CAPÍTULO 16

CHARACTERIZATION AND ASSESSMENT OF AQUATIC ENVIRONMENTS IN THE TURVO/GRANDE BASIN

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ABSTRACT

The Turvo/Grande basin is located in the northwestern portion of the São Paulo State and is composed by 64 municipalities, with a drainage area of 15.925 km^2. Total human population accounts for 1,3 millions inhabitants, with 91% located in urban areas. This predominance of urban populations with the low availability of surface water, low rates of natural vegetation coverage, and soils with high potential to erosion can be cited as factors that threat the quality and quantity of aquatic resources of the basin. In this chapter, we described the main biotic and abiotic features of the Turvo/Grande basin and provided an evaluation on the present condition of streams, main rivers, and marginal lagoons, aiming to identify the major threats to the aquatic resources of the basin and provide suggestions to management. The main threat to small streams is physical habitat degradation, mostly derived from the lack of forest vegetation along the riparian buffer. For main rivers, metal contamination is of high concern, additionally to siltation, that is related to the lack of forest coverage in the basin. Knowledge on the marginal lagoons dynamics is still scarce, albeit preliminary efforts have revealed high biodiversity of fish and aquatic macrophytes, as also the existence of complex biotic interactions yet to be elucidated. Riparian forest recovery, soil conservation, control of metals and other contaminants, and floodplain protection must be of utmost interest to managers regarding aquatic resource conservation of such important river basin.

1 INTRODUCTION

The quality of water resources is of critical importance to the economic and social development of a country. Notwithstanding, the rapid population growth and industrialization have been leading to high rates of contamination of water resources making it unsuitable for its intended use in accordance with Brazilian laws (RESOLUÇÃO CONAMA 357/05). To promote the conservation, preservation, and restoration of water resources, the São Paulo State Government created in 1994 the Law 9,034 that divides the State in 22 units for water resource management (*Unidades de Gerenciamento de Recursos Hídricos* - UGRHI). The Turvo/Grande basin (BHTG) is the UGRHI 15, located in northwestern region of the São Paulo State. This basin is considered of critical importance for conservation because its water availability is around 960 m^3/inhabitants/year (HERNANDES et al., 2006), lower than what is recommended (1,500 m^3/inhabitants/year) by the United Nations (JIMENEZ; ASANO, 2008).

The rural areas in the BHTG are mainly impacted by agricultural activities, which result in erosion and contamination by agrochemicals from the main crops of the basin, as sugar cane and citrus (SILVA et al., 2007a). The urban areas contribute to the contamination of water bodies, mainly by domestic sewage discharge, since wastewater treatment efficiency ranges from 55 to 98% in different municipalities that compose the BHTG (CETESB, 2012).

Hence, in order to identify the main threats to the aquatic ecosystems of the basin as a way to subsidize water resources conservation actions, we describe in this chapter the main biotic and abiotic characteristics of the BHTG, as well as the current situation of streams, large rivers, and marginal lagoons, which are the main aquatic ecosystems in this basin.

2 GENERAL CHARACTERISTICS OF THE BHTG

The BHTG is composed by 64 municipalities and has a drainage area of 15.925 km^2. Total human population accounts for 1,3 millions inhabitants, 91% of whom are located in urban areas and the remaining in rural areas (PERFIL REGIONAL, 2007), which yields a density of 84 inhabitants/km^2 (SILVA et al., 2007b). The Turvo River rises in the municipality of Monte Alto at 772 m height, north of São Paulo State, and flows about 267 km to the left margin of the Rio Grande, in the municipality of Cardoso at 442 m height.

The original vegetation is currently reduced to 3.7% of its former area (NALON et al., 2008), and is distributed in small (< 10 ha) and unconnected fragments (SMA/IF, 2005) that are characterized as Semideciduous Forest with patches of a savannah-like vegetation (named “Cerrado”) and riparian forests (SALIS et al., 1995). The extensive land use for livestock grazing, sugar cane and citrus crops, established itself as the main matrix in which a large part of the remaining forests in the region are embedded (SILVA et al., 2007b). The fertile soil and slightly rough topography – more than 80% of the basin area is flat (slope < 3%) or smoothly rolling (slope < 8%) (SILVA et al., 2007b) – are factors that favor the activities such as ranching, coffee production and other perennial crops, which turned the region into economic exploration target since the nineteenth century.

The region has investments from various industries such as the food industry of agricultural animal and origin, beverages, sugar and alcohol, rubber, leather, footwear, furniture, jewelry, machinery, and equipments (PESQUISA DA ATIVIDADE PAULISTA, 2009). There is a regular monitoring of surface water contaminants that is conducted by CETESB (Companhia de Tecnologia de Saneamento Ambiental) in nine sampling points, four of them in the Onça and São Domingos rivers (Catanduva) and the rest are distributed along the Preto, Turvo, and Grande rivers (CETESB, 2012).

3 AQUATIC ENVIRONMENTS

3.1 SMALL STREAMS

Small tributaries represent the major contribution to large rivers. In the BHTG, first to third order streams correspond to more than 12,000 km in extension. Streams often exhibit high degree of fish endemism, and are the first aquatic environments to receive diffuse and point stressors from human activities. In the BHTG these stressors do not differ from those broadly known around the world (ALLAN; FLECKER, 1993; BARLETTA et al., 2010): habitat degradation (including sand removal from the river bottom), invasion of non-native organisms (mostly the North African catfish *Clarias gariepinus*, the Nile tilapia *Oreochromis niloticus*, and the guppy *Poecilia reticulata*), pollution, and fish overexploitation.

During our study in the Turvo/Grande streams from 2003 to 2005, we conducted measurements on 75 m reaches of 60 randomly chosen streams (1st to 3rd order, according to Strahler, 1957) aiming to conduct integrity assessments. Casatti et al. (2006) proposed a protocol to determine physical and chemical water integrity in lowland streams of the region by calculating the Stream Water Index (SWI). The analysis of the water physical and chemical integrity was made from comparisons with minimally affected local conditions (Score 4 in Table 1).

Table 1: Scores for physical and chemical water variables for small streams in the Turvo/Grande basin. Stream Water index is the total score for a site: good (36-30); fair (29-23); poor (22-16); very poor (15-9)

Variables	**Score 4**	**Score 3**	**Score 2**	**Score 1**
Dissolved oxygen (mg/l)	≥ 6.0	5.0-5.9	4.0-4.9	< 4.0
Conductivity (µS/cm)	≤ 50	51-100	101-150	> 150
pH	6 to 9	5.0-5.9	4.0-4.9	< 4.0
		9.1-10.0	10.1-11.0	> 11.0
Turbidity (NTU)	≤ 40	41-150	151-300	> 300
Nitrate (mg/l)	≤ 1.0	1.1-1.5	1.6-1.75	> 1.75
Ammonia (mg/l)	≤ 0.01	0.02-0.5	0.6-1.0	> 1.0
Orthophosphate (mg/l)	≤ 0.03	0.04-0.5	0.6-1.0	> 1.0
Odor	normal	-	-	sewage, oil, chemical, dead fish
Surface oils	absent	-	-	Present

The raw values of physical and chemical variables obtained in the 60 BHTG rural stream reaches are presented in Table 2. Regarding water conditions, just one site (nº 40) was evaluated as poor due to sewage releasing; four (7%) were evaluated as fair and the 55 remaining (92%) were good. The main land use in the region was pasture for cattle and the loss of physical and chemical integrity is often associated in such condition to pollution due to sewage and organic enrichment from cattle waste. Despite a high percentage of the studied streams theoretically presenting appropriate conditions to support the aquatic life, it is important to mention that the present data does not represent urban influence and there are indications that at least six other streams in the survey area, not selected in our analysis, received sewage without treatment (CETESB, 2008).

The assessment of physical habitat integrity was conducted from comparisons with conditions at minimally impacted sites (Table 3). We calculated the Physical Habitat Index (PHI), adapted by Casatti et al. (2006) from previous studies (BARBOUR et al., 1999; ROTH et al., 1996; KASYAK et al., 2001). After analyzing the PHI from 60 sampling sites, one was considered good (2%), 10 were fair (17%), 42 poor (70%), and seven very poor (12%). The physical habitat is a major factor influencing the abundance and diversity of aquatic biota (GORMAN; KARR, 1978; KASYAK, 2001), mainly due to its effect on the availability of sites for food, shelter and reproduction. Overall, 77% of the sampled reaches showed poor or very poor conditions, which means a serious deviation from reference conditions and high levels of degradation (Table 3).

Variables associated with riparian vegetation, such as bank stability and riparian cover, obtained the lowest scores (Table 4). The removal of riparian vegetation usually accompanies the development of agriculture, which commonly occurs without environmental planning (RODRIGUES; GANDOLFI, 2000). Wichert; Rapport (1998), analyzing drainages in agricultural areas, suggested that improving habitat for stream fishes can be achieved through the rehabilitation of riparian vegetation. However, this rehabilitation should be prioritized and intensified in headwaters because the negative impacts of deforestation are more pronounced in small streams (GREGORY et al., 1991), henceforth extending downstream (DALE JONES et al., 1999).

Table 2: Physical and chemical values obtained in each stream reach in the Turvo/Grande basin and final classification. DO, dissolved oxygen (mg L^{-1}); pH; C, conductivity (mS cm^{-1}), TURB, turbidity (NTU), T, temperature (^{o}C); NO_3^-, nitrate (mg L^{-1}), AMNI, ammoniac nitrogen (mg L^{-1}), ORTH, orthophosphate (mg L^{-1}), odor, and oils

Streams	OD	pH	C	TURB	T	NO_3^{-1}	AMNI[1]	ORTH[1]	Odor[2]	Oils[2]	Classification
1	6.0	7.31	0.083	20	20.6	0.42	0.053	<0.01	normal	absent	good
2	7.4	8.32	0.058	46	22.5	1.10	0.052	<0.01	normal	absent	good
3	10.1	8.44	0.075	25	19.6	2.20	0.014	<0.01	normal	absent	good
4	7.2	8.03	0.017	5	21.0	0.36	0.014	<0.01	normal	absent	good
5	1.1	7.77	0.245	262	21.7	0.57	0.386	2.2	sewage	present	poor
6	6.1	7.66	0.059	20	19.2	0.57	0.033	<0.01	normal	absent	good
7	6.3	7.27	0.018	2	20.2	0.37	0.018	<0.01	normal	absent	good
8	8.2	8.16	0.034	9	25.1	0.34	0.015	<0.01	normal	absent	good
9	6.4	7.95	0.081	8	19.3	0.69	0.018	<0.01	normal	absent	good
10	7.2	7.47	0.050	22	20.3	0.42	0.016	<0.01	normal	present	good
11	7.3	8.01	0.110	10	25.9	2.10	0.022	0.1	normal	absent	fair
12	7.6	8.40	0.090	7	20.8	0.38	0.033	<0.01	normal	absent	good
13	7.6	7.74	0.045	7	18.2	0.42	0.039	<0.01	normal	absent	good
14	3.1	7.21	0.080	344	22.7	2.30	<0.001	0.1	normal	absent	fair
15	12.0	8.22	0.079	30	23.4	2.70	<0.001	<0.01	normal	absent	good
16	4.7	7.68	0.145	10	22.0	0.38	<0.001	<0.01	normal	absent	good
17	11.6	8.00	0.023	16	20.4	0.41	<0.001	0.1	normal	absent	good
18	9.1	7.70	0.050	32	20.6	0.37	<0.001	0.1	normal	absent	good
19	10.0	8.03	0.129	1	16.9	0.65	<0.001	<0.01	sewage	absent	good
20	9.4	7.29	0.028	2	19.9	0.50	<0.001	<0.01	normal	absent	good
21	9.8	7.55	0.103	20	21.2	2.30	0.054	0.3	sewage	absent	fair
22	8.3	7.02	0.081	38	17.3	0.20	0.003	0.1	normal	absent	good
23	6.6	6.80	0.048	6	17.2	0.30	0.009	<0.1	normal	absent	good
24	9	6.97	0.035	4	20.3	<0.01	0.006	0.1	normal	absent	good
25	6.9	6.50	0.060	4	20.6	0.50	0.005	<0.1	normal	absent	good
26	7.8	7.15	0.057	47	18.9	0.50	0.005	<0.1	normal	absent	good
27	6.7	7.11	0.049	3	17.1	0.20	0.010	<0.1	normal	absent	good
28	8.0	6.42	0.046	9	17.3	<0.01	0.008	0.07	normal	absent	good
29	8.8	7.40	0.038	3	19.7	0.10	0.002	<0.1	normal	absent	good
30	6.9	6.74	0.041	360	25.4	0.40	0.007	0.1	normal	absent	good
31	7.4	6.82	0.060	10	19.5	<0.01	<0.001	<0.1	normal	absent	good
32	8.9	7.40	0.059	5	19.1	0.20	<0.001	<0.1	normal	absent	good
33	7.0	6.82	0.061	4	18.1	0.10	0.008	0.1	normal	absent	good
34	11.2	5.67	0.026	3	21.6	1.30	0.006	<0.1	normal	absent	good
35	7.4	6.60	0.035	23	18.4	0.20	0.008	0.1	normal	absent	good
36	8.1	6.90	0.036	9	25.2	2.00	0.006	0.1	normal	absent	good
37	8.7	6.98	0.066	6	19.0	1.20	0.01	0.1	normal	absent	good
38	7.6	6.80	0.042	24	21.5	0.70	0.006	0.1	normal	absent	good
39	7.9	6.75	0.043	4	19.1	0.09	0.007	0.09	normal	absent	good
40	8.2	6.84	0.039	2	20.1	0.20	<0.001	0.1	normal	absent	good
41	7.6	6.19	0.012	5	19.2	0.10	0.012	0.09	normal	absent	good
42	8.0	6.91	0.072	9	18.3	0.20	0.009	0.1	normal	absent	good
43	8.6	6.97	0.064	4	17.7	0.10	0.006	0.2	normal	absent	good
44	6.3	6.35	0.052	43	21.5	0.10	0.004	0.07	normal	absent	good
45	8.2	6.31	0.017	4	19.9	0.20	<0.001	0.08	normal	absent	good
46	7.5	6.25	0.029	4	16.5	0.10	0.001	0.02	normal	absent	good
47	9.6	6.84	0.028	3	18.3	0.30	<0.001	<0.1	normal	absent	good
48	8.1	6.83	0.073	2	18.3	0.50	0.008	0.1	normal	absent	good
49	7.8	6.90	0.019	13	21.0	0.53	0.001	<0.1	normal	absent	good
50	6.9	6.26	0.047	1	19.5	0.08	<0.001	0.07	normal	absent	good
51	8.3	6.12	0.039	17	17.0	0.60	0.004	0.05	normal	absent	good
52	8.9	5.62	0.035	1	21.4	1.00	0.007	0.1	normal	absent	good
53	11.3	6.80	0.061	80	20.4	0.10	0.006	0.1	normal	absent	good
54	7.6	7.42	0.229	42	26.2	2.50	0.008	0.4	sewage	absent	fair
55	4.7	6.63	0.092	13	19.6	0.20	0.006	<0.1	normal	absent	good
56	12.4	6.67	0.091	28	22.6	0.80	0.007	0.1	normal	absent	good
57	13.4	7.03	0.065	40	21.6	0.80	0.008	<0.1	normal	absent	good
58	13.7	6.47	0.051	50	18.7	0.10	0.009	<0.1	normal	absent	good
59	13.2	7.17	0.079	11	22.4	0.50	0.006	<0.1	normal	absent	good
60	7.7	6.94	0.176	25	18.1	0.10	0.007	0.1	normal	absent	good
Average	8.2	7.1	0.060	30.9	20.2	0.10	0.006	0.1	normal	absent	-

[1] the mode was calculated; [2] the most frequent category was considered to represent the average.

Although our data were obtained nearly ten years ago, there are evidences that the physical habitat quality is of major concern, especially considering that, on average, only 10% of the riparian buffer are covered by forests and only 5% of the microbasin area are forested. The importance of a forested riparian buffer is reinforced by the fact that fish species richness is positively related with the amount of riparian forests (Figure 1). Another issue that deserves attention is the presence of numerous small dams built for cattle watering, which break the fluvial connectivity at multiple scales by interrupting the downstream movement of sediment, woody debris, and peak flow discharges, as well as the upstream movement of organisms (USDA, 2010). On average, there are three dams per channel, and some third order streams have 10 to 12 dams upstream the sampling reach (Frederico T. S. Miranda and Camilo A. Roa-Fuentes, pers. observations).

Table 3: Description of stream physical habitat condition (adapted from ROTH et al., 1996)

Categories	Sum of scores	Description
Good	180-136	Comparable to minimally disturbed reference streams. Fits within upper 75% of theoretical reference condition.
Fair	135-91	Some aspects of physical habitat may not resemble those found in minimally disturbed streams. Fits within the lower portion of the range of the theoretical reference sites (75-50% of the reference).
Poor	90-46	Significant deviation from minimally disturbed reference conditions, with many aspects of physical condition not resembling those of minimally disturbed streams, indicating some degradation (50-25% of the reference).
Very poor	45-0	Strong deviation from minimally disturbed reference conditions, with most aspects of physical condition not resembling those found in minimally disturbed streams, indicating severe degradation (below 25% of the reference).

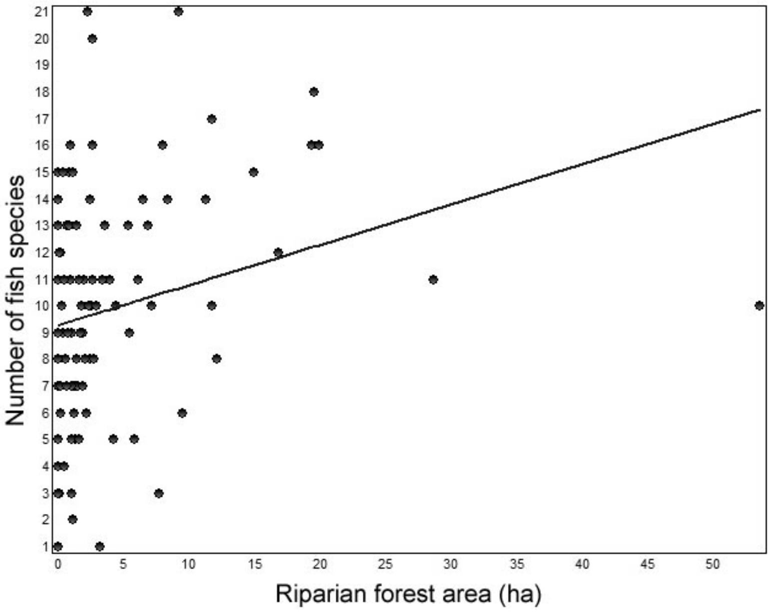

Figure 1: Scatter plot showing the relationships between the number of fish species and the area of forests in the riparian buffer (in hectares). Data from 95 stream stretches from the region ($R^2_{adj} = 0.064$, $P = 0.014$).

3.2 RIVER CHANNELS

The main river channels in the BHTG are the Preto River, the Piedade Stream, the Jataí Stream and the Turvo River, which cross to urban areas as São José do Rio Preto, Mirassol, Tanabi, and Catanduva, respectively. In rivers near urban areas, it is common to have problems associated with excessive load of both domestic and industrial pollution, along with increased demand for water consumption. Metals are among the constituents of industrial wastewater and its direct inputs without prior treatment can come from either punctual or diffuse sources. Punctual sources are easier to be identified and diffuse sources are more difficult to be identified, since the last derive mainly from runoff. The knowledge of the concentration of metals in the water and its possible sources of contamination is essential for measurement and assessment control of aquatic bodies, thus avoiding the use of compromised water. However, the spatial and temporal information generated in the monitoring studies of metals, end up producing many data, which are difficult to interpret and evaluate as a whole. Thus, some tools are used to facilitate the understanding of the dynamics of metals in aquatic bodies, one of them it’s the Geographic Information System (GIS).

The development of the Geographic Information System (GIS) has advanced considerably in assisting the acquisition of spatial data, which in turn can be combined with theme maps that include environmental data, enabling environmental regional profiles to be made. These last are important tools to guide decision making towards appropriated regional development.

In order to investigate the Geoestatistics distribution of pollutants in the main rivers and reservoirs of BHTG (Figure 2), the Inverse Distance Weighted (IDW), a deterministic method, was used to interpolate physical, chemical, and metal parameters data. The IDW is calculated under the assumption that there is a spatial relation, thus the samples that are close to one another are more alike than those that are farther apart. In this case, to predict an unknown value the algorithm assumes that each measured point has a local influence that diminishes with distance. Compared with other methods, the IDW method is simpler to programme and does not require pre-modeling or subjective assumptions in selecting a semi-variogram model (HENLEY, 1981; TOMCZAK, 1998).

Geostatistical data of monitored pollutants offered a better visualization and enabled better planning and management of that region. Figure 3 shows the Geostatistical graphs to the metals Aluminum (Al), Arsenic (As), Barium (Ba), Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Antimony (Sb), and Zinc (Zn). Metals in aquatic environments can directly influence biological functions of aquatic organisms. Depending on the concentration, metals can act positively, being considered essential for the development of organisms, or negatively, when it is considered toxic. Concentrations in the order of 5 g L^{-1} are toxic to some aquatic organisms (ANTUNES et al., 2007; BROOKS et al., 2008; REMYLA et al., 2008). In Brazil, Resolution No. 375 of the National Council of the Environment, enacted in 2005, is the Environmental Legislation that establishes the maximum values of several pollutants in freshwater, depending on the use and soil occupation. BHTG has rivers classified as Classes 1 and 2, which are those more restricted. In other words, with a higher exigency on maximum permissible concentration of some parameters according the main water uses. There are also two rivers classified as Class 4 and therefore present less restrictive values.

In the Figure 3 it is evident that all Al concentration are higher than the values established by the Brazilian Law (200 µg L^{-1}). Melo (2010) demonstrated that higher concentrations of Al were obtained in months of higher rainfall and suggested that this metal comes from diffuse sources (BHTG runoff). Okonkwo et al. (2005) also observed the highest concentrations of Al, along with other metals (*i. e.* Cd, Cu, Pb and Zn), during rainy periods in three South African rivers. On the other hand, Jordão et al. (2007) and Macdonald (2007) associated the increase of Al concentration to runoff in waters from regions where the soil is naturally acid (pH < 4). As observed by other authors, Al comes from fuel burn, industrial activities (construction, electronics, petrochemical and metallurgic), and soil resuspension, due to its abundance on the crust (around 8%) (PARRINGTON et al., 1983; NICHOLSON, 1988; HASHIMOTO et al., 1992; CONSTANTINO et al., 2002; WANG et al., 2003; THORPE; HARRISON, 2008).

Arsenic was the only element that presented lower concentration than allowed according to the Brazilian environmental legislation (10 µg L^{-1}), though high concentrations were observed in agricultural areas used mainly to sugarcane and orange crops. Higher concentrations of Ba, Cd, Cu, Cr, Ni and Pb were observed in the urban area (Figure 3). The main source of Cd, Cu, Cr, Ni, Pb and Zn is associated to fuel burning, industrial processes and vehicle traffic, which are more intense in urban centers (ÁLVAREZ-AYUSO et al., 2003; WANG et al., 2003). In urban areas, Ba is associated to anthropic activities as fuel burning and use of brakes and car tires (STERNBECK et al., 2002; SHARMA et al., 2005; THORPE; HARRISON, 2008). Ba, Cd, Cr and Pb concentrations were lower than maximum values recommended by Brazilian law, that were 700 µg L^{-1}, 1 µg L^{-1}, 50 µg L^{-1} and 10 µg L^{-1}, respectively (Figure 3). Notwithstanding, Cu and Ni concentrations (9 and 25 µg L^{-1}, respectively) exceeded law values (Figure 3).

Table 4: Values obtained for nine habitat variables (ranging from 0 to 20) in each stream reach in the Turvo/Grande basin (see CASATTI et al., 2006 for variables explanation) and final classification. SUB, substrate stability; VEL/DEP, velocity and depth variability; FLO, flow stability; BOT, bottom deposition; PRR, combination of pools-riffles-runs; CHA, channel alteration; COV, streamside cover; BVS; bank vegetative stability; BAS, bank stability

Streams	SUB	VEL/DEP	FLO	BOT	PRR	CHA	COV	BVS	BAS	Sum	Classification
1	3	6	10	4	6	11	0	8	4	52	poor
2	3	6	10	4	5	11	0	4	4	47	poor
3	16	14	11	11	16	6	5	8	6	93	fair
4	5	10	11	13	10	13	4	9	9	84	poor
5	3	2	5	2	1	5	0	4	2	24	very poor
6	8	13	10	4	11	11	0	8	10	75	poor
7	9	9	8	7	11	6	1	4	6	61	poor
8	3	5	9	4	3	11	0	6	6	47	poor
9	15	13	14	10	12	13	3	8	8	96	fair
10	9	12	13	5	11	9	0	4	4	67	poor
11	4	10	11	3	8	10	0	6	6	58	poor
12	9	8	6	4	11	10	0	2	0	50	poor
13	10	6	9	9	8	11	0	4	2	59	poor
14	0	1	1	1	1	3	0	0	0	7	very poor
15	3	3	6	2	4	11	0	2	0	31	very poor
16	5	7	8	6	7	11	0	4	6	54	poor
17	6	7	7	7	8	6	0	6	8	55	poor
18	7	7	10	9	6	10	4	6	8	67	poor
19	5	7	8	6	7	11	0	4	6	54	poor
20	6	8	8	6	7	11	0	4	6	56	poor
21	18	15	13	10	16	11	1	4	6	94	fair
22	12	14	14	10	7	9	17	6	6	95	fair
23	3	7	14	3	2	17	2	6	6	60	poor
24	4	13	6	2	6	13	1	1	1	47	poor
25	6	8	10	4	8	19	4	10	8	77	poor
26	2	2	5	4	6	19	8	10	6	62	poor
27	9	19	15	8	18	19	4	4	4	100	fair
28	16	18	18	17	19	19	9	7	6	129	fair
29	5	13	10	9	11	11	4	1	1	65	poor
30	4	5	4	3	3	18	2	2	1	42	very poor
31	3	7	5	3	5	13	2	8	6	52	poor
32	19	15	18	14	18	19	8	14	6	131	fair
33	7	15	10	7	6	13	0	2	2	62	poor
34	12	10	8	11	12	16	4	2	2	77	poor
35	6	14	18	9	13	14	2	6	4	86	poor
36	3	4	3	2	2	16	0	0	0	30	very poor
37	15	20	18	16	20	20	4	14	12	139	good
38	3	12	13	5	10	14	2	6	4	69	poor
39	5	6	6	5	4	11	4	2	1	44	very poor
40	5	9	10	3	3	13	1	2	2	48	poor
41	2	2	2	2	2	12	4	4	4	34	very poor
42	4	5	5	3	5	15	2	8	6	53	poor
43	11	13	13	10	12	14	13	8	4	98	fair
44	10	14	13	15	6	13	4	2	4	81	poor
45	4	10	11	5	5	16	6	2	4	63	poor
46	5	12	6	4	5	17	8	6	6	69	poor
47	11	13	17	10	11	16	5	4	2	89	poor
48	3	10	8	3	7	15	3	4	2	55	poor
49	17	16	16	6	14	15	12	12	10	118	fair
50	6	11	5	3	6	13	4	4	4	56	poor
51	6	13	10	4	10	14	2	2	2	63	poor
52	16	10	13	14	7	18	4	2	4	88	poor
53	6	10	10	5	3	13	8	6	4	65	poor
54	3	5	12	4	3	12	2	4	2	47	poor
55	5	6	4	4	4	12	2	2	2	41	very poor
56	3	3	5	2	2	14	3	4	4	40	very poor
57	8	10	10	9	5	15	4	4	4	69	poor
58	14	10	12	11	4	11	6	6	6	80	poor
59	6	12	4	3	5	10	4	4	4	52	poor
60	6	5	5	5	6	13	2	6	6	54	poor
Average	7.2	9.5	9.6	6.4	7.7	12.9	3.2	5.0	4.5	66	-

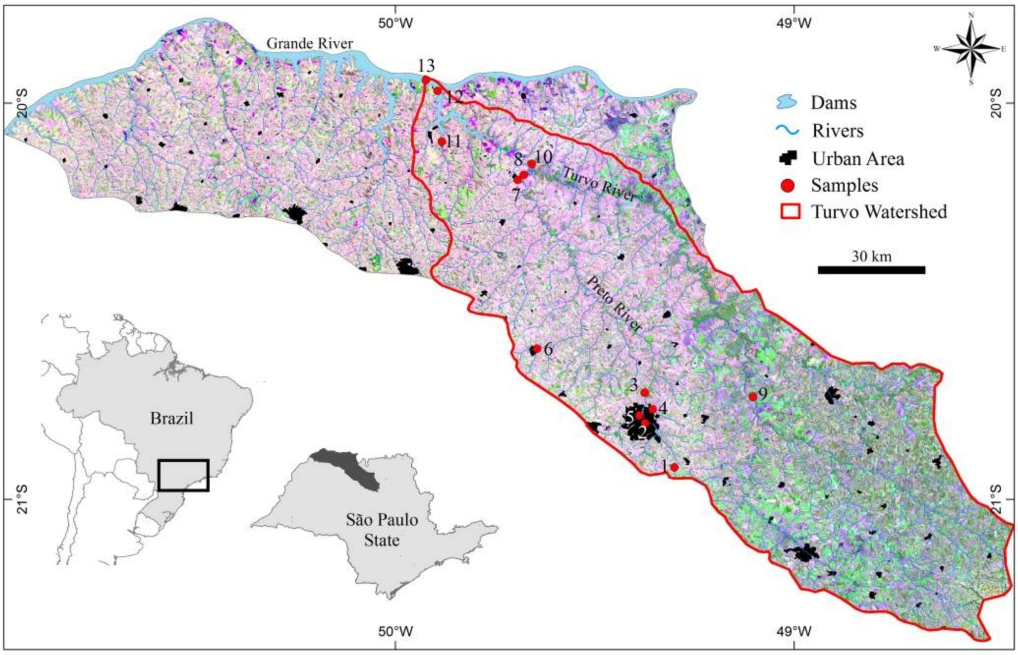

Figure 2: Location of the Turvo/Grande basin in Brazil and in the São Paulo State (below), showing the sampling sites (red dots above).

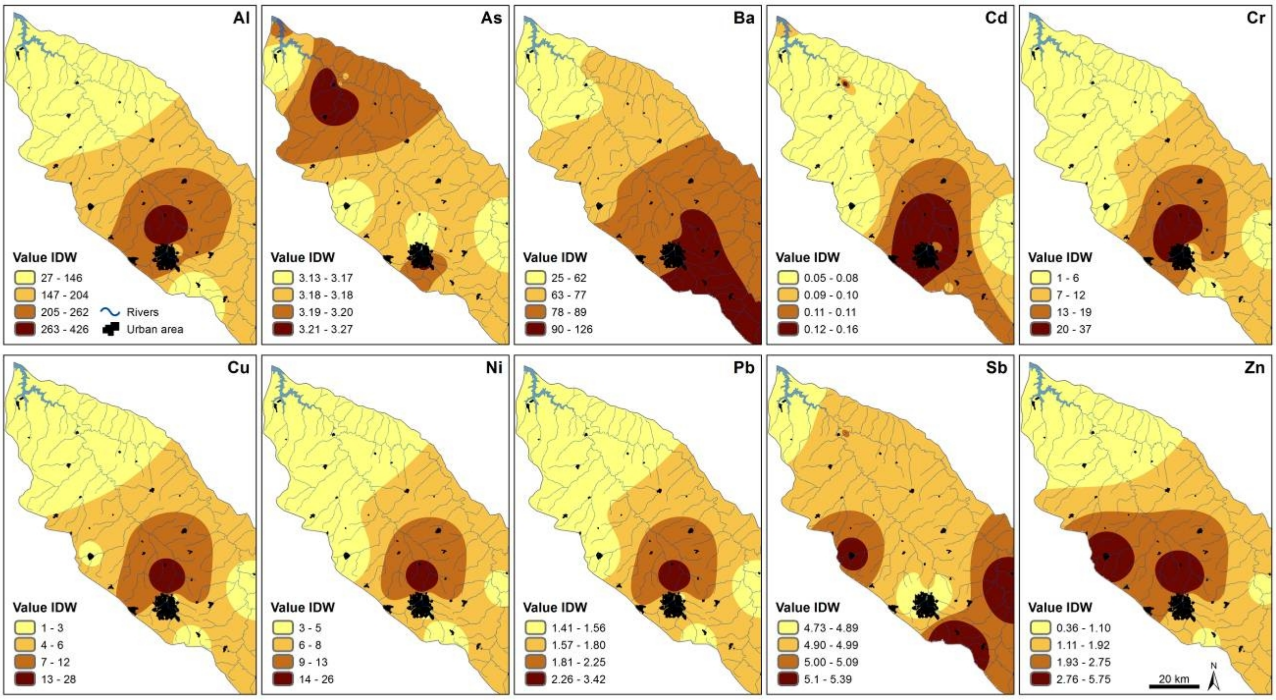

Figure 3: Geostatistical distribution of metals in the Turvo/Grande watershed.

One interpretation considering the seasonal variability of metal concentrations (Cr, Cu, Ni, and Al) was obtained by Melo (2010). Cr concentrations above 50 $\mu g\ L^{-1}$ were observed in samples collected in the months with lower rainfall, indicating punctual sources to this element. Yaymtas et al. (2007) found 229 $\mu g\ L^{-1}$ of Cr in a stream at Turquia and associated these values to leather industries in the surroundings. In the industrial area at Ranipet, Índia, Cr concentration reached 247.2 $\mu g\ L^{-1}$ around the tanneries (GOWD; GOVIL, 2008). Gallo et al. (2006) found chromium (10 to 30 $\mu g\ L^{-1}$) in several places in the Salado River, Argentina, and associated this result to industries around the rivers. Note that further evaluations need to be conducted to investigate whether Cr comes from natural (from the ground) or anthropogenic (originated from tanneries or other industrial activities in the region) sources.

High concentrations of Cu were found during the dry period, indicating punctual sources for this element at this region, as pointed by Melo (2010). Wastewater from metallurgic industries can contribute to river pollution (DOUAY et al., 2008). Farag et al. (2007) found Cu concentrations at 140 μg L^{-1} in waters from the Jack Creek, United States. Nickel concentrations exceeded 25.0 μg L^{-1} for the months with low rainfall. Metallurgic and mining industries employ nickel in their processes, where concentrations up to 742 μg L^{-1} were found in water samples near these areas (NIETO et al., 2007).

Other important element is Sb and Brazilian Law establish a maximum value of 5 μg L^{-1}, where more toxic varieties are inorganic Sb(III) and Sb(V) (NORDBERG et al., 2007). Usually, Sb is employed in the industry as a metal of sacrifice, being added as an alloy with tin and in a battery as a conductor (VEADO et al., 2006). Studies showed that the contamination by antimony is due to the fact that it is found in the form of impurity (lead arsenate) in crop-applied insecticides, which were banned in some countries like the United States and Brazil (WAGNER et al., 2003; STEELY et al., 2007). Shotyk et al. (2006) and Westerhoff et al. (2008) found Sb concentrations 0.09 a 0.52 μg L^{-1} in United States drinking water, and concentrations from 0.11 to 0.37 μg L^{-1} for drinking water from Canada and Europe, bottled in polyethylene terephthalate (PET). PET is employed as a catalyst due to low cost, being demonstrated by some authors that Sb can be leached in contact with water (SHOTYK et al., 2006; WESTERHOFF et al., 2008). Maximum allowed concentration of Sb was found in agricultural regions in the Turvo/Grande watershed (Figure 3).

An important finding is that the parameters Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Total Organic Carbon (TOC), when evaluated seasonally at sampling sites from urban areas (Melo, 2010), presented higher concentrations during the dry periods, indicating punctual sources for these compounds (Figure 4).

The sediment is a dynamic compartment in the aquatic environment and provides habitat for benthic organisms (SEDNET, 2004); it can also act as source and sink of metals to the water column (WILLIAMS et al., 1998; BLASCO et al., 2000; PAKHOMOVA et al., 2007; SANTOS-ECHEANDIA et al., 2009). Sink is associated with metal removal from water column by adsorption and/or co-precipitation process with suspended particulate matter, such as clay particles, organic matter, iron, and manganese oxyhydroxides, and their subsequent deposition in the sediment (CORTECCI et al., 2009; DESSAI et al., 2009). Due to constant deposition of particles that represent the pollution to which water bodies are subject, sediments can be used to reconstruct the pollution history of a river (MIL-HOMENS et al., 2009). Moreover, the process of metal accumulation in sediment is of high concern, since high concentrations can have a toxic effect on benthic organisms, reducing species diversity (YI et al., 2008). Therefore, metals quantification in sediments is necessary for the purpose of ecological risk assessment and aquatic life protection.

Campanha et al. (2012) studied diffusive fluxes of metals in rivers from BHTG and concluded that the sediment acted as a source of Cr and Ni to the water column and this phenomenon was more intense during the dry period. Diffusive fluxes of metals from sediment to water column ranged from 0.38 to 264.9 μg m^{-2} day^{-1} for Cr, 0.23 to 516.9 μg m^{-2} day^{-1} for Cu, 0.09 to 145.2 μg m^{-2} day^{-1} for Ni, and 0.1 to 58.4 μg m^{-2} day^{-1} for Pb. It is noteworthy to mention that it was precisely in this period that the highest concentrations of these elements in the water column were observed, as indicated by Melo (2010), which may be associated with the own sediment.

Metal availability in water resources is also largely associated with the characteristics of aquatic humic substances (AHS). Complexation capacity studies between AHS and metals can enable understanding the availability, toxicity, and transport of metals in the aquatic environments (ROCHA; ROSA, 2003).

Melo et al. (2012) evaluated the role of aquatic humic substances (AHS) in the metals availability in water bodies from the BHTG. Conditional Stability Constant was 2.0×10^{-2}, 1.1×10^{-5} e 2.6×10^{-2} for the complexes AHS−Cr^{3+}, AHS−Ni^{2+}, and AHS−$CrO4^{2-}$, respectively. In the same study the authors demonstrated that solar radiation provokes a decrease in the complexation capacity of 15-26% for AHS−Al^{3+}, 15-72% for AHS−Cr^{3+}, 12-18% for AHS−$CrO4^{2-}$ and of 13-

42% for AHS−Ni^{2+}. This result indicated that solar radiation plays an important role in metals availability, which were previously complexed to AHS.

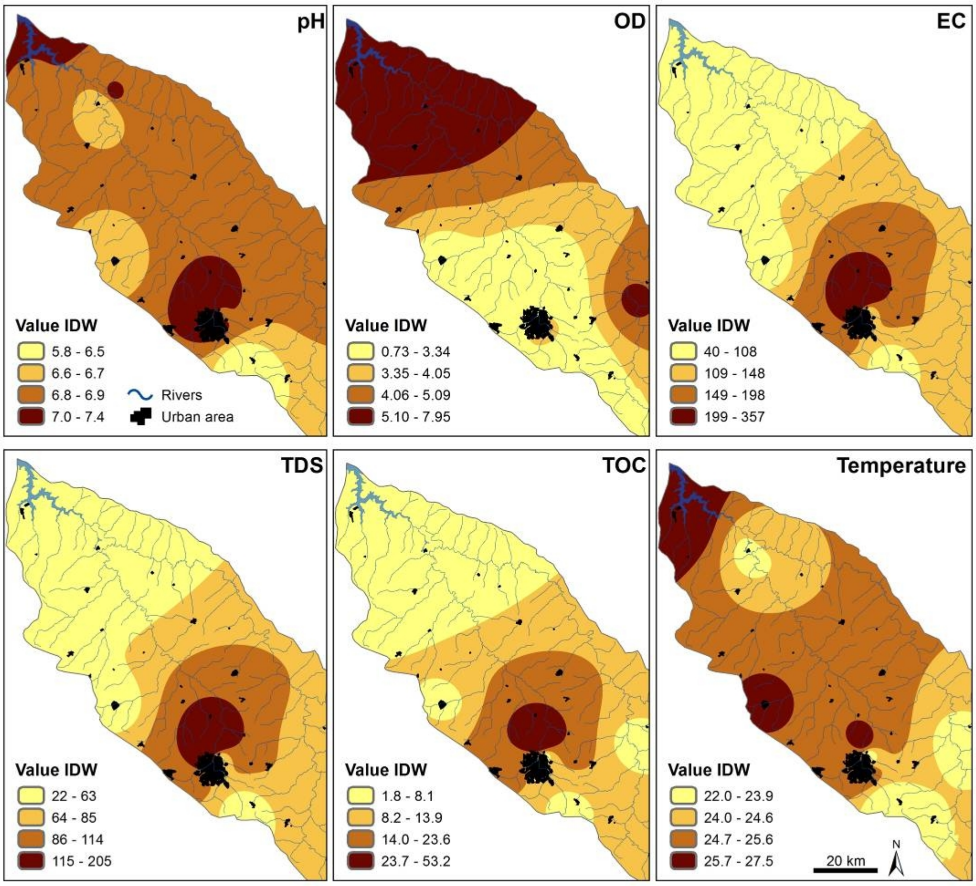

Figure 4: Geostatistical distribution of physical and chemical variables in the Turvo/Grande watershed.

Pantano et al. (2014) extracted and characterized humic substances (HS) from sediment samples of water bodies in the Turvo/Grande watershed and determined the complexation capacity of HS with Cr and Cu. In this study, it was demonstrated that complexation capacity of HS from sediment extracted from agricultural regions presented the highest stability, being these values bellow those found in other regions of in the world. Sediment humic substances presented a higher amount of aromatic groups in their structure during the rainy season, and areas of sugar cane cultivation are composed by humic acid, as those that were sampled.

3.3 MARGINAL LAGOONS

Along most of its extension, the Turvo River overflows to adjacent areas in an extensive floodplain, resulting in many lagoons. Floodplains can be defined as areas that are periodically flooded by the lateral overflow of rivers and or by direct precipitation or groundwater. In these areas, the habitat heterogeneity allows a considerable variety of resources and refuge against predators, favoring species diversity and the development of adaptations to the water level periodic fluctuations caused by flooding (JUNK et al., 1989). These aquatic/terrestrial transition zones can be divided in two components: a plain seasonally flooded, which remains dry during most of the year, and marginal lagoons, which can persist until the next flood or dry up (WELCOMME, 1985).

Among the numerous marginal lagoons existing along the Turvo River, Araujo et al. (2010 a, b) studied fish and macrophytes communities of six marginal lagoons (Table 5). The study area is near to km 12 of BR-153 highway between the municipalities of Icém and Nova Granada (20º21’11”S 49º15’52”W). The composition and abundance of fish communities in seasonally isolated lagoons (temporary and permanent) of the Turvo River was investigated by Araujo (2008).

The results revealed a remarkable seasonality, with highest species richness and abundance registered in the rainy season. A total of 7,457 specimens, distributed among 52 species, 40 genera, 19 families, and five orders, were collected in the six marginal lagoons. Among the species, 63% belonged to the Order Characiformes, 25% to Siluriformes, 8% to Perciformes, 2% to Cyprinodontiformes, and 2% to Synbranchiformes. The presence of larvae and young individuals of the migratory species *Salminus brasiliensis*, *S. hilarii*, *Brycon* sp., *Schizodon nasutus*, and *Rhamdia quelen* only in the rainy season, and of *Prochilodus lineatus* and *Leporinus friderici* in both seasons, in all studied lagoons, suggests that these environments are also explored by adult individuals which perform lateral migration in the floodplain for spawning, and as a recruitment place for juveniles.

Table 5: Characteristics of the six studied marginal lagoons (T = temporary, P = permanent) of the Turvo River

Parameters	**T1 (Ganzella)**	**T2 (Mustafá)**	**T3 (Braço Morto)**	**P1 (45)**	**P2 (Federal)**	**P3 (Parente)**
Coordinates	20º25'11.9"S 49º16'00.1"W	20º24'37.9"S 49º16'05.3"W	20º21'11.6"S 49º16'39.0"W	20º24'56.1"S 49º15'53.7"W	20º22'45.6"S 49º16'36.1"W	20º21'30.1"S 49º16'48.6"W
Altitude (m)	459	454	432	456	441	436
Area (m^2)	6,887	12,584	27,680	22,798	48,587	124,442
Depth (m)	0.05-1.7	* - 1.6	0.4-1.8	0.6-2.7	0.65-3.0	0.1-2.8
Air temperature (ºC)	14.2-38.4	14.2-38.4	14.2-38.4	15.2-34.6	15.2-34.6	15.2-34.6
Water temperature (ºC)	19.2-26.0	21.0-29.0	22.1-31.0	22.3-27.8	23.1-34.0	20.1-32.1
pH	5.9-6.5	6.3-6.8	6.3-7.2	6.6-8.3	6.3-6.7	6.9-7.2
Alkalinity (mg/l)	48.0-86.0	34.0-48.0	26.0-38.0	28.0-63.0	25.0-50.0	21.0-45.0
Conductivity ($uS.cm^{-1}$)	145.5-414.0	104.1-155.1	61.4-128.0	122.3-172.4	40.4-150.1	77.2-117.4
Turbidity (NTU)	32.0-100.0	22.0-53.0	18.0-83.0	15.0-32.0	30.0-121.0	16.0-79.0
Dissolved O_2 (mg/l)	2.4-13.0	0.0-6.6	6.5-12.1	2.3-11.1	4.3-10.7	6.0-12.9
Substrate type	sand, silt and clay	sand, silt and clay	sand, silt and clay	sand, silt and clay	sand, silt and clay	sand, silt and clay
Number of macrophyte species	26	7	5	24	21	27
Number of fish species	15	24	34	26	24	38

*T2 was desiccated.

The number of fish species recorded by Araujo (2008) was higher than those found in other studies performed in the State of São Paulo. In marginal lagoons of the Sorocaba (SMITH; BARRELLA, 2000), Paranapanema (CARVALHO et al., 2005), and Mogi-Guaçu (GALETTI et al., 1990; FERREIRA et al., 2000; MESCHIATTI et al., 2000; GONÇALVES; BRAGA, 2008) rivers, a total of 17, 24, 24, 29, 31 and 36 species, respectively, was registered. In the marginal lagoons of the Turvo River, 52 (17%) of the 310 fish species listed by Langeani et al. (2007) for the upper rio Paraná system were found.

The taxonomic composition of aquatic and marginal macrophytes sampled manually was studied by Araujo et al. (2010 b) in the same marginal lagoons. The results of this survey showed a total of 54 species, 36 genera and 22 families. This number of species represents approximately 14% of the 400 species of aquatic flora listed by Amaral et al. (2008) for the São Paulo State, suggesting that it is necessary to preserve these environments. The families with greater number of species were Poaceae, Cyperaceae, and Polygonaceae. *Eichhornia crassipes* (Pontederiaceae) was the only species encountered in all six lagoons. The presence of high diversity and abundance of macrophytes have been considered a very special factor that influences the high diversity of vertebrates and invertebrates fauna due to the structural complexity of macrophytes that provides higher quality and quantity of resources and shelters to many species (THOMAZ; CUNHA, 2010).

Several aspects of biotic and abiotic dynamics along seasonal cycles are being studied in the marginal lagoons of the Turvo River floodplain, in an ongoing research project coordinated by one of us (MSM Castilho-Noll). In this floodplain there are many kinds of aquatic lagoons, with different kinds of connectivity to the river. According to Ward; Stanford (1995), depending on the connectivity, lagoons in floodplains can be classified as palaeopotamon (meander bends that have become disconnected), plesiopotamon (interlaced segments disconnected from the main river channel) and parapotamon (dead arms connected with the river just downstream). These observations reflect the complexity of the whole system, which was also observed in a one-year study of some physical and chemical attributes and of zooplankton diversity in the Turvo system.

The high levels of space-time heterogeneity observed in floodplains have been considered the main factor for the high species diversity in these ecosystems (ROCHA, 2010).

The influence of dry and rainy seasons is pronounced by the lagoons' water level and by dryness of some lagoons that disappear in the dry season. Variations in water conductivity, pH, and dissolved oxygen can be associated with high decomposition of organic matter mainly from macrophytes that die in the dry season and decompose in the flood. The flooding of plants that developed on dry sediments was also associated with changes in physical and chemical water parameters in the Paranapanema floodplain (HENRY et al., 2006).

In a one-year study with monthly samples in the lagoons, 22 microcrustaceans species (19 cladocerans and 3 copepods) were identified, with predominance of littoral species. From the 19 cladocerans, 11 belong to Chydoridae, Macrothricidae, and Ilyocriptidae. The dominance of species from littoral zones has been observed in other studies, as pointed by Abra et al. (2014) that associate this fact with the shallow characteristic of lagoons and high macrophytes density. Some preliminary studies regarding fish diet in lagoons of the Turvo floodplain have evidenced the importance of cladocerans, especially chydorids, as food for fish.

Although preliminary, our data shows that marginal lagoons of the Turvo River floodplain are a very complex ecosystem and that each kind of lagoon seems to have their own dynamics. As this flooded plain is located in one of the areas that is most impacted by human occupation (mainly agriculture and urbanization) of the State, we stress the importance of studies to describe the dynamics of this ecosystem.

4 IMPLICATIONS FOR MANAGEMENT AND CONCLUSIONS

The main threat for small streams in the BHTG is associated with the physical habitat degradation, mostly derived from the lack of forest vegetation along the riparian buffer. The benefits of the presence of riparian vegetation for water bodies are numerous (see PUSEY; ARTHINGTON, 2003, and authors cited there) and may yet represent a great opportunity to increase connectivity between terrestrial habitats (BECKER et al., 2004). Studies conducted by Harding et al. (1998), Teels et al. (2006), and Lévêque et al. (2008) demonstrated that the restoration of the land strips adjacent to the streams is insufficient to improve stream integrity as a way to maintain natural diversity. However, restoration of the entire watersheds is completely out of the priorities list in Brazil, and we must find alternatives to reduce stress and mitigate the impacts on aquatic biota at lower costs. The isolation of the riparian zones themselves along the drainage, preventing their use for other activities, must represent a cheaper strategy to start the preservation of small streams and their biota (CASATTI et al., 2009) that may be complemented with good land use practices in the rural environment. Conservation and restoration efforts on large rivers often focus on mainstream, but there are ecological evidences to consider that restoration targeting small tributaries could benefit large-river biodiversity (PRACHEIL et al., 2013). Additionally, some studies reported the efficiency and limitations of certain restoration methods and provided good examples of lower cost actions (e.g., HOLL et al., 2000; BIANCONI et al., 2007).

The BHTG is also impacted by the discharge of domestic and industrial effluents, being the Preto River, Felicidade, Piedade, and Jataí streams the most degraded aquatic bodies because of the high concentrations of total organic carbon and thus lower concentrations of dissolved oxygen, and also because of the presence of metals, like aluminum, copper, chromium and nickel. It can be also concluded that the pollutants responsible by the increase of TOC, TDS, EC in the rainy seasons can be associated to diffuse sources (urban runoff and/or atmospheric deposition) in the BHTG, whereas the metals copper, chromium and nickel seem to come from nonpoint sources pollution, as these metals showed higher concentrations in the dry season. It is necessary to control the point sources pollution to the management of BHTG water bodies, since this type of pollution is more predictable and involves the treatment of liquid effluents. The control of pollutants that arise from nonpoint sources is much more complicated because it implies in the removal of pollutants originated from agricultural and urban runoff (MELO, 2010).

The sampling location with the most impacted sediment was the Preto River. It was related to the slightly higher presence of particles of fine fractions compared to the other sampling locations, what caused an increased accumulation of metals. In this sampling location the presence of Zn had an anthropic origin, likely associated to the urban growth and development of São José do Rio Preto city, as well as to metallurgic industries located in the region. In Turvo River the presence of K in the sediment also had anthropic origin, which is related to the sugar cane culture, and in Grande River (agricultural area) increased metal inputs over the years may be associated both to natural sources (higher deposition of particles after river damming) and agricultural practices.

The sediments from BHTG acted as source of metals (except for K) to the water column in both dry and rainy seasons, and the higher export to the water occurred, for most metals, in the dry season. Variations of the diffusive fluxes occurred between seasons and sampling positions, and were influenced by the porosity of the sediment and by the heterogeneity of the factors that drive the mobility of metals into the pore water, like Fe and Mn geochemistry and, hypothetically, the precipitation with sulfides. However, the contribution of the sediment to the water column is still low compared to the other external sources.

The floodplains, like those at BHTG, are unique ecosystems that provide important services, such as hydrological buffering effect, which reduces the peaks of flood and drought and provides water for headwater streams and groundwater by infiltration; groundwater recharge; sediment retention; provision of food and raw materials; retention of organic carbon; and water purification (JUNK et al., 2013), besides their exuberant diversity representing several plant and animal phyla. Additionally, several aquatic organisms use microhabitats among the aquatic macrophytes for refuge, source of food, protection against predators, and site of reproduction. Thomaz et al. (2007) have suggested that three factors are interrelated and are determinant for species richness: the intermediate disturbance caused by the flood pulse, the ecotone existence, and the hydrological connectivity. Therefore, any change that affects the hydrological dynamics of the flood pulse, as well as the ecotonal areas, results in meaningful losses of biodiversity and services originally provided by these ecosystems. Dam constructions, for example, have been cited as the major threat for wetlands, resulting in species losses due to alteration of the pulse dynamics (MIDDLETON, 2002; AGOSTINHO et al., 2008). This suggests that it is necessary to preserve the overall wetland structure and processes to assure the survival of a viable number of individuals for conservation purposes, including target migratory fish species, and ecosystem services like those mentioned above. Therefore, these habitats must be considered priority areas for conservation and management.

In synthesis, riparian forest recovery, soil conservation, control of metals and other contaminants, and floodplain protection must be of first interest to managers in the conservation of the aquatic resources of this important river basin. To support these actions, we have a long way on the basic knowledge to be conducted about the structure and functioning of aquatic environments in the Turvo/Grande basin.

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