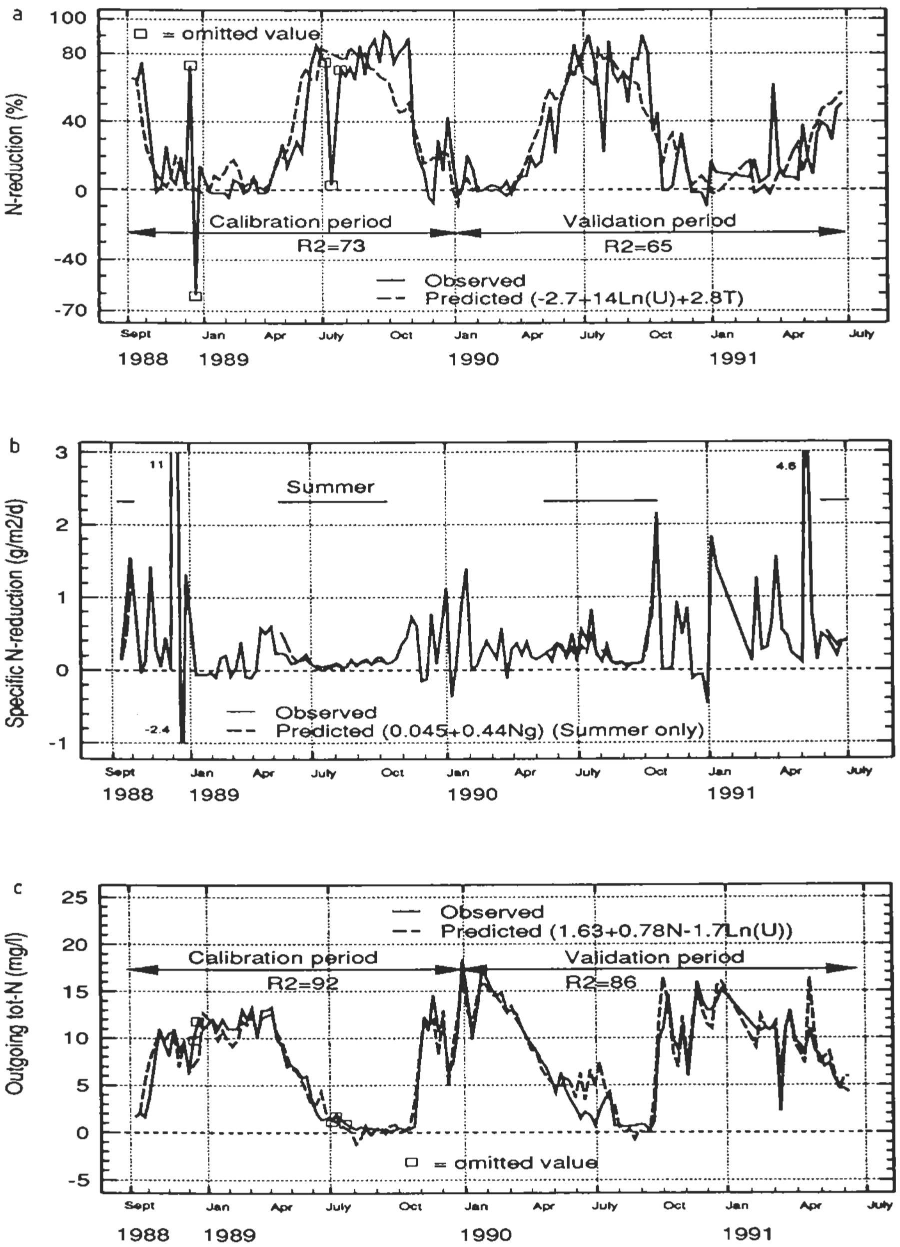

Fig. 2. Performance of the submersed macrophyte pond at Snogeröd, observed and predicted by regression model, for (a) percent nitrogen reduction, (b) specific nitrogen reduction, (c) outging nitrogen concentration, (d) percent phosphorus reduction, (e) specific phosphorus reduction, and (f) outgoing phosphorus concentration.

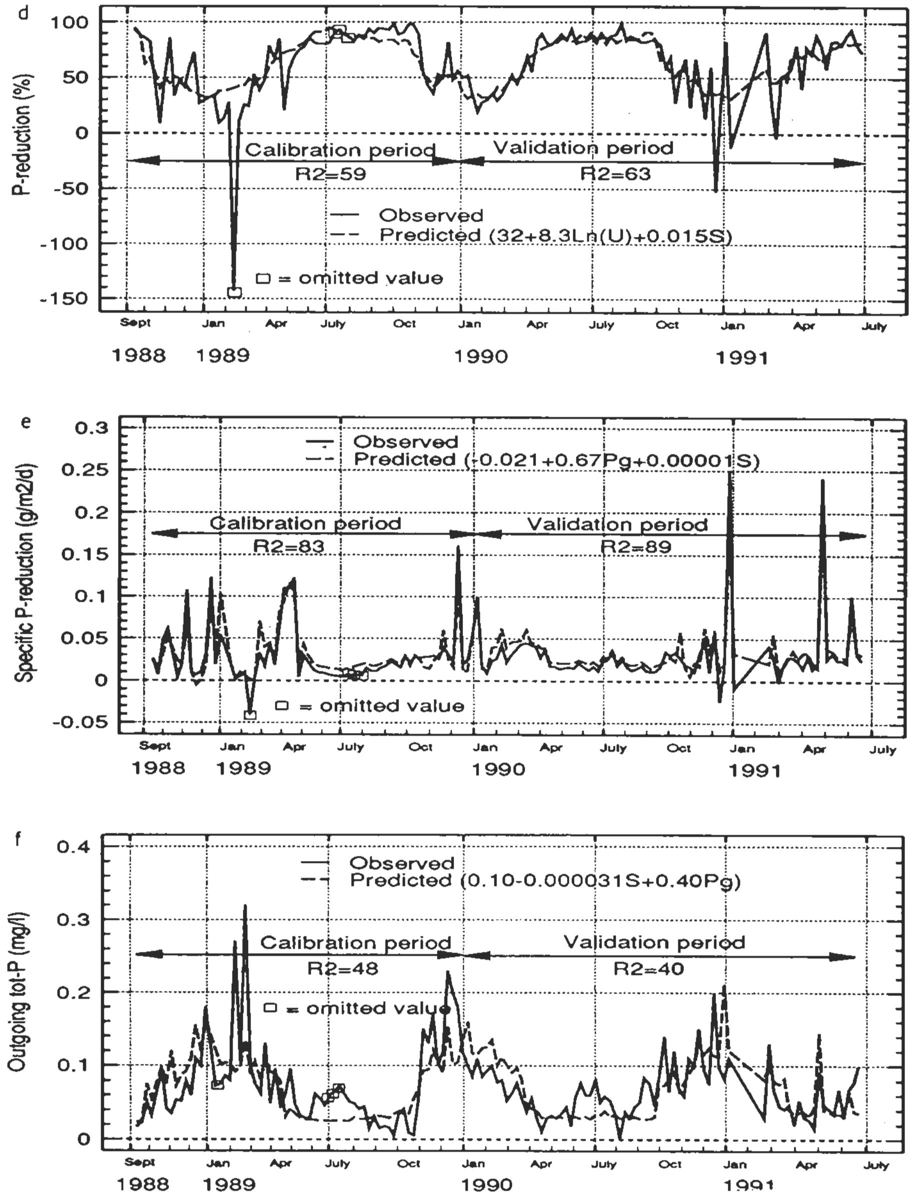

Fig. 2. (continued).

depth was determined in 81 points. Twelve samples were taken out, mixed, and analysed for total nitrogen and phosphorus (methods as for plant material given above). It was estimated that the accumulated sediments

TABLE 2

Mass balance for total nitrogen and total phosphorus for the submersed macrophyte pond at Snogeröd for the period September 1988–June 1991

Period	Substance	Incoming		Outgoing		Harvest		Residual	
		kg	%	kg	%	kg	%	kg	%
1988	tot-N	6750	100	4720	70	65	1	1965	29
Sept–Dec	tot-P	105	100	47	45	8	8	50	42
1989	tot-N	14500	100	12900	89	193	1	1400	10
Jan–Dec	tot-P	280	100	115	41	23	8	140	51
1990	tot-N	21200	100	18600	88	273	1	2300	11
Jan–Dec	tot-P	280	100	125	45	33	12	120	44
1991	tot-N	12600	100	11400	91	60	0.5	1140	9
Jan–June	tot-P	190	100	81	42	7	4	100	54

contained 1400 kg of nitrogen and 110 kg of phosphorus. The standing crop of biomass at the same time was estimated to contain 110 kg of nitrogen and 40 kg of phosphorus. By a mass balance calculation for incoming amounts on one hand and outgoing and harvested amounts on the other (from September 1988 to October 1990), 3700 kg of nitrogen and 140 kg of phosphorus were found unexplained. Assuming that the missing nitrogen had been denitrified gives a denitrification rate of 0.3 g N m^{-2} d^{-1}.

From June 1990 to June 1991 one canal was not harvested, and reduction of nitrate and phosphate was measured (HACH DR-2000, spectrophotometer with test kits) in this canal and in the nearest harvested canal (weekly point samples at common inlet and the individual outlets). Mean nitrate reduction was 17% in the unharvested and 18% in the harvested canal. Mean phosphate reduction was 33% for the unharvested and 41% for the harvested pond. There was no significant difference in either nitrate or phosphate removal ($P > 0.05$).

Statistical regression analysis

Regression analysis used the parameters in Table 3 as independent variables. For both nitrogen and phosphorus statistical regression models fitting percentage removal, specific (g m^{-2} d^{-1}) removal, and outgoing concentration were attempted. Only relevant variables were allowed in the modelling (Table 3). The reduction of nitrogen was assumed to depend heavily on denitrification and thus on temperature and nitrate levels. Assimilation was assumed to be of less importance (indicated by the relatively small amount that was harvested, Table 2), thus eliminating insolation and phosphorus levels as important for nitrogen reduction.

TABLE 3

Statistical regression models for nitrogen and phosphorus removal and outgoing concentration for the submersed macrophyte pond at Snogeröd

Model for	Independent variables[1]	Regression model	Calibration period (R^2)	Validation period (R^2)
N-reduction (%)	N_g	$122-19\ln(N_g)$	77	30
	T	$-6.5+4.8T$	67	57
	U	$9.8+27\ln(U)$	65	63
	$T+N_g$	$92+1.3T-15\ln(N_g)$	77	43
	U+T	$-2.7+14\ln(U)+2.8T$	73	65
Outgoing N ($mg\ l^{-1}$)	N	$-2.4+1.1N$	87	76
	T	$13-0.71T$	71	64
	U	$10.6-4.1\ln(U)$	71	81
	N+U	$1.63+0.78N-1.7\ln(U)$	92	86
	T+N	$0.65-0.17T+0.89N$	88	83
	U+T	$12-2.4\ln(U)-0.39T$	79	80
P-reduction (%)	S	$30+0.021S$	54	57
	U	$48+17\ln(U)$	48	48
	T	$37+3.2T$	48	37
	U+S	$32+8.3\ln(U)+0.015S$	59	63
	S+C	$34+0.015S+17C$	57	59
P-reduction (g m^{-2} d^{-1})	P_g	$0.59P_g$	77	79
	P_g+S	$-0.021+0.67P_g+0.00001S$	83	89
	P_g+T	$-0.014+0.67P_g+0.0012T$	79	84
	P_g+C	$-0.01+0.67P_g+0.014C$	79	83
Outgoing P ($mg\ l^{-1}$)	$S+P_g$	$0.10-0.000031S+0.40P$	48	40

[1] S = insolation, W h m^{-2} d^{-1}
T – water temperature, °C
U = detention time, days
N = nitrogen concentration, mg N l^{-1}
N_g = nitrogen load, g N m^{-2} d^{-1}
P = phosphorus concentration, mg P l^{-1}
P_g = phosphorus load, g P m^{-2} d^{-1}
C = connection (0 = parallel, 1 = in series)

Phosphorus removal on the other hand was hypothesised to depend on biomass uptake and thus on insolation, temperature and nutrient availability. Photosynthesis was assumed to depend linearly on insolation up to a saturation level of 3000 W h m^{-2} d^{-1} (Gumbricht, 1993). For both nutrients detention time was considered having great importance, and also having the system connected in series was thought to be advantageous. Variables with similar meaning or interdependence (i.e. insolation and temperature, detention time and specific load, etc.) were not allowed in the same multiple regression.

To be able to test the validity of the regression models as prognostic tools, the test period was divided in two periods, one for calibrating the regression models, and one for verification of model predictability. Calibrations were done for the 16-month period September 1988 to December 1989 using the least squares method. By studying the residuals it was apparent that a few values caused a great problem for the model fitting. Except for one value, this problem was caused by extremely high or low flows. The problematic values were simply omitted and the models were calibrated without them. The values that were left out are indicated in Fig. 2. The derived regression models with their R^2 value are given in Table 3. Only the regression models where all variables had individually significant meaning ($P < 0.05$) are shown. The 18-month period January 1990 to June 1991 was used for model validation. The agreement between observed values and model predictions during the validation period was also measured by the least squares method, and expressed as R^2 in Table 3.

The specific nitrogen removal could not be statistically interpreted. This was due to the great fluctuations in nitrogen levels during winter, with nitrogen escaping the pond from time to time (Fig. 2b). When analysing only the summer period, the variation in specific removal is very well described by variations in specific load ($R^2 = 91\%$) (Fig. 2b).

DISCUSSION

Approximately 20% of the removed phosphorus and 10% of the removed nitrogen were found in the harvested biomass (Table 2). Even if this figure is rough, direct plant uptake and subsequent harvest can be eliminated as the most important removal process. Other studies on submersed systems show similar results (McNabb, 1976; Eighmy and Bishop, 1988). That removal can be as high in unharvested submersed aquatic systems was confirmed by the result of leaving one canal not harvested. However, we feel that if left unharvested for longer periods than 1 to 2 year, resuspension is likely to decrease the efficiency. An alternative to harvesting would be to clear out the sediments on regular intervals, still allowing the nutrients that are caught in the system to recycle.

Recalculating the harvest (Table 2), annual average plant uptake was 0.05 g N m^{-2} d^{-1} and 0.005 g P m^{-2} d^{-1} (about double those rates during the actual growing season). However, as only part of the biomass was harvested, these figures are probably lower than total plant uptake. Denitrification was 0.3 g N m^{-2} d^{-1} or almost a magnitude higher than nitrogen removal through harvest. Sedimentation was equivalent to approximately

0.15 g m^{-2} d^{-1}. Total removal was 0.5 g m^{-2} d^{-1}. In the regression analysis water temperature explained approximately 60% of the nitrogen removal variation. Nitrogen removal was also dependent on nitrogen load. As denitrification is highly dependent on temperature and nitrogen load (Gumbricht, 1993), it is probably the major nitrogen removal mechanism. Because ammonia levels were low neither nitrification nor volatilisation of ammonia were believed to be of any significant importance for nitrogen removal.

Bishop and Eighmy (1989) and DeBusk et al. (1989) reports specific nitrogen removal to be strongly dependent on nitrogen load for submersed and free-floating plants respectively. This also holds for our submersed system during summer (Fig. 2b). During winter however, high flow and extremely short detention times (often < 1 day) caused the system to release nitrogen. Obviously the flow was too high for maximum nitrogen removal.

Using *Elodea nuttalli* under similar conditions, Bishop and Eighmy (1989) report that nitrogen removal (0.04 to 0.5 g m^{-2} d^{-1}) was correlated to growth and biomass density. Nuttall (1985) reports biomass uptake of nitrogen from 0.05 to 1.26 g m^{-2} d^{-1} using *Myriophyllum aquaticum*, with highest mean assimilation in an aerated pond (0.22 g m^{-2} d^{-1}). Cooper and Cooke (1984) and Cooke and Cooper (1988) report nitrogen uptake in polluted streams from 0.4 to 2.0 g m^{-2} d^{-1} for *Glyceria fluitans* and *Nasturtium officinale*. In a stream near our test site, Jansson et al. (1991) report nitrogen retention between -3.3 to $+5.1$ g N m^{-2} d^{-1}, with an annual mean of 0.2. For a small (2 ha) pond they report nitrogen removal as 1.3 g N m^{-2} d^{-1} annually.

Of the total phosphorus removal of 0.04 g m^{-2} d^{-1}, approximately 20% was found in the harvested biomass. Nuttall (1985) reports biomass uptake of phosphorus from 0.02 to 0.40 g m^{-2} d^{-1} using *Myriophyllum aquaticum*, with highest mean assimilation in an aerated pond (0.12 g m^{-2} d^{-1}) during summer. The reduction of phosphorus is hence more tightly associated with plant uptake, and thus to photosynthesis. The rate of photosynthesis is largely determined by insolation and temperature, and those two factors explain approximately 50% of the variation in P-removal respectively (Table 3). Specific removal rate of phosphorus was highly dependent on loading rate, similar to Bishop and Eighmy (1989) and DeBusk et al. (1989).

Detention time strongly influences both nitrogen and phosphorus removal. With longer residence time, entering nitrate and phosphate is more likely to undergo biological transformations, and it increases the probability of contact between a nitrogen or phosphorus containing molecule in the water column and sediment or plant surfaces (Hill, 1988). Higher velocity may also erode the sediment surface, increase resuspension (removing surface micro-sites for denitrification), and inhibit deeper sediment denitrification by aeration of the sediments to greater depth.

CONCLUSION

The main conclusion from this full-scale experiment is that submersed macrophyte pond systems have a potential of polishing natural waters and pretreated wastewater. As both nitrogen and phosphorus can be removed and recirculated (i.e. used as fertilisers), the method is advantageous. However, harvesting and pond management have to be conducted by skilled workers, and the pond system requires large areas. An alternative to harvesting could be to clear the sediments on regular intervals. Further research is needed to clarify the potential and management of such a system. For larger systems it is probably advantageous to have several ponds in series, instead of one larger pond (Reed et al., 1988).

Even if assimilation and subsequent harvest are not major mechanisms for either nitrogen or phosphorus removal, plant growth may still be very important for total removal of nutrients. Sediment accumulation of both nitrogen and phosphorus are dependent on macrophyte growth. Dense stands of macrophyte probably promote denitrification by creation of anaerobic zones during darkness (Gumbricht, 1993). These hypotheses are supported by Bishop and Eighmy (1989) who report nitrogen and phosphorus removal to increase with productivity and biomass density for a harvested experimental system employing *Elodea nuttalli*.

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REFERENCES

Bishop, P.L. and T.T. Eighmy, 1989. Aquatic wastewater treatment using *Elodea nuttalli*. J. Water Pollut. Control. Fed., 61(5): 651–648.

Brix, H. and H.H. Schierup, 1989. The use of aquatic macrophytes in water-pollution control. Ambio, 18(2): 100–107.

Cooke, J.G. and A.B. Cooper, 1988. Sources and sinks of nutrients in a New Zealand hill pasture catchment III. Nitrogen. Hydrol. Processes, 2: 135–149.

Cooper, A.B. and J.G. Cooke, 1984. Nitrate loss and transformation in 2 vegetated headwater streams. N. Z. J. Mar. Freshwater Res., 18: 441–450.

Cooper, P.F. and B.C. Findlater (Eds), 1990. Constructed Wetlands in Water Pollution Control. Pergamon Press, Oxford, 605 pp.

DeBusk, T.A., K.R. Reddy, T.D. Hayes and B.R. Schweler, Jr, 1989. Performance of a pilot-scale water hyacinth-based secondary treatment system. J. Water Pollut. Control Fed., 61(7): 1217–1224.

Eighmy, T.T. and P.L. Bishop, 1988. Autotrophic nitrification and its role in nitrogen removal in *Elodea nuttalli*-based aquatic treatment systems. Water Supply, 6: 119–124.

Frederiksen, O.T., 1987. The fight against eutrophication in the inlet of "Odense fjord" by reaping of sea lettuce (*Ulva lactuca*). Water Sci. Technol., 19(10): 81–88.

Grasshoff, K., 1983. Determination of nitrate. In: K. Grasshoff, K. Erhardt and K. Kremling (Eds), Methods of Seawater Analysis, 2nd ed. Verlag Chemie, Weinheim.

Gumbricht, T., 1992. Tertiary wastewater treatment using the root-zone method in temperate climates. Ecol. Eng., 1: 199–212.

Gumbricht, T., 1993. Nutrient removal processes in freshwater submersed macrophyte systems. Ecol. Eng., 2: 1–30.

Hammer, D.A. (Ed), 1989. Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Lewis Publishers, Chelsea, MI, 831 pp.

Hill, A.R., 1988. Factors influencing nitrate depletion in a rural stream. Hydrobiologia, 160: 111–122.

Jansson, M., L. Leonardsson and J. Henriksson, 1991. Kväveretention och denitrifikation i jordbrukslandskapets rinnande vatten. Naturvårdsverket rapport 3901, 50 pp. (In Swedish, summary in English).

KLK (Kungliga Lantbrukskungörelsen), 1966. nr 15, 3:77, 8 pp. Stockholm, Sweden. (In Swedish).

Koroleff, F., 1970. Determination of total nitrogen in natural waters with peroxodisulphate. International Council for the Exploration of the Sea, ICES. Council meeting 1969, paper C8 revised version 1970.

Koroleff, F., 1976. Determination of phosphorus. In: K. Grasshoff (Ed), Methods of Seawater Analysis. Verlag Chemie, Weinheim/New York, pp. 117–126.

McNabb, C.D., 1976. The potential of submersed vascular plants for reclamation of wastewater in temperature zone ponds. In: J. Tourbier and R.W. Pierson (Eds), Biological Control of Water Pollution. University of Pennsylvania Press, Philadelphia, PA, pp. 123–132.

Nuttall, P.M., 1985. Uptake of phosphorus and nitrogen by *Myriophyllum aquaticum* (*Velloza*) Verd. growing in wastewater treatment system. Aust. J. Mar. Res., 36: 493–507.

Reddy, K.R. and W.F. DeBusk, 1987. State-of-the-art utilization of aquatic plants in water pollution control. Water Sci. Technol., 19(10): 61–79.

Reed, S.C., E.J. Middlebrooks and R.W. Crites, 1988. Natural Systems for Waste Management and Treatment. McGraw Hill, New York, NY, 308 pp.

Solórzano, K., 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr., 14: 799–801.

Tchobanoglous, G., 1987. Aquatic plant systems for water treatment: engineering considerations. In: K.R. Reddy and W.H. Smith (Eds), Aquatic Plants for Water Treatment and Resources Recovery. Magnolia Publ. Inc., Orlando, FL, pp. 27–48.