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Pristine aquatic systems in a Long Term Ecological Research (LTER) site of the Brazilian Cerrado

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Abstract The maintenance of limnological monitoring programs in the Cerrado Domain is crucial as a provision of useful information about temporal variations in land use and their respective water quality responses, considering its importance as water source for different Brazilian hydrographic basins. The purpose of this research was to describe limnological variables of low-order lotic systems located in the Cerrado Long Term Ecological Research (LTER) site (Environmental Protection Area (APA) Gama and Cabeça de Veado, Federal District of Brazil). Altogether, nine different streams were considered in this study. Samplings were conducted between 2010 and 2012, concentrated in the dry and rainy seasons. The sampling sites were generally characterized by low nutrient concentrations (e.g., medians, TP=14.8 μg L^{-1}, TN=20.0 μg L^{-1}, NO_3= 13.8 μg L^{-1}) and slightly acidic waters (median, pH= 5.3), with quite low electrical conductivity values (median=6.4 μS cm^{-1}). However, water quality degradation as a response to diffuse pollution was reported in some sampling points (e.g., Onça and Gama streams), expressed by relatively higher N and P concentrations, which were probably highlighted by the good water quality of the data set as whole. Although there was a trend to higher values of nitrogen forms during the dry season, significant statistical differences between the seasonal periods were reported only for the variables temperature and dissolved silica, which were higher in the dry and rainy season, respectively. The streams located in the preserved areas inside the ecological stations of APA Gama and Cabeça de Veado can still be considered good examples of reference lotic systems in the Cerrado Domain; notwithstanding, this study reported incipient signs of water quality degradation which cannot be overlooked in future limnological monitoring.

Keywords Protected areas · Nutrients · Savanna · Tropical limnology

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Introduction

The Cerrado Domain (Brazilian savanna) occupies the great plateau of Central Brazil with a phytophysiognomic mosaic ranging from woodlands to open savannas (Ribeiro and Walter 2008; Bustamante et al. 2012). Although its international recognition as a biodiversity hotspot (Myers et al. 2000), Cerrado ecosystems are currently among the most threatened in Brazil due to intense urban occupation and, mostly, due to landscape fragmentation resulted from the increase in agricultural and pasture activities in the last decades (Carvalho et al. 2009). These changes in land cover have caused impacts on catchments of Cerrado Domain, especially related to water pollution, stream silting, and loss of riparian vegetation (e.g., Wantzen et al. 2006; Silva et al. 2007, 2011; Fonseca et al. 2013). In savannas, which are ecosystems frequently recognized by their nutrient-limited soils, these changes can affect nutrient cycling by the additional inputs of nitrogen and phosphorus in human activities, especially through fertilizers used to improve agricultural productivity (Bustamante et al. 2006; Filoso et al. 2006). Influences of agricultural land use on whole-stream metabolism (e.g., benthic microbial biomass, community respiration, and gross primary production) of Cerrado streams were also reported by Gücker et al. (2009).

The region is rich in headwaters and low-order streams which flow into different Brazilian hydrographic basins. This peculiarity highlights the importance of conservation practices in the Cerrado considering its role as a water source to hydrographic regions such as Pantanal, Amazon, and São Francisco (Lima and Silva 2007). Furtherly, the maintenance of local limnological monitoring programs is crucial as a provision of useful information about temporal variations in land use and their respective water quality responses.

The Brazilian Long Term Ecological Research (LTER) Program is funded by the Ministry of Science,Technology and Innovation and the National Counsel of Technological and Scientific Development (MCTI/CNPq). It is focused on the establishment of permanent research sites and has as one of its missions to consolidate the knowledge about the functioning of Brazilian ecosystems. Brazil officially joined the International Long Term Ecological Research network in the year 2000 (Barbosa et al. 2004); currently, it comprises 28 sites distributed along Brazilian biomes (CNPq. National Counsel of Technological and Scientific Development 2013), including the Environmental Protection Area (APA) "Gama and Cabeça de Veado," located in the Federal District of Brazil (FD), where this research was conducted. This APA was created in 1986 with the goal of protecting the headwaters of Paranoá watershed, whose water resources have been strategic for the FD. Some of its streams have been studied in previous papers. For example, Silva et al. (2011) evaluated the effects of different land covers and seasonality on limnological variables of Cerrado streams and included Pitoco and Taquara streams among the ones located in areas with natural land cover. Also, Parron et al. (2011) studied the flows of N and P in solution along the topographic gradient from upland to stream in Pitoco's gallery forest. Another important issue explored in Cerrado LTER sites is the influence of frequent burning on nutrient cycling (Pivello et al. 2010; Resende et al. 2011).

Recently, Fonseca et al. (2013) proposed nutrient baselines in Cerrado low-order streams and included some streams of the mentioned APA among their sampling sites (Capetinga and Gama streams). These authors reported point source inputs as the main factor responsible for the water quality deterioration in the FD and emphasized the low nutrient concentrations in Cerrado pristine lotic systems when compared to data from other regions such as the Amazon and southeast Brazil, highlighting the importance of headwaters as reference areas. They also mentioned the importance of collecting data about pristine environments, considering that they are becoming progressively scarce under the increase of anthropogenic pressures on natural environments around the world (Smith et al. 2003; Pardo et al. 2012).

The goal of this research was to describe limnological variables of aquatic systems located in the Cerrado LTER site. This study continues the monitoring program which has been conducted in the streams mentioned above (Pitoco, Taquara, Capetinga, Gama) and brings new data about lotic systems still not studied, most of them under pristine conditions. It increases the number of streams that should be considered as "reference" sites in the Cerrado region, refining the values proposed by Fonseca et al. (2013).

Study area

This study was conducted in the Environmental Protection Area (APA) Gama and Cabeça de Veado, located in the Federal District of Brazil, in the core of Cerrado Domain (Brazilian savanna). This area comprises 23,650 ha including urban, rural, and preserved areas such as the ecological stations located at Água Limpa Farm (thereafter FAL), at IBGE Reserve (Brazilian Institute of Geography and Statistics) (thereafter RECOR), and at Brasília's Botanical Garden (thereafter JBB) (Fig. 1). These three areas represent 44.71 % of the APA (UNESCO. Organização das Nações Unidas para a Educação, a Ciência e a Cultura 2003).

Altogether, nine different low-order streams were considered in this study (Table 1). All of them are located in the ecological stations cited above or around their borders (Fig. 1), but still inside de APA. Some of the streams (Catetinho and Cabeça de Veado) have been used as water supply by the Federal District sanitation company (CAESB). Predominant land cover in the subwatersheds is natural vegetation, with untouched riparian forests, except in the Gama stream, which

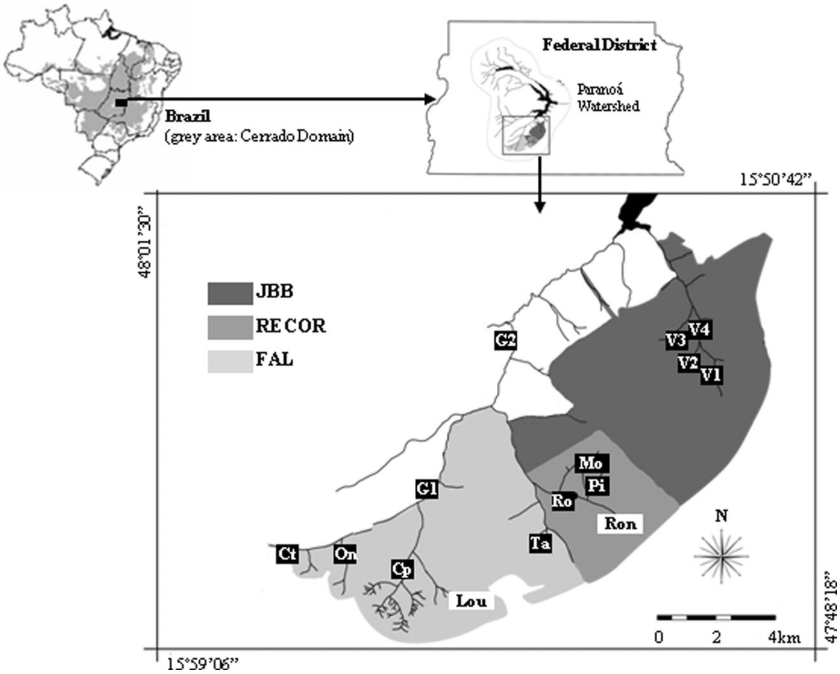

Fig. 1 Location of study sites in the Federal District of Brazil. *JBB* = Brasília's Botanical Garden, *RECOR* = Ecological Reserve of the Brazilian Institute of Geography and Statistics (IBGE), *FAL* = Água Limpa Farm. *Black rectangles* correspond to streams (codes can be seen in Table 1)

presents agricultural activities in one of its margins. Moreover, Onça stream headwaters are located in a rural area, although the sampling site is within FAL.

Climate in the Cerrado Domain is Aw (rainy tropical, according to Köppen classification), marked by strong seasonality, with a rainy season from October to April (mean temperature around 29 °C) and a dry season from May to September (mean temperature around 18 °C). Annual mean precipitation is around 1,500 mm, ranging from 750 to 2,000 mm (da Silva et al. 2008).

The most common soils in the Cerrado Domain are Latossolos (46 %), according to the Brazilian Soil Classification; it corresponds to Oxisols in the US soil classification. These typically tropical soils are weathered and highly acidic; their permeability can be compared to sandy soils. They have low phosphorus availability and variable drainage, and their colors vary from red to yellowish due to the high concentration of iron and aluminum oxides and hydroxides (Reatto and Martins 2005; Vendrame et al. 2010). Gleissolos (there is no analogous order in US Soil Taxonomy, although the Aquox suborder would be similar) are also common near streams (Silva et al. 2011). These are reduced hydromorphic soils generally occupying landscape depressions frequently flooded (Reatto and Martins 2005; Bispo et al. 2011).

Material and methods

Samplings were conducted between 2010 and 2012, concentrated in the dry (August-September, 2010, 2011) and rainy (March-April, 2011, 2012) seasons, between 9 a.m. and 3 p.m. In the streams Taquara (March and September 2011) and Cabeça de Veado (S4) (September 2011, March 2012), samplings were done only two times. There was one sampling site in each stream, except in the streams Gama and Cabeça de Veado, with two and four sampling sites, respectively.

Water temperature, dissolved oxygen, pH, and electrical conductivity were measured in the field using standard electrodes (Yellow Spring Instruments). Turbidity was measured using a turbidimeter HACH 2100P. Water samples were collected in previously acid-washed polypropylene bottles and kept in a cold storage unit until returning to the laboratory. Ammonium, nitrate, dissolved silica, and soluble reactive phosphorus were analyzed after water filtration in glass fiber GF/F filters. Unfiltered samples were used for total nitrogen (TN) and total phosphorus (TP) determinations. Nutrients along with total solids, dissolved solids, and suspended solids were analyzed according to standard methods (APHA 2005).

Table 1 Description of sampling sites in streams

Area	Stream	Code	Order	Depth (m)	Width (m)	Water velocity (m s^{-1})	Stream substrate	Geographical coordinates
FAL	Onça	On	2nd	0.5	4.7	0.20	Silt/clay, sand	15° 57′ 18.00” S 47° 57′ 45.40” W
FAL	Capetinga	Cp	2nd	0.3	2.3	0.60	Gravel	15° 57′ 40.1” S 47° 56”36.5” W
FAL	Taquara	Ta	1st	0.1	0.4	0.30	Litter	15° 57′ 15.2” S 47° 53′ 43.8” W
JBB	Cabeça de Veado (S1)	V1	1st	0.6	1.3	0.20	Gravel	15° 53′ 51.4” S 47° 50′ 16.1” W
JBB	Cabeça de Veado (S2)	V2	1st	0.5	1.0	0.27	Silt/clay, litter	15° 53′ 43.3” S 47° 50′ 41.8” W
JBB	Cabeça de Veado (S3)	V3	1st	0.3	1.4	0.22	Silt/clay, litter	15° 53′ 18.9” S 47° 50′ 52.0” W
JBB	Cabeça de Veado (S4)	V4	3rd	0.4	2.4	0.80	Boulder	15° 53′ 20.4” S 47° 50′ 33.6” W
RECOR	Pitoco	Pi	1st	0.3	0.8	0.30	Boulder	15° 55′ 47.3” S 47° 52′ 37.2” W
RECOR	Monjolo	Mo	1st	0.2	1.8	0.25	Sand	15° 55′ 47.5” S 47° 52′ 55.9” W
RECOR	Roncador	Ro	2nd	1.1	1.0	0.20	Silt/clay	15° 56′ 12.95” S 47° 53′ 12.1” W
[a]	Catetinho	Ct	1st	0.3	2.5	0.60	Gravel/boulder	15° 57′ 06.7” S 47° 58′ 54.7” W
[a]	Gama (S1)	G1	3rd	0.7	7.0	0.25	Silt/clay	15° 55′ 37.6” S 47° 55′ 48.6” W
[a]	Gama (S2)	G2	3rd	0.6	7.0	0.35	Silt/clay	15° 53′ 08.7” S 47° 54′ 21.3” W

FAL Água Limpa Farm, *JBB* Brasília’s Botanical Garden, *RECOR* Ecological Reserve of the Brazilian Institute of Geography and Statistics (IBGE)

[a] Sites located nearby FAL

Data analysis

Descriptive analysis was applied to data using medians and minimum/maximum values as measures of central tendency and variation, respectively, considering each sampling site (Tables 2, 3, 4, 5). Mann–Whitney non-parametric test was used to check significant statistical differences between dry and rainy seasons (α=0.05), considering all the streams together. Multivariate descriptive analysis was carried out by applying principal component analysis (PCA) to the abiotic data in the streams using a covariance matrix with data transformed by ranging (Figs. 2–3). Some selected variables were also used in box plot graphs using median and minimum/maximum values (Fig. 4). Statistical software used for multivariate analyses was PC-ORD version 5.0, and for box plots, Statistica 7.

Results

The sampling sites were characterized by nutrient-poor, slightly acidic waters (pH ranging from 4 to 7), with quite low electrical conductivity values (in general, <10 μS cm^{-1}) (Tables 2–5). Principal component analysis using 12 abiotic variables and sampling units corresponding to all the lotic systems showed higher nutrient concentrations in the streams located around the site FAL (mainly streams Onça and Gama) (Fig. 2), whose sampling units were the main responsible for the ordination pattern in the first axis, along with Taquara and some of the sampling units from Catetinho. They were located in the left side of the axis 1, related to higher values of total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate, ammonium, and electrical conductivity. These variables presented the higher Pearson

Table 2 Limnological variables (median, minimum, and maximum values) of sampling sites located in the Água Limpa Farm (FAL) (APA Gama and Cabeça de Veado, Federal District, Brazil)

Variable	Onça Stream (On)			Capetinga Stream (Cp)			Taquara Stream (Ta)		
	Med	Min	Max	Med	Min	Max	Med	Min	Max
pH	5.7	5.3	6.2	4.7	4.6	5.5	5.9	5.8	5.9
EC (μS cm^{-1})	14.0	5.6	17.2	5.2	3.6	8.3	6.5	4.6	7.1
DO (mg L^{-1})	4.8	4.6	6.6	6.1	5.6	6.3	3.9	3.8	5.1
WT (oC)	19.6	15.5	25.7	18.7	15.6	21.0	22.6	21.2	23.6
TP (μg L^{-1})	39.5	13.0	63.0	6.0	<1.0	12.0	82.0	73.0	91.0
SRP (μg L^{-1})	13.5	6.4	25.0	2.8	<1.0	5.0	29.5	19.0	40.0
NH_4^+ (μg L^{-1})	47.5	5.0	69.0	3.5	2.0	17.0	62.0	34.0	90.0
NO_3^- (μg L^{-1})	130.9	11.2	163.0	19.1	9.7	33.5	31.0	24.9	37.0
TN (μg L^{-1})	161.6	12.1	200.1	23.0	11.6	54.0	161.6	63.2	260.0
Turbidity	3.7	0.7	6.4	1.5	0.9	2.2	3.0	0.8	5.3
TS (mg L^{-1})	3.5	<1.0	8.0	<1.0	<1.0	2.0	2.5	<1.0	4.0
SS (mg L^{-1})	1.5	<1.0	3.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0
DS (mg L^{-1})	2.5	<1.0	5.0	<1.0	<1.0	<1.0	2.0	<1.0	3.0
SiO_2 (mg L^{-1})	1.8	1.6	2.0	0.8	0.7	1.0	1.2	1.1	1.2

and Kendall coefficients in relation to axis 1 (>0.9), which explained 42 % of data variability. Sampling units of other streams were all located in the right side of the graph. This trend of more nutrients in the streams located in the borders of FAL is also clear in the box plot graphs (Fig. 4).

The axis 2, which explained only 17 % of data variability, ordinated the sampling units by seasonal differences. In general, sampling units corresponding to rainy season were placed in the upper side of the graph, related to higher values of total solids, suspended solids, turbidity, and dissolved solids. For the dry

Table 3 Limnological variables (median, minimum, and maximum values) of sampling sites located in the Brasília's Botanical Garden (JBB) (APA Gama and Cabeça de Veado, Federal District, Brazil)

Variable	Cabeça de Veado (V1)			Cabeça de Veado (V2)			Cabeça de Veado (V3)			Cabeça de Veado (V4)		
	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max
pH	5.2	4.7	7.5	4.8	4.6	6.4	5.8	4.8	6.6	5.8	5.8	5.8
EC (μS cm^{-1})	4.9	3.8	7.8	4.2	3.8	5.8	3.4	3.0	3.8	5.2	4.7	5.7
DO (mg L^{-1})	6.3	6.2	6.5	5.5	5.2	5.5	6.1	5.0	6.4	5.1	5.1	5.1
WT (oC)	21.1	19.5	21.8	20.8	18.9	22.5	20.3	18.8	22.2	22.9	21.4	24.4
TP (μg L^{-1})	7.1	5.0	19.0	3.0	<1.0	10.0	3.5	2.0	15.0	24.0	22.0	26.0
SRP (μg L^{-1})	<1.0	<1.0	7.0	<1.0	<1.0	4.0	<1.0	<1.0	6.0	8.0	6.0	10.0
NH_4^+ (μg L^{-1})	<1.0	<1.0	10.0	6.5	2.0	25.0	3.5	2.0	18.0	6.5	5.0	8.0
NO_3^- (μg L^{-1})	4.0	1.1	29.8	6.2	2.0	33.0	4.2	2.0	30.0	26.5	25.0	28.0
TN (μg L^{-1})	4.4	2.0	43.0	9.3	5.4	59.0	6.4	4.8	49.0	34.9	32.0	37.8
Turbidity	0.7	0.4	1.6	1.0	0.6	1.5	1.4	1.3	2.2	1.6	1.4	1.7
TS (mg L^{-1})	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	4.0	2.5	2.0	3.0
SS (mg L^{-1})	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	1.5	<1.0	2.0
DS (mg L^{-1})	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	3.0	<1.0	<1.0	<1.0
SiO_2 (mg L^{-1})	1.1	<1.0	1.5	1.9	1.0	2.3	1.4	1.1	2.0	2.0	2.0	2.1

Table 4 Limnological variables (median, minimum, and maximum values) of sampling sites located in the Ecological Reserve of the Brazilian Institute of Geography and Statistics (RECOR) (APA Gama and Cabeça de Veado, Federal District, Brazil)

Variable	Pitoco Stream (Pi)			Monjolo Stream (Mo)			Roncador Stream (Ro)		
	Med	Min	Max	Med	Min	Max	Med	Min	Max
pH	4.6	4.1	4.9	5.1	4.1	6.0	4.6	4.1	5.2
EC (μS cm^{-1})	5.7	5.2	7.3	3.7	3.3	6.3	7.9	7.4	8.6
DO (mg L^{-1})	5.2	4.6	5.8	5.5	5.3	6.6	5.2	5.0	6.5
WT (oC)	22.6	21.9	24.4	21.0	19.2	22.5	19.4	17.0	22.0
TP (μg L^{-1})	17.0	12.5	25.0	9.5	<1.0	20.0	15.3	9.0	29.0
SRP (μg L^{-1})	4.3	3.8	11.0	1.5	<1.0	8.0	3.6	3.0	12.0
NH_4^+ (μg L^{-1})	<1.0	<1.0	3.0	6.5	5.0	11.0	3.0	2.0	6.0
NO_3^- (μg L^{-1})	1.5	1.2	6.1	13.8	9.0	21.2	4.6	2.1	8.3
TN (μg L^{-1})	1.8	1.7	17.0	21.2	18.0	39.0	8.5	5.1	18.0
Turbidity	0.8	0.3	1.0	1.2	0.8	3.1	1.2	0.5	1.5
TS (mg L^{-1})	<1.0	<1.0	<1.0	2.0	2.0	6.0	<1.0	<1.0	<1.0
SS (mg L^{-1})	<1.0	<1.0	<1.0	<1.0	<1.0	5.0	<1.0	<1.0	<1.0
DS (mg L^{-1})	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
SiO_2 (mg L^{-1})	1.6	0.8	2.5	1.4	1.1	1.7	1.6	1.1	2.7

seasons, the analysis suggested higher concentrations of dissolved silica, and also a trend to higher values of nitrogen in the water. Although with these trends, Mann–Whitney test reported significant statistical differences ($p<0.05$) between seasons only for the variables temperature and dissolved silica, with higher values in the rainy and dry seasons, respectively.

The PCA also suggested an increase in nutrient concentrations in 2011, especially during the dry season. No sampling unit from 2010 was placed in the left side of

Table 5 Limnological variables (median, minimum, and maximum values) of sampling sites located nearby the Água Limpa Farm (FAL) (APA Gama and Cabeça de Veado, Federal District, Brazil)

Variable	Catetinho Stream (Ct)			Gama Stream (G1)			Gama Stream (G2)		
	Med	Min	Max	Med	Min	Max	Med	Min	Max
pH	5.0	4.8	5.7	5.3	4.7	5.8	6.5	5.4	6.8
EC (μS cm^{-1})	6.9	6.6	7.5	10.3	6.5	11.3	15.9	13.6	27.4
DO (mg L^{-1})	5.9	5.2	7.0	6.0	1.9	6.3	6.1	5.5	6.3
WT (oC)	21.6	20.5	22.2	20.3	19.0	22.7	20.5	17.9	23.3
TP (μg L^{-1})	31.0	5.0	61.0	37.2	10.0	57.0	27.0	4.0	43.0
SRP (μg L^{-1})	8.0	<1.0	24.0	13.3	5.0	25.0	7.8	<1.0	18.0
NH_4^+ (μg L^{-1})	2.0	<1.0	12.0	9.2	7.0	27.0	15.6	5.0	39.0
NO_3^-(μg L^{-1})	20.0	10.0	38.9	38.2	13.1	81.0	35.4	12.0	63.0
TN (μg L^{-1})	23.4	12.0	53.0	49.4	14.2	96.0	51.4	23.0	82.0
Turbidity	1.9	1.1	3.2	13.0	5.4	1,230.0	11.3	4.5	29.2
TS (mg L^{-1})	18.5	<1.0	40.0	9.0	3.0	300.0	16.5	9.0	49.0
SS (mg L^{-1})	<1.0	<1.0	37.0	3.0	2.0	280.0	3.5	3.0	16.0
DS (mg L^{-1})	3.0	<1.0	32.0	6.0	<1.0	20.0	6.5	6.0	46.0
SiO_2 (mg L^{-1})	0.9	0.8	1.2	0.7	0.6	0.9	0.7	0.5	1.7

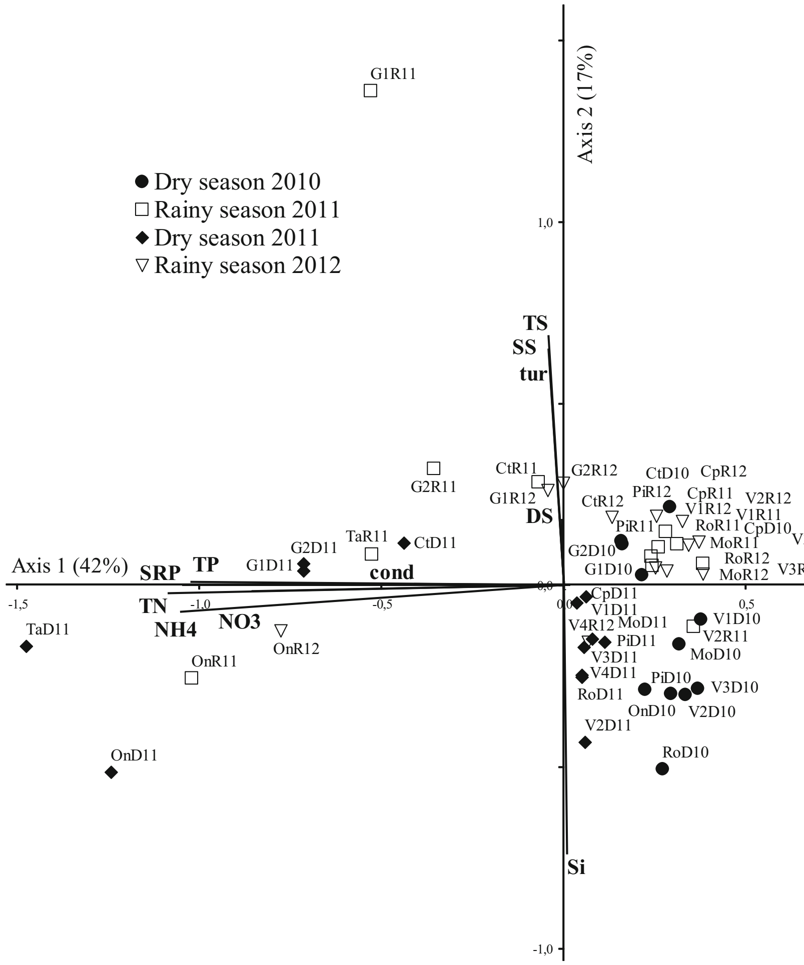

Fig. 2 Biplot of PCA for 12 water abiotic variables (*cond* = electrical conductivity, *alk* = alkalinity, *temp* = water temperature, *DO*= dissolved oxygen, SRP, TP, TN, NH4, NO_3, NO_2, pH, and turbidity) and 48 stream sampling sites (the *first two letters* represent the name of the stream according to Table 1; the *third letter* represents dry=*D* or rainy=*R* seasons; the *numbers* represent the year: 2010, 2011, or 2012)

the graph, even the ones belonging to the sites with more nutrients (Onça, Gama, and Catetinho). In Onça stream, in special, there was an abrupt increase in nutrient concentrations between the dry season of 2010 and the rainy season of 2011 (PT from 13.0 to 42.0 μg L^{-1}, SRP from 6.4 to 15 μg L^{-1}, NH_4^+ from 5.0 to 54.0 μg L^{-1}, NO_3^- from 11.2 to 129.4 μg L^{-1}, TN from 12.1 to 200.1 μg L^{-1}).

In order to better explore the limnological variables in the more pristine systems, another PCA was conducted excluding sampling units from the streams Onça, Gama, and Taquara (Fig. 3). In this new data set, the sampling units were more spread out on the graph, and the seasonal gradient was the main responsible for data ordination. This can be seen in the axis 1, which explained 38 % of data variability. Samples from the dry season were generally located in the right side, related to higher concentrations of dissolved silica and, in a smaller extent, nitrogen forms, while samples from the rainy seasons appeared on the opposite side of the graph.

Discussion

General literature has described lower nutrient concentrations in Cerrado natural waters than in other tropical regions, for both phosphorus and nitrogen (Wantzen 2003; Bustamante et al. 2006; Fonseca et al. 2013). Complementing the median values of nutrient concentrations reported in this study with other research studies conducted in pristine low-order streams of Cerrado (e.g., Gücker et al. 2009; Silva et al. 2011; Fonseca et al. 2013), TP values in Cerrado reference areas have ranged from 0.006 to 0.015 mg L^{-1}, nitrate from 0.004 to 0.040 mg L^{-1}, and ammonium from 0.002 to 0.056 mg L^{-1} (Table 6). For TN values in Cerrado pristine streams, no literature was

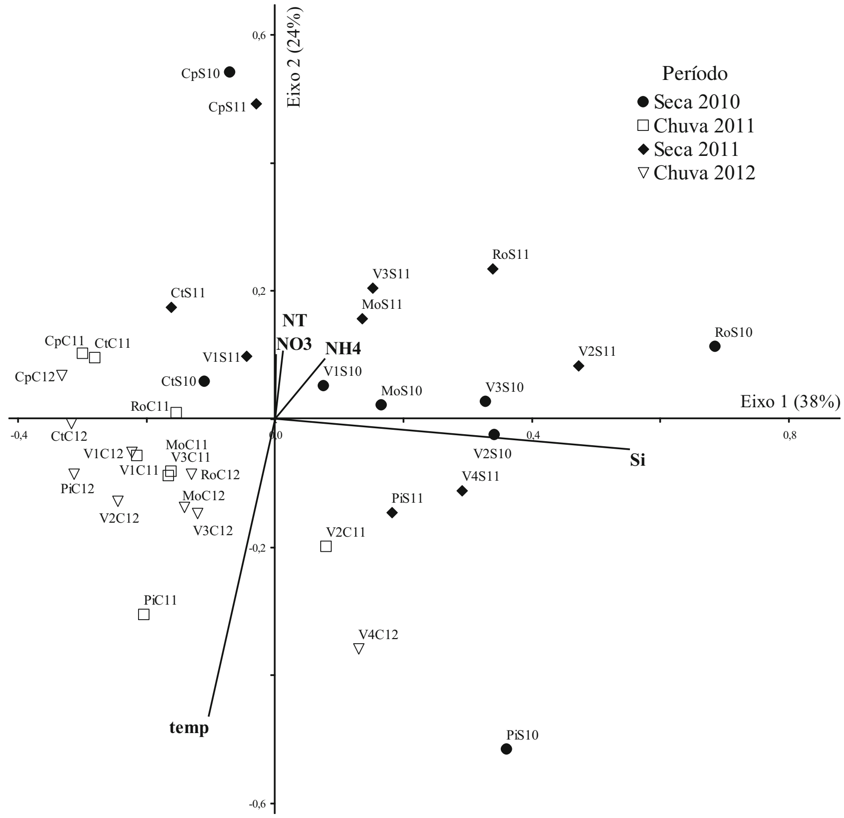

Fig. 3 Biplot of PCA for 12 water abiotic variables (*cond* = electrical conductivity, *alk* = alkalinity, *temp* = water temperature, *DO*= dissolved oxygen, SRP, TP, TN, NH4, NO_3, NO_2, pH, and turbidity) and 36 stream sampling sites (the *first two letters* represent the name of the stream according to Table 1; the *third letter* represents dry=*D* or rainy=*R* seasons; the *numbers* represent the year: 2010, 2011, or 2012). The streams Onça, Gama, and Taquara were not considered in the analysis

found. In any manner, the median value reported here (0.017 mg L^{-1}) was quite low when compared to that of reference streams from Southeastern Brazil (0.34 mg L^{-1}, in Cunha et al. (2011)).

A direct consequence of N and P enrichment in aquatic systems is a shift in their trophic status toward eutrophic conditions. This process has been accelerated worldwide by anthropogenic activities, being considered a specific case of water pollution which has affected both lotic and lentic systems all over the world (Hilton et al. 2006; Dodds 2006). Most of the systems in APA Gama and Cabeça de Veado have been in their pristine conditions. Notwithstanding, the present study reported local signs of incipient water quality degradation in the streams Onça and Gama when nutrient concentrations are considered.

The sampling sites in Gama stream have been monitored since 2006, and previous results can be found in Fonseca et al. (2013). Based on a protocol of rapid and qualitative assessment, these authors have already described these sampling sites as "impacted," in a scale ranging from "natural" to "very impacted." The presence of agricultural activities in their margins occupying what was once covered by riparian vegetation, associated with precarious housing, was responsible for this poor classification. In fact, the maintenance of limnological monitoring in Gama stream was justified by the interest of local population on their water resources.

According to Fonseca et al. (2013), although with the low ecological status of Gama streams resulting from the visual impressions, this stream was in an intermediary position considering water nutrient concentrations compared to other streams located in the Federal District under different impact levels, some of them receiving effluents from sewage plants. However, in a data set composed mostly by reference areas located very close to Gama stream, its relatively higher nutrient concentrations are highlighted.

The same occurrence happened with Onça stream. Although the sampling site presents preserved riparian forest, its headwater is closed to a small rural community (Núcleo Rural Córrego da Onça), which probably explains the results reported. The rural community of Córrego da Onça was created in 1993 and comprises

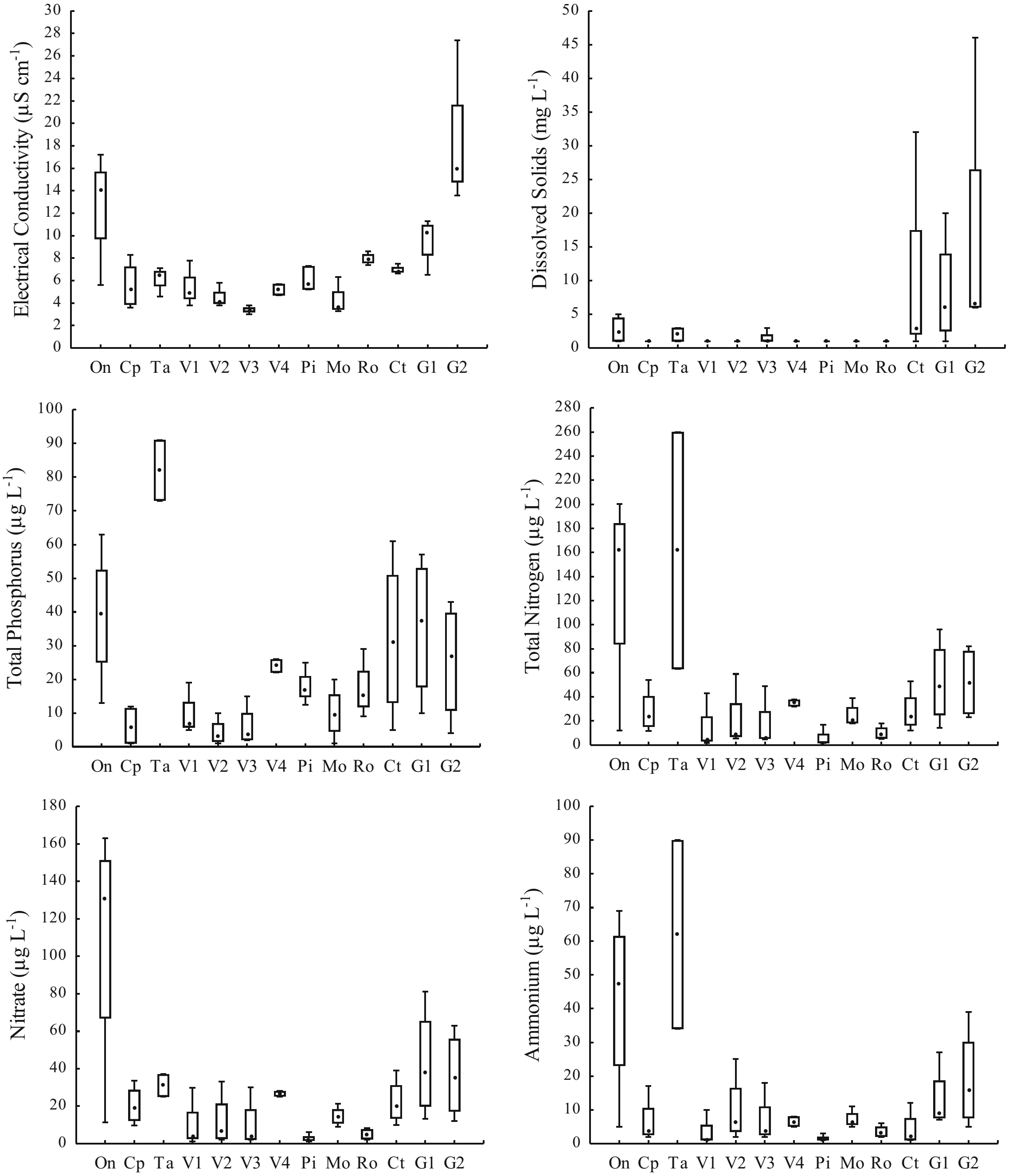

Fig. 4 Box plot graphs (median, minimum, and maximum values) of some selected limnological variables in streams located in the APA Gama and Cabeça de Veado. Stream codes can be seen in Table 1

324 occupants, whose main activities are fruit growing and grain production, along with bovine, poultry, and shepherding (GDF. Government of the Federal District 2012). Lorenz and Feld (2013) have already discussed the importance of considering the basin occupation as a whole in order to better understand local water quality data. In some cases, even though with significant changes in the predominant watershed land cover, water quality did not appear to respond immediately. As an example, Chaves and Santos (2009) studied a small watershed in the FD and did not report variations in water quality parameters after 13 years of significant land use

Table 6 Comparison between the values reported by this paper and the literature about reference areas

	This paper Central Brazil	Fonseca et al. (2013) Central Brazil	Silva et al. (2011)[a] Central Brazil	Gücker et al. (2009) Central Brazil	Cunha et al. (2011) Southeastern Brazil	Biggs et al. (2004)[a] Brazilian Amazon
DO	5.56	5.27	6.98–7.79	2.6	–	–
pH	5.3	6.42	–	6.2	–	–
EC	6.4	7.3	4.03–3.99	30.9	–	–
TP	0.015	0.006	–	–	0.04	–
SRP	0.005	<0.001	0.006–0.001	0.002	–	–
TN	0.019	–	–	–	0.34	–
Ammonium	0.005	0.039	0.056–0.042	0.002	0.1	–
Nitrate	0.014	0.040	0.009–0.007	0.004	–	0.091–0.082
Nitrite	–	0.005	0.032–0.012	–	–	
TDN	–	–	0.284–0.250	–	–	0.266–0.182

DO dissolved oxygen, *EC* electrical conductivity, *TP* total phosphorus, *SRP* soluble reactive phosphorus, *TN* total nitrogen, *TDN* total dissolved nitrogen (all nutrients are expressed in mg L^{-1}) (adapted from Fonseca et al. (2013))

[a] Values for wet and dry seasons, respectively

intensity and landscape fragmentation. According to these authors, probably the maintenance of undisturbed riparian vegetation had buffered the impacts on the water quality. Ammonium values reported in the cited article was around 0.04 mg L^{-1}, while conductivity was around 4.0 μS cm^{-1}.

Another stream that deserves some attention is Catetinho, which presented relatively high values of TP and dissolved solids, comparable to the ones reported in Onça and Gama streams. But, nitrogen forms did not follow this same pattern nevertheless.

Taquara stream can be considered an irregularity among the pristine streams studied here, with the highest values of TN, TP, and ammonium. In fact, this sampling site was located in a shallow (~10-cm depth) spring area, with abundant litter and a closed canopy promoted by the riparian vegetation. Probably, these relatively higher values resulted from litter decomposition, considering that dissolved oxygen in this sampling point was lower (median 3.9 mg L^{-1}) when compared to that in the other sampling sites. Furthermore, oxidized nitrogen compounds such as nitrate showed relatively lower concentrations when compared to reduced forms such as ammonium.

Nitrogen yields from undisturbed watersheds in the American tropics (mainly Amazon) were studied by Lewis et al. (1999), who reported a strong relationship between yields of all nitrogen fractions and runoff. In this regard, some variables directly related to runoff, such as precipitation and vegetation type, will also influence nitrogen yields. For example, according to these authors, savanna yields far less total nitrogen and individual nitrogen fractions than the forest. They also reported that the proportion of ammonium in dissolved inorganic nitrogen (DIN, as the sum of ammonium and nitrate concentrations considering that nitrite is a negligible contributor to inorganic nitrogen in flowing waters) under natural conditions is between 15 and 23 %. In the present study, the average proportion was 33 % considering all streams, which is in agreement to values reported by Gücker et al. (2009) in Cerrado streams from the State of Minas Gerais. Nevertheless, Silva et al. (2011) reported N-NH_4^+ as the predominant inorganic nitrogen form in Cerrado streams with different land cover, and this predominance was even higher under natural cover, representing around 70 % of the total dissolved inorganic nitrogen. All this data suggests that although the ratio between ammonium and nitrate in Cerrado streams has been quite variable when different research studies are compared, a trend to a slightly higher ammonium/nitrate proportion (when compared to Lewis et al. (1999)) has been detected. Probably, this pattern may not be attributable to high ammonium values itself, but to the relatively low values in nitrate concentrations.

The concentration of ammonium and nitrate in Cerrado streams may be 5–10 times lower than in the streams of the eastern Amazon, according to the review of Bustamante et al. (2006). In forested watersheds in the Brazilian Amazon, Biggs et al. (2004) reported relatively high concentration values of nitrate, ranging from 0.081 to 0.092 mg L^{-1}. They attributed these values to the natural sandy soils of their region, emphasizing that soil type (texture and nutrient status) can influence regional patterns in the concentrations of dissolved and particulate nutrients in streams.

According to Nardoto and Bustamante (2003), nitrate content in Cerrado soils is quite low, which could be related to low nitrification rates. These authors reported higher nutrient availability in Cerrado soils located at RECOR during the rainy season and attributed this to inputs through rainfalls along with peaks in microbial activities during the first rain events. They discussed that the soil microbial biomass dynamics in savannas allows accumulation and conservation of nutrients in biologically forms during the dry season, when plant activities are low; at the beginning of the rainy season, nutrients are released but rapidly taken up by plants. As a consequence, it can be inferred that the output to streams for nitrogen by runoff is relatively low. Parron et al. (2011) studied fluxes of N and P in a gallery forest located in the same area and also reported very low values of these nutrients in soil solution, with small outputs to streams for both of them. Considering phosphorus, Cerrado soils are also poor, and it has been attributed to phosphorus adsorption by aluminum and iron oxides (Silva et al. 2011).

In regards to seasonality, the present study reported a slight trend for more nutrients during dry season. Silva et al. (2011), however, reported an opposite pattern in natural streams from the FD. Although with these trends, neither found significant statistical differences between seasons for nutrient variables (except here, for silica). In Silva et al. (2011), samplings were conducted bi-weekly in the wet season and monthly in the dry season, while in the present study, samplings were concentrated at the end of the dry (September) and wet (March) seasons. As already mentioned in the papers cited above, although more nutrients are released in Cerrado soils at the beginning of the rainy season, their rapid absorption by plants results in a decrease in inorganic nitrogen concentrations (Nardoto and Bustamante 2003). In such dynamic ecosystems, maybe short-term fluctuations in water nutrient concentrations should be considered more carefully instead of to consider the season as whole, as is usually done in the papers.

It may be particularly relevant when fire events happen in these subwatersheds releasing the nutrients retained in plant tissues or in litter on the soil surface, in a process called pyromineralization (Resende et al. 2011). Over the long term, however, repeated fires may decrease organic P fraction availability in the top soil (Resende et al. 2011). As was concluded by Pivello et al. (2010), the nutrient availability in Cerrado soils is not affected by the time of burning, but by fire frequency. During this study, no fire events had occurred immediately before the fieldwork. There was only a large burning in September 2011, but a few weeks after the end of dry season samplings. The following samplings were done 4 months later, at the end of the wet season (March 2012), and no significant alterations in water variables that would be attributed to fire influence were detected. In this sense, interannual or even spatial variations sometimes can be more representative than seasonality.

Conclusions

The presence of protected areas in the ecological stations of FAL, RECOR, and JBB has been responsible for the general maintenance of good water quality in their subwatersheds. However, the present results also showed that some of these systems have been responding to anthropogenic pressures through slight increases in their nutrient concentrations. Diffuse nutrient sources are probably the main cause for that, coming from small agricultural occupation around them.

The low-order streams located in the preserved areas inside the ecological stations of APA Gama and Cabeça de Veado can still be considered good examples of reference lotic systems in the Cerrado Domain, with their clear, nutrient-poor, and slightly acidic waters. Certainly, because of these pristine features around their neighborhood, streams such as Onça and Gama, although not yet strongly impacted, stayed apart from the others in this data set. These incipient signs of water quality degradation cannot be disregarded, and oncoming studies in the same LTER sites considering biotic communities and sediment variables should confirm the results reported here.

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