ELSEVIER

Aquatic Botany 76 (2003) 17–29

Aquatic botany

www.elsevier.com/locate/aquabot

A combined approach of photogrammetrical methods and field studies to determine nutrient retention by submersed macrophytes in running waters

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Received 14 June 2002; received in revised form 28 October 2002; accepted 31 December 2002

Abstract

Photogrammetrical methods were combined with field studies to map macrophytes in a medium-sized river, which has not been practised prior to our studies.

In August 2001, aerial photos were made at a 15 km long section of the Lower River Spree. In the same time, we described the spatial distribution of submersed macrophytes along two 50 m long river stretches within the photographed section, and correlated the results of both methods. Macrophytes were harvested above defined areas, and their biomass and nutrient concentrations were determined for various degrees of river bottom coverage. Field data and photogrammetrical data were combined to determine nutrient retention by macrophytes.

Aerial photos provided results of the same magnitude as field observations, but underestimated plant coverage by as much as 36.8%. The large error was mainly due to the occurrence of trees partly overshadowing and overhanging the water surface. Changing water levels and turbidity caused minor errors (11.2%). According to field data, macrophytes had high small-scale spatial heterogeneity, but this could not be measured using aerial photos.

Phosphorus retention due to biomass fixation amounted to 1.9% of total phosphorus load during the vegetation period between May and August, and the nitrogen retention was 1.2%. In comparison to nutrient retention due to sedimentation, nutrient incorporation into biomass contributed little to total nutrient retention. The considerable discrepancy between nutrient pools and spatial distributions of some macrophyte species underlines the necessity to combine photogrammetrical methods with field studies, if the aim is to quantify nutrient retention.

Keywords: Aerial photos; Submersed macrophytes; Plant biomass; Nutrient retention; River ecology

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0304-3770/03/$ – see front matter
doi:10.1016/S0304-3770(03)00015-9

1. Introduction

We attempted to quantify nutrient retention due to nutrient uptake by submersed macrophytes. Macrophytes directly store nutrients in their biomass in spring and summer, which otherwise may have contributed to an eutrophication in downstream waters.

Körner (1995) recognised that nutrient fixation contributed little to the total nutrient retention in the sewage effluent Wuhle, which is an extremely eutrophic running water. Our study site is less eutrophic. Therefore, macrophytes may directly retain nutrients in greater percentages here. Previous studies at the same river (Schulz et al., 2003) delivered a good estimate of nutrient retention due to sedimentation: deposition was found to retain up to 12% of total phosphorus load. The highest retention occurred during the vegetation period, due to the fact that macrophytes act as filters for organic seston, reduce the flow velocity and therefore enhance the settling of suspended matter.

In order to quantify nutrient retention by biomass fixation, stocks of submersed macrophytes have to be quantified and analysed. Field investigations alone have seldom been performed on large river stretches, and have focussed primarily on indication of trophic states rather than nutrient retention (Krausch, 1976). During the last decades, aerial photos have been increasingly used to describe the spatial distribution of macrophytes in the littoral region of lakes. Schmieder (1997) mapped the vegetation in the near shore area of Lake Constance utilising aerial photos in combination with field observations. Real colour photos were found to be best for mapping submersed macrophytes; nevertheless, it was nearly impossible to distinguish between different species on the photos. In Lake Geneva, Lehmann et al. (1994) estimated the nutrient retention due to biomass fixation by submersed macrophytes using aerial photos. Lehmann et al. (1994) found the biomass uptake to be of minor importance for the nutrient cycle in the lake.

Little attention has been paid to applications of aerial photos to running waters. Large streams have not been considered to be good objects for geobotanical surveys, since they do not provide adequate habitats for submersed macrophytes, and were too deep for the use of aerial photos. Small rivers provide difficult conditions for mapping underwater vegetation, because of trees on the riverbanks overhanging and overshadowing the water surface to a large extent. In contrast, medium-sized rivers like the Lower River Spree, which we studied, provide sufficient habitats for submersed macrophytes, and are less covered by bank vegetation.

In addition to the determination of nutrient retention, we successfully tested a combination of field studies and photogrammetrical methods to map the submersed vegetation in the Lower River Spree. For this purpose, we used exact field observations and true colour aerial photos, a combination that formerly provided good results in standing waters, but has not previously been applied to medium-sized rivers.

2. Materials and methods

The River Spree is a lowland river in northern Germany originating in the Lusatian mountains (Saxony, Germany) and flowing for 380 km through several shallow lakes to Berlin (Köhler, 1994). We investigated a river stretch near the village of Freienbrink, approximately 10 km upstream of Berlin (13°48′E, 52°22′N). The study site is part of the Müggelspree, a sixth-order section of the Lower River Spree that extends from Grosse Tränke to the village of Neu Zittau, east of Berlin. As a result of straightening in the 1970s, the Müggelspree has a trapezoid channel profile with a mean slope of 0.015%, a mean water depth of 1.25 m at medium discharge, and a mean channel width of 25 m. Since 1998, discharge has ranged between 2.5 $m^3 s^{-1}$ in summer and 30 $m^3 s^{-1}$ in early spring. In the early 1990s, the Lower River Spree changed from a turbid to a macrophyte-dominated state (Köhler and Hoeg, 2000). Shifting sand covers the midstream riverbed, whereas stable sand prevails in the lateral parts of the riverbed. The latter is often colonised by macrophytes or mussels. Total nitrogen and total phosphorus concentrations in the water body range between 0.7 and 3.4 mg N l^{-1}, and 70 and 180 µg P l^{-1}, respectively. Therefore, the Lower River Spree is classified as a eutrophic section. About 53% of its banks are lined by trees such as willow trees (*Salix* spp.), poplar trees (*Populus* spp.), and alder trees (*Alnus glutinosa*).

We used a combination of field observations and aerial photos to map submersed macrophytes on a large scale. The mapping was carried out once in August 2001, when the biomass of macrophytes reached its maximum.

Near the station Freienbrink, two river stretches each 50 m long were precisely mapped by diving, and from a boat, on August 1st and 2nd, 2001. We described the submersed vegetation using a grid of 2 m × 2 m. The coverage of macrophytes was divided into three abundance classes: <30, 30–70 and >70%. After description, mono-specific macrophyte stands were harvested consisting of *Nuphar lutea* (J.E. Smith), *Potamogeton pectinatus* (C. Linnaeus), *Ranunculus fluitans* (Lam.) and *Sagittaria sagittifolia* (C. Linnaeus) using a metal frame of 0.5 m × 0.5 m length. Within the photographed river reach, we took 4 samples of each abundance class of each species, so that there was a total of 40 samples. We harvested the total plant matter above the river bottom within the frame by hand, and tried to avoid tearing roots out of the river sediment. Immediately after sampling, we determined the weight of the harvested fresh material and sub-samples. Sub-samples of approximately 200–300 g fresh weight were representatively taken from the harvested plants. Sub-samples consisted of leaves and stems and were visually of equal composition as the harvested material. All sub-samples were dried at 60 °C for 3 days and then weighed in order to determine the dry weight of the samples. The dried material was ground for 15 min with an automatic agate grinder. Afterwards, it was analysed for total nitrogen (TN) and total carbon (TC) with a thermal conductivity measuring analyser (Vario EL, Elementar). The dried plant matter was treated with 5 M sulphuric acid, 5 M sodium hydroxide, hydrogen peroxide (30%) and *p*-nitrophenol (0.02 g l^{-1}), before phosphorus analyses were carried out according to the photometric principle (Murphy and Riley, 1962).

In order to determine TN and TP concentrations in the water body, water samples have been taken at Fürstenwalde and at Neu Zittau twice a month since 1980. Phosphorus analyses were carried out according to the procedures described above. TN analyses were conducted according to the thermal conductivity measuring principle (Abimed). Daily values of discharge at the two stations were provided by the Regional Office of Environmental Protection Brandenburg, so that monthly nutrient loads could be calculated.

On August 23rd, 2001, aerial photos were taken along a 15 km long river stretch between Hangelsberg and Neu Zittau (Fig. 1). A total of 36 orthogonal true colour photos were taken

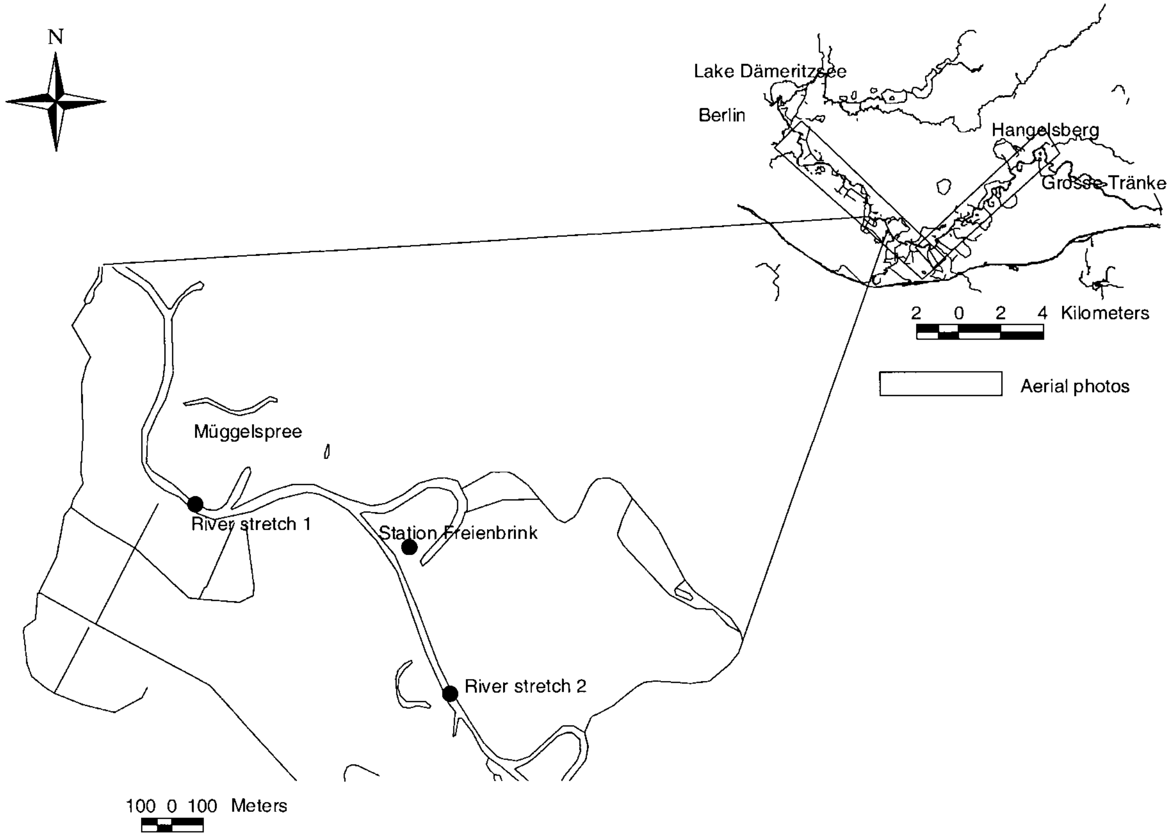


Fig. 1. Topographical map of the study site on the Lower River Spree.

at a scale of 1:4000 from a height of 1120 m, using a special camera (LMK 30, Jenoptik), a 5.6 diaphragm, and an exposure of 1/350 s. The photos overlapped by as much as 60% in order to make a stereoscopic photo evaluation possible.

The evaluation of the photographs was carried out according to the procedures described by Lehmann et al. (1994). Digitised areas were automatically calculated by the software (Arcview, Esri). In order to determine the methodological error, the quantified areas of the two 50 m river reaches were compared with the results of the field descriptions at the same river stretches.

Plant dry weight and nutrient data of submersed macrophytes were related to an area of 1 m^2, and than multiplied with digitised areas of the photographed river stretch. Plant specific nutrient contents and biomass were assumed to be of the same magnitude in the entire river section, as in plant samples. The so-calculated nutrient pool of total submersed vegetation in the "Müggelspree" was then related to the nutrient load during the vegetation period.

Finally, we calculated multiple linear regressions between plant density and plant nutrient parameters. The P-levels of the correlations were automatically determined by t-tests using the same statistical software (Statistica, StatSoft).

3. Results

3.1. Field studies

Field and laboratory studies revealed significant linear increases of dry weight and nutrient concentration per square meter depending on the degree of coverage of macrophytes (Fig. 2a and b). In contrast, phosphorus and nitrogen concentrations related to biomass did not vary significantly (Table 1).

A correlation matrix is given in Table 2. The dry weight did not vary significantly according to species composition, except for *R. fluitans*, which related to area, had a high dry weight. The fresh weight of *S. sagittifolia* related to an area of 1 m^2 varied between 1.0 and

Table 1
Mean total phosphorus (TP) and total nitrogen (TN) concentrations related to plant dry matter (DM)

Species	Degree of coverage (%)	TP concentration (%PDM)	TN concentration (%NDM)
S. sagittifolia	<30	0.64 ± 0.06	2.9 ± 0.36
	<30–70	0.43 ± 0.08	2.5 ± 0.18
	>70	0.45 ± 0.03	2.8 ± 0.16
P. pectinatus	30–70	0.41 ± 0.05	2.6 ± 0.19
	>70	0.32 ± 0.03	2.6 ± 0.23
R. fluitans	30–70	0.41 ± 0.05	2.9 ± 0.21
	>70	0.52 ± 0.08	2.8 ± 0.26
N. lutea	<30	0.36 ± 0.01	2.7 ± 0.23
	30–70	0.38 ± 0.10	2.7 ± 0.45
	>70	0.40 ± 0.06	3.1 ± 0.27

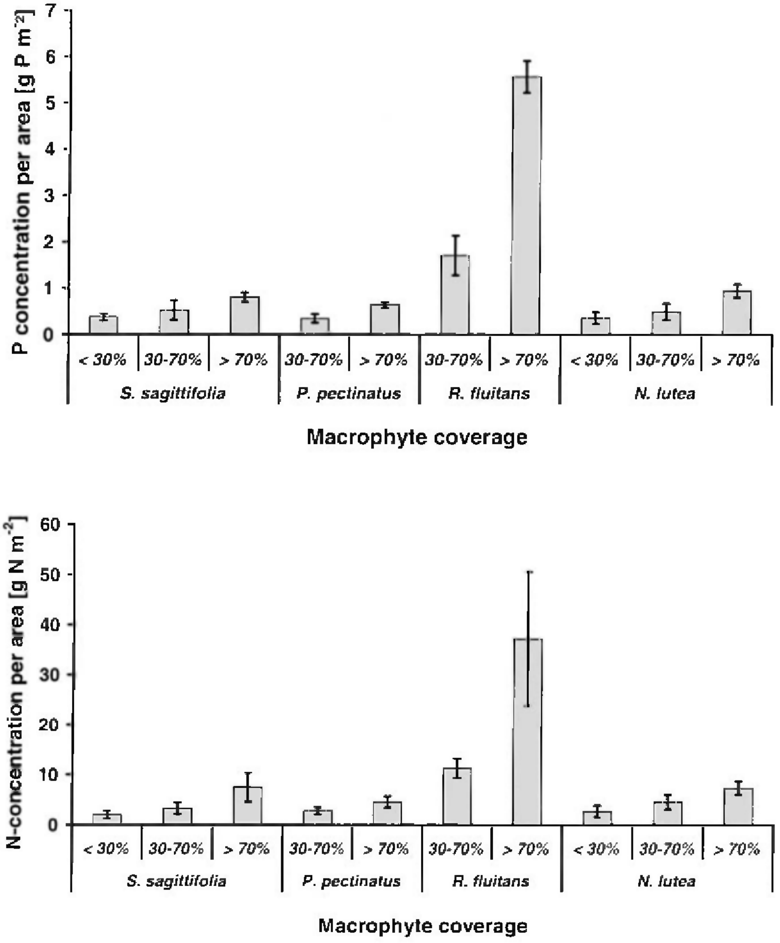


Fig. 2. Phosphorus (a) and nitrogen (b) concentrations per square meter for four macrophyte species and various degrees of coverage: mean and standard deviation.

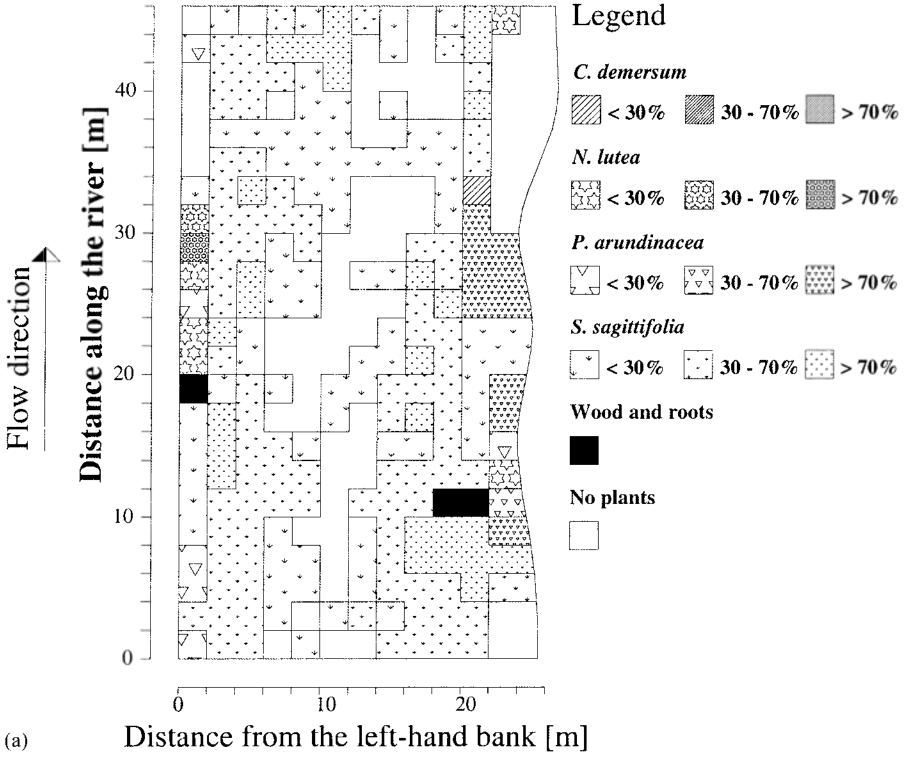
3.6 kg FM m^{-2} according to the degree of coverage, and the fresh weight of *P. pectinatus* and *N. lutea* ranged between 1.1 and 1.8, and 1.0 and 2.3 kg FM m^{-2}, respectively. The fresh weight of *R. fluitans* was markedly higher than of the other species, but also varied in dependency on the degree of coverage between 4.5 and 15.3 kg FM m^{-2}. The percentage dry weight of fresh weight did not vary significantly according to species composition between 7.2 and 11.1%.

Phosphorus concentrations related to dry plant matter ranged between 0.3 and 0.65% of dry matter (%DM), and did not show any significant changes due to degree of coverage or species composition (Table 1). Nitrogen concentrations related to plant dry matter varied between 2.5 and 3.2%DM, and did not follow any systematic trend. Phosphorus contents per square meter followed the same pattern as biomass, which is illustrated by Fig. 2.

Table 2
Correlation matrix: dependency on abundance

		N. lutea	*P. pectinatus*	*R. fluitans*	*S. sagittifolia*
TP ($g\,m^{-2}$)	r^2	0.67	0.78	0.96	0.58
	P-level	<0.047*	<0.12	<0.019*	<0.078
TN ($g\,m^{-2}$)	r^2	0.64	0.46	0.73	0.56
	P-level	<0.001***	<0.065	<0.002**	<0.005**
TP (%DM)	r^2	0.44	0.53	0.41	0.47
	P-level	<0.15	<0.27	<0.36	<0.013*
TN (%DM)	r^2	0.18	0.01	0.07	0.02
	P-level	<0.15	<0.88	<0.45	<0.65

DM, dry matter.
* $P < 005$.
** $P < 0.01$.
*** $P < 0.001$.



(a)

Fig. 3. (a) Map of macrophyte distribution along a 48 m reach of the Lower River Spree, determined by field studies. Signatures represent the dominant species only. (b) Map of macrophyte distribution in the same river reach, based on the evaluation of aerial photos.

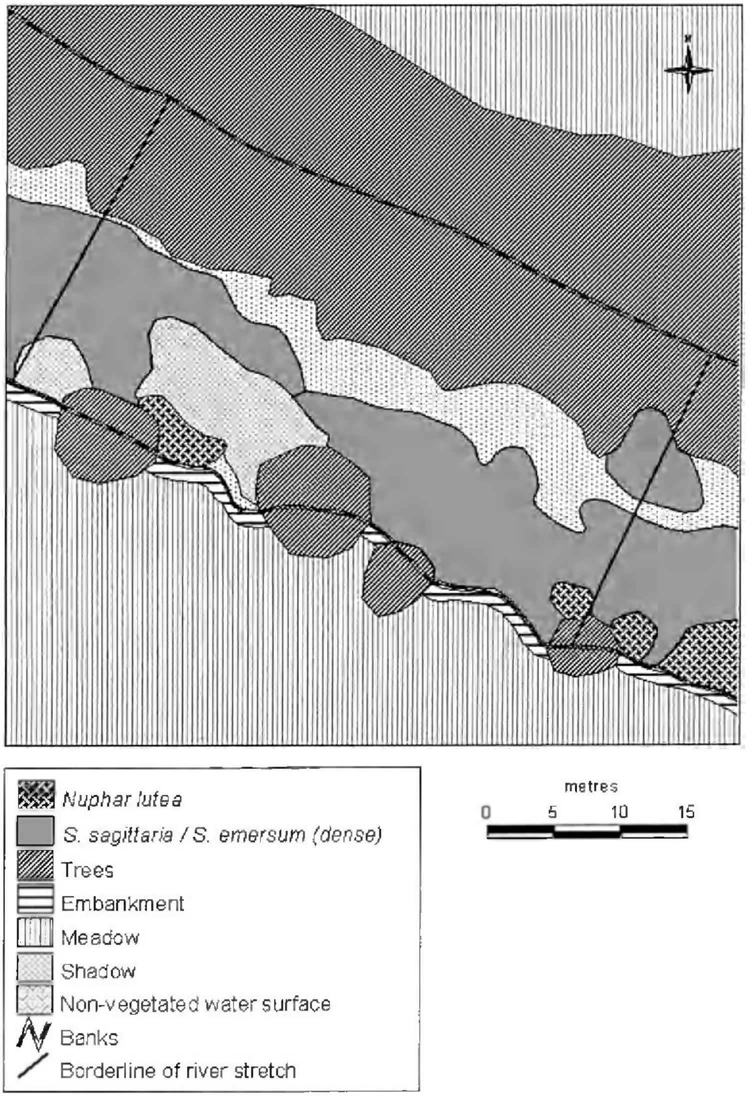


Fig. 3. (*Continued*).

3.2. Mapping of submersed macrophytes

S. sagittifolia, *P. pectinatus* and *N. lutea* were the dominant submersed macrophyte species in the investigated river section. According to field data, macrophytes showed a high small-scale spatial heterogeneity (Fig. 3a). However, this small-scale heterogeneity could not be recognised using aerial photos (Fig. 3b). Corrected photogrammetrical data revealed that submersed macrophytes covered 25% of total area, and emersed macrophytes, such as *Phalaris arundinacea* and *Phragmites australis*, covered 14% of the total area

Table 3
Percentages of digitised classes, shadow, riparian vegetation and dominant macrophytes in the photographed reach of the Lower River Spree

Digitized class	Percentage of river surface (%)	Macrophyte species	Percentage of vegetated area (%)
Uncovered water surface	28 ± 3.1	–	–
Shadow	20 ± 2.6	–	–
Overhanging trees	20 ± 2.6	–	–
Emersed macrophytes	5 ± 0.6	*P. arundinacea*	24 ± 2.6
Submersed macrophytes	27 ± 3.0	*S. sagittifolia*/*S. emersum* (dense)	37 ± 4.1
		S. sagittifolia/*S. emersum* (light)	6 ± 0.7
		P. pectinatus/*R. fluitans*	10 ± 1.1
		N. lutea	12 ± 1.3
		Mixed submersed macrophytes stands	11 ± 1.2

(Table 3). The most common submersed species were *S. sagittifolia* and *Sparganium emersum*. Since it was impossible to distinguish between the two species on the photographs, we classified them together in one category, as we also did for *R. fluitans* and *P. pectinatus*. Except for *S. sagittifolia*/*S. emersum*, it was impossible to distinguish between different degrees of coverage on the photographs. For this reason, we calculated mean dry weight and nutrient values per square meter (field data) for the other species, and multiplied these with digitised areas of the different vegetation classes. The resolution of species composition in the photos is illustrated by Fig. 3b, a digital map of the same river section as given in Fig. 3a.

The evaluation of aerial photographs was impeded by the bank vegetation, which overhung the water surface to a large extent. Therefore, a correction of photogrammetrical data with field data was necessary. Approximately 18% of the river surface was overshadowed by the riparian vegetation, and about 18% was overhung with trees. The resulting total

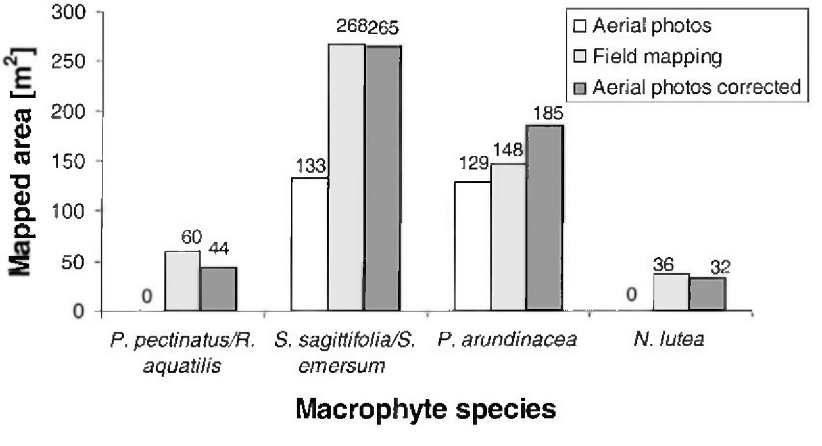


Fig. 4. Comparison of macrophyte coverage determined by aerial photography, field mapping, and aerial photography (corrected).

Table 4
Total phosphorus (TP) and total nitrogen (TN) pool of submersed macrophytes related to river water during the vegetation period of 2001

Macrophyte species	TP biomass pool (kg)	TN biomass pool (kg)	TP river pool (kg)	TN river pool (kg)	TP ratio of biomass/river water (%)	TN ratio of biomass/river water (%)
S. sagittifolia (dense)	24.4 ± 2.6	165.4 ± 18.2	13490	142034	0.2	0.1
S. sagittifolia (light)	7.4 ± 0.8	32.6 ± 3.6	13490	142034	0.1	0.02
P. pectinatus/*R. fluitans*	103.0 ± 11.4	793.4 ± 87.2	13490	142034	0.7	0.6
N. lutea	70.6 ± 7.8	395.2 ± 43.4	13490	142034	0.5	0.3
Mixed stands of *S. sagittifolia*/*P. pectinatus*	52.2 ± 5.8	297.4 ± 32.8	13490	142034	0.4	0.2
Total submersed vegetation	515.2 ± 56.8	1684.0 ± 185.2	13490	142034	1.9	1.22

error amounted 36%. We corrected the photogrammetrical results in the covered areas with abundances of macrophytes in these areas, as determined by our field studies (Fig. 4). Thus, we could minimise the total error from 36 to 11.2%, which remained due principally to the small resolution on the photos (Fig. 3b).

Table 4 provides an overview of the nutrient pools in the above river bottom biomass of macrophytes and water of the entire river section. Stands of *R. fluitans*/*P. pectinatus* contributed the greatest proportion to nutrient storage among all investigated species, although their percentage of river surface coverage only amounted to 10% (Table 3). Stands of S. *sagittifolia* comparatively retained nutrients in their biomass to a much smaller extent, but 43% of vegetated area consisted of stands of the latter species.

We set the extrapolated results in relation to calculated nutrient loads, and found phosphorus retention due to biomass fixation to amount to 1.9% of total phosphorus load during the vegetation period, between May and August. Nitrogen retention was 1.2% of total nitrogen load, in the same period.

4. Discussion

Submersed macrophytes not only retain nutrients by biomass uptake, but also by increasing sedimentation. Clarke and Wharton (2001) calculated deposition rates of $1\,\mathrm{cm\,y^{-1}}$ in macrophyte stands due to filtration of organic seston and senescence of vegetation, indicating that the submersed vegetation more effectively retains nutrients by acting as filter for organic seston than by fixing nutrients into biomass (Madsen et al., 2001; Sand-Jensen, 1998). Investigations at the Lower River Spree (Schulz et al., 2003) agree with these statements. They demonstrated that during the vegetation period of 2001, phosphorus retention due to deposition amounted to approximately 12% of total phosphorus load. In comparison to those results, we found nutrient retention due to nutrient uptake by macrophytes to range between 1 and 2% of total phosphorus and nitrogen load in the same river, indicating the low importance of nutrient storage by macrophytes. Other retentive structures, such as biofilms, have also to be considered. Carpenter and Lodge (1986) classified the periphyton as much more active within the nutrient cycle than their plants.

The photogrammetrical approach to determine nutrient retention in the Lower River Spree, provided results of the same magnitude as the botanical mapping. However, a considerable error in the former was due to vegetation on the riverbanks covering the water surface. It was possible to minimise the error by correcting the photo evaluation with field results. The remaining differences compared to the field descriptions can be explained by low resolution of the photos, changing water levels, and turbidity of the water, mainly caused by phytoplankton. We found a combination of aerial photos and field methods applicable to the estimation of plant abundance in a medium-sized river. However, using the photos alone, it was difficult to distinguish between the various species of submersed macrophytes. Schmieder (1997) solved the same problem in the littoral region of Lake Constance by diving and mapping in short distances. Field studies were also necessary to accompany photogrammetrical methods in our case, because of all the reasons mentioned above. More intense field studies accompanying the evaluation of aerial photos are recommended, if more exact results, than provided by the present study, are needed. The large discrepancy between the nutrient pool and the spatial distribution of *R. fluitans*/*P. pectinatus* in the Lower River Spree is primarily due to the high above river bottom biomass of *R. fluitans*, and additionally demonstrates the importance to combine photogrammetrical methods with field measurements.

We calculated mean values for plant dry matter according to the degree of coverage, for in nearly all cases, abundance classes could not be distinguished by stereoscopic methods. Consequently, the extrapolation of nutrient retention to the entire Müggelspree still has an error of 11.2%, but retention is of the same magnitude as calculated by Körner (1995) for the sewage effluent Wuhle.

A comparison reveals that the use of aerial photos increases the efficiency of field studies to map submersed macrophytes. Our combined approach needed 35 days, considering one active person a day, whereas pure field studies would have taken approximately 1200 days to map the entire photographed river section. Overall, taking aerial photos is quite expensive for large river stretches, and the error of the photo evaluation is great for small rivers with abundant riparian vegetation overhanging the water. The small resolution of the photographs also confines its application to an essential minimum of river size. However, the evaluation of aerial photos provided good results when combined with field studies for medium-sized rivers. Furthermore, the photogrammetrical approach is far more effective than pure field studies considering the time needed for the acquisition of data. In addition, field studies are not faultless, too, considering the adaptation of mapped units to a grid and the turbidity of the water.

Acknowledgements

We thank K. Lehmann and S. Poynton who reviewed the different drafts of our paper. B. Gücker, A. Rother, M. Venohr, I. Schauser and G. Köhler are thanked for their technical assistance. We thank the employees of the chemical laboratory at the Institute of Freshwater Ecology and Inland Fisheries in Berlin for help with our chemical analyses. The Freie Universität Berlin facilitated the stereoscopic evaluation of aerial photos. Our investigations were financed by the European Union (project BUFFER, EVK1-1999-00094).

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