The influence of castanhão reservoir on nutrient and suspended matter transport during rainy season in the ephemeral jaguaribe river (CE, Brazil)

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Abstract

Measurements of nutrient and suspended matter concentrations and loads entering and leaving the Castanhão reservoir during the rainy season were carried out to assess the influence of this large reservoir on land-sea fluvial transport in the ephemeral Jaguaribe river basin. Spatial variation indicated statistically significant attenuation of concentrations only for total phosphorous and suspended matter across the reservoir. Strong retention of nutrients and suspended matter loads by the reservoir was observed with average trapping efficiency of 89% for dissolved silicon, 98% of soluble reactive phosphorus, 71% for ammonium, 87% for total nitrogen, 98% for total phosphorus and 97% for suspended matter compared to the reservoir inflow. The dam operational procedure defined by the ephemeral conditions of the river reduced water releases compared to reservoir inflow and induced strong retention of nutrient and suspended matter loads within the reservoir when fluvial transfer occurs in this semiarid watershed.

Keywords: dam, semi-arid, nutrient budget, sediment retention, impoundment.

Influência do açude Castanhão no transporte de nutrientes e materiais em suspensão durante a estação chuvosa no intermitente rio Jaguaribe (CE, Brasil)

Resumo

Medidas de concentrações e fluxos de nutrientes e material particulado em suspensão de entrada e saída do Açude Castanhão foram efetuadas para determinar a influência de um grande reservatório no transporte fluvial entre o continente e o oceano na bacia hidrográfica intermitente do Rio Jaguaribe. A variação espacial indicou uma atenuação estatisticamente significativa ao longo do reservatório somente para as concentrações de fósforo total e material particulado em suspensão. Os resultados indicam uma forte retenção de nutrientes e do material particulado em suspensão com eficiências de retenção de 89% para sílica dissolvida, 98% para fósforo solúvel reativo, 71% para amônia, 87% para nitrogênio total, 98% para fósforo total e 97% para o material particulado em suspensão em relação aos fluxos de entrada no reservatório. A rotina de operação da barragem definida pela condição intermitente do Rio Jaguaribe reduz a descarga de água comparada com a entrada no reservatório e induz forte retenção do fluxo fluvial de nutrientes e material particulado em suspensão pelo reservatório.

Palavras-chave: barragem, semiárido, balanço de nutrientes, retenção de sedimentos, represamento de águas.

1. Introduction

The influence of dams on land-sea river transport and the related effects on the coastal zones have been reported in many areas around the world adjacent to dammed drainage basins (Humborg et al., 1997; Gong et al., 2006; Schöne et al., 2006). Additionally, some studies have focussed on the trapping efficiency of reservoirs and the effects on hydrograph, sediment and nutrient transport as well as the overall ecological conditions of the dammed watersheds (Friedl and Wüest, 2002; Gubiani et al., 2010).

Nutrients are important river constituents trapped by dams. In the literature, alterations of nutrient fluxes by dams vary from small to strong retention capacity, although the same reservoir which traps nutrients, seasonally can act as a source (Jossette et al., 1999; Friedl et al. 2004); Teodoru and Wehrli, 2005; Cook et al., 2010). This variability occurs because nutrient loadings are dominated by flows and thus dam management imposed by various reservoir purposes determines specific inflow and outflow rates and consequently the variability of nutrient loadings. Additionally, nutrient retention might occur due to attenuation of spatial concentration across the reservoir by in-lake biogeochemistry processes. Dams reduce the water transport and consequently decrease the turbidity providing favourable conditions for enhancing particles settling and *in situ* primary production. More phytoplankton might reduce particulate and dissolved nutrient loads across the flooded river stretch by processes such as nutrient uptake followed by sedimentation and adsorption on suspended matter (Friedl and Wüest 2002); Harrison et al., 2009).

Most of the described effects imposed by dams involve changes on water and sediment transports. In general, dams alter hydrographs by modifying the frequency and magnitude of seasonal discharges, the storage capacity relative to basin runoff and the influence of tributaries (Batalla et al., 2004; Molisani et al., 2006a; Singer, 2007). Similarly, sediment load is modified when a river is flooded. The changing of rivers into reservoirs increases the water residence times and induces particulate deposition across the impoundment. Estimates of global sediment flux trapped behind large reservoirs ranges from 20 to 30% of the modern continental runoff, but would increase with an additional small reservoirs inventory (Syvitski et al., 2005).

In ephemeral watersheds, the influence of dams on land-sea river transport seems to be more critical than usually described in the literature. In reservoirs located in semi-arid Northeastern Brazil, water is kept behind dams preferentially to supply drinking water for human consumption and irrigation during dry periods. In those reservoirs, strong water regulation reduces the output from dam, contrasting to reservoirs constructed preferentially to flood control and electric-power generation, usually described in the literature, where water enters and leaves the reservoir with similar discharges. Modelled estimates indicated high retention of nitrogen by reservoirs located in the semi-arid Brazilian region (Harrison et al., 2009). The state of Ceará is a region in Northeastern Brazil where all major watersheds are dammed, totalling about 8,000 reservoirs (Ceará, 2008). To minimise water loss by evaporation, the current practice is to construct larger and deeper reservoirs with a high impounded runoff index (calculated as reservoir capacity divided by mean annual runoff), which entails reducing or eliminating downstream discharges during the rainy season and always releasing operationally defined flows only to supply the estimated water volume for downstream demand requirements. Therefore, reduced outflow based on the operational procedure of reservoirs located in ephemeral watersheds suggests critical alteration of nutrient transport. Additionally, hydrological alteration of water transport induces long water residence times which can favour in-lake biogeochemical processes and additionally reduce nutrient concentrations across the reservoir.

This study measured input and output concentrations and loads of nutrients and suspended matter in the Castanhão reservoir located at the ephemeral Jaguaribe River, Northeastern Brazil, in order to determine, during the rainy season, the reservoir retention capacity of the nutrients and suspended matter transport.

2. Methods

2.1. Study area

The Jaguaribe River basin is the largest watershed in the state of Ceará, Northeastern Brazil, with 72,645 km^2 (Figure 1). The watershed is under the influence of a semi-arid climate, with average annual rainfall increasing from 450 mm in land to about 1,000 mm at the coast. Most of the rainfall (95%) occurs during the rainy season (December to June) and is characterised by discrete precipitation pulses. During the dry period (July to November), there is almost a total lack of rainfall. Potential evaporation amounts to about 2,100 mm (Ceará, 2008). Rainfall regime and high evaporation are key environmental factors inducing the ephemeral conditions of the Jaguaribe River. During the rainy season, the river flow averages 71 $m^3.s^{-1}$, with maximum discharge reaching 3,485 $m^3.s^{-1}$, measured in the middle river basin during 1984-1996 (COGERH, 1997). Considering ephemeral conditions, the runoff is absent during the dry period.

The inter-annual rainfall variability is high (Gaiser et al., 2003) which is a major factor influencing water management across the watershed. Pronounced time and space variability of rainfall, as well as recurrent droughts, is a major constraint for economic and social development which leads to poverty and widespread migration out of the affected regions during prolonged dry periods. To supply water for human consumption and irrigation, many reservoirs were constructed across the watershed varying from small farming reservoirs to the largest one, the Castanhão reservoir. About 30 dams regulate 81% of the Jaguaribe river basin.

This study was carried out in the "açude" Castanhão reservoir, the largest reservoir in the state of Ceará that

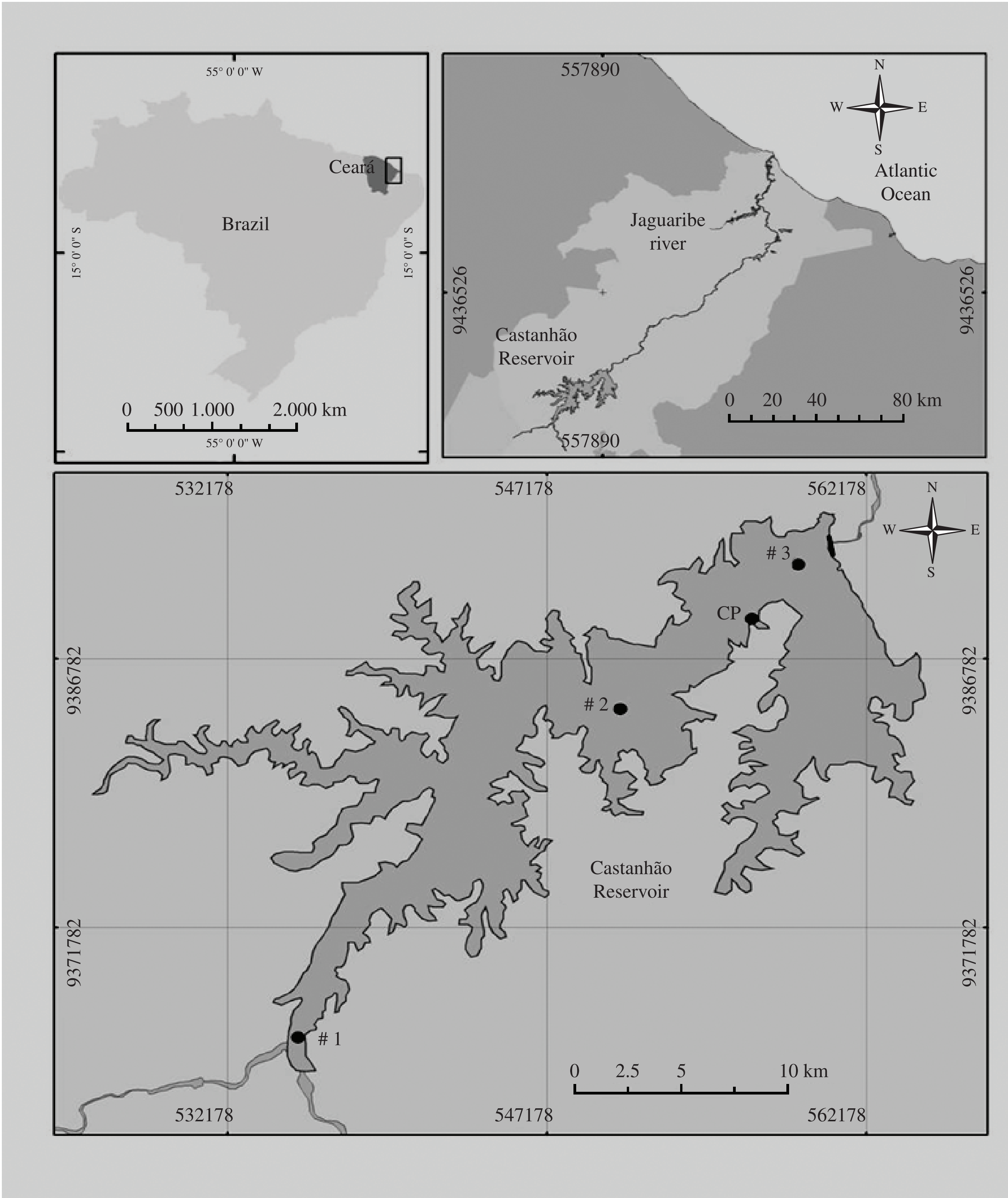

Figure 1. Study area and sampling sites across the Castanhão reservoir (#1 inlet, #2 middle and #3 dam reservoir).

marks the border of the middle and lower Jaguaribe River basin (Figure 1). The reservoir was flooded in 2004 and is classified as mesotrophic/eutrophic (Molisani et al., 2010). The reservoir is 48 km long and 3.5 km wide with a maximum depth of 60 m and can store 6.7×10^9 m^3 of water, although 4.5×10^9 m^3 is the mean storage volume. The reservoir has hypolimnetic release from the dam. The water stored in Castanhão reservoir will supply 2.5 million inhabitants across the state of Ceará through a large-scale water diversion system; it also irrigates about 40,000 ha of agricultural lands and also provides water for industrial and aquaculture purposes (Ceará, 2008).

2.2. Sampling and chemical analysis

Considering the ephemeral conditions of the river system, the monitoring of the Castanhão reservoir extended from the end of the dry season in November 2006 until the end of the rainy season in June 2007. Monthly samples were taken during six events at sampling stations in the inlet, middle and dam section of the reservoir (Figure 1).

Samples were collected from 1 m depth at the surface and at the bottom of the water column using a Van Dorn bottle and stored in pre-cleaned (HCl 1%) bottles which were vigorously rinsed with local water before filling. Physical-chemical parameters (temperature, conductivity, pH, and dissolved oxygen) were measured *in situ* using a YSI 556 Multi Probe System. Transparency was measured with a Secchi disk.

Duplicate water samples were filtered through 0.45 µm membrane filter immediately after sampling and kept frozen until analysis was performed within one day from sampling. Filters were used to obtain the suspended sediment concentration in water samples by the gravimetric procedure. Filtered water samples were analysed by spectrophotometric methods for nitrate (NO_3^- cadmium reduction), nitrite (NO_2^- colorimetric method), ammonium (NH_4^+ phenate method), orthophosphate (PO_4^{3-}) and dissolved silicate (D-Si) (vanadomolybdophosphoric acid method). Non-filtered samples were analysed simultaneously for total nitrogen (TN) and total phosphorous (TP) (persulphate method) (APHA et al., 2005; Hubaux and Vox, 1970). Water samples were also filtered through GF/F glass fibre filters and chlorophyll *a* determination was carried out by 90% acetone extraction and spectrophotometric analysis (APHA et al., 2005).

Water inflow into the reservoir from Jaguaribe River and releases from the dam are daily monitored by the water distribution company that operates the reservoir. Briefly, dam operational rules are defined by the water volume stored during the antecedent rainy season and by the demand withdrawal throughout the subsequent hydrological year (COGERH and DNOCS, 2006). The approach for calculating loads entering and leaving the reservoir was to use mean daily discharge flows and nutrient and suspended matter concentrations over the sampling period as summarised by the formula 1:

$$\text{Load (ton rainy season}^{-1}) = K\sum_{i=1}^{n} (CiQi/n) \qquad (1)$$

Where K is the conversion factor to take account of the rainy season (K = 6 months/number of sampling months); *Ci* is the instantaneous concentration as determined by discrete samples ($mg.L^{-1}$); *Qi* is the instantaneous discharge at the time of sampling (i.e. daily average) ($m^3.s^{-1}$); and n is the number of sampling campaigns. Differences of nutrients and suspended matter concentrations between surface and bottom waters and among sampling sites across the reservoir were tested by the nonparametric Wilcoxon Signed Rank Test.

3. Results

3.1. Limnological analysis

Limnological conditions of the Castanhão reservoir are summarised in Table 1. All samples showed concentrations below the quantification limit for nitrite (5 $\mu g.L^{-1}$) and nitrate (35 $\mu g.L^{-1}$). Reservoir inlet (riverine input) was characterised by fluvial physiographic, narrow transversal section (~200 m), lower mean depth and higher turbidity waters. All limnological variables could not be statistically

Table 1. Mean ±SD and range of limnological variables measured in the inlet, middle and dam reservoir (n = 6).

Variables	#1 (Inlet)	#2 (Middle)	#3 (Dam)
Mean depth (m)	7.0	19	32
Secchi disk depth (m)	1.1 (0.38) 0.65-1.5	1.9 (0.32) 1.6-2.3	2.0 (0.33) 1.7-2.4
Suspended matter ($mg.L^{-1}$)	8.3 (9.3) 2.5-25	3.7 (2.1) 0.72-8.4	1.5 (0.7) 0.72-2.5
Temperature (°C)	29.2 (0.7) 28.3-30.4	28.9 (1.0) 27.8-30.9	28.6 (1.2) 27.3-30.8
pH	7.1 (0.4) 6.6-7.8	7.4 (0.20) 7.2-7.7	7.7 (1.7) 7.2-8.1
Dissolved Oxygen ($mg.L^{-1}$)	2.2 (1.7) 0-4.4	4.0 (2.2) 1.2-6.5	5.1 (1.7) 2.7-7.7
D-Si ($mg.L^{-1}$)	5.7 (0.79) 4.8-6.7	5.1 (1.3) 3.4-7.7	5.4 (1.5) 4.0-7.5
NH_4^+ ($\mu g.L^{-1}$)	118 (42) 80-168	130 (13) 110-150	216 (269) 80-695
PO_4^{-3} ($\mu g.L^{-1}$)	77 (89) 10-228	46 (21) 23-76	22 (28) 7-71
TN ($\mu g.L^{-1}$)	870 (279) 530-1,192	850 (410) 320-1,700	661 (309) 216-1,040
TP ($\mu g.L^{-1}$)	151 (114) 61-345	58 (29) 24-84	29 (26) 7.0-74
Chlorophyll-*a* ($\mu g.L^{-1}$)	3.3 (1.4) 1.6-5.5	7.5 (4.5) 0.71-15	6.7 (3.5) 1.7-13

distinguished between surface and bottom waters of this reservoir section ($p > 0.05$). The middle and dam stations have wider transversal section (4-6 km), higher mean depth and less turbid waters compared to reservoir inlet.

In the middle reservoir, a statistically significant lower concentration of TP was found in surface (33 µg.L^{-1}) than in bottom waters (57 µg.L^{-1}) ($p < 0.05$). For all other limnological variables, statistically significant differences were not found between surface and bottom waters. The dam station presented statistically significant higher values of temperature and dissolved oxygen in surface waters (29.6 °C and 6.0 mg.L^{-1}, respectively) than in bottom waters (28.4 °C and 4.8 mg.L^{-1}, respectively) ($p < 0.05$). For all other variables, surface and bottom waters could not be statistically distinguished.

The spatial distribution of nutrients and suspended matter across the reservoir indicated that concentrations of D-Si, SRP and TN in the inlet reservoir were not statistically different than other sampling sites ($p > 0.05$). Only TP and suspended matter concentrations were statistically higher in the inlet than the middle and dam stations, showing attenuation of these variables across the reservoir. Ammonium concentrations in the inlet were statistically higher than in the middle ($p < 0.05$), but similar to the dam station. The attenuation of nutrient and suspended matter concentrations was not observed between middle and dam stations, which had similar values of D-Si, SRP, NH_4^+, TP, TN, Chlorophyll-*a* and suspended matter.

3.2. Nutrients and suspended matter loads

Reservoir input and output loadings were constructed based on nutrient and suspended matter concentrations at the inlet and dam stations, and measured water discharge into the reservoir from the Jaguaribe River and regulated dam water discharge downstream to the basin (Tables 2 to 7). Since there was not a clear vertical gradient of nutrients within the water column, the concentration values were averaged over depth. River water discharge input into the reservoir ranged from zero m^3.s^{-1} during the first sampling event in November, 2009, illustrating the ephemeral conditions of the Jaguaribe River, to a maximum of 131 m^3.s^{-1} in February, 2010. On the other hand, the outlet dam discharge, imposed by downstream demand withdrawal, varied from 5.0 m^3.s^{-1} to 15 m^3.s^{-1} during the sampling period.

The first sampling event showed no water inputs into reservoir because of the ephemeral river conditions and the absence of D-Si inflow (Table 2). However, dam releases 5.4 kg.day^{-1} of D-Si, which confers the reservoir as a source of D-Si to downstream areas during dry season when no runoff occurs across the Jaguaribe Basin. For all other sampling events during the rainy season, D-Si retention efficiency of the reservoir compared to Jaguaribe river input varied from 32% to 97%. On average for the rainy season, D-Si input into reservoir was 5100 tons while only 600 tons were released which represents a retention efficiency of 88% for this nutrient.

For SRP, the first sampling in the dry season showed the reservoir as a source of this nutrient in the absence of inflow. The outflow was measured at 18 kg.day^{-1} from the dam (Table 3). For all other sampling events, the reservoir retention varied from 85% to 99%. On average, the SRP inflow to the reservoir in the rainy season was 111 tons and the outflow was 1.9 tons which represents retention of 98% of the nutrient inputs from the Jaguaribe River.

The ammonium fluxes indicated that during the dry season, the reservoir also acts as a source of this nutrient transferring 2.0 kg.day^{-1} to the downstream basin (Table 4). For all other sampling events, less ammonium was released from the reservoir than entered from the Jaguaribe River, which represents a reservoir retention efficiency varying from 34% to 97%. On average, the Castanhão reservoir receives during the rainy season from its upstream basin, 105 tons of ammonium while 30 tons are transferred seaward, which represents a retention capacity of the reservoir of 71% of the ammonium inputs.

Total nitrogen measurements also showed reservoir exportation of 12 kg.day^{-1} during the dry season considering the absence of nitrogen input into reservoir by the Jaguaribe River (Table 5). For all other sampling events during the rainy season, retention capacity of TN for the reservoir varied from 1% to 99%. On average for the rainy season, TN input to the reservoir was 733 tons and the output

Table 2. Dissolved silica (D-Si) fluxes across the Castanhão reservoir for each sampling period and for the rainy season. Retention percentages expressed in parentheses.

Month	Inflow D-Si (mg.L^{-1})	Water discharge (m^3.s^{-1})	Inflow (kg.day^{-1})	Outflow D-Si (mg.L^{-1})	Water discharge (m^3.s^{-1})	Outflow (kg.day^{-1})	Export retention (kg.day^{-1})
Nov/2006	-	-	-	4.15	15	5.4	5.4*
Jan/2007	5.95	13	6.7	4.72	11	4.5	2.2 (32%)
Feb/2007	4.83	131	55	4.32	5.0	1.9	53 (96%)
Mar/2007	5.06	56	25	4.03	5.0	1.7	23 (92%)
May/2007	6.65	71	41	7.48	8.0	5.2	36 (87%)
Jun/2007	6.32	35	19	6.35	5.0	2.7	16 (85%)
Tons per rainy season			5,100			600	4,500 (88%)

*Reservoir as a source of D-Si (export).

Table 3. Soluble reactive phosphate (SRP) fluxes across the Castanhão reservoir for each sampling period and for the rainy season. Retention percentages expressed in parentheses.

Month	Inflow PO_4 ($mg.L^{-1}$)	Water discharge ($m^3.s^{-1}$)	Inflow ($g.day^{-1}$)	Outflow PO_4 ($mg.L^{-1}$)	Water discharge ($m^3.s^{-1}$)	Outflow ($g.day^{-1}$)	Export retention ($g.day^{-1}$)
Nov/2006	-	-	-	14	15	18	18*
Jan/2007	41	13	46	7.0	11	6.7	39 (85%)
Feb/2007	228	131	2580	19	5.0	8.1	2572 (99%)
Mar/2007	84	56	406	71	5.0	31	375 (92%)
May/2007	23	71	138	7.0	8.0	4.8	133 (96%)
June/2007	10	35	29	7.0	5.0	3.0	26 (89%)
Tons per rainy season			111			1.9	109 (98%)

*Reservoir as a source of SRP (export).

Table 4. Ammonium (NH_4^+) fluxes across the Castanhão reservoir for each sampling period and for the rainy season. Retention percentages expressed in parentheses.

Month	Inflow NH_4^+ ($\mu g.L^{-1}$)	Water discharge ($m^3.s^{-1}$)	Inflow ($kg.day^{-1}$)	Outflow NH_4^+ ($\mu g.L^{-1}$)	Water discharge ($m^3.s^{-1}$)	Outflow ($kg.day^{-1}$)	Export retention ($kg.day^{-1}$)
Nov/2006	-	-	-	132	15	0.17	0.17*
Jan/2007	158	13	0.18	123	11	0.12	0.061 (34%)
Feb/2007	106	131	1.2	80	5.0	0.035	1.17 (97%)
Mar/2007	80	56	0.39	100	5.0	0.043	0.34 (88%)
May/2007	168	71	1.03	695	8.0	0.48	0.55 (53%)
June/2007	80	35	0.24	80	5.0	0.035	0.21 (85%)
Tons per rainy season			105			30	75 (71%)

*Reservoir as a source of NH_4^+ (export).

Table 5. Total nitrogen (TN) fluxes across the Castanhão reservoir for each sampling period and for the rainy season. Retention percentages expressed in parentheses.

Month	Inflow TN ($\mu g.L^{-1}$)	Water discharge ($m^3.s^{-1}$)	Inflow ($kg.day^{-1}$)	Outflow TN ($\mu g.L^{-1}$)	Water discharge ($m^3.s^{-1}$)	Outflow ($kg.day^{-1}$)	Export retention ($kg.day^{-1}$)
Nov/2006	-	-	-	804	15	1.0	1.0*
Jan/2007	1192	13	1.34	1404	11	1.33	0.001 (0.4%)
Feb/2007	889	131	10	216	5.0	0.093	9.9 (99%)
Mar/2007	657	56	3.18	718	5.0	0.31	2.87 (90%)
May/2007	530	71	3.25	530	8.0	0.37	2.88 (88%)
June/2007	1084	35	3.28	803	5.0	0.35	2.93 (89%)
Tons per rainy season			733			85	648 (88%)

*Reservoir as a source of TN (export).

was 85 tons, representing a retention capacity of 88% of TN inputs.

For total phosphorus, the flux in the dry season also indicated that the reservoir is a source of TP exporting 0.29 $kg.day^{-1}$, since no input occurred from the ephemeral upstream basin (Table 6). During the rainy season, the reservoir had a retention capacity from 80% to 99% of the total phosphorus income. For the rainy season, the average TP inflow was 189 tons while the outflow was 2.65 tons, representing a nutrient retention of 187 tons or 98% of the total phosphorus input from the upstream basin.

The estimated suspended matter loads also showed the reservoir acting as a source of suspended matter during the dry season, exporting 92 $g.s^{-1}$, and retaining 79% to 99% of the incoming SM during the rainy season (Table 7). On average, for the rainy season, 17,507 tons of SM were received by the reservoir while 151 tons were transferred

Table 6. Total phosphorus (TP) fluxes across the Castanhão reservoir and for each sampling period and for the rainy season. Retention percentages expressed in parentheses.

Month	Inflow TP (µg.L^{-1})	Water discharge (m^3.s^{-1})	Inflow (kg.day^{-1})	Output TP (µg.L^{-1})	Water discharge (m^3.s^{-1})	Outflow (kg.day^{-1})	Export retention (kg.day^{-1})
Nov/2006	-	-	-	19	15	0.025	0.025*
Jan/2007	92	13	0.10	21	11	0.020	0.083 (80%)
Feb/2007	345	131	3.9	22	5.0	0.010	3.9 (99%)
Mar/2007	161	56	0.78	74	5.0	0.032	0.74 (96%)
May/2007	61	71	0.37	7.0	8.0	0.005	0.37 (99%)
June/2007	97	35	0.29	22	5.0	0.010	0.28 (97%)
Tons per rainy season			189			2.65	187 (98%)

*Reservoir as a source of TP (export).

Table 7. Suspended matter (SM) fluxes across the Castanhão reservoir for each sampling period and for the rainy season. Retention percentages expressed in parentheses.

Month	Inflow SM (mg.L^{-1})	Water discharge (m^3.s^{-1})	Inflow (kg.day^{-1})	Outflow SM (mg.L^{-1})	Water discharge (m^3.s^{-1})	Outflow (kg.day^{-1})	Export retention (kg.day^{-1})
Nov/2006	-	-	-	6.1	15	7.9	7.9*
Jan/2007	7.1	13	8.0	1.8	11	1.7	6.3 (79%)
Feb/2007	25	131	277	2.5	5.0	1.1	276 (99%)
Mar/2007	4.8	56	23	0.7	5.0	0.30	22.7 (98%)
May/2007	2.5	71	15	1.2	8.0	0.82	15(94%)
June/2007	2.6	35	7.8	1.1	5.0	0.48	7.3 (96%)
Tons per rainy season			11,507			151	11,356 (98%)

*Reservoir as a source of SM (export).

downstream which represents suspended matter retention of 98% within the reservoir.

4. Discussion

Before major damming, the intermittent discharge of the Jaguaribe River into the coastal zone ranged from zero up to 7,000 m^3.s^{-1}, but could stay more than 18 months completely dry during extended drought periods. Cascade reservoirs along the river basin reduced the average freshwater discharge into Atlantic Ocean from 200 m^3.s^{-1} to 80 m^3.s^{-1} by 1980 and 60 m^3.s^{-1} after 1986. With the flooding of the Castanhão reservoir, the discharge into the coast was further reduced to about 20 m^3.s^{-1} (Campos et al., 1997).

The results indicated that the river section downstream from the Castanhão reservoir is made perennial by a dam spill of 15 m^3.s^{-1} in the dry season (November 2006) when the river is naturally dry. When the river flows again in the rainy season, the outlet discharge of the Castanhão is reduced (5-8 m^3.s^{-1}) due to the increase of basin runoff and water availability to downstream demands. Therefore, during the rainy season, the runoff contribution of 60% of the Jaguaribe river basin is artificially determined by downstream human consumption. On the other hand, the artificial runoff from dam spill keeps a permanent freshwater flow even in the dry season. Water management can retain behind the dam 89% of runoff incoming from the Jaguaribe River. The reservoir volume and inflow/outflow determined the residence time of about 4,000 days which is higher than those for registered reservoirs with the purpose of flood control and hydropower generation (Teodoru and Wehrli, 2005; Jossette et al., 1999; Hart et al., 2002).

As nutrient and suspended matter loadings can be determined by flows, the strong water regulation in the Castanhão reservoir induces higher retention of river material than in reservoirs with smaller water regulation. Dam cascading in the Siene Basin, for example, retains 13 to 73% of the suspended matter income, 60% of phosphate, 40% of total phosphorus and 50% of silica. On the other hand, these reservoirs can also export suspended sediments (158% of the income) and ammonium (100 to 350% of the income) according to dam management (Jossette et al., 1999). Similarly, the management of Iron Gate I Reservoir retains 56% of the suspended matter income and 4% of D-Si, but also exports 18%, 60% and 13% of TN, SRP and TP, respectively (Friedl et al., 2004; Teodoru and Wehrli, 2005). Thus, the average retention capacity of the Castanhão for suspended matter and nutrients estimated in this study (89% for D-Si, 98% for SRP, 71% for NH_4^+, 87% for TN, 98% for TP, 97% for suspended matter) is higher than for registered reservoirs in the literature. During the dry season, when the ephemeral river is naturally dry, the Castanhão reservoir acts as a source of river materials, as measured in the first sampling event (November). However, when extrapolated for the entire dry season, the order of magnitude of suspended matter and nutrient loads measured in November would not compensate the loads retained during rainy season.

Additionally to loads dominated by flows, attenuation of nutrient and suspended matter concentrations by in-lake biogeochemical processes across the reservoir could explain its retention capacity. For suspended matter, concentration attenuation from the inlet to dam across the reservoir was reported for Iron Gate I (from 34 to 17 $mg.L^{-1}$) and for the Saguling (141 to 24 $mg.L^{-1}$), as well as for the Castanhão reservoir (from 11 to 2.6 $mg.L^{-1}$), demonstrating that, independent of the reservoir purpose, the slowdown of river flow by dam induces deposition of the suspended matter across the impoundment. For nutrients, the spatial distribution of concentrations from inlet to dam is highly variable. The cascade reservoirs in the Siene Basin, for example, showed a marked decrease of phosphate, nitrogen and silica when water flow through the reservoirs and attenuation were related to phytoplankton uptake and benthic denitrification (Jossette et al., 1999). The Iron Gate I reservoir presented statistically significant higher outflow concentrations of dissolved inorganic nitrogen (9% increases along the reservoir), orthophosphate (60% increase) and total nitrogen (12% increase) attributed to resuspension and anthropogenic emission. The same pattern was reported for total phosphorus and D-Si between inflow and outflow (Friedl et al., 2004; Teodoru and Wehrli, 2005). The Saguling reservoir also showed variable nitrogen and phosphorus outlet concentrations compared to inflow (Hart et al., 2002). Across the Castanhão reservoir, only TP and suspended matter showed statistically significant attenuation ($p < 0.05$). Statistical significant positive correlation between TP and suspended matter ($p < 0.05$) (Molisani et al., 2010) suggests that the nutrient and suspended matter are being trapped into the reservoir by deposition from the water column to the bottom of the reservoir. Total phosphorus retention is in agreement with existing models derived from temperate lakes and reservoirs (Cook et al., 2010). The comparison among reservoirs showed that, independently of dam management and water residence time, nutrient concentration distribution is highly variable and controlled by many factors, including anthropogenic inputs, which might increase concentrations across the reservoir and makes it function as a nutrient source to downstream areas.

TP retention induces increasing ratios of TN:TP measured at 21, 56 and 87 for inlet, middle and dam reservoir, respectively. The prevalence of nitrogen species illustrated by ammonium availability and positive correlation with chlorophyll a ($p < 0.05$) induces the dominance of non-fixing nitrogen *Cyanophyceae* species, such as *Planktolyngbya limnetica* (Lemmerman), *Pseudanabaena galeata* (Böcher), *P. catenata* (Lauterborn), *Pseudanabaena limnetica* (Lemmerman) Komárek, *Pseudanabaena cf. raphidioides* (Geitler), *Synechocystis aquatilis* (Sauvageau) in Castanhão reservoir (Molisani et al., 2010). Some studies have discussed the importance of nitrogen-fixing phytoplankton on TN:TP loading and nutrient loadings in semi-arid reservoirs (Howarth et al., 1988; Cook et al., 2010). Thus, we can suggested that nitrogen inputs from in-lake and land-based anthropogenic activities such as urbanisation, agriculture, husbandry and cage aquaculture, supply this nutrient to the water column and might be a key factor influencing the dominance of the non-fixing nitrogen algae *Cyanophyceae*.

In conclusion, the present study indicated that the Castanhão reservoir inserts a strong regulation on water outflow compared to inflow which induces high retention rates of nutrients and suspended matter during the rainy season behind the dam when the ephemeral Jaguaribe River flows seaward. Although downstream dam measurements of fluxes were not provided we suggested that land-sea material transport and watershed interaction to the adjacent coastal zone are highly threatened. Freshwater inflow into estuaries of the state of Ceará was estimated and the results indicated that the downstream position of the cascade reservoirs across all watersheds and dam operational procedure are important factors reducing and artificially controlling the continental runoff to the sea (Molisani et al., 2006b). As a result of decreasing river influence on this Brazilian coastal zone, changes on coastal ecosystems have been identified, such as increasing saline wedge intrusion into estuaries, landward mangrove migration, erosion of seaward mangrove fringes and changes on communities of the local crab *Ucides cordatus* (Linnaeus, 1763) and estuarine fishes such as mullets (*Mugil* spp.) and robalos (*Centropomus* spp.) (Lacerda and Marins, 2002; Maia et al., 2006; Lacerda et al., 2007).

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