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Export and retention of dissolved inorganic nutrients in the Cachoeira River, Ilhéus, Bahia, Brazil

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ABSTRACT

*Dissolved inorganic nutrient concentrations and physical-chemical variables were determined in the lower reaches of the Cachoeira River watershed, from November 2003 to October 2004. Concentration of nutrients were high and highly variable. Mean concentrations and standard deviation of ammonium, nitrite, nitrate, phosphate and silicate were 25.4 ± 25.1; 3.9 ± 3.9; 62.2 ± 54.9; 15.8 ± 9.0 and 129.0 ± 5.6 (µmol L^{-1}), respectively. Nutrient retention was observed mainly during the dry season. Chlorophyll-*a *concentrations were especially high in those periods. The Cachoeira River can be considered eutrophicated, and such condition becomes more intense with low fluvial flow during the dry months. Despite the spatial/temporal changes of the species of inorganic nitrogen, a removal of dissolved inorganic nitrogen was observed in relation to dissolved silicon and to phosphorus, with consequences for estuarine biogeochemistry. The basin exports annually about 3.5, 2.2 and 0.3 t y^{-1} of dissolved silicon, nitrogen, and phosphate to the estuary, respectively. The eutrophication and growth of macrophytes is responsible for most of these changes in nutrient fluxes to the estuary and coastal waters.*

Key words: eutrophication, macrophytes, nitrogen, phosphorus, silicon, fluvial inputs

1. INTRODUCTION

Anthropogenic activities over drainage basins have been continuously increasing the point and diffuse sources of nitrogen and phosphorus to rivers around the world. Such activities include intensified use of fertilizers in crops, and deposition of domestic and industrial effluents. Determination of dissolved inorganic nutrients (such as nitrogen, phosphorus and silicon) has been used in the evaluation of eutrophication in aquatic ecosystems, since these substances are closely related to the system´s degree of pollution (Carmouze 1994; O'Donohue & Denisson 1997).

Eutrophication implies changes of biogeochemical cycling of aquatic ecosystems, leading to several ecological consequences, such as increase of the biomass of certain kinds of algae and aquatic macrophytes. The occurrence of such flourishing harms the water quality and may thus reduce concentration of dissolved oxygen, changing the competitive balance among species, which results in loss of biodiversity (Cooper *et al*. 2002). In addition to the increase of algae density there are also other significant changes, such as the appearance of new species and the disappearance of others (O'Donohue & Denisson 1997). The growth of aquatic macrophytes may also influence the transportation of nutrients, favoring their retention and providing an additional substratum for peryphiton and its biochemical transformations (Kronvang *et al*. 1999; Peterson *et al*. 2001; Merriam *et al*. 2002).

The nutrient loading by the rivers influences the biotic activity in estuaries and coastal seas and may be an important indicator of changes in the condition of such waters (Sawidis & Tsekos 2004). The fluvial discharge also influences the capacity to dilute the excessive amount of nutrients and pollutants that reach the estuaries, minimizing the impact in these areas. Otherwise, a short residence time may not allow maximum removal through absorption, as usually occurs when there is low water flow (Sanders *et al*. 1997).

The purpose of this study was to quantify nutrient (ammonium, nitrate, nitrite, phosphate and silicate) retention at the lower basin of Cachoeira River and its export to the estuary.

2. METHODS

The hydrographic basin of the Cachoeira River covers a total area of around 4600 km^2 in the south of Bahia State, Northeastern Brazil (BAHIA 2001; Fig. 1). The river crosses the cities of Itabuna and Ilhéus, from which receives input of domestic and industrial effluents. Average regional temperature is 24.6 ºC; precipitation is 1500 mm y^{-1} in Itabuna and 2000 mm y^{-1} in Ilhéus. The Atlantic Forest and shaded cacao crops (*cabrucas*) cover large areas of the river basin. This kind of culture has prevented soil erosion; however, the increase of coffee plantations and pasture has intensified this process (Klumpp *et al*. 2002). The Cachoeira River is characterized by extreme irregularity, with ill-defined dry and rainy seasons. Annual average pluvial discharge

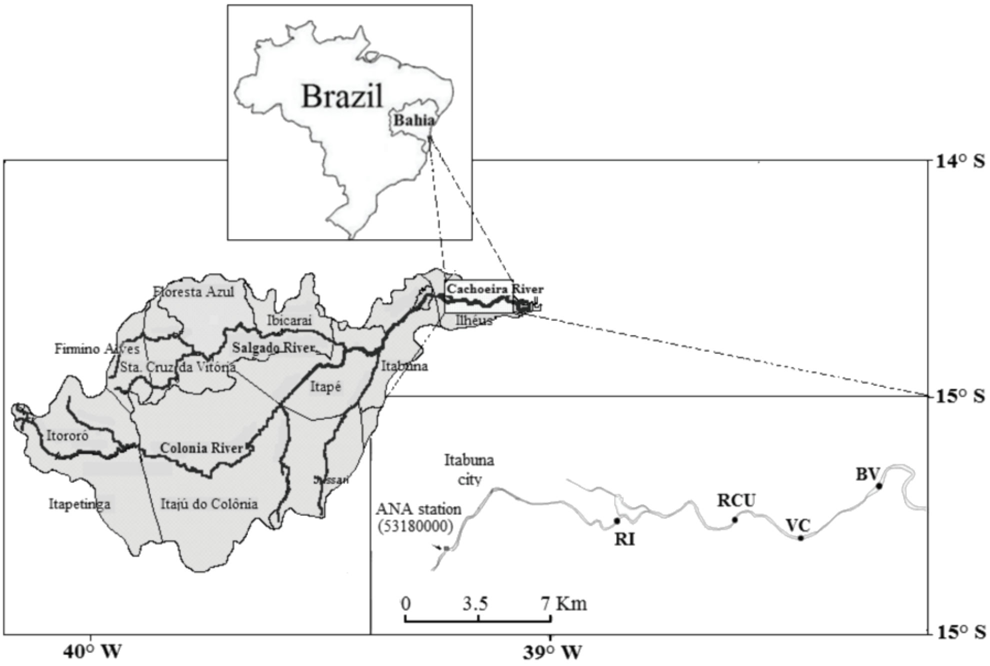

Fig. 1. Map with the localization of the sampling points in the Cachoeira River Basin, Bahia, Brazil: RI (Itabuna Reservoir); RCU (Cachoeira River near UESC, Universidade Estadual de Santa Cruz); VC (Cachoeira Village); BV (Vitoria Bank).

is 24.1 m^3 s^{-1}, although 0.2 and 1.460 m^3 s^{-1} have already been recorded. During the dry season its rocky bed is mostly exposed, remaining only small residual streams of water that are completely covered by floating macrophytes, mainly Eicchornia crassipes (BAHIA 2001). A small clear overflow weir in Itabuna (~1.5 m height) increases stagnation and growth of macrophytes during the dry season. Plants are transported towards the estuary during rainy season, and large amounts can reach coastal waters and beaches 14 km southward during peak discharges (Souza 2005).

Sampling was carried out between 2003 (November and December) and 2004 (January, February, March, April, August and October) in four stations (Fig. 1) between the small dam on Itabuna city (RI) and the upper estuary limit (BV). Sampling was also done about 5 km downstream the dam, after a stretch of rapids (RCU) and after a natural 6 m depth reservoir created by geological faults (VC). One sample was collected in each station, from the upstream station till the upper estuary boundary, comprising a total of 30 samples. Physical-chemical parameters such as pH, temperature, conductivity and dissolved oxygen (DO) were determined in the field with a WTW Multiline P4 and a Hanna HI 9143 portable meters, respectively. Samples were collected in polyethylene bottles previously washed with HCl 1:1 and distilled water, and kept under refrigeration during transportation. In the laboratory, samples were filtered in GF/C type fiberglass filters used further to chlorophyll-*a* analysis by the spectrophotometric trichromatic method on a 80% acetone extract (Parson *et al*. 1984). Aliquots of filtered samples were frozen until analysis of dissolved inorganic nutrients. Concentration of nutrients was determined by spectrophotometric methods according Grasshoff *et al.* (1983) and dissolved silicate (orthosilicate) as described in Carmouze (1994). Nitrite was determined using the diazotation method (detection limit 0.02 μM); nitrate was determined by cadmium reduction into nitrite (nitrite limit plus a coefficient of variation ±3% in the range 0-10 μM); ammonium was measured spectrophotometrically by the indophenol blue method (detection limit 0.05 μM); orthophosphate by the ascorbic acid molybdate method (detection limit 0.01 μM); dissolved silicate was determined by the ammonium molybdate method (detection limit 0.1 μM).

Daily fluvial discharge data (Q, m^3 s^{-1}) for a station located in Itabuna was obtained at ANA Hidroweb (Agencia Nacional de Águas, National Water Agency; www.hidroweb.ana.gov.br/hidroweb, station no. 53180000). This station is located upstream from our sampling stations, and the total increment of the area drained by the station is about 220 km^2. A correction of the total monthly outflow for each drained area of the basin (Q_{St}) was done according to (equation 1):

$$Q_{St} = (Q_{ANA} \times A_{St})/A_{ANA} \qquad (1$$

where Q_{St} and A_{St} respectively mean total monthly fluvial outflow and drainage area of each station; and Q_{ANA} and A_{ANA} represent fluvial discharge and drainage area at the ANA gauging station, respectively.

Flux of dissolved inorganic nutrients was obtained by multiplying concentration values of each dissolved inorganic nutrient in the sample by the calculated fluvial

Tab. 1. Mean values of electrical conductivity, temperature, pH, dissolved oxygen (DO) concentration and saturation percentage in the Cachoeira River stations. Mean ± standard deviation; minimum and maximum in parenthesis. N = 4 except in * (N = 3) and ** (N = 1).

	Conductivity ($\mu S\ cm^{-1}$)	Temperature (°C)	pH	DO ($mg\ L^{-1}$)	DO (% saturation)
November 2003	0.553 ± 0.036	29.5 ± 0.1	7.3 ± 0.1	4.1 ± 1.5	54.2 ± 19.5
	(0.505 – 0.582)	(29.4 – 29.7)	(7.2 – 7.4)	(2.3 – 5.6)	(30.2 - 73.1)
December 2003	0.572 ± 0.024	29.3 ± 0.8	7.6 ± 0.5	12.2 ± 13.4	158.8 ± 172.4
	(0.555 – 0.606)	(28.5 – 30.4)	(7.2 – 8.3)	(2.7 – 31.2)	(35.0 - 402.2)
January 2004	0.603 ± 0.024	27.9 ± 0.3	7.2 ± 0.1	2.3 ± 1.2	29.4 ± 15.7
	(0.585 – 0.638)	(22.4 – 28.2)	(7.1 – 7.3)	(1.2 – 3.7)	(15.4 - 47.3)
February 2004	0.722**	26.9**	8.1**	-	-
March 2004	0.208 ± 0.015	25.5 ± 0.3	7.2 ± 0.2	7.2 ± 0.2	88.0 ± 2.6
	(0.196 – 0.228)	(25.1 – 25.8)	(7.0 – 7.5)	(6.9 – 7.4)	(84.5 - 90.1)
April 2004	0.433 ± 0.039 *	26.2 ± 0.8	7.8 ± 0.2	6.7 ± 0.5	82.7 ± 5.6
	(0.389 – 0.462)	(25.3 – 27.0)	(7.6 – 7.9)	(6.3 – 7.4)	(78.0 - 90.4)
August 2004	0.570 ± 0.042	21.3 ± 3.1	7.9 ± 1.2	6.2 **	75.1**
	(0.531 – 0.609)	(17.1 – 24.7)	(7.1 – 9.7)		
October 2004	0.609 ± 0.015	23.8 ± 0.6 *	7.0 ± 0.3		
	(0.595 – 0.630)	(23.4 – 24.5)	(6.8 – 7.4)	-	-

discharge values of each station on monthly basis. For nutrient concentration (Y) below detection limit, a value immediately below was used for monthly flow estimation. Fluxes were normalized dividing them by the area of each drainage basin, according to equation 2:

$$F_{NY} = F_Y / A_{St} \qquad (2$$

where F_{NY} represents normalized flow of dissolved inorganic nutrients, F_Y represents actual flow of nutrients and A_{St}. represents drainage area of each sampling station.

We assumed that changes of nutrient concentrations in the river water during time scales lower than a month became insignificant when the actual concentration of the sample was multiplied by total monthly discharge values higher by 5-8 magnitude order, when fluxes were significant.

3. RESULTS

3.1. Fluvial discharge

Runoff ranged from 0 to 826 $m^3\ s^{-1}$ during the period studied (Fig. 2). Sampling during the dry season were represented by November and December 2003, and October 2004, with an average flow under 4 × $10^6\ m^3$ $month^{-1}$. December was the driest month, with the rainy season starting in January 2004. Maximum fluvial discharge occurred in March 2004.

3.2. Physico-chemical variables

Physico-chemical variables are shown in table 1. The conductivity varied from 722 $\mu S\ cm^{-1}$ when the runoff begins to increase to <196 $\mu S\ cm^{-1}$ at peak discharge. Temperatures were higher between November and December, and decreased until August. The higher concentration of DO it was found at RI (12 mg L^{-1}/160% saturation) in December. Most samples presented oxygen subsaturation. The pH presented only small changes among the sampling sites.

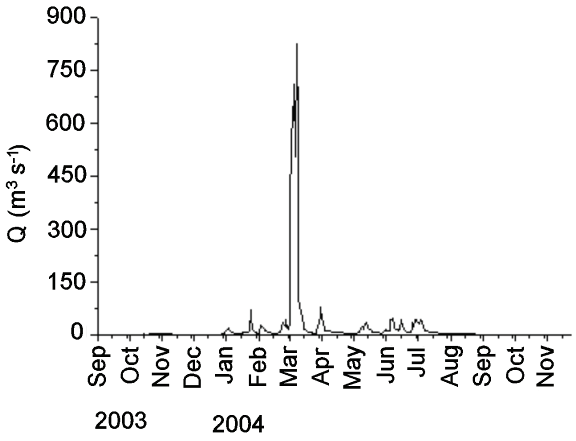

Fig. 2. Daily runoff at the ANA (Agência Nacional de Águas; National Water Agency) station No.53180000 during the study period.

3.3. Dissolved inorganic nutrients

The highest concentrations of ammoniacal nitrogen and phosphate were observed at station RI; nitrite and nitrate reached maximum concentrations at station RCU. Silicate presented small changes along sampling stations, without a marked spatial pattern (Fig. 3e).

Maximum concentrations of ammoniacal nitrogen (Fig. 3a) and phosphate (Fig. 3d) occurred in January 2004 (beginning of the rainy season) while minimum values were observed in March 2004 (rainy season). For nitrite and nitrate (Figs 3b and 3c, respectively), the lowest concentrations were observed in November 2003 and March 2004 (rainy season). There was a decrease of the mean concentration of silicate (Fig. 3e) during January, February and March of 2004.

3.4. Chlorophyll-a

The highest concentrations were found at station RI during the dry and beginning of the rainy season (Fig.

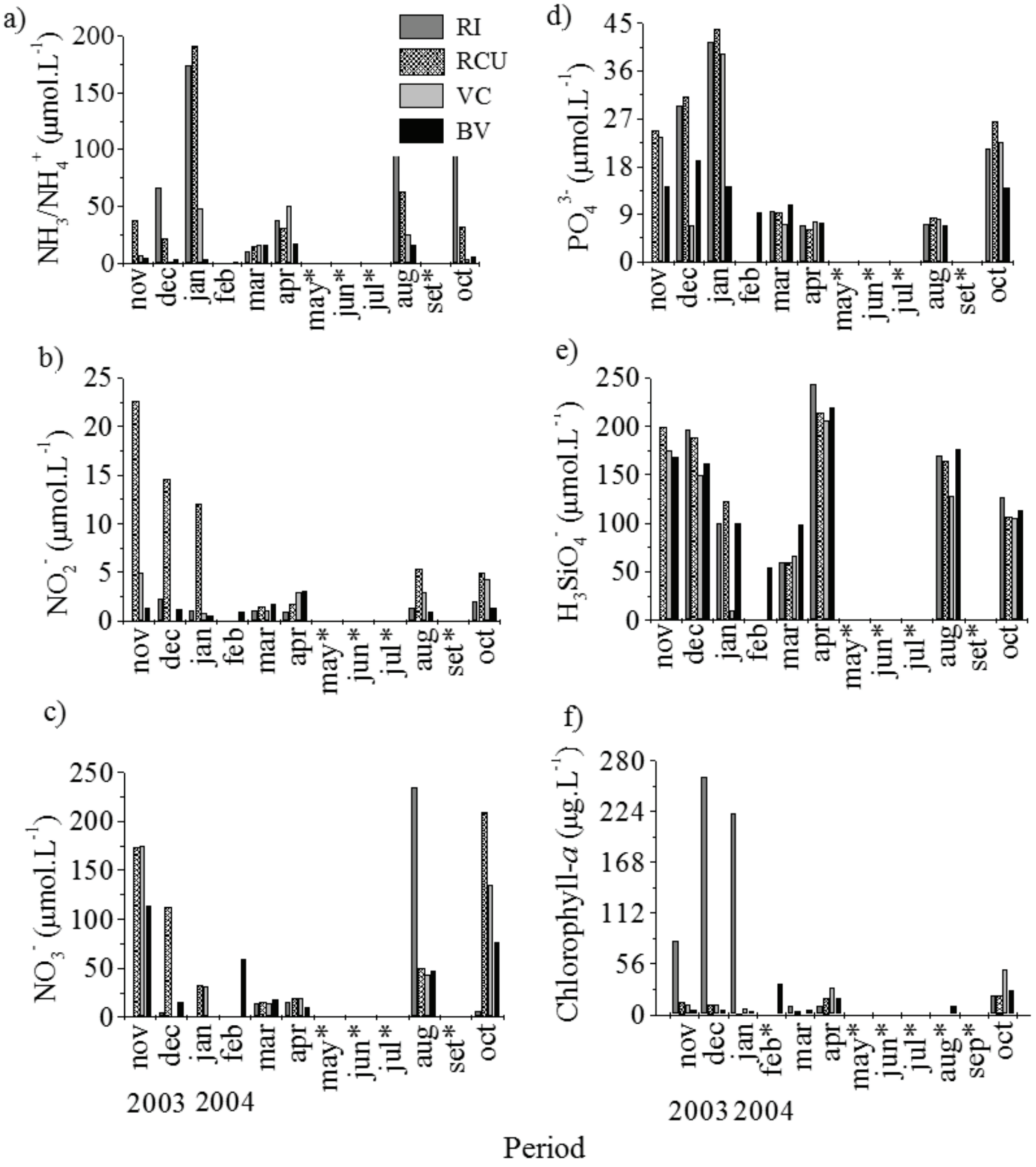

Fig. 3. Distribution of concentrations of dissolved inorganic nutrients (µmol L^{-1}) and of chlorophyll-*a* (µg . L^{-1}) in the Cachoeira River. * = months in which data was not gathered.

3f). Lowest concentrations were observed in March and April. At stations BV, VC and RCU, the highest concentrations were recorded in April and October. Lowest concentrations at these points were observed in January and March. Chlorophyll-*a* was not detected in the station VC in March.

3.5. Nutrient fluxes and inputs to estuary

Nutrient fluxes through sampling stations and inputs to the estuary can be observed in figure 4 and table 2, respectively. The highest values of nutrient fluxes occurred in March 2004, period of greatest fluvial discharge (Fig. 2; Tab. 2). Despite the low fluvial discharge observed in November 2003, nutrient fluxes were higher than in December. There was an overall increase of nutrient transport along this stretch of the river (RI to BV) during March 2004 and retention during the other months (Fig. 4f). December, January 2003 and October 2004 was marked by an increase of nitrate fluxes. Inputs of dissolved inorganic phosphorus, nitrogen and silicon (DIP, DIN and DSi, respectively) to the estuary ranged from 0.1 – 110 kg month^{-1}, 0.1 – 830 kg month^{-1}, and 0.6 – 1100 kg month^{-1}, respectively.

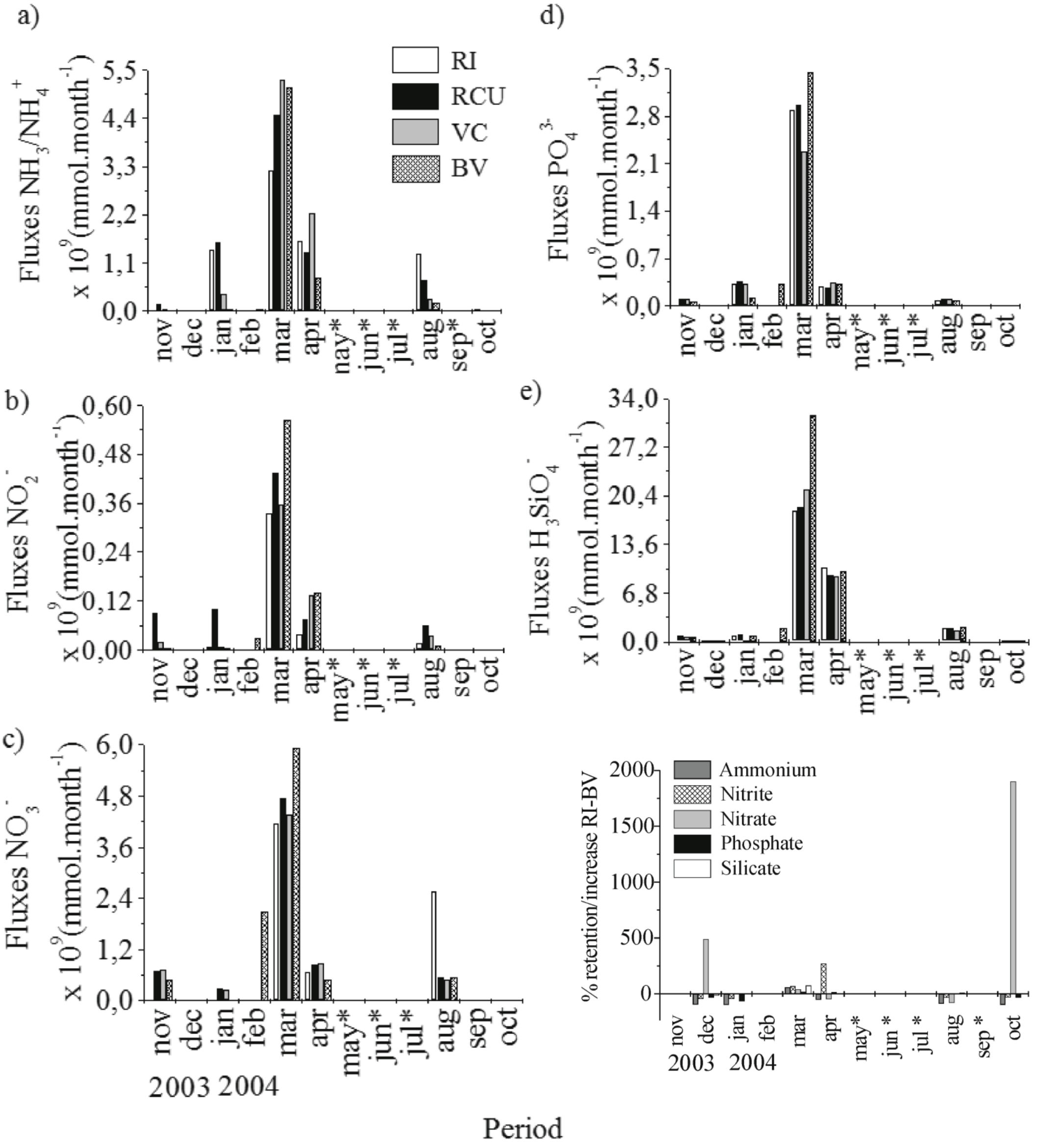

Fig. 4. Fluvial fluxes (×10^9 mmol month^{-1}) of dissolved inorganic nutrients into the Cachoeira River (**a** = ammonium, **b** = nitrite, **c** = nitrate, **d** = phosphate and **e** = silicate); **f** = Increase/retention of the normalized fluxes of dissolved inorganic nutrients in the Cachoeira River between RI and BV (%). * = months in which data sampling were not performed.

Tab. 2. Inputs of dissolved inorganic nutrients to the estuary of the Cachoeira River through station BV, normalized by the drainage basin area (10^3 mol km^2 month^{-1}), and molar ratios.

	Nov/03	Dec/03	Jan/04	Feb/04	Mar/04	Apr/04	Aug/04	Oct/04
NH_3/NH_4^+	4.2	0.1	7.2	9.1	1200	180	42	0.3
NO_2^-	1.3	~ 0	1.1	7.2	130	33	2.4	0.1
NO_3^-	1.1	0.3	0.4	490	1400	110	130	4.7
PO_4^{3-}	14	0.4	0.3	78	810	77	19	0.9
H_3SiO^-	160	3.7	200	460	7500	2300	480	7.1
DIN:DIP	8.4	1.0	0.3	6.5	3.4	9.2	9.2	6.0
DIN:DSi	0.7	0.1	0.04	1.1	0.4	0.1	0.4	0.7
DSi:DIP	11.8	8.4	7.1	5.9	9.2	29.9	25.2	8.2

4. DISCUSSION

The high water residence time during the dry period increased the relevance of the autochtonous biogeochemical processes, which can act as important sinks or sources of dissolved nutrients for photosynthesis, in addition to external fluxes. During dry months high concentrations of ammonium nitrogen and phosphate were observedat the reservoir in Itabuna (RI), which receives several inflows of urban sewage, the leachate waste of a garbage dumping site,a butchery and other smaller industrial effluents. Additionally, high rates of organic matter degradation might be responsible for the high concentrations observed at this point (Goller *et al.* 2006). These conditions allowed a development of phytoplanktonic biomass, reaching high concentrations of chlorophyll-*a*. (up to 261 µg L^{-1}). High primary production rates of phytoplankton should be responsible for the elevated values of pH and DO observed.

This river flows over an irregular and rocky bed and the rapid water current virtually ceases during the dry season, forming lentic environments (Souza 2005). From November to January, these ponds formed at sampling stations BV, VC and RCU become completely covered by floating macrophytes. Growth of such plants can block light and thus growth of phytoplankton, causing the low concentrations of chlorophyll-*a* observed. Colonization and accumulation of macrophytes at the dam (station RI) was slower, allowing phytoplankton to flourish. In the rainy season dilution of nutrients, water renovation, turbulence and turbidity leaded to lower concentrations of chlorophyll-*a*.

The nutrient fluxes were higher during the period of enhanced runoff (March and April 2004; Figs 4a - 4e). High nutrient concentrations observed in November 2003 and August 2004 resulted in an expressive mass transport of dissolved constituents, despite low water flow. During the rainy season the increment of basin area between the sampling points resulted in a general increase of dissolved material fluxes towards the estuary. However, in some months (such as August 2004, low fluvial discharge) a reduction of such fluxes at the RI point was probably due to the retention of such nutrients by macrophytes (Merriam *et al.* 2002). The long water residence time favors removal of nitrate by biological consumption by photoautotrophic/ heterotrophic organisms (Peterson *et al.* 2001). Reduction of inorganic nitrogen can also be explained by denitrification in biofilms in the root surface of floating macrophytes (Kronvang *et al.* 1999).

The percent of nutrient increase/retention at the RI-BV segment is shown in figure 4f. A general increase in the fluxes was only observed in March 2004. Removal processes account for a retention of 37 – 97% of the DIN along this stretch. All retention percentages must be underestimated, since there is an unaccounted inputs from two sewage channels from Itabuna villages right downstream from the RI point, and to the presence of small villages along the river stretch between the RCU - VC and VC - BV points.

Nitrification processes can also explain ammonia retention and the increase of nitrate fluxes in December 2003 and October 2004, especially at station RCU, where high concentrations of nitrite and nitrate were observed, possibly due to the conversion of a large part of the ammonium originating from RI (Kronvang *et al.* 1999; Peterson *et al.* 2001; Merriam *et al.* 2002).

Removal of dissolved inorganic nitrogen caused a DIN:DIP ratio which was always lower than 16:1 in the fluvial flow to the estuary (Tab. 2). This process can be partially responsible for the low DIN:DIP ratios observed in the estuary (Souza 2005).

Dissolved silicon concentration tended to reduce downstream during the dry season, which may be related to tisular incorporation in macrophytes (Goller *et al.* 2002). Just like the other nutrients, silicate concentration was reduced by dilution with a higher fluvial current, increasing again after the peak phase in March. However, the highest concentrations were observed in April, after a period of heavy rainfall. In addition to the dilution/concentration effect, transportation and reworking of the eroded material of the basin during the precipitation peak may explain such behavior. In fact a positive correlation (Tab. 3) of silicate concentrations and 1-5 days accumulated runoff appeared only with 4 and 5 days discharge (Spearman coefficient, $r_s = 0.49$; **P* <0.05). Phosphate presented negative correlations with runoff at all tested time scales (Spearman coefficient, $r_s \sim -0.57$; **P* <0.05). Results suggest that weathering and soil leaching are the main factors controlling silicate, while phosphate concentration depends mainly of the urban inputs and its concentration is more controlled by the runoff dilution effect. DIN species presented no significant correlation with runoff but amongst themselves, denoting that biological processes control the dynamics of inorganic nitrogen. These results contrast with those of Muylaert *et al.* (2009) showing that enrichment in N and P and consequent increase of planktonic and benthic diatoms biomass can exert an important role in silicate concentrations. Despite effective silicate retention in macrophyte tissues, mainly during the dry season, leaching of drainage basin during peak discharge events prevails in an annual time scale.

The DIN:DSi ratio was also lower than 1:1, except in February. The beginning of the rainy period promoted leaching of nitrate from the watershed. In this month nitrate became the main nitrogen species and DIN:DSi increased. Except for April and August, DSI:DIP relation was always lower than 16:1. These ratios do not necessarily imply that limitation of primary production by nitrogen or silicate, since concentration of these nutrients is high in fluvial waters.

Fluvial export of the Cachoeira River was high compared with the western African Rio del Rey, espe-

Tab. 3. Spearman correlation matrix of 1-5 days accumulated discharge (Q1 – Q5) and measured variables. Coefficients in bold are significant at *P* <0.05.

	Q1	Q2	Q3	Q4	Q5	T ºC	Cond.	pH	DO mg L^{-1}	DO %	TSS	Chl-*a*	NH_3/NH_4^+	NO_2^-	NO_3^-	PO_4^{3-}	H_3SiO^-
Q1	1.00	**0.99**	**0.99**	**0.99**	**0.99**	**-0.42**	**-0.66**	0.24	**0.63**	**0.61**	**0.48**	0.00	0.04	-0.16	-0.11	**-0.57**	-0.07
Q2		1.00	**0.97**	**0.95**	**0.95**	**-0.45**	**-0.61**	0.22	**0.58**	**0.55**	**0.50**	-0.05	0.07	-0.20	-0.16	**-0.55**	-0.12
Q3			1.00	1.00	1.00	**-0.39**	**-0.69**	0.26	**0.65**	**0.63**	**0.45**	0.05	0.01	-0.12	-0.05	**-0.58**	-0.03
Q4				1.00	1.00	-0.38	**-0.51**	**0.47**	**0.54**	**0.53**	0.24	0.27	0.01	-0.01	0.10	**-0.58**	**0.49**
Q5					1.00	-0.38	**-0.51**	**0.47**	**0.54**	**0.53**	0.24	0.27	0.01	-0.01	0.10	**-0.58**	**0.49**
T ºC						1.00	0.14	0.22	-0.44	-0.42	-0.25	0.11	-0.14	-0.01	-0.15	**0.40**	0.16
Cond.							1.00	-0.13	**-0.68**	**-0.69**	**-0.39**	0.17	0.09	0.09	0.11	**0.54**	-0.04
pH								1.00	0.35	0.36	0.23	**0.52**	-0.26	-0.03	-0.07	-0.33	**0.61**
DO mg L^{-1}									1.00	**0.99**	0.44	0.10	-0.18	-0.10	-0.27	**-0.51**	0.01
DO %										1.00	0.45	0.15	-0.22	-0.07	-0.27	**-0.56**	0.07
TSS											1.00	0.39	0.32	0.11	-0.27	-0.18	-0.03
Chl-*a*												1.00	0.17	0.19	-0.12	-0.22	**0.50**
NH_3/NH_4^+													1.00	**0.42**	-0.05	**0.46**	-0.05
NO_2^-														1.00	**0.48**	**0.41**	**0.39**
NO_3^-															1.00	0.13	0.18
PO_4^{3-}																1.00	-0.28
H_3SiO^-																	1.00

Tab. 4. Monthly export of dissolved inorganic silicon (DSi), nitrogen (DIN) and phosphorus (DIP) of some tropical small basin rivers during different fluvial discharge regimes. [a] Gabche & Smith (2001); [b] Sousa (2009); [c] Souza (1999); [d] Souza & Smith (2000); [e] Souza *et al*. (2003).

River	Basin area (km^2)	Discharge regimes	DSi	DIN (kg $month^{-1}$)	DIP
Rio del Rey. Western Africa[a]	3800	Dry	-	0.1	0.1
		Rainy	-	0.5	0.2
Mandovi. Western India[b]	1150	Pre monsoon	-	1.1	0.1
		Monsoon	-	230	13.7
		Post monsoon	-	3.7	1.1
Sergipe. Northern Brazil[c]	3800	Dry	-	157	4.9
		Rainy	-	17.4	<0.1
Piauí. Northern Brazil[d]	4440	Dry	-	0.0	0.0
		Rainy	-	136	4.1
Real. Northern Brazil[e]	4320	Dry	116.3	11.3	0.2
		Rainy	1310	234	7.1
Inhambupe. Northern Brazil[e]	4146	Dry	125	16.3	0.3
		Rainy	260	15.4	0.3
Jucuruçu Norte. Northern Brazil[e]	3048	Dry	76.1	54.4	0.5
		Rainy	1210	61.8	5.3
Cachoeira. Northern Brazil[e]	4600	Dry	168	251	11.0
		Rainy	802	174	26.7
Cachoeira, This study	4600	Dry	0.6	0.1	0.1
		Rainy	1130	828	111
		Post rainy	349	99	11.5

cially during the rainy season, but in general is similar to the Indian and other Brazilian East Coast rivers (Tab. 4). Our results are similar to that of the Mandovi River (India), with a monsoon regime. Estimates based on average interpolation of data resulted in an annual export of dissolved silicon, nitrogen and phosphate to the estuary of about 3.5, 2.2 and 0.3 t y^{-1} respectively. Despite high fluxes of DIN and DSi observed in the rainy season, the export of DIN on an areal basis (~0.5 kg km^{-2} y^{-1}) is about four magnitude order lower than the estimates of contemporary and even pre-industrial total nitrogen fluxes (360 – 430 kg km^{-2} y^{-1} respectively; Meybeck & Vörösmarty 2005). This can be partially explained by a large stock of organic fractions of nitrogen (not addressed in this study) and the fact that most of the basin is still covered by primary and secondary forest. But temporary retention of inorganic nitrogen in floating macrophyte tissues and losses by denitrification, driven by eutrophication, might be playing a more important role in these fluxes. During most of the year the amount and relative availability of these nutrients to coastal waters is altered by differential retention in the watershed caused by water residence time and the nature of prevailing primary producers. But a large amount of these nutrients retained in living organic matter should be delivered to the estuary and/or directly to coastal waters during the episodic high discharge events.

5. CONCLUSIONS

The combined action of eutrophication and low discharge promoted great changes in nutrient concentration and fluxes in a short river stretch. Modifications of this magnitude could only be expected as result of direct input and/or activities developed within sub-basins, with larger drained areas.

Changes in the proportion of nutrients transported along this river may have deep consequences on the estuarine biogeochemistry and nutrient availability. Eutrophication and nutrient retention in macrophyte tissues can also result in qualitative changes of organic matter export, prevailing macrophyte debris with a low labile characteristic. Small amounts of living macrophytes are delivered to the inner estuarine zone whith the runoff increase, which die after some time and decay within the estuary. But the pulsed nature of the river discharge periodically promotes direct export of a huge mass of floating macrophytes to the coastal waters.

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