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TRANSPORT OF PARTICULATE NUTRIENTS AND POLLUTANTS IN THE LOW LAND RIVER SPREE

H.-P. KOZERSKI, J. KOHLER & G. SCHELLENBERGER
Institute of Geography and Geoecology, Dept. Aquatic Ecosystems, O-1162 Berlin, Müggelseedamm 260, Germany

ABSTRACT In the river Spree organic particles play an important role as carriers of nutrients and pollutants. These particles are mostly produced autochthonously in lakes along the course of the river. The concentration of the mineral component of seston (loss on ignition ≈ 50%) is very closely related to that of the organic component, so that total transport of particulate matter has to be viewed as the result of biologically affected processes. The seston concentration exhibits a typical temporal pattern of annual and diurnal variation. Matter balances show that these temporal variations are driven by the biological activity of the river ecosystem and by processes of exchange between water and sediment. Regular deposition of the very different particles (according to their chemical composition and fall velocity) only occurs in reaches with low current velocity.

INTRODUCTION

Whereas allochthonous suspended solid loads composed of mineral particles, sludges and organic rich material, eroded from river banks and soils or derived from terrestrial vegetation have been investigated for many years (Golterman *et al.*, 1983), autochthonous particles formed in the river itself have only more recently become the focus of investigation (Ingri *et al.*, 1990; Kalbe, 1986). These particles adsorb, incorporate and transport pollutants and nutrients and are therefore of importance for human health and eutrophication. Polluted mud deposits and their removal causes many problems. There is some knowledge about the behavior of fine mineral particles (Hadley, 1986), but we know very little about autochthonous particles such as organic detritus, algae and other microbes. The question, therefore, arises: How do the particles, formed in the water itself, behave in rivers?

METHODS AND LOCALITIES

The River Spree is a typical lowland river (Schellenberger, 1981). Its mean discharge is 30.3 $m^3\ s^{-1}$ at Beeskow and the average slope is 0.05%, but weirs, canalized sections, and lakes modify it strongly. There are parts with nearly no slope and sections with 0.13% slope between Fürstenwalde and Neu Zittau. The current velocity ranges from 0.08 to 0.7 $m\ s^{-1}$. The catchment area upstream of Lake Müggelsee is 6900 km^2. An important portion of the water, which is rich in iron, originates from open cast lignite mining upstream of the Spreewald. Between Beeskow and Neu Zittau, there are no major tributaries entering the River Spree. The annual discharge regime is regulated and smoothed by reservoirs and weirs immediately downstream of the lakes. The discharge also is controlled by drainage and shipping canals linked to the Dahme river system (Fig. 1). All the lakes and reservoirs are

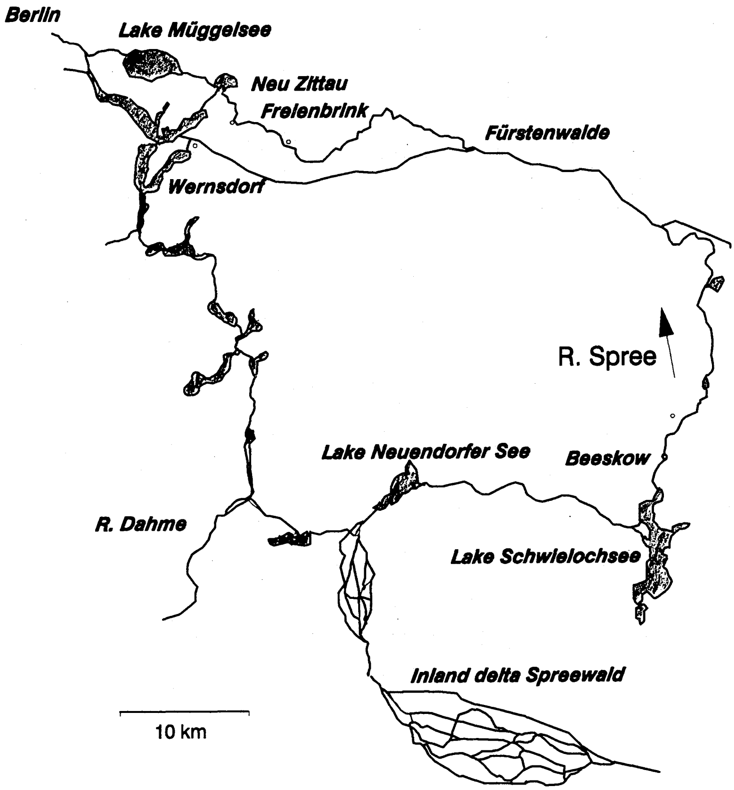

FIG. 1 Map of the study area.

eutrophic because they are shallow, landscape gradients are low, and the nutrient loading from agriculture, industry, and towns is high.

A two years investigation (Schellenberger *et al.*, 1990) was conducted on the River Spree (Fig.1) from March 1988 to March 1990. Four stations (Beeskow, Fürstenwalde, Neu Zittau, and Wernsdorf) were investigated biweekly. Some special surveys and intensive measurements were conducted at other points and sections.

Standard methods were used for most analyses. Seston was measured by membrane filtration (0.6 μm) and fluorescence by means of a Turner 111 fluorometer using excitation at different wave lengths (Schellenberger *et al.*, 1990). Phytoplankton biomass was determined by the classic method of Utermöhl. For oxygen measurements, a commercial sensor was used and, for phosphorus analysis, the method described by Gelbrecht *et al.* (1991) was employed. New methods were used for fluorometric estimates of algae groups at the continuous monitoring station Freienbrink (Schellenberger *et al.*, 1990). Fall velocity spectra were measured by a sedimentation column method (Kozerski, 1991).

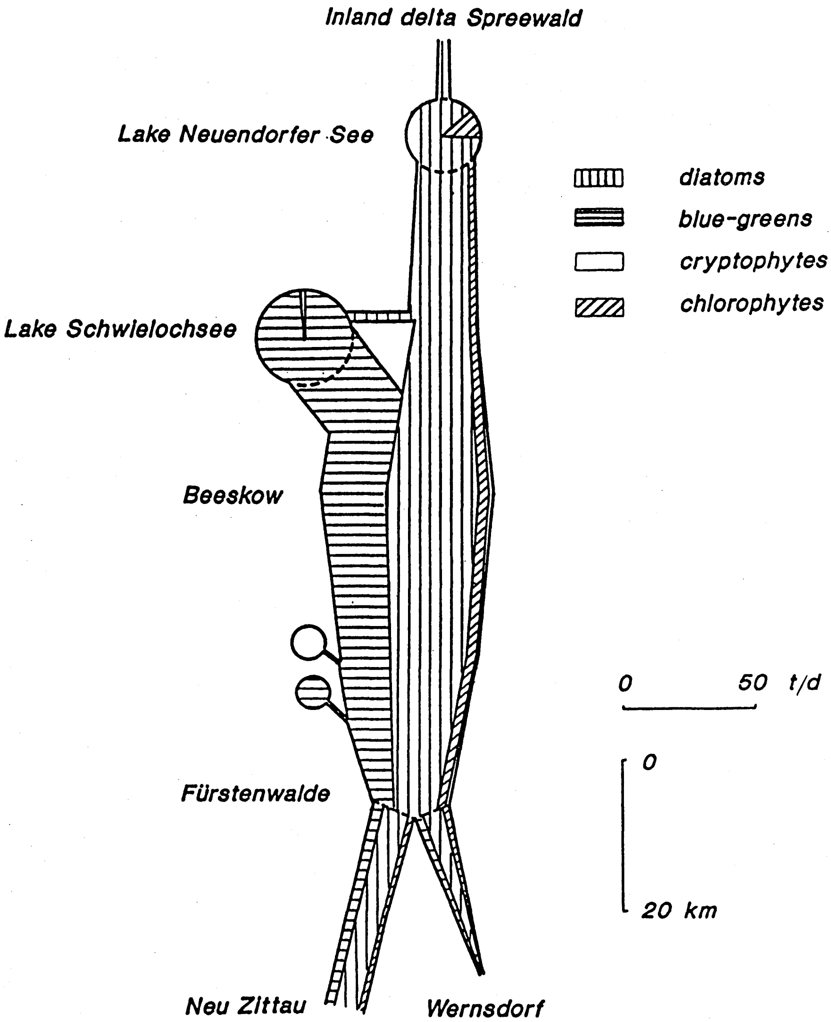

FIG. 2 Development of phytoplankton load (t wet weight day^{-1}) from the inland delta of the Spreewald to Neu Zittau and Wernsdorf, 26-30 June 1988.

RESULTS AND DISCUSSION

The sources of particles in the River Spree

Nearly half of the particles in the water or the River Spree are organic (loss on ignition at 550°C is 50%) and an important part of the organic dry weight is living or dead phytoplankton. Therefore one part of the research focused on these primary producers. The investigations show that large amounts of phytoplankton originate from Lake Neuendorfer See and Lake Schwielochsee. In these lakes and in the inland delta of the Spreewald suitable habitats exist for the organisms to survive unfavorable seasons and the residence time is suitably long for substantial phytoplankton growth. Considerable amounts of diatoms originate from the inland delta of the Spreewald (esp. pennate species) and in L. Neuendorfer See (esp. centric species). Very dense populations of blue-greens are formed regularly in L. Schwielochsee, which exports large amounts of these algae into the Spree (Fig.2). The organisms influence the quality of the river water (e.g. by oxygen production/consumption, assimilation/respiration of CO_2).

Annual pattern of variation of seston concentrations

In the spring phytoplankton grow rapidly in the river, whereas in summer and autumn the losses including respiration, sedimentation, and grazing by zoobenthos and planktonic protozoans, exceed the production. In Fig. 3, this behavior is illustrated by the higher biomass

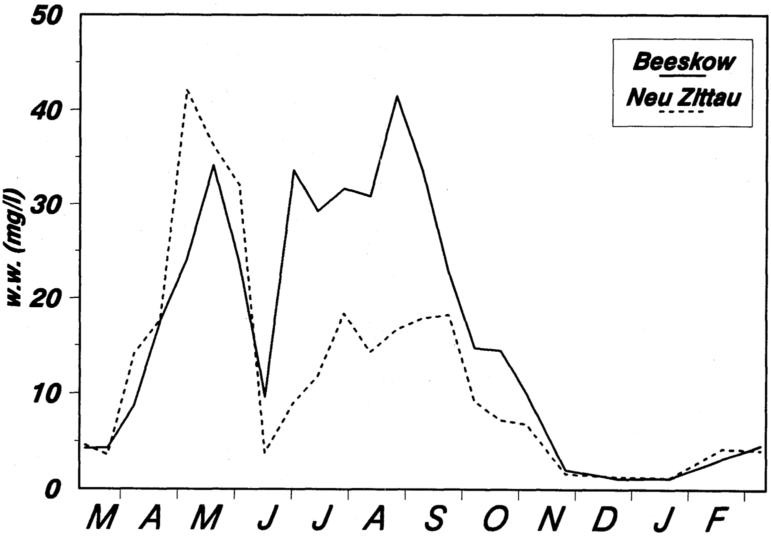

FIG. 3 Mean annual variation of phytoplankton biomass at Beeskow and Neu Zittau of the River Spree from March 1988 to March 1990.

from April to the beginning of June in Neu Zittau than in Beeskow and a lowering of the biomass from July to November along the river reach from Beeskow to Neu Zittau. Figure 3 also shows that phytoplankton concentrations vary strongly between summer and winter and that there is a period of low values at the end of May, a so called clear water phase. Such phases are well known in lakes, but here they originate from the processes operating within the river ecosystem itself. Clear water phases occur in the Spree even if they do not occur in Lake Schwielochsee, which supplies the river with algae.

The nature of suspended matter

Total seston includes both organic and inorganic particles. Living algae contribute about 40% to the total dry weight of organic particles. The other part including detritus, bacteria, and protozoans) depends for its formation primarily on the primary production of phytoplankton. The concentration of organic matter, therefore, is small in periods of low algae abundance such as occurs in winter and during the clear-water phases. In winter, increased concentrations of mineral particles should be expected, because of high discharge and the lack of terrestrial vegetation cover to protect against land erosion. In contrast, a relatively strong correlation was observed between phytoplankton biomass and total seston content. At very low phytoplankton concentrations almost no mineral matter is suspended (Fig.4).

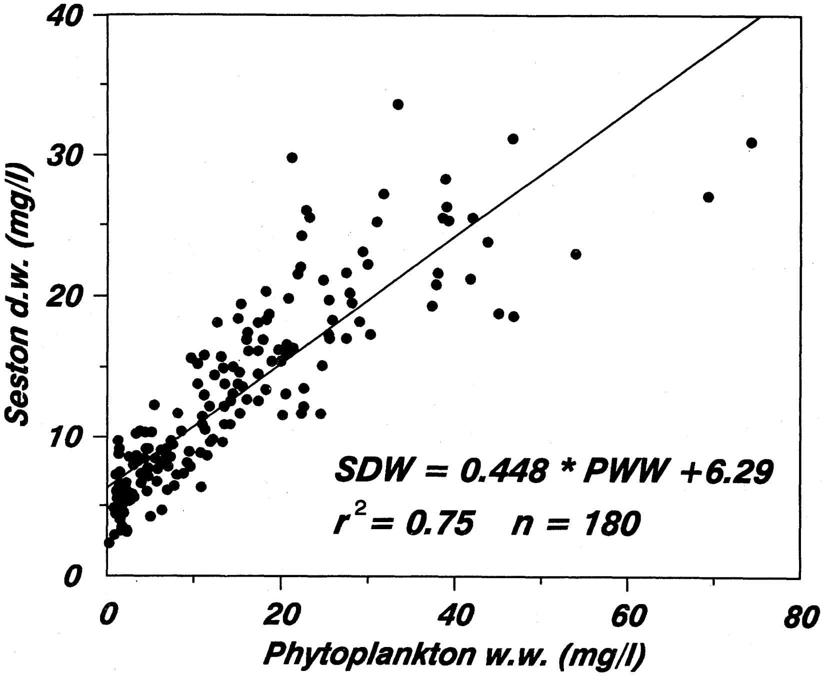

FIG. 4 Relation between phytoplankton wet weight (PWW) and total seston dry weight (SDW).

In the section from Beeskow to Neu Zittau the mineral load is not correlated with discharge. A similar situation also exists for the non-algae organic matter. This leads to the following two conclusions for the river Spree:

(1) The occurrence of mineral matter depends to a large extent on the metabolic activity of organisms.

(2) The organic detritus does not originate from a more or less continuous sludge import but primarily from dead organisms. We estimate that about 32% of inorganic particles are frustules of diatoms, but our knowledge of the nature of the inorganic particles is limited. Lehmann (1990, unpublished) pointed out that organogenic silica phases were dominant in the samples investigated by scanning microscopy.

River seston is a mixture of particles with a high diversity in size, shape, chemical composition, and physical behavior. This is confirmed by sedimentation analysis. A splitting of total seston into fractions with different fall velocities (Fig. 5), the so called fall- or sinking-velocity spectrum, shows that the majority of particles are small and light (Kozerski, 1991).

More than 40% of the dry weight sinks slower than 0.3 m/d and only 13% can settle down under ideal conditions faster than 24 m d^{-1}. These fast sinking particles are mostly flocs of detritus. They are characterized by a low content of chlorophyll and phosphorus. These particles absorb and scatter less light in relation to their masses. They are bigger or have a higher density than the other ones.

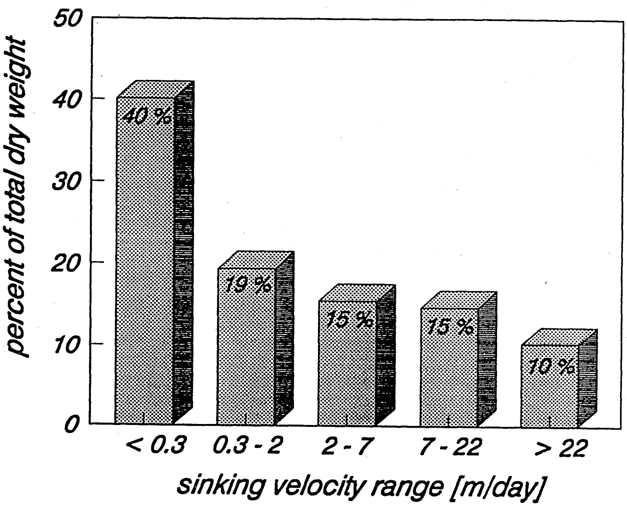

FIG. 5 Distribution of seston dry matter between the different fall velocity ranges (fall velocity spectrum) in the River Spree taken as an average for the growing season in 1989 at the lowermost station near NeuZittau.

Differences between seston in lakes and rivers

A comparison of the fall velocity spectra of seston from the River Spree with equivalent fall velocity spectra for lakes (Fig. 6) indicates that the variability of the spectra from the river at different stations and times is relatively small. The same was true for different lakes, but the contrast between lakes and rivers is marked. Much higher proportions of particles with high fall velocities occur in the river. From this fact we conclude:

(1) Particles with high fall velocities are formed only under flowing conditions, probably due to aggregation of fine particles.

(2) These particles with high fall velocities are removed from the river water after entering a lake as a result of sedimentation.

The role of sedimentation

As shown by the mass balances computed for points along the river, sedimentation does not play, in most cases, an important role along the course of the river Spree. Nevertheless, a significant decrease of phytoplankton between Beeskow and Neu Zittau in the second half of the year (Fig. 3) and the fact that in the same period iron is removed from the river, indicate that particles transfer from the flowing water to the boundary occurs. Sedimentation and resuspension (in the spring, when the iron concentration increases from one station to

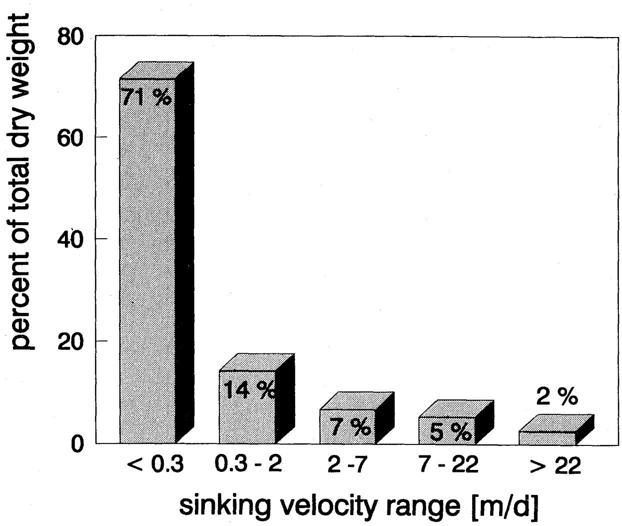

FIG. 6 A typical sinking velocity spectrum for lakes derived from an average of three measurements at Lake Müggelsee and Neuendorfer See in 1989.

the next) seem to affect the mass balance of the river. This conclusion is confirmed by the fact that the amount of resuspendable organic matter located on or within the uppermost bottom layer of the sandy river bed reaches a maximum in autumn and a minimum in winter. Significant losses occur only in branches from the main river, where the current velocity is drastically reduced. In the 2.7 km old branch near Sawall, immediately upstream of Lake Schwielochsee, 23 - 76% of dry weight, 20 - 80% of iron, and 9 - 56% of phosphorus was removed (Kozerski & Böhme, 1990).

Diurnal variation of seston concentration

At the Freienbrink station, 5 km upstream of Neu Zittau (Fig. 1), samples were taken every 3 hours and analyzed to determine the biomass of different algal groups, seston concentration and, in some cases, phosphorus. Average diurnal changes in phytoplankton concentration of 20% were observed in the spring (Schellenberger *et al.*, 1990). Figure 7 shows the mean diurnal variation of phytoplankton biomass expressed as particulate carbon (POC) in the water. Positive values occur from 0900 to 2100 h. This means that the maximum biomass is reached in the afternoon. During the night, the biomass decreases. These fluctuations have important implications for water use. For example, water quality is better in the morning than in the afternoon or evening. Parallel measurements of oxygen (Schellenberger *et al.*,1990) demonstrate a time delay between the increase of oxygen and the increase of the biomass in the water, indicating that in the morning biomass is produced outside the flowing water and that this biomass transfers into the pelagial of the river only between 0900 and 1800. This time delay, the very strong increase of organic matter in the afternoon

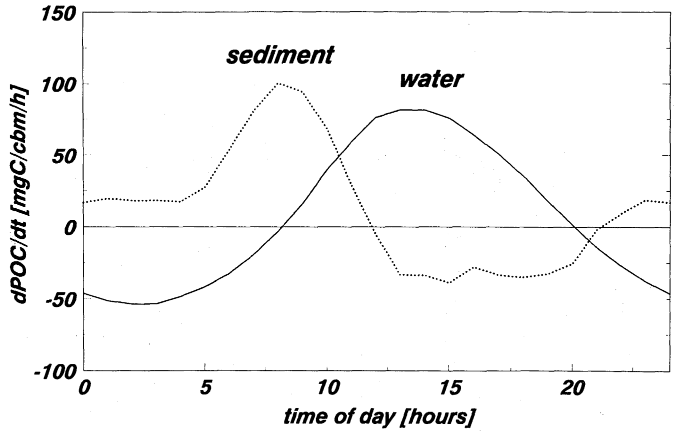

FIG. 7 Diurnal variation of algal biomass, as particulate carbon (POC), in flowing water and sediment of the River Spree at Freienbrink.

and its fast removal during the night, as well as the diurnal variation in the concentration of total seston and total phosphorus can only be explained by an exchange of organic matter between the water and sediment of the river.

CONCLUSION

In a lowland river such as the River Spree, the transport of most nutrients and pollutants is a biologically affected process in which sediment interactions play an important role. The suspended load of a lowland river flowing through reservoirs and lakes is mainly of biological origin. In the river photosynthesis of planktonic algae continues and diurnal biological rhythms driven by solar radiation and temperature occur.

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