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Does High Silicate Supply Control Phytoplankton Composition and Particulate Organic Matter Formation in Two Eutrophic Reservoirs in the Brantas River Catchment, Java, Indonesia?

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Abstract: The Brantas River catchment on the Indonesian island of Java is among the most densely-populated regions in the world. Damming of the river and intensive agriculture in the catchment are supposed to affect the biogeochemistry and ecology of the river, its reservoirs and coastal waters. We collected water, suspended matter and phytoplankton samples from the Sutami and the Selorejo lakes, two major reservoirs in the catchment, in May 2001 and June 2002. Water samples were analyzed for dissolved inorganic nutrients and suspended matter was analyzed for carbon and nitrogen contents and stable carbon and nitrogen isotope composition. Phytoplankton cells were counted, identified and grouped into four major classes. Both reservoirs displayed clear signs of eutrophication as shown by high nutrient concentrations and high phytoplankton abundance. Phytoplankton abundance was generally higher in the Sutami than in the Selorejo reservoir and in the Sutami reservoir it was much higher in June 2002 than in May 2001. Phytoplankton responded to the amount and composition of nutrients in such a way that diatoms dominated when silicate concentrations and N/P ratios were high in the Sutami reservoir in May 2001.

The mass occurrence of the water hyacinth *Eichhornia crassipes* in the Selorejo reservoir was probably responsible for a high uptake of dissolved nutrients resulting in an N/P ratio <8. This favoured the growth of cyanobacteria which can fix atmospheric nitrogen. Excessive phytoplankton growth in the Sutami reservoir in June 2002 led to a drastic silicate reduction (165 μM in May 2001, 95 μM in June 2002). This and an N/P ratio <4 consequently resulted in a much lower abundance of diatoms and a much higher abundance of cyanobacteria than in May 2001. The biogenic extraction of silicate by diatoms in reservoirs has often been observed in high latitude regions where it, in combination with high anthropogenic additions of nitrogen and phosphorus and a lack of silicate replenishment downstream of reservoirs, leads to eutrophication of coastal waters and a shift from biomineralizing to non-biomineralizing phytoplankton. Because of the high weathering rates in the tropical Brantas River catchment, silicate concentrations in the downstream portion of the river were as high as in the headwaters and coastal phytoplankton was dominated by diatoms despite nutrient extraction in reservoirs. It indicates that human activities in river catchments in the humid tropics affect coastal ecosystems in a different way than in high latitude regions.

Key words: Eutrophication, artificial lakes, suspended organic matter, nutrients, phytoplankton, dam.

Introduction

The worldwide increasing population and growing economic demands are more and more reshaping natural landscapes which, in turn, alter the structures and functions of aquatic ecosystems. This is of particular relevance in coastal regions of SE Asia where population density is high and natural resources are the major source of income and nutrition. Land-use change and hydrological alterations in river catchments are among

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the most important factors affecting the water quality, biogeochemistry and ecology of rivers, lakes and coastal seas. Deforestation and conversion of land for agriculture and the building of infrastructure and settlements generally increase erosion and hence the river load of dissolved and particulate substances. This is partly counteracted by hydrological alterations, mainly through the constructions of dams and weirs retaining nutrients and sediments (Smith et al., 2003; Nilsson et al., 2005; Syvitski et al., 2005). In terms of nutrients the net effect is a three-fold increase of inputs into the ocean between the 1970s and the 1990s (Smith et al., 2003) resulting in eutrophication and shifts in phytoplankton community composition and foodwebs in many coastal areas (Humborg et al., 1997; Rabalais et al., 2000; Zhang et al., 2010). This eutrophication fuelled by anthropogenic additions of nitrogen and phosphorus is considered one of the major problems affecting water quality and integrity of aquatic ecosystems. In combination with the building of dams this does not only have profound effects on rivers and lakes, but also on coastal waters (Conley et al., 1993).

The combined effect of river damming and land-use change is quite often a change in amounts and ratios of the essential nutrients Si, N and P which entail changes in the biogeochemical cycles and in the plankton community (Dudgeon, 2000; Ittekkot et al., 2000; Rosenberg et al., 2000). A prominent example in this respect is the Danube, the second longest river of Europe. It has major impoundments, the so-called “Iron Gate” dams, besides numerous other small ones. The “Iron Gate” dams are located about 1000 km upstream of the estuary and were constructed in the early 1970s. Sediments and the dissolved nutrients—nitrogen, phosphorus and silicon—are retained in the large reservoir lakes because of the so-called “artificial-lake effect”. When a river is dammed the reduced flow and energy decrease turbidity, increase light penetration and allow for primary production converting dissolved nutrients into organic matter and skeletal parts. This can sink to the bottom of the reservoir and nutrient-depleted water leaves the reservoir.

In the case of the Danube there is little downstream input of silicon which almost exclusively comes from natural sources because of generally much lower chemical weathering rates in temperate than in tropical regions (Gaillardet et al., 1999). However, large inputs of nitrogen and phosphorus from agriculture and urban and industrial wastewater in the Romanian lowlands changed the amount and composition of nutrients finally entering the NW Black Sea (Humborg et al., 1997). There, nitrate and phosphate concentrations increased and silicate concentrations decreased from the 1970s to the 1990s leading to a drop in the Si/N ratio from about 45 to 3. This was accompanied by a strong increase in phytoplankton and a change in community composition. In the 1960s only diatoms and dinoflagellates were observed while blooms of calcareous algae as well as a disproportionate increase of the non-biomineralizing dinoflagellates were observed in the NW Black Sea in the 1990s (Humborg et al., 1997).

Such a loss of dissolved silicate has also been observed in other regions, for example, in the Rhine River, in the Colorado River and the Mississippi River (Mayer and Gloss, 1980; Admiraal et al., 1990; Turner and Rabalais, 1991). Because of lower weathering rates dissolved silicate concentrations in rivers are much lower in high latitude regions than in tropical regions (Gaillardet et al., 1991; Humborg et al., 2006; Jennerjahn et al., 2006). The resulting silicate depletion leads to the abovementioned changes in Si/N ratios and in phytoplankton abundance and community composition entailing further changes in foodwebs and biogeochemical cycles. In tropical regions there is a strong increase in eutrophication and the damming of rivers, but less is known on the potential ecological response of coastal systems to these changes than from high latitude regions (Milliman, 1997; Ragueneau et al., 2006).

The Indonesian island of Java may serve as a model region in this respect. It is among the regions with the highest weathering rates worldwide, its rivers discharge high loads of dissolved and particulate substances into the coastal ocean and it is strongly affected by intensive agriculture and the damming of rivers (Gaillardet et al., 1991; Milliman et al., 1999; Jennerjahn et al., 2004, 2006; Aldrian et al., 2008). The Brantas is the second largest river of Java located in the East of the island and it discharges into Madura Strait. Major land-use in its catchment is agriculture and the river is impounded by eight major dams. Although eutrophication of the river and reservoirs has been stated (Othman and Sholichin, 2008), little is known on the consequences for the biogeochemistry and the ecology of the river, its reservoirs and adjacent coastal waters of Madura Strait. Here we present results of a study investigating physicochemical properties, dissolved inorganic nutrients, biogeochemistry of total suspended matter and phytoplankton abundance and community composition in two eutrophied reservoirs of the Brantas River. The study aims at delineating the response of phytoplankton to the abundance and composition of dissolved inorganic nutrients and the possible consequences for coastal waters.

Material and Methods

Study Area

The Brantas River originates near the volcano Mount Arjuno and has a length of 320 km and a catchment area of 11,050 km^2 (Figure 1). The geology of the region is dominated by Quaternary volcanic rocks, but also includes some uplifted Tertiary limestones (Whitten et al., 1996). Because of the high tectonic activity, high temperature and high runoff eastern Java is among the regions with the highest weathering rates worldwide (Gaillardet et al., 1999). The climate is dominated by the monsoons with one wet season between November and April during which approx. 80% of the annual average precipitation of 2330 mm falls (Aldrian et al., 2008). In the lowlands the river bisects in two major branches, the Porong and the Surabaya River. The Porong discharges approx. 80% of the annual freshwater and sediment load of the Brantas into Madura Strait coastal waters. The Surabaya River also bisects in two branches near the city of Surabaya, the Kali Mas which is flowing through the city and discharges into Surabaya Strait while the Wonokromo flows eastward and discharges into Madura Strait.

The Brantas River catchment is characterized by numerous hydrological alterations. Active water resources management in the catchment started in the early 1960s in order to prevent floods, to generate energy and to provide water for irrigation, households and industry (Seno Adi, this volume). Besides other hydrological alterations there are eight larger dams and reservoirs in the Brantas catchment, the largest of which are the Sutami, the Wonorejo and the Selorejo reservoirs (Hidayat et al., 2008). The Sutami reservoir is the largest in the Brantas catchment and it is located in the upstream portion of the river at an elevation of 270 m (Figure 1). It was built in 1972, drains an area of 2052 km^2 and had an initial storage capacity of 343×10^6 m^3. The Selorejo reservoir is the third largest in the catchment and located

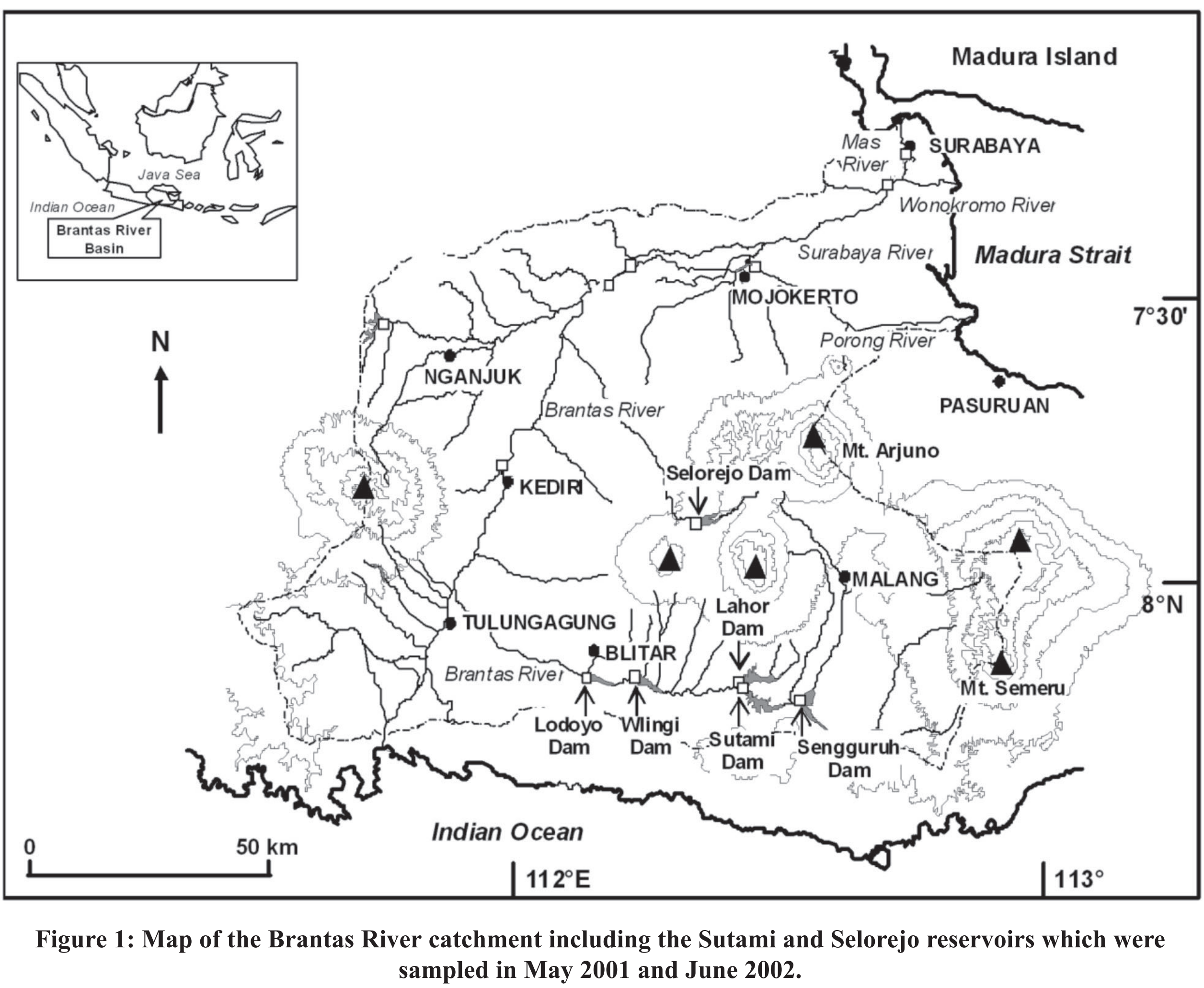

Figure 1: Map of the Brantas River catchment including the Sutami and Selorejo reservoirs which were sampled in May 2001 and June 2002.

at an elevation of 620 m in the upstream portion of the Konto River, a major tributary of the Brantas entering it in the middle portion. It was built in 1970, drains an area of 236 km^2 and had an initial storage capacity of 62×10^6 m^3 (Hidayat et al., 2008).

Sampling and Sample Preparation

The Sutami reservoir was sampled in May 2001 and June 2002 while the Selorejo reservoir was sampled only in May 2001. Samples were taken along E-W transects from the incoming river to the dam. Water samples were taken with a Niskin bottle from 1 m water depth (surface) and from deeper layers (max. depth 20 m). Water samples for nutrient analysis were filtered through single use membrane filters into prewashed PE bottles, preserved with mercury chloride solution (20 g l^{-1}) and stored cool and dark until analysis. A subsample for phytoplankton analysis was taken from the Niskin bottle in brown glass bottles. Samples were preserved with 5 ml of formol solution (36%) and stored in the dark until analysis. Water samples for total suspended matter (TSM) filtration were taken in PE tanks, cooled and stored in the dark until filtration. Samples were filtered over precombusted (5 h, 450°C) Whatman GF/F filters and dried at 40°C.

Analytical Methods

Physicochemical measurements of water were conducted with a WTW MultiLine F/Set-3 multiparameter instrument. Water samples were analyzed for dissolved inorganic nutrients (nitrate, nitrite, ammonium, phosphate, silicate) in a continuous flow autoanalyzer and detected spectrophotometrically as a coloured complex (precision ±0.1 µM; Grasshoff et al., 1999). Ammonium values were always below the detection limit. Phytoplankton cells were identified and counted by using Utermöhl chambers (10-50 ml; Utermöhl, 1958) and a Zeiss Axiovert 100 microscope. Suspended matter samples were analyzed for organic carbon and total nitrogen by high-temperature combustion in an Carlo Erba NA 2100 elemental analyzer (Verardo et al., 1990). Particulate organic carbon (POC) was determined after removal of carbonate by acidification with 1 N HCl and subsequent drying at 40°C. Duplicate analyses resulted in an average relative error of 0.2% for carbon and 0.1% for nitrogen.

The stable carbon ($\delta^{13}C_{org}$) and nitrogen isotope composition ($\delta^{15}N$) was determined in a ThermoFinnigan Delta Plus gas isotope ratio mass spectrometer connected to a Flash 1112 EA elemental analyzer by a ConFlo III continuous flow interface. $\delta^{15}N$ is given as ‰-deviation from the nitrogen isotope composition of atmospheric air. The carbon isotope composition ($\delta^{13}C_{org}$) was determined similarly after removal of carbonate by adding 1 N HCl and subsequent drying at 40°C. $\delta^{13}C_{org}$ is given as ‰-deviation from the carbon isotope composition of the VPDB standard. The standard deviation of replicate measurements was 0.1‰ for $\delta^{15}N$ and 0.2‰ for $\delta^{13}C_{org}$.

Results

Physicochemical Characteristics and Dissolved Inorganic Nutrients

In general, temperature was highest in the respective reservoir and a few degrees centigrade lower in the rivers at entrance and at sample depths of 6-20 m in the reservoirs. Temperature was generally higher in the Sutami than in the Selorejo reservoir. Dissolved oxygen (DO) generally varied between 1.1 and 9.0 mg l^{-1} and between 14 and 130% saturation. A DO oversaturation was measured in surface water of the Sutami reservoir in both years and decreased to levels <76% in water depths between 6 and 20 m in May 2001 and to levels of 14% in June 2002. Similar trends were observed in the Selorejo reservoir (Tables 1 and 2). Highest concentrations of dissolved inorganic nitrogen (DIN = nitrate + nitrite; ammonium below detection limit of 1 µM) were generally measured at the river entrance to the reservoir and decreased towards the dam. DIN concentrations were higher in May 2001 than in June 2002 and they were higher at depth than at the surface. A similar pattern was observed for phosphate, which was generally low in May 2001, but displayed high concentrations in the Sutami reservoir in June 2002. Dissolved silicate displayed little variations along transects and with depth in May 2001, but was much lower in the Sutami reservoir in June 2002 (Tables 1 and 2; Figure 2).

Phytoplankton Amount and Composition

Phytoplankton cell counts varied over two orders of magnitude (10^5-10^7 cells l^{-1}) and generally increased from the river entrance to the centre of the reservoir (Tables 1 and 2). Much higher cell concentrations were observed in the larger Sutami than in the Selorejo reservoir and cell counts in the Sutami reservoir were higher by a factor of 5-10 in June 2002 than in May 2001. The observed species belonged to four major classes: Bacillariophyceae (diatoms), Dinophyceae (dinoflagellates), Chlorophyceae

Table 1: Physicochemical and biogeochemical parameters and phytoplankton counts in the Sutami and Selerojeo reservoirs in May 2001. Data are displayed along E-W transects from the river input towards the dam (Sutami E-W: Br = Brantas River, Su1, Su2, Su3; Selorejo E-W: Ko = Konto River, Se1, Se2, Se3).

Station	*Water depth*	*Temp.*	*Dissolved oxygen*		*DIN/P*	*Phytoplankton*	*TSM*	*POC*	*N*	*C/N*	$\delta^{13}C_{org}$	$\delta^{15}N$
	(m)	*(°C)*	*(mg l^{-1})*	*(%)*		*(10^3 cells l^{-1})*	*(mg l^{-1})*	*(%)*	*(%)*		*(‰)*	*(‰)*
Br (1 m)	7	23.2	3.6	52	51.5	69.2	8.8	7.8	1.1	7.5	-26.9	7.0
Su1 (1 m)	8	30.0	7.1	130	901.8	596.3	6.1	32.5	5.3	6.2	-25.2	15.3
Su2 (1 m)	33	30.9	5.9	124	971.5	1799.3	4.5	30.2	3.6	8.5	-27.2	9.2
Su3 (1 m)	50	30.7	5.3	108	1062.9	293.6	4.8	30.3	3.6	8.4	-27.6	7.3
Br (6 m)		21.2	3.6	56	57.8							
Su1 (7 m)		28.0	4.2	76	105.8							
Su2 (15 m)		28.3	2.9	68	1082.2							
Su3 (15 m)		28.6	3.6	72	1533.6							
Ko (1 m)	1	19.2			43.8		121.4	8.1	0.4	20.8	-21.1	3.5
Se1 (1 m)	9	21.7	5.6	73	4.4	94.3	12.3	37.7	4.5	8.5	-29.7	4.7
Se2 (1 m)	7	22.6	8.5	130	1.5	341.4	14.1	52.3	4.6	11.3	-26.7	5.9
Se3 (1 m)	30	21.1			7.3	275.4	12.3	39.1	4.7	8.4	-28.2	5.5
Se1 (8 m)		20.2	1.4	19	76.5							
Se2 (6 m)		20.2	4.5	65	648.9							
Se3 (20 m)		19.9			247.8							

Table 2: Physicochemical and biogeochemical parameters and phytoplankton counts in the Sutami reservoir in June 2002. Data are displayed along the E-W transect from the river input towards the dam (E-W: Br = Brantas River, Su1, Su2, Su3).

Station	*Water depth*	*Temp.*	*Dissolved oxygen*		*DIN/P*	*Phytoplankton*	*TSM*	*POC*	*N*	*C/N*	$\delta^{13}C_{org}$	$\delta^{15}N$
	(m)	*(°C)*	*(mg l^{-1})*	*(%)*		*(10^3 cells l^{-1})*	*(mg l^{-1})*	*(%)*	*(%)*		*(‰)*	*(‰)*
Br (1 m)	11	26.2	6.5	82	3.5		11.9	7.9	1.1	7.2	-28.5	2.6
Su1 (1 m)	8	27.1	9.0	115	3.2	5535.1	8.8	29.9	3.4	8.8	-27.0	5.8
Su2 (1 m)	33	27.5	8.1	106	3.2	4857.4	8.2	31.0	3.4	9.0	-29.8	6.8
Su3 (1 m)	50	26.8	7.5	97	1.9	4100.6	11.4	29.8	3.8	7.9	-30.0	6.3
Br (6 m)												
Su1 (7 m)												
Su2 (15 m)		26.6	1.2	14	3.7		2.4	23.0	2.7	8.7	-29.8	9.0
Su3 (15 m)		26.6	1.1	14	12.7		3.1	24.6	2.5	10.0	-29.9	7.1

(green algae) and Cyanophyceae (blue algae, cyanobacteria). In the Sutami reservoir Bacillariophyceae were the most abundant group in May 2001 while in June 2002 almost equal proportions of Bacillariophyceae, Chlorophyceae and Cyanophyceae were found. Bacillariophyceae and Cyanophyceae were the most abundant groups in the Selorejo reservoir (Figure 3).

Total Suspended Matter Composition

TSM concentrations were generally low (2.4-14.1 mg l^{-1}) with the only exception of 121.4 mg l^{-1} in the Konto River before its entrance into the Selorejo reservoir in 2001. The POC contribution to TSM varied around 30% in the Sutami reservoir while it was around 8% in the Brantas River before and after the reservoir in both years. In the reservoir POC decreased to 23 and 25% at 15 m depth. In the Konto River POC amounted to 8% while it ranged between 38% and 52% in the Selorejo reservoir (Tables 1 and 2; Figure 4). Distribution patterns of N concentrations were similar resulting in C/N ratios between 6 and 11 with a somewhat higher C/N ratio of 20.8 in the Konto River. In the Sutami reservoir $\delta^{13}C_{org}$ varied between –27.6‰ and –25.2‰ in May 2001 and

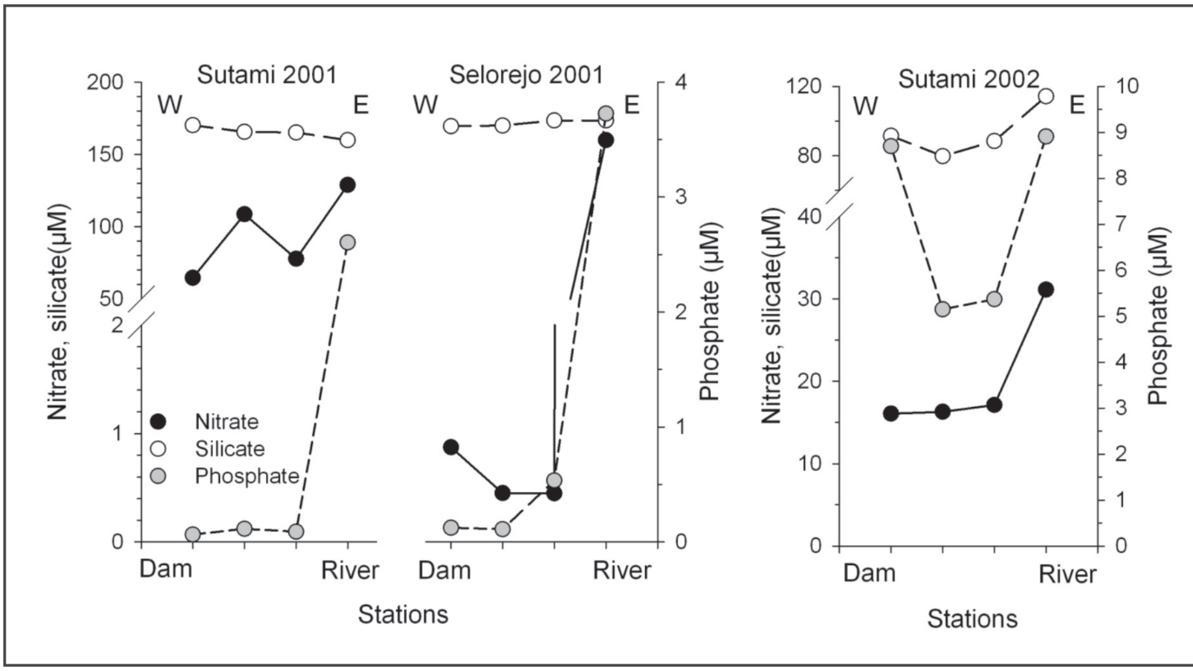

Figure 2: Dissolved inorganic nutrients in surface water of the Sutami and Selorejo reservoirs. Data are displayed along E-W transects from the river input towards the dam. Note different scales for nutrient concentrations in 2001 vs. 2002.

between –30.0‰ and –27.0‰ in June 2002. In the Selorejo reservoir it varied between –29.7‰ and –26.7‰ and was much higher in the Konto River (–21.2‰). In May 2001 $\delta^{15}N$ varied between 3.5 and 5.9‰ in the Konto River and in the Selorejo reservoir which was lower than or equal to the ranges observed in the Sutami reservoir of 7.0-15.3‰ in May 2001 and of 2.6-6.8‰ in June 2002 (Table 1, Figure 5).

Discussion

Phytoplankton Abundance and Community Composition Related to Nutrient Inputs

Sutami and Selorejo Reservoirs in 2001

High nitrate and phosphate concentrations were measured in the entering rivers Brantas and Konto in May 2001 and decreased along the transects towards the outlets. This decrease was much more pronounced in the Selorejo reservoir (Figure 2). Phosphate was almost completely exhausted in both reservoirs. The resulting DIN/P ratio was well above the Redfield ratio of 16, the ratio in which phytoplankton take up N and P to build their tissue (Redfield et al., 1963), indicating P limitation of phytoplankton production in the Konto and Brantas rivers. However, different trends were observed in the two reservoirs. While the high nitrate concentrations in the much larger Sutami reservoir never dropped below 65 µM, nitrate fell to extremely low levels in the Selorejo reservoir. As a consequence the DIN/P ratio increased to values >1000 in the Sutami reservoir while it dropped to values <7 in the Selorejo reservoir. Silicate concentrations were high in both cases and near the average concentration of 179 µM for tropical rivers (Jennerjahn et al., 2006).

Total phytoplankton of 70,000 cells l^{-1} in the Brantas River at the Sutami entrance were in the range of those reported from the estuary (Jennerjahn et al., 2004). In the reservoirs the phytoplankton abundances between 3×10^5 and 6×10^5 cells l^{-1} and the exceptional 1.8×10^6 cells l^{-1} in the centre of the Sutami reservoir were lower than in the eutrophic Finnish Vasikkalampi Lake (10^5-10^8 cells l^{-1}; Eloranta, 1993) or in eutrophic Mediterranean coastal waters of Sicily and in front of the Po River (10-40$\times10^6$ cells l^{-1}; Penna et al., 2004; Giacobbe et al., 2007). The phytoplankton community composition also displayed changes along the transects and between the reservoirs which appear to be related to the amount and stoichiometry of nutrients. While the relatively low phytoplankton abundance in the Brantas when entering the Sutami reservoir consisted to almost 80% of Chlorophyceae, diatoms made up a very small portion and cyanobacteria were virtually absent (Table 1, Figure 3).

Along the transect diatoms increased to almost 80% at the expense of chlorophytes and cyanobacteria made

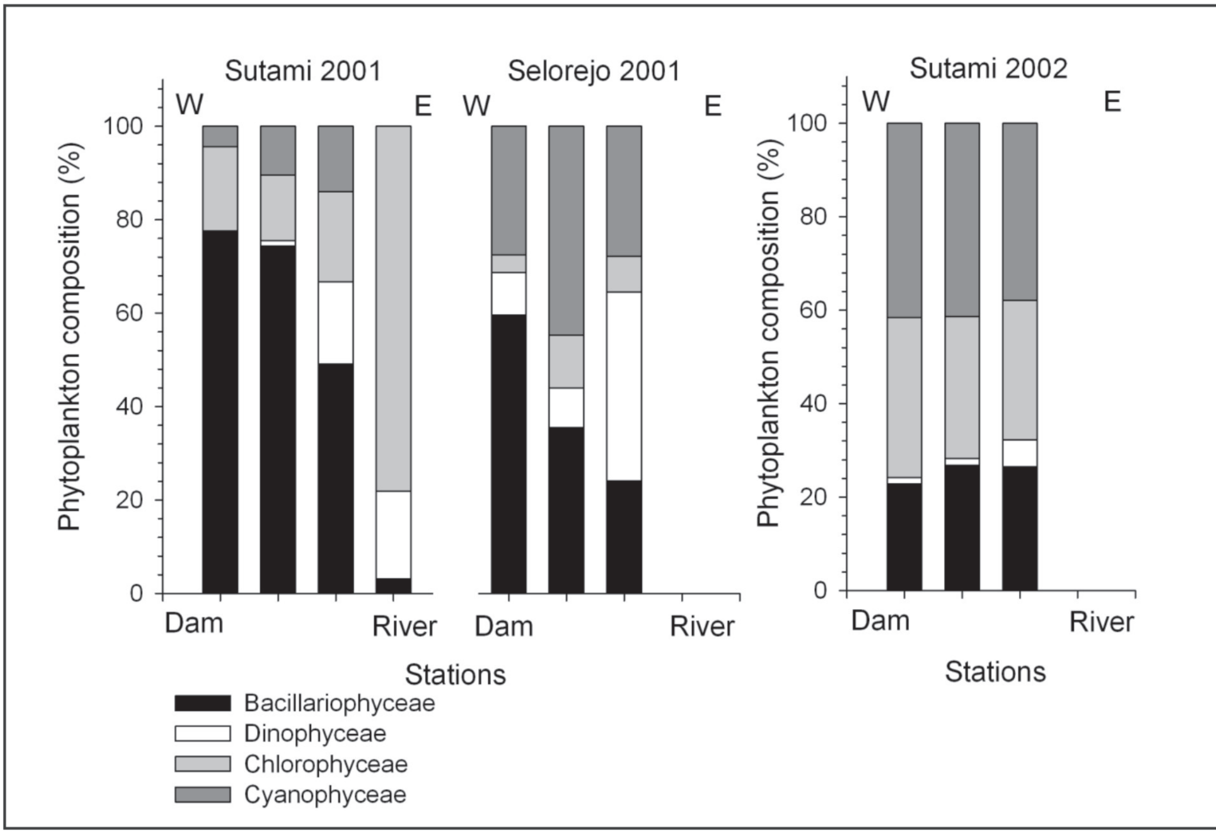

Figure 3: Relative composition of the four major phytoplankton groups in surface water of the Sutami and Selorejo reservoirs. Data are displayed along E-W transects from the river input towards the dam.

up only a small portion. Cell volume and biomass and elemental stoichiometry can vary largely between phytoplankton species or groups (Finkel et al., 2010). This has to be taken into account with regard to our comparison of cell numbers. When compared to the abovementioned eutrophic water bodies the observed cell numbers were not extremely high although the levels of silicate and nitrate were much higher in the Sutami reservoir and hence would support much more phytoplankton growth, particularly of diatoms. However, the almost complete exhaustion of P in the reservoir and the extremely high DIN/P ratio suggest that further phytoplankton growth was limited by the availability of phosphorus. With regard to the intimately linked dynamics of phytoplankton growth and nutrient cycles it has to be taken into account that our data simply reflect a certain point in time of an ongoing process.

Conditions were different in the Selorejo reservoir where diatoms and chlorophytes were dominant, but cyanobacteria also made up a considerable portion of the phytoplankton community. There, nitrate and phosphate both dropped after the river entrance, but in contrast to the Sutami reservoir the DIN/P ratio dropped below the Redfield ratio (Table 1). Because of the high silicate supply diatoms generally dominated the phytoplankton community at least as long as N and P were available in Redfield proportions, but the observed N deficiency then obviously favoured the growth of cyanobacteria which can meet part of their demand by fixation of atmospheric nitrogen. Despite almost similar nitrate and phosphate inputs into the reservoirs the patterns of nutrient distribution and phytoplankton abundance and community composition were completely different. A major reason for that may have been the high abundance of the water hyacinth *Eichhornia crassipes* in the Selorejo reservoir. From visual inspection we estimate that about one third of the lake was covered with water hyacinths. The roots of this floating aquatic plants can take up nutrients directly from the water and they have a high rate of reproduction. For example, a model study has shown that water hyacinths in a eutrophic environment (nitrogen >1 mg l^{-1} or >70 µM) and at temperatures of 30°C can grow to a high density (from 0.1 kg m^{-2} to 10 kg m^{-2}) within 50 days (Wilson et al., 2005). Because of this, water hyacinths occur frequently in eutrophic water bodies resulting in manifold adverse effects to the ecosystem like, for example, reduced light penetration because of dense cover with water hyacinth mats and oxygen depletion because of decomposition of dead plants as has been observed for example in Lake Victoria (Lung'ayia et al., 2001). Because of its rapid and efficient uptake of nutrients and metals it is also used as an ecological indicator (Sujatha et al., 2001) and as a tool for water treatment like, for example, in a duck farm in China (Lu et al., 2008). In the case of the Selorejo reservoir it is conceivable that *Eichhornia crassipes* contributed significantly to nutrient removal and hence affected the phytoplankton community. There, a P concentration above the growth-limiting threshold of 0.1 µM (Fisher et al., 1992) allowed further phytoplankton growth despite an N/P ratio <7.3. Therefore, nitrogen-fixing cyanobacteria had an advantage and consequently made up 25-45% of the phytoplankton community in terms of cell numbers (Figure 3).

Sutami Reservoir in 2002

The situation was completely different in the Sutami reservoir in June 2002 when the water displayed a strong green discolouration. Though still on a high level, silicate and nitrate concentrations were much lower and phosphate concentrations much higher than in May 2001. Despite the phytoplankton abundance being an order of magnitude higher than in May 2001 nutrient concentrations were still sufficiently high to support further phytoplankton growth (Figure 2). However, the DIN/P ratio was <4 (Tables 1 and 2). This N limitation and the high P availability favoured the growth of cyanobacteria, which consequently made up about 40% of the phytoplankton while diatoms only made up one quarter (Figure 3). In contrast to the Selorejo reservoir no massive occurrence of water hyacinths was observed in the Sutami reservoir. The N-limitation as displayed by the low DIN/P ratio was comparable to that observed in the Selorejo reservoir in May 2001, however at much higher P levels. It is therefore conceivable that the high P supply promoted the much higher overall phytoplankton growth, but with a high portion of ca. 40% cyanobacteria which met their nitrogen demand from the atmosphere.

Studies dealing with eutrophication and/or phytoplankton growth and community composition in freshwater ecosystems including reservoirs identified a number of control factors one of which is nutrient availability. Other factors are zooplankton grazing, underwater light climate, carbon availability and hydrological flushing (Naselli-Flores, 2000). In the case of reservoirs which often drain larger areas than natural lakes and depending on the land use/cover pattern nutrient and sediment input may play a more prominent role than other factors (Wetzel, 1990). Investigations on phytoplankton primary production in 12 reservoirs along a gradient of land use (agriculture vs. forest) in the United States found that primary production and phosphorus increased significantly with increasing percentage of agricultural land in the watershed (Knoll et al., 2003). A study on phytoplankton assemblages in 21 reservoirs on Sicily, Italy, found relationships between species composition and a number of environmental factors. Conditions in these reservoirs ranged from oligotrophic to hypertrophic. While the influence of nutrients on phytoplankton assemblage was largest in the lower trophic spectrum, other environmental factors, such as hydrological instability over the year, were more important in the higher trophic spectrum. The dominant species in all cases were green and blue-green algae (Naselli-Flores, 2000).

In two oligotrophic subtropical Brazilian reservoirs phytoplankton biomass was relatively low and the community was dominated by Chlorophyceae (35.6%), Bacillariophyceae (21.2%) and Cyanophyceae (18.6%). Average nitrate concentrations ranged between 20 and 38 µM and phosphate amounted to 0.1 µM on average. The resulting N/P ratio ranged between 24 and 45. While diatoms (Baciallariophyceae) dominated the phytoplankton assemblage during times of low productivity, cyanobacteria were by far the most abundant group during peaks of productivity (Borges et al., 2008). Similarly, the phytoplankton assemblage was dominated by cyanobacteria in three reservoirs in subtropical Queensland, Australia. There, nutrient concentrations ranged between 1.6 and 6.4 µM for nitrate, 0.1-0.2 µM for phosphate and 29.9-77.0 µM for silicate and the N/P ratio ranged between 42 and 53 (Burford and O'Donohue, 2006).

In contrast to the Sutami and Selorejo reservoirs, the phytoplankton assemblage was dominated by cyanobacteria, occasionally by green algae, in all the abovementioned cases regardless of trophic state. In general, silicate concentrations are much lower in rivers draining temperate and subtropical watersheds than those in the humid tropics. Moreover, the island of Java is located in the zone with maximum mechanical and chemical weathering rates leading to very high silicate concentrations in rivers (Gaillardet et al., 1999; Jennerjahn et al., 2006). Additionally, the pH varying between 8.0 and 8.3 in surface waters of the reservoirs may have contributed to the large pool of dissolved silicate through rapid recycling of silica shells. It is therefore likely that the high silicate supply is a major control of the phytoplankton productivity and community composition dominated by diatoms in the Sutami and Selorejo reservoirs.

Although a strong reduction of silicate was observed during the extreme phytoplankton bloom in the Sutami reservoir in June 2002 minimum silicate concentrations were still on the order of 80-100 µM. However, despite this depletion in the upstream reservoirs silicate concentrations again reached 180 µM downstream in the Brantas estuary (Jennerjahn et al., 2004). Obviously, intense weathering in combination with the high runoff replenish the silicate stock of the river in a way that even in Madura Strait coastal waters silicate concentrations were as high as in the NW Black Sea before damming of the Danube River. Consequently, in contrast to the NW Black Sea, for example, the phytoplankton community in Madura Strait coastal waters was and is strongly dominated by diatoms (Jennerjahn et al., 2004; Damar, 2012) although the Brantas River catchment suffers from similar hydrological alterations and land use changes as the Danube catchment.

Sources and Composition of Particulate Organic Matter

Except for the Konto River the TSM concentrations were generally low which can be expected during the dry season when precipitation and hence river discharge are low. The green colour of the water and the TSM filters, the POC content >38%, a C/N ratio between 8.5 and 11.3 and the $\delta^{13}C_{org}$ between –26.7 and –29.7‰ indicate that major part of TSM in the Selorejo reservoir consisted of autochthonous organic matter, i.e. phytoplankton. While the $\delta^{13}C_{org}$ of marine phytoplankton in low latitudes varies between –18 ‰ and –22‰ (Fischer, 1991), freshwater plankton is usually enriched in the light isotope due to large amounts of isotopically light CO_2 of organic origin reaching the water body with groundwater (Galimov, 1985). The fairly high TSM content of 121.4 mg l^{-1} in the Konto River in combination with the low POC content of 8.1% indicates that the river transported a large portion of suspended sediment, the majority of which apparently settled at the reservoir entrance (Figure 4). The C/N ratio of 20.8, the $\delta^{13}C_{org}$ of –21.1‰ and the $\delta^{15}N$ of 3.5‰ of that TSM (Figure 5) which are in the range of those from sugar cane and rice soils from the catchment (Jennerjahn et al., 2004) indicate that major part of TSM transported in the river originated from soils of the area.

The $\delta^{15}N$ of TSM was generally lower in the Selorejo than in the Sutami reservoir. Values in the Selorejo reservoir were in the range of those for TSM collected in the freshwater section of the Brantas estuary (Jennerjahn et al., 2004). The $\delta^{15}N$ of that TSM could be influenced by a number of sources and processes like atmospheric nitrogen fixation, the degree of nutrient utilization in the water column, nitrification and/or denitrification,

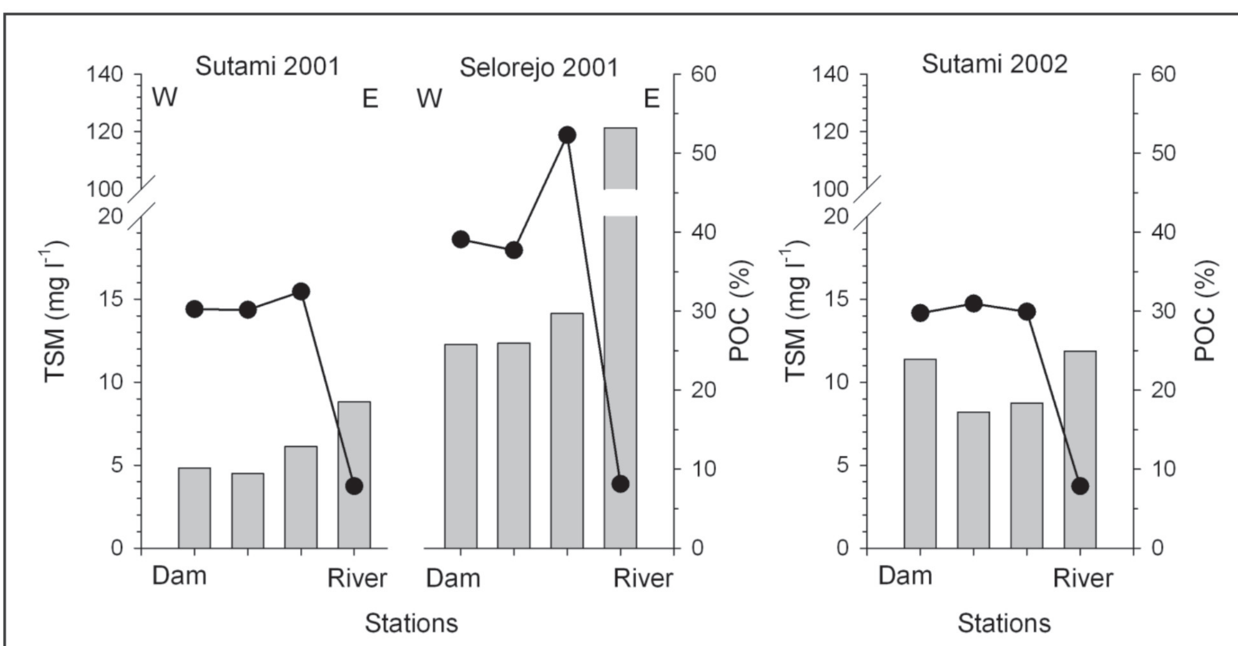

Figure 4: Concentration of TSM (grey bars) and POC content of that TSM (solid circles) in surface water of the Sutami and Selorejo reservoirs. Data are displayed along E-W transects from the river input towards the dam.

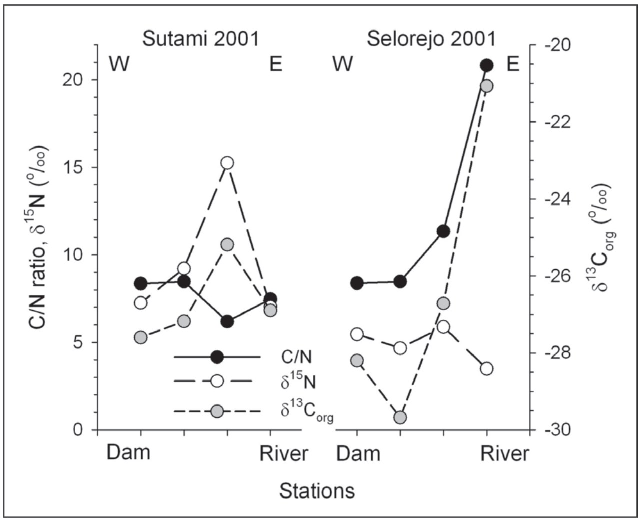

Figure 5: C/N ratio, $\delta^{15}N$ and $\delta^{13}C_{org}$ of TSM in surface water of the Sutami and Selorejo reservoirs. Data are displayed along E-W transects from the river input towards the dam.

fertilizer application and organic matter diagenesis (e.g. Liu and Kaplan, 1989; Wada and Hattori, 1990; Schäfer and Ittekkot, 1993; Holmes et al., 1998; Ostrom et al., 1998; Carpenter et al., 1999; Voss et al., 2001; Stewart et al., 2002). The $\delta^{15}N$ of seawater nitrate is around 6‰ (Liu and Kaplan, 1989) while it varied between 6‰ and 9‰ in three temperate estuaries (Middelburg and Nieuwenhuize, 2001) and between 4.5‰ and 8.5‰ over one year in Lake Lugano (Lehmann et al., 2004).

The DO availability, nitrate depletion and the large portion of nitrogen-fixing cyanobacteria indicate that fractionation during uptake and denitrification were insignificant. Investigations in three reservoirs of varying trophic state in Texas, USA, have shown that particularly the transition zones between rivers and reservoirs are zones of high nitrogen fixation while rates were lower in the lacustrine area. Maximum nitrogen fixation was measured in the transition zone regardless of the trophic state. However, highest rates were measured in eutrophic systems (Scott et al., 2009). It appears that the fixation of atmospheric nitrogen ($\delta^{15}N = 0‰$) by cyanobacteria was generally responsible for the lower $\delta^{15}N$ of TSM in the Sutami and Selorejo reservoirs when compared to other freshwater systems. The minimum $\delta^{15}N$ observed in the zone, where the river enters the reservoir in both our cases, appears to be related to the abovementioned zone of maximum nitrogen fixation.

The $\delta^{15}N$ of TSM from the Sutami reservoir collected in May 2001 was in the range of that of nitrate and TSM from other freshwater systems (Middelburg and Nieuwenhuize, 2001; Lehmann et al., 2004). This, the high nitrate concentration and the small portion of cyanobacteria, indicate that particulate nitrogen mainly resulted from phytoplankton production except for station Su3 where $\delta^{15}N$ and $\delta^{13}C_{org}$ were higher (Figure 5). Tropical soils generally have a higher $\delta^{15}N$ (ca. 6 to 20‰) than soils in temperate regions (ca. –2 to 10‰; Martinelli et al., 1999) and due to preferential removal of isotopically lighter compounds $\delta^{15}N$ also increases with increasing degradation. The higher values at station Su3 therefore indicate an admixture of more degraded soil organic matter introduced by the river. In June 2002 the situation in the Sutami reservoir was similar to that in the Selorejo reservoir in May 2001. High primary productivity, nutrient depletion and a high proportion of cyanobacteria resulted in C/N, $\delta^{13}C_{org}$ and $\delta^{15}N$ values similar to those in Selorejo TSM in May 2001 indicating that the particulate organic matter was almost exclusively of planktonic origin. Strong oxygen depletion at water depths of 6-20 m as shown by low DO concentrations and saturations between 1.4 and 4.5 mg l^{-1} and 19-76%, respectively, indicate severe degradation of the high amount of freshly produced planktonic organic matter when sinking to the bottom of the reservoir. This contributes to the release of CO_2 to the atmosphere, which is much higher in tropical (3000 mg m^{-2} d^{-1}) than in temperate reservoirs (1500 mg m^{-2} d^{-1}; St. Louis et al., 2000). Moreover, the low DO at depth may impair the performance of planktonic and benthic organisms in the reservoirs (Vacquer-Sunyer and Duarte, 2008; Zhang et al., 2010).

Summary and Conclusions

The Sutami and Selorejo reservoirs in the Brantas River catchment suffer from eutrophication because of high nutrient input from the environs where major land use is agriculture. During the dry seasons of 2001 and 2002 we found high amounts of autochthonous particulate organic matter fuelled by the high nutrient input. The amount and composition of phytoplankton varied according to nutrient amount and stoichiometry. In contrast to temperate aquatic systems silicate was very abundant and therefore not a limiting factor for phytoplankton growth. Accordingly, high N and P supply at a high N/P ratio promoted the growth of diatoms in the Sutami reservoir. While diatoms also played a major role in the Selorejo reservoir, N limitation caused by intensive water hyacinth growth there led to a strong development of cyanobacteria which can meet part of their nitrogen demand by fixation from atmospheric air.

Consequently, particulate organic matter in both reservoirs was more or less exclusively of autochthonous origin during the dry season.

The high silicate supply resulting from the very high weathering and erosion rates in Indonesia is also responsible for a different response of the phytoplankton community to eutrophication than observed in temperate regions. There, silicate limitation often entails a shift of the phytoplankton community from biomineralizing diatoms to non-biomineralizing species like, for example, euglenophytes or dinoflagellates. In contrast, the two reservoirs in the Brantas River catchment serve as a model displaying the phytoplankton response to eutrophication in a system that is not limited by silicate. The decomposition of that high amount of organic matter leads to strong oxygen depletion, which may endanger the well-being of organisms at depth and on and in the sediment and promote the release of greenhouse gases.

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