Ecological Complexity 43 (2020) 100852

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

An applied ecological approach for the assessment of anthropogenic disturbances in urban wetlands and the contributor river

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ARTICLE INFO

Keywords:
Aquatic ecosystems
Benthic macroinvertebrates
Macrophytes
Landscape
Human interference
Environmental management

ABSTRACT

An applied ecological approach was used to assess the anthropogenic disturbances on the aquatic systems of the Sorocaba river and its wetlands in the Sorocaba-SP municipality (Southeastern Brazil). Two samplings of water, sediment, macroinvertebrates, and macrophytes were performed in 2017, during the rainy season (February) and dry season (June). Traditional limnological methods were applied to the biological material (macrophytes and macroinvertebrates) and limnological variables. In 2017, domestic wastewater and diffuse pollution were the main anthropogenic impacts on the aquatic ecosystems of the Sorocaba municipality. The used approach allowed the verification of the human disturbances on aquatic systems, sediment, biological communities, and landscape. We found that biochemical oxygen demand, thermotolerant coliforms, total phosphorus, dissolved oxygen, and turbidity are above reference concentrations from the Brazilian guideline CONAMA Resolution 357/05. Four macroinvertebrates orders (Diptera, Oligochaeta, Hirudinea, and Gastropoda) and three macrophytes species (*Eichhornia crassipes, Salvinia auriculata* and *Pistia stratiotes*) allowed inferring that Sorocaba river and associated wetlands suffer water quality loss due to organic pollution. The major land use classes were anthropogenic agricultural and non-agricultural (75.42%) disturbances, contributing to limnological alterations and low quality of riparian vegetation. Urban wetlands were similar (e.g. sediment properties, limnological variables, bioindicators) and differed from the contributor river, a situation probably related to the wetlands bimodal pulse. Considering the hydric network of tropical countries in the same geographic region, the similar dynamics of the water bodies, and the context of urbanization, the approach can be applied to assess the human disturbances in the region.

1. Introduction

Wetlands are important aquatic ecosystems that have been losing area during the last decades due to the landscape cover changes, and the economic development, and natural area conversion (Sannigrahi et al., 2018, Quintela et al., 2019). Among the main threats to the wetland ecosystems, the following elements stand out: (i) water pollution and (ii) biological invasion by exotic species, and (iii) human activity development, and the (iv) socioeconomic development context (Yang et al., 2018, Garcia et al., 2017).

This increasing pressure on water resources, including wetlands, may be worse in urban areas once in those spaces the superficial water quality is affected by point sources (e.g. waste pipe) or non-point sources (e.g. nutrient discharges during heavy rainfall) (Delkash et al., 2018). The city area increase causes physical degradation to the aquatic ecosystems, due to the rupture in the wetland connectivity (Guida et al., 2016), the substance insertions (e.g. sediments, heavy metals), and structural changings (e.g. plumbing, rectification).

Furthermore, those environments contribute to the water quality loss due to the nutrient discharging, which is one of the greatest

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https://doi.org/10.1016/j.ecocom.2020.100852
Received 16 February 2020; Received in revised form 22 June 2020; Accepted 24 June 2020

urbanization consequences (Delkash et al., 2018). When in excess, the nutrients (i.e. phosphorus and nitrogen) reduce the water quality, creating conditions for the eutrophication, affecting the human and biodiversity needs (Laterra et al., 2018).

Wetlands play an important role, those ecosystems are responsible for sustaining the ecological and socio-cultural processes, providing essential ecosystem services (e.g. Silva et al., 2019) to cities and collaborate positively with human health and urban quality of life (Hettiarachchi et al., 2014; Lavoie et al., 2016). Besides the many ecosystem services provided for all society, the wetlands still face reductions in its area and increasing human appropriations on the ecosystem's services (Sannigrahi et al., 2018).

An urban wetland should be characterized by its functions and processes (Haase et al., 2014). The appropriate decisions for the wetlands management have a dependence relation with the (i) regional environmental characteristics, (ii) resources changes, (iii) regional differences in the changes processes, and (iv) the changes drivers (Omernik and Griffith, 2014).

The management must be based on ecological precepts, in addition to considering the local characteristics and stimulating the development process without compromising the wetlands ecosystem integrity. There is a need for assessment methods that allow an integrated evaluation of these systems, characterizing human interference and indicating the main interference drivers to management strategies formulation.

Another important characteristic to be observed is the regional influence on wetlands, a factor that generates changes in the system dynamics. For example, the precipitation regimes have a strong influence on South America wetlands, and this situation implies in terrestrial and aquatic oscillation due to the flood pulse (Fushita and Santos, 2017, Bozelli et al., 2018), resulting in changes of the river connection and water volume.

The constant debates in the academy and the public environmental policy formulation have not been enough to reverse the current wetlands degradation and water quality loss. Some implemented development policies are affecting wetlands ecosystems (Veléz et al., 2018).

In the Brazilian scenario, there is a lack of a robust normative dispositive to provide effective protection and reinforce the institutional compromises for the wetland protection (e.g. Sousa et al., 2011; Junk et al., 2014; Maltchik et al., 2018; Grasel et al. 2018). In this sense, there is an urgent need to verify ways to evaluate the human impact on Brazilian wetlands ecosystems, which can contribute to an efficient management.

The Sorocaba municipality (SP) is inserted in a region where the land has been exploited for more than four centuries, but the last thirty years have been marked by the urbanization process increase, natural areas reduction (Silva, 2010; Bortoleto et al., 2016) and the Sorocaba river wetlands degradation.

The present work aims to assess the relationship between the Sorocaba river and its wetlands, using an ecological applied approach, based on land use, and physical-chemical, and biological analysis, pointing out the human interference and implications for environmental management. We hypothesized that: urban wetlands that have a low order river as a contributor experience human disturbance, however, the wetlands undergo a strong effect from the flood pulse, which implies wetlands similarities during the seasonal periods and differences between the contributor river and wetlands.

2. Material and methods

2.1. Study area

The Sorocaba Municipality (47 ° 34 '12,000′ 'W / 23 ° 21′ 3,600 " S and 47 ° 18 '10,800′ 'W / 23 ° 35′ 20,058 " S) is inserted in the São Paulo southwest region (Figure 1) and belongs to the Hydric Resources Management Unit (UGRH) Sorocaba-Médio Tietê. The climate according to Köppen's classification is Cwa type, characterized by a dry season from April to October and a rainy season from November to March; the average annual rainfall is around 1311.2 mm (Centro de Pesquisas Meteorológicas e Climáticas a Agricultura, 2018). The municipality has a total area of 450,382 km^2 and, a population of 586,625 inhabitants (Instituto Brasileiro de Geografia e Estatística, 2010Ibge, 2010). In this area, many economic activities (e.g. agriculture, industrialization, business process outsourcing) have been influencing the natural environment (Smith et al., 2018).

The present study was carried out in the Sorocaba river section that corresponds to the river course within the Sorocaba municipality, a stretch of 68 km (considering all the water body meanders) that presents distinct characteristics regarding marginal vegetation, wetlands ecosystems and proximity to the main highway of the city (Cruz and Piratelli, 2011). The study stretch is a third-order river according to Strahler's classification. The sampling stations were selected considering the remaining wetlands and the Sorocaba river adjacent section, totalizing seven (7) sampling stations.

2.2. Sampling

The sampling periods occurred during February (rainy season) and June (dry season) of 2017. On each sampling occasion, three water samples were collected in each locality with sterile polypropylene bottles (1 L), wrapped in a thermal box, and then transported to the laboratory, where they were preserved at 4°C. Following standardized methods (Table S1), we obtained total suspended solids, total coliforms, thermo tolerant coliforms, biochemical oxygen demand, total phosphorus, and total nitrogen, turbidity, pH, dissolved oxygen, total dissolved solids, and electrical conductivity. The water temperature was measured in the field with a quicksilver thermometer.

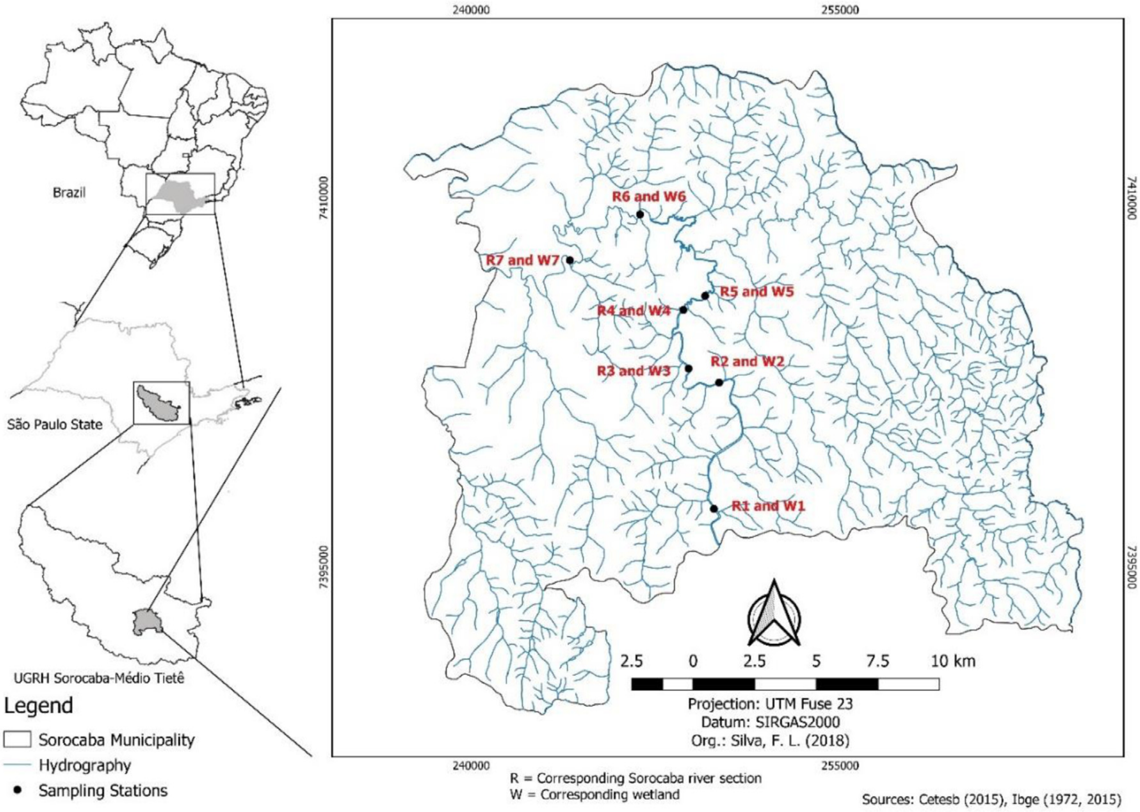
Three sediment samples were collected manually with a metal shovel from the subsurface (ca. 20 cm) and packed individually in plastic bags. Subsequently, the samples were dried in an oven at 60°C until constant mass to remove moisture. After crushing, 100 grams of each sample were weighed on an analytical balance. The gravimetric analysis was employed to have the sediment distribution as follows: gravel/boulders - 2 mm sieve; sand - 250 μm sieve and silt/clay - 25 μm sieve. The organic and inorganic matter of the sediment was achieved by the complete combustion method (Westtake, 1965; Esteves, 1979).

The benthic macroinvertebrates were collected in each locality using a Surber sampler (area 0.09 m^2, 250 μm mesh). Three samplings were randomly collected, and packed in plastic bags, and fixed with 70% formaldehyde, and then taken to the laboratory for the sorting process. The samples were washed in metal sieves (25 μm mesh), and then placed in a plastic tray, arranged on a reflector, and next to a stereoscopic magnifying glass for identification (Brinkhurst and Marchese, 1989; Costa et al., 2004; Pes et al., 2005; Trivinho-Strixino, 2011).

Aquatic macrophytes were collected (three samples) above and below the water surface in an area of 0.25 m^2, and then placed in a plastic bag to be identified in the laboratory (Companhia Ambiental do Estado de São Paulo, 2011). The following structural indexes of aquatic macrophytes were analyzed: (i) number of species, (ii) macrophyte cover area (projective cover), (iii) frequency of each species occurring, and (iv) ecological structure. The percentage of macrophyte coverage (MC) was classified in the following classes: (1) 0 - 20%, (2) 20 - 40%, (3) 40-60% and (4) 60-80% and (5) 100%.

2.3. Limnological indexes

In order to obtain a complete diagnosis and to generate useful information related to water quality, two indexes were calculated: the Trophic State Index (TSI) and the Water Quality Index (WQI) (Companhia Ambiental do Estado de São Paulo, 2017). The TSI was calculated using Eq. (1) and the water bodies corresponded to one of the six trophic classes (Table 1).



R = Corresponding Sorocaba river section
W = Corresponding wetland

Sources: Cetesb (2015), Ibge (1972, 2015)

Fig. 1. Geographic localization of the study area and sampling stations. R = Corresponding Sorocaba river section, W = corresponding wetland.

Table 1
Classification of water bodies based on TSI.
Source: Cetesb (2017)

Category	Score
Ultraoligotrophic	TSI ≤ 47
Oligotrophic	47 < TSI ≤ 52
Mesotrophic	52 < TSI ≤ 59
Eutrophic	59 < TSI ≤ 63
Supereutrophic	63 < TSI ≤ 67
Hypereutrophic	TSI > 67

Table 2
WQI classification.
Source: Cetesb (2017)

Category	Score
Very Good	79 < WQI ≤ 100
Good	51 < WQI ≤ 79
Regular	36 < WQI ≤ 51
Bad	19 < WQI ≤ 36
Poor	00 < WQI ≤ 19

The TSI was calculated using Eq. (1) and the water bodies corresponded to one of the six trophic classes (Table 1).

$$\mathrm{TSI}\,(\mathrm{TP}) = 10 \times (6 - ((0.42 - 0,\, 36 \times (\ln \mathrm{TP}))/\ln 2)) - 20 \tag{1}$$

Where: TP: Total Phosphorus concentration (μg L^{-1}) ln: natural logarithm.

The WQI was developed by the Environmental Company of the São Paulo State (Ceteb) and was calculated using Eqs 2 and 3, considering nine limnological variables: (i) thermotolerant coliforms, (ii) biochemical oxygen demand, (iii) total phosphorus, (iv) total nitrogen, (v) dissolved oxygen, (vi) pH, (vii) total suspended solids, (viii) temperature, and (ix) turbidity. The WQI classifies water bodies into one of five quality levels (Table 2).

$$WQI = \prod_{i=1}^{n} {q_i}^{w_i} \tag{2}$$

Where: Water Quality Index (a number between 0 and 100), qi: quality of the ith variable, a number between 0 and 100 obtained as a concentration function or variable mensuration and wi: weight corresponding to i-th variable, assigned according to the importance of this variable for overall quality compliance, a number between 0 and 1.

$$\sum_{i=1}^{n} w_i = 1 \tag{3}$$

Where: n: the number of variables entering the calculation

2.4. Riparian vegetation assessment

The Riparian Forest Evaluation (RFE) (Magdaleno and Martínez, 2014) assesses the quality of the riparian vegetation considering: (i) longitudinal connectivity; (ii) transversal connectivity; (iii) vertical connectivity and (iv) regeneration capacity. For each parameter, one of the following statuses was established: very good (5), good (4), regular (3), poor (2), and bad (1). The score sum-product results in the final ecological assessment (Table 3), which provides a qualitative description of the state of riparian vegetation. In each sampling station, 50 meters were considered for the application.

2.5. Land use

The land use was obtained by manual polygon digitalization of LandSat-8 image (sensor OIL, path 220, raw 76; dated February 23, 2017; Spatial resolution: 30 m) provided by the United States Geological Service (USGS). A multispectral composite of three bands

Table 3
RFE score and qualitative result.
Source: Magdaleno and Martinez (2014)

Category	Score
Very good - the vegetation shows continuous connectivity in all dimensions, has a great regeneration potential given the found representative species and high ecological value, given its structure and composition	19 - 20
Good - the vegetation shows great connectivity in all dimensions, has a notable regeneration potential given the found representative species and a good ecological value, given its structure and composition	16 – 18
Moderate - the vegetation shows connectivity modifications in all dimensions; the regeneration potential is compromised or is possible to observe anthropic interference in its structure and composition	12 – 17
Poor - the vegetation shows a deep connectivity modification in all dimensions; the regeneration potential is high compromised/non-existent or is possible to observe a high anthropic interference in its structure and composition	8 – 15
Bad - the vegetation shows a complete connectivity alteration in all dimensions; the regeneration potential does not exist or there is no ecological value	4 – 11

(6R5G4B) was carried out to classify the land use/cover, and we identified the land use according to the image's texture and tone. The urban area distance and the riparian vegetation width were measured using the software QGIS (version 3.0.2).

2.6. Data analysis

The Principal Components Analysis (PCA), Redundancy Analysis (RD), and Cluster Analysis (method "average") were applied to all the limnological data, biotic communities, sediment data, macrophyte coverage, RFE, urban distance area, and riparian vegetation width. PCA allowed formulated the dimensional description of the environmental data and the linear combinations provided by the analysis allowed postulations. RD is a canonic analysis of PCA, we aimed to verify the environmental data correlations (biotic communities and abiotic data). The hierarchical Cluster Analysis contribute to verify the hydric bodies groups based on the dissimilarity matrix; groups were formed according to the agglomerative method ("average"). The dissimilarity matrix was calculated using the Euclidean metric, based on pairwise dissimilarities between the average linkage algorithm (weighted or unweighted) (Härdle and Simar, 2015). All the statistical analyses were performed in R language (R Core Team, 2018). The function " decostand" was applied for the data transformation and standardization. The TC, FC, TN, and TP parameters did not receive statistical treatment, were analyzed according to the Brazilian guideline CONAMA Resolution 357/05.

3. Results

The physical and chemical variables for the sampling stations and associated wetlands are provided in the supplementary material (Tables S2 and S3). The rainy season showed higher mean temperature values (23.28°C) than the dry season (19.85°C), but temperature varied with sampling hour and the depth of the aquatic environments.

According to the thermotolerant coliforms values, the Sorocaba river stations (i.e. R1, R2, R6, and R7) present concentrations above the CONAMA Resolution 357/05 (1,000 CFU/100 ml). In both seasons, the major sewage input occurred before the Sorocaba river entrance in the municipality, situation probably associated with the sewage from precarious Sewage Treatment Plant in the Votorantim municipality.

Considering the longitudinal gradient, there is a reduction in the thermotolerant coliforms values from R1 to R7 (ranged from 528,000 to 195,200 CFU/100 ml). Although, an increase of thermotolerant coliforms was observed in R7 during the dry season, which can indicate sewage entrance in the system before the river leaves the urban area. The nutrient analysis (total phosphorus and nitrogen) in the places correspondent to the river entrance (R1), medium course (R2) and before the river leaves the municipality (R7) exhibits some enrichment during the dry season and lower values in the rainy one, main in the function of the water volume in the system. Total phosphorus ranged from 14 to 118 μg/L, the total nitrogen varied from 1,084 to 3.435 mg/L.

Concerning the electrical conductivity values (ranged from 44.50 to 312.67 μS/cm), it is possible to note that Sorocaba river has a huge dissolved solids charge (probably organic matter) from R1 to R7, which may be influenced by urban area discharges. The wetlands were influenced by human interference, but increases and decreases in electrical conductivity concentrations were observed according to the longitudinal gradient. The highest values recorded for total dissolved solids in the river were found in the rainy season (ranged from 33.90 to 172.90 mg/L), in the wetlands the same situation was noted and the higher values was registered in the dry season (ranged from 20.47 to 83.53 mg/L).

Considering the Sorocaba river is evident that the higher values of total suspended solids for the river occurred during the rainy season (ranged from 9.87 to 81.67 mg/L) and a small variation was observed in the dry season, although wetlands showed higher values in the dry season (ranged from 3.33 to 90.33 mg/L). As expected, turbidity followed the same pattern observed in the Sorocaba river (values from 26.66 to 144,34 NTU) and wetlands (values from 15.33 to 472.66 NTU) concerning to total suspended solids.

Both climatic periods indicated dissolved oxygen variation (ranged from 1.40 to 7.07 mg/L) in the Sorocaba river, represented by a decrease and increase, mainly during the rainy period. Wetlands ecosystems demonstrated a similar situation (ranged from 0.40 to 7.72 mg/L). All that variation is probably associated with the organic matter degradation in the system and sewage discharges in the longitudinal river gradient.

The pH values indicate that the environments tend to be slightly alkaline (> 7, 0), except W3 during the first water sampling, which was characterized as mildly acidic (< 7, 0), due probably in the function of the vegetal biomass degradation.

An important point is that according to a national guideline (CONAMA Resolution 357/05), some limnological parameters are above references concentrations (thermotolerant coliforms - 1,000 UFC/100 ml; biochemical oxygen demand - 5 mg/L; total phosphorus - 0,1 mg/L; dissolved oxygen - ≥ 5 mg/L turbidity - 100 NTU), indicating an anthropic interference on the evaluated aquatic systems.

The trophic degree of Sorocaba river increased along with the longitudinal profile, varying from oligo to supereutrophic (Table 4), and along the seasons, without lower values during the rainy period and higher values during the dry season.

Thermotolerant coliforms, dissolved oxygen, and biochemical oxygen demand were the most important limnological parameters that influenced the WQI result, proving once again the anthropic interference on the river, given the water quality loss during the longitudinal gradient.

The sediment data (Table S5) revealed that the sampling stations have silt/clay as the main fraction in the sediment, the samples were composed mainly for inorganic material (> 79%). Concerning the organic material concentrations, usually, the wetlands ecosystems had higher organic material (mean = 13.25%, min. = 3.50, max. = 20.07%) than Sorocaba river stations (mean = 8.10%,

Table 4
Obtained values for TSI and WQI.

Index	Season	R1	R2	R7	R8
TSI	Rainy	Oligotrophic (50.22)	Oligotrophic (51.42)	Oligotrophic (49.23)	Mesotrophic (52.10)
	Dry	Oligotrophic (47.64)	Supereutrophic (63.87)	Supereutrophic (63.78)	Mesotrophic (58.71)
WQI	Rainy	Regular (36.55)	Bad (29.58)	-	Bad (26.84)
	Dry	Regular (42.42)	Regular (39.45)	-	Bad (35.42)

min. = 4.61, max. = 12.54%). The results reinforce the idea of those anthropic activities (e.g. civil sector, sugar cane) might contribute to soil revolving and material disposition in the aquatic environments, likewise, the degradation process predominance in wetlands favors a higher organic matter in the sediment.

During the rainy season, the river connection with the wetlands is well established, bearing the higher values for organic matter in these environments when the dry season was considered; the connectivity allows organic matter entrance, and the rain result in allochthone material input.

In face of the silt/clay fraction relevance, the Sorocaba river and wetlands may accumulate several substances (e.g. Cu, Cr, Mg, Pb, organochlorine) because of the large contact surface of the fine particles.

Aquatic macrophytes species and macroinvertebrate orders were found in some sampling stations, and group predominance was observed in some cases (Table 5). Four macro invertebrates' orders (i.e. Diptera, Oligochaeta, Hirudinea, and Gastropoda) were identified, and six families of aquatic macrophytes were found: (i) Cyperaceae (*Cyperus giganteus*), and (ii) Pontederiaceae (*Eichhornia crassipes*), and (iii) Hydrocharitaceae (*Egeria densa*), and (iv) Araceae (*Pistia stratiotes*), and (v) Salniniacea (*Salvinia auriculata*), and (vi) Phocaea (*Urochloa arrecta*).

Five aquatic plants occurred in W5, two in W2 and W7, and only one in W3 and W4. Macrophyte occurrence was not recorded in two wetlands (W1 and W6). On the other hand, the W3 coverage was equal class 5 (100%) in both sampling campaigns, *P. stratiotes* covered all the water area. The seasonality influenced the cover in some wetlands (W5 and W7), but no variation was observed in W4. The areas where macrophytes did not occur were framed as Class 1, concerning the vegetal cover.

We can infer that Sorocaba river wetlands undergo water quality loss, occasioned by domestic effluent input, given that three macrophyte species (i.e. *S. auriculata, P. stratiotes* and *E. crassipes*) are strongly associated with impacted areas and high nutrients concentrations. There was possible to see a higher species occurrence in W5, which can indicate a lower anthropic perturbation degree when compared with the other ecosystems. W4 is under high human interference probably by sewage input, a situation that contributes to *P. stratiotes* domination. The remaining areas might be in an intermediate human interference degree.

Seasonality influenced the macroinvertebrate number, during the dry season, the rain that occurred in the previous day possibly contributed to the low number of the collected organism. The identified orders are characterized to be tolerant and resistant to pollution. The low richness can be related to anthropic interference on Sorocaba river and its wetlands (e.g. limnological parameters).

There are some similarities in the biological groups' composition in the sampling stations, a factor that may go through influence from organic pollution, an element that creates conditions to resistant groups surviving and water quality loss, besides the habitat homogenization (heterogeneity reduction). This scenario indicates that anthropic activities caused alterations in nutrients levels and other limnological parameters, as verified. There is a possible water quality compromising, in some cases is possible to observe anoxia (W4). Aquatic macrophytes and macro invertebrates emphasize the limnological analysis results,

Table 5
Macrophytes species occurrence and macroinvertebrate order abundance.

		MACROPHYTES				
Species	Season	W2	W3	W4	W5	W7
C. giganteus	Rainy				X	
	Dry				X	
E. crassipes	Rainy					
	Dry					
E. densa	Rainy	X			X	
	Dry	X			X	
P. stratiotes	Rainy		X			
	Dry		X			
S. auriculata	Rainy	X		X	X	X
	Dry	X		X	X	X
U. arrecta	Rainy					
	Dry					
Cover	Rainy	1	3	5	3	3
	Dry	1	2	5	2	2

		MACROINVERTEBRATE										
Order	**Season**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**W2**	**W3**	**W5**	**W6**	**W7**
Diptera	Rainy	3	2	0	7	0	0	0	0	0	0	0	1
	Dry	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	Rainy	69	5	67	2	70	144	150	0	0	78	0	4
	Dry	0	7	0	4	0	0	0	0	0	0	0	0
Hirudinea	Rainy	5	1	1	0	0	0	0	0	1	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	Rainy	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	1	1	0	0	2	0
Total	Rainy	77	8	68	9	70	144	150	0	1	78	0	5
	Dry	0	7	0	4	0	0	1	1	0	0	2	0
Richness	Rainy	3	3	2	2	1	1	1	0	1	1	0	2
	Dry	0	1	0	1	0	0	1	1	0	0	1	0

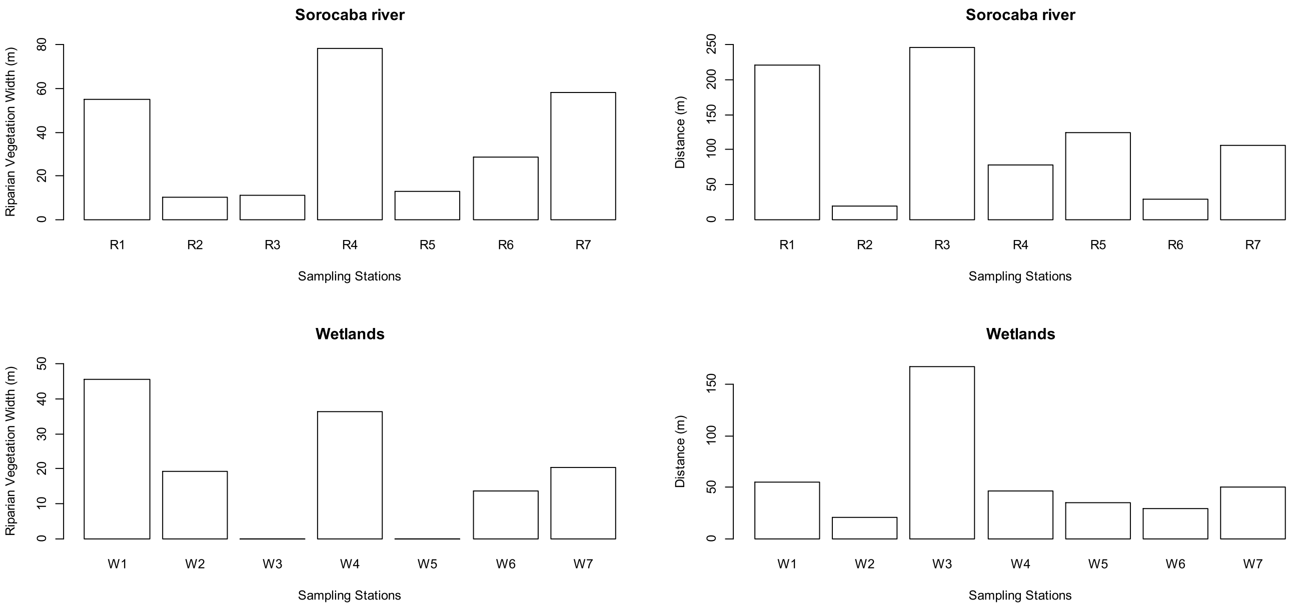


Fig. 2. Urban area distance and the riparian vegetation width for the sampling stations.

the bioindicators of low quality prove that wetland ecosystems are in a debility state and have alterations in the ecological functions. The lentic system bears up the macrophytes growth, as well as their development process, thanks to the decomposition process and nutrient realizing during the detritus decomposition.

Fig. 2 demonstrates the values for riparian vegetation width and urban area distance obtained for the sampling stations. Some localities (W3 and W5) do not have riparian vegetation; instead, others have a small vegetation width (W2, W6, and W7) or large vegetation in the adjacent area (R1, R4, R8, and W1). Urban areas are very close to almost all the sampling stations (< 60 m). Table 6 shows the human interference in the connectivity and regenerative capacity of Sorocaba river (except W7) and wetlands ecosystems. The low quality attributed had, as main causes, isolated individuals, ruderal species, natural regeneration impedance, and low or inexistent connectivity. High connectivity, dense riparian vegetation, and a great population structure contribute to good quality and a relevant ecological value (e.g. R1, W1, and W1). The urban areas proximity and the vegetation width might favor human interference, contributing to poor riparian vegetation, reflecting in the water quality.

So, the sampling stations can be categorized as being under stress for urban structures proximity.

PCA analysis (Fig. 3) explained 66, 76% of the data variation (axe 1 = 35, 68%, axe 2 = 31, 08%). Electrical conductivity, turbidity, urban area distance, sediment inorganic matter, riparian vegetation width, and total suspended solids were the parameters that most contributed to the axis formation and sampling stations segregation. The turbidity, Oligochaeta order, and total suspended solids caused some localities segregation (R2, R6, W2, W3), as the urban area distance (R1, R3, R5) and riparian vegetation width (R4, R7, W1, W4). It seems that the wetlands (except W3 and W2 during the dry season) can be characterized by similarity and a great relation with some parameters (total suspended solids, and total dissolved solids, and electrical conductivity, and sediment inorganic matter), situation supported by the limnological and sediment data. The river sampling stations showed dissimilarity in both sampling campaigns, mainly in the initial longitudinal gradient (R1, R2, and R3). Negative relations were noticed between urban area distance - macrophyte coverage, turbidity - sediment inorganic matter, and total suspended solids - silt/clay, but a positive relation was also noticed (total dissolved solids - electrical conductivity). The other parameters considered did not imply in localities segregation.

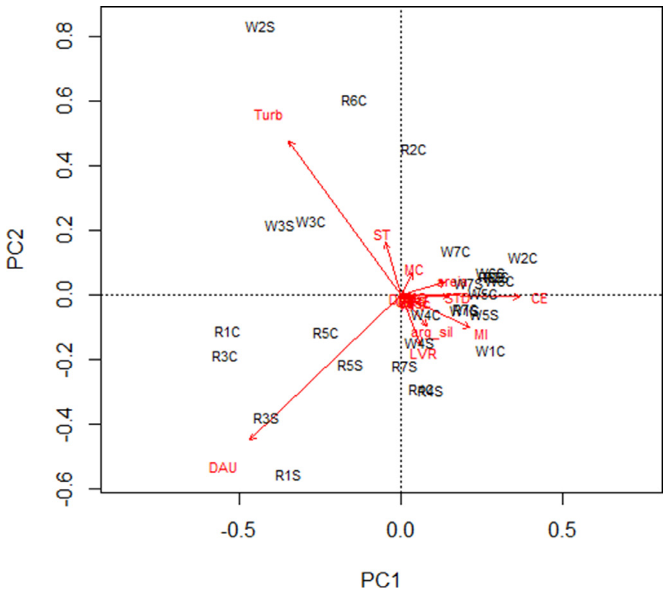


Fig. 3. PCA diagram ordination for the sampling stations. Legend = biochemical oxygen demand (DBO), dissolved oxygen (DO), dry season (S), electrical conductivity (EC), gravel/boulders (Casc), macrophyte coverage (MC), rainy season (C), riparian forest evaluation (RFE), riparian vegetation width (RVW), sand (areia), silt/clay (arg_sil), Sorocaba river stations (R), temperature (T), total dissolved solids (STD), total suspended solids (TS), turbidity (turb), urban area distance (UAD), and wetland stations (W).

Table 6
Results of RFE application to evaluated sampling stations.

SOROCABA RIVER						
R1	R2	R3	R4	R5	R6	R7
Moderate	Poor	Moderate	Moderate	Moderate	Moderate	Good
WETLANDS ECOSYSTEMS						
W1	W2	W3	W4	W5	W6	W7
Good	Good	Poor	Good	Poor	Moderate	Moderate

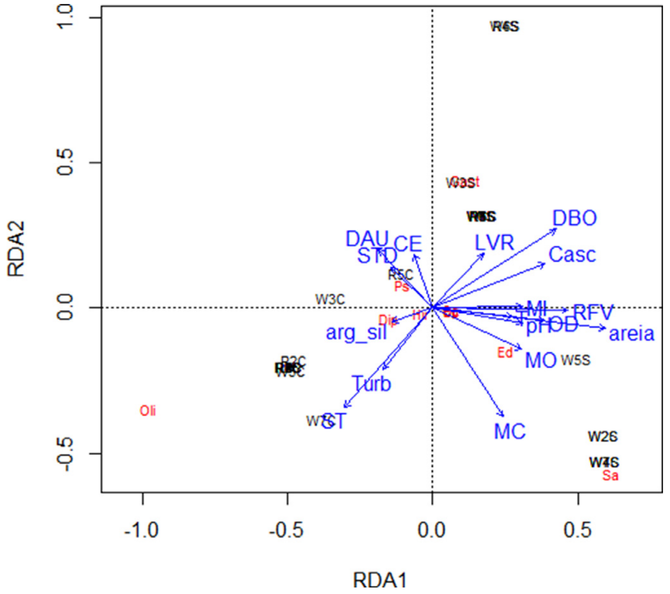


Fig. 4. RD ordination diagram for the sampling stations. Legend = biochemical oxygen demand (DBO), Diptera (Dip), dissolved oxygen (DO), dry season (S), *E. crassipes* (Ec), *E. densa* (Ed), *C. giganteus* (Cg), electrical conductivity (EC), Gastropoda (Gast), gravel/boulders (Casc), Hirudinea (Hir), macrophyte coverage (MC), *P. stratiotes* (Ps), Oligochaeta (Oli), rainy season (C), riparian forest evaluation (RFE), riparian vegetation width (RVW), *S. auriculata* (Sa), sand (areia), silt/clay (arg_sil), Sorocaba river stations (R), temperature (T), total dissolved solids (STD), total suspended solids (TS), turbidity (turb), *U. arrecta* (Ur), urban area distance (UAD) and wetland stations (W).

The environmental gradient analysis was based on the RDA (Fig. 4), that explain 54, 62% of the data variation (axe 1 = 37, 48%, axe 2 = 17, 14%). Macroinvertebrate has a positive relation with some limnological parameters (total suspended solids, turbidity, and silt/clay), especially the Oligochaeta order, but the Gastropoda showed a negative relation to the previous parameters and had a positive relation with biochemical oxygen demand, riparian vegetation width, and gravel/boulders. In general, the macrophytes presented a positive relationship with sediment inorganic matter, riparian vegetation width, pH, dissolved oxygen, sand, and sediment organic matter (especially *E. densa*). *S. auriculata* had a strong relation with macrophyte coverage. However, *P. stratiotes* showed a relation with other parameters (urban area distance, total dissolved solids, and electrical conductivity). The sampling stations can be characterized for a similarity, some localities showed positive relations with limnological parameters and biotic communities (e.g. R2 and Oligochaeta, W7, and total suspended solids, W3 and *P. stratiotes*, W2 and *S. auriculata*). *C. giganteus, E. crassipes*, and *U. arrecta* presented a small relation with sediment inorganic matter, RFE, temperature, pH, dissolved oxygen, sand, and sediment organic matter. A negative relation was observed between macrophyte coverage and some parameters (urban area distance, total dissolved solids, and electrical conductivity).

Cluster Dendrogram (Fig. 5) consistently aggregated the sampling stations in two groups: one composed by W2 during the dry season (possibly influenced by the high turbidity), and two Sorocaba river's stations (R2 and R6 - rainy season), and others in the remaining places. The larger group is subdivided into two groups because of the dissimilarities from limnological data, and sediment, and riparian vegetation, and biological groups. The first one can be described as being more affected by human disturbances in the function of the limnological data, biological existent groups and variation along with the seasonality when compared with the other group, which is marked by similarities, especially during the dry season, where a low data variation was observed. Also, it is possible to infer that the Sorocaba river wetlands are more similar among them (salve W2 during the dry season and W3) than the Sorocaba river during its longitudinal gradient. Besides that, some river stations can be considered similar to the wetlands during the dry season (R2 and R6).

During the year of 2017, 11 land use typologies were identified (Figure 6), which can be grouped in four land use classes: (i) anthropogenic non-agricultural (i.e. mining, road, and urban area), (ii) anthropogenic agricultural (i.e. annual crop, bare soil, pasture, and silviculture), (iii) natural (i.e. native vegetation) and (iv) water (i.e. reservoir, water body, and wetlands). The most abundant land uses were correspondent to anthropogenic agricultural and non-agricultural, which together occupied 75.42% of the total area (45,071.69 ha), followed by natural (23.47%) and water (1.11%). Annual crop, and urban areas, and pasture are the main drivers in the area. The native vegetation in the municipality is highly fragmented, especially in the urban areas; the remaining vegetation is associated with hydric bodies. The remaining wetlands are associated with the Sorocaba river and located mostly in the urban area.

4. Discussion

The River Continuum Concept (Vannote et al., 1980) is based on the premise that a lotic environment shows a continuum gradient from spring to river mouth of physic variables (e.g. flood, temperature, width) that deeply influence the biological communities and ecological process. Sorocaba river is a large river, the discharge favors reductions in temperature, and electrical conductivity values, and pH, and total dissolved solids, and total suspended solids, and dissolved oxygen concentrations, mainly during the dry season. Furthermore, the disturbances occasioned by elements input in the Sorocaba river change the stability because of energy flow in the rainy season.

Flood Pulse Concept (Junk et al., 1989) explains the dynamic observed in wetlands ecosystems, the exerted force on biota control, and floodplains resulting in elements transference (e.g. organic matter) between the river and wetlands along with the water level variation. During the dry season, the water level favored the lower variation observed in the wetland's limnological characteristics (electrical conductivity, pH, total dissolved solids). Over the rainy season, the connection with the Sorocaba river increase, contributing to material input in wetlands, what results in the variation of limnological parameters displaying higher values than in the dry season (electrical conductivity, biochemical oxygen demand, and total suspended solids).

Some limnological parameters (total dissolved solids, total suspended solids, biochemical oxygen demand, and turbidity) presented higher concentrations during the rainy season than the dry season, as consequence from the increase in the surface runoff during the rise in the precipitation, altering the elements input in the aquatic systems (Andrietti et al., 2016). Low dissolved oxygen concentrations were related to organic matter decomposition due to microbial community metabolism (Furtado et al., 2015). The pH variation is a consequence of the decomposition process ($pH < 7$) and photosynthetic activities ($pH > 7$) (Bambi et al., 2008) by changing the inorganic carbon balance.

The nutrient spiraling in streams that address the nutrient cycling in aquatic systems (Newbold et al., 1981), contemplating the spatial and temporal dimensions (assimilation and sequestration) (Ensing and Doyle, 2006). Both total phosphorus and nitrogen were not retained by the Sorocaba river, and the increase in nutrients in some sampling stations was associated with interference factors (as Sewage Treatment Plants effluent, organic matter input). The rise in a load of those nutrients was related to the input of domestic sewage (Rocha et al., 2014). High total phosphorus concentrations are indicative of allochthone material intake (Furtado et al., 2015), as observed in R6.

The nutrient excess (especially the lentic ones) generate alterations in the metabolism of the aquatic ecosystem, as the primary production increase, that reduce the dissolved oxygen due to the biomass degradation, as well as cyanotoxin production by algae communities and turbidity rise. All these processes affected the local biota and represent

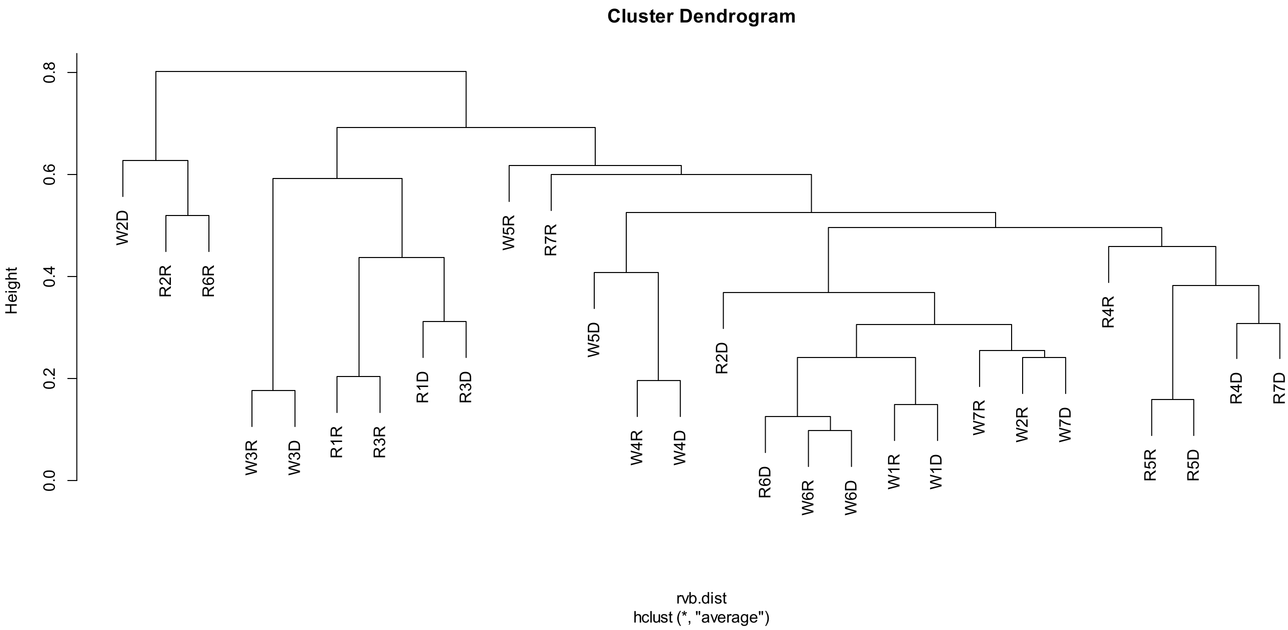


Fig. 5. Cluster dendrogram (average method) of the limnological data, biological communities, and riparian vegetation variables for all sampling stations. Legend = dry season (S), rainy season (C), Sorocaba river stations (R), and wetland stations (W).

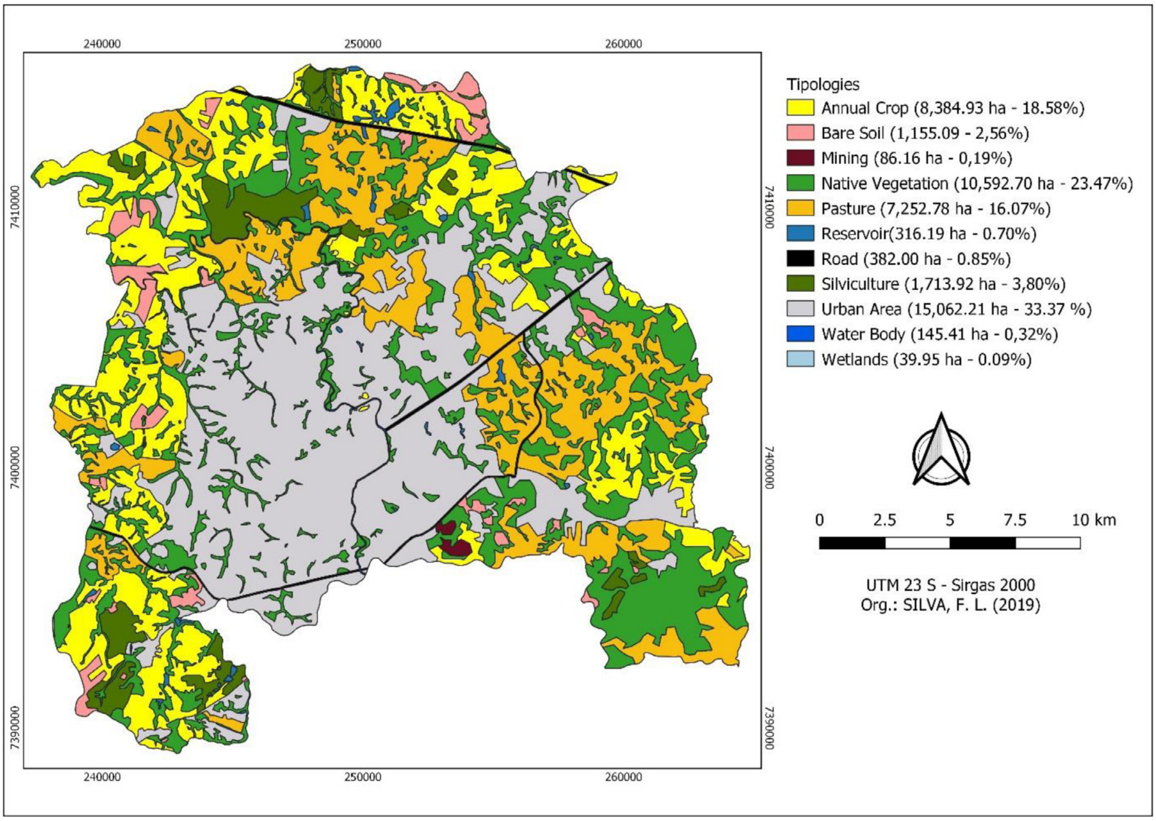


Fig. 6. Sorocaba-SP Land Use distribution and cover typologies and area (ha and %) in 2017.

a negative aspect for the water multiple uses (e.g. water supply, recreation).

Former limnological data from sampling stations in 1993, showed that the wetlands presented higher values of dissolved oxygen than in our study and the temperature and pH showed a low variation among the environments (Smith and Barrela, 2000). The limnological report from Cetesb (https://cetesb.sp.gov.br/aguas-interiores/publicacoes-e-relatorios/) for 2015 and 2016, pointed that the sampling stations R2 and R6 were influenced by untreated sewage input, given the obtained limnological parameters (electrical conductivity, total phosphorus, biochemical oxygen demand).

The temperature is influenced by the climatic regime and geographic factors (e.g. altitude), playing a relevant role in aquatic systems, due to physical and chemical parameter influence and in the biota metabolism (Companhia Ambiental do Estado de São Paulo, 2017). Sampling time and riparian vegetation degradation or lack of riparian vegetation were the components that differentiate sampling stations (e.g. R1, R3, R6, V4, V5, and V7) concerning the water temperature. Wetlands that presented a good ecological status (WI and W2) showed no higher temperature as that observed in the river. The opposite situation was found in the following wetlands: W4, W7, and W8 that was characterized by human interference in the riparian vegetation.

Escherichia coli is a microbiological group that occurs in the intestinal flora of endothermic animals, largely used as a fecal contamination indicator and pathogens organism existence in the aquatic bodies (Arruda et al., 2016). The water of Sorocaba river presented organisms associated with water-related diseases, which indicates that these environments' water is not appropriated for human consumption without previous treatment.

Biochemical oxygen demand was considered an indirect pollution indicator once this limnological parameter is related to the domestic sewage input (Petry et al., 2016) resulting in a reduction of dissolved oxygen levels. Low biochemical oxygen demand values can be associated with less anthropic interference and lower effluent discharges (Damasceno et al., 2015). Wetlands may experience dissolved oxygen reduction because of the biomass (i.e. macrophyte) degradation process (Azevedo et al., 2014), a condition observed in W3.

Biological communities reflected the human disturbance in the study area. The identified macroinvertebrate orders were characterized to be tolerant and resistant to pollution. These organisms live in environments with low habitat diversity and consume the organic matter in the sediment (Schiller et al., 2017). The low richness was associated with sewage (domestic and industrial) discharge, and deforestation, and river canalization (Laura Miserendino et al., 2011), a scenario observed in the Sorocaba river and the wetlands.

The evaluation of an area located before R1 (Itupararanga reservoir drainage area), reported the predominance of some orders (Diptera, Hemiptera, and Odonata) related with human disturbances, mainly organic and chemical pollution, once organisms associated with good quality indicators (e.g. Ephemeroptera, Tricoptera and Plecoptera) were not found (Taniwaki and Smith, 2011). The identified orders usually live under low dissolved oxygen concentrations and high trophic degrees (Fusari and Fonseca-Gessner, 2006; Beghelli et al., 2015), indicating that the aquatic ecosystems have fragilities occasioned by human impacts, as reinforced by limnological analysis (electrical conductivity, thermotolerant coliforms and dissolved oxygen).

In the same way, aquatic macrophytes reflected organic pollution in the wetlands. The loss of water quality contributes to the maintenance and excessive macrophytes growth, as the *S. auriculata* and *P. stratiotes* (Thomaz et al., 1999; Pedralli, 2003; Pompêo, 2008; Trindade et al. 2010; Galal and Farahat, 2015; Lu et al., 2018) found in our study

Considering perturbation events (i.e. domestic sewage input, deforestation, diffuse pollution) that influenced the communities in the sampling stations, we inferred that the aquatic ecosystems had alterations in the community structure (Niemi and McDonald, 2004; Danz et al., 2007). Unsustainable agricultural activities confer a threat to the aquatic systems (Guerreiro, 2019), a common practice observed in the adjacent areas in the Sorocaba river.

Riparian vegetation degradation is a factor that propitiates the inorganic material and sand adduction increase because of the accelerated erosive processes (Santiago and Cunha-Santino, 2014). The sediments are carried from agribusiness activities as a result of soil rotating and from urban drainage systems by car emissions, and industries, and home building, and deforestation (Tucci, 2002; Minella et al., 2007; Taylor et al., 2008).

The aquatic ecosystem quality is reflected by their sediment properties, the fraction < 63 μm is largely observed in studies that aim to verify pollutants in the sediment (e.g. Cesar et al., 2011) for being chemically active and retaining heavy metals (Lemes et al., 2003). We found silt/clay fractions, indicating that the sediment in the sampling stations may accumulate metals and other pollutants, situation favored by the lack of riparian vegetation, and the particulate material input during rainy periods (Oliveira et al., 2010; Tundisi and Tundisi, 2010). Although lower total suspended solids concentration occurs during the dry season due to water level stability and low particulate material input, particulate material emitted by human activities is a relevant heavy metal source (Ribeiro et al., 2012; Andrietti et al., 2016).

Sorocaba municipality has a high fragmented landscape and the remnant vegetation is distributed in small areas, a situation associated with the protection proportioned by normative dispositions (Mello et al., 2014; Mello et al., 2016), as the Federal Law 12,651/2012 (Native Vegetation Protection Law - NVPL), the mechanism that establishes Permanente Protected Areas (an area that must protect in public and private lands) around water bodies and Legal Reserves (areas that must be protected inside rural properties). Besides this scenario, the municipality presented 166 vegetal species (Kortz et al., 2014), indicating that the remaining vegetation contributes to biodiversity conservation. Silva (2010) identified during the periods of 1988-1995 and 1995-2003 that Sorocaba's main land use were urban areas and pasture, situation verified also by (Bortoleto et al., 2016). The intense land-use verified in Sorocaba was similar to the Prata Basin, where the agricultural practices and urbanization constitutes the main drivers of changes in the landscape (Zeni et al., 2019).

The lack of riparian vegetation contributes to water quality loss, mainly by the retention capacity reduction and physical-chemistry parameter alterations (Rodrigues et al., 2015). Urban process, and agribusiness, and industrialization imply negative impacts on natural systems and cause alterations in their stability, due to the high landscape modification (Silva et al., 2017). The recovery of natural areas in Sorocaba is necessary, as well as the reduction of the pollutant load of the aquatic ecosystems. The establishment of regulatory rules and strong monitoring efforts can favor Sorocaba's wetlands stability.

Sorocaba municipality has a large population and human activities are based on the agribusiness and industrial sector. The indirect drivers contributed to natural landscape conversion in urban areas and agribusiness development, sewage loadings increase, and nutrient input from organic pollution in the aquatic systems. Indirect drivers resulted in many ecological effects that promote alterations in the ecosystem services and excess pressure on indirect drives (Fig. 7).

Urban ecosystem provision is much related to the provision structures in the urban areas, especially the blue (e.g. pounds, rivers, wetlands), and green (e.g. urban forest) areas (Artmann et al., 2017; Pueffel et al., 2018). These areas should be taken into consideration during land planning and the impact need to be reduced in the intent to establish a healthy place for society (Li et al., 2017) and ecosystem. The scenario we found demonstrated that the sampling stations are under human interference, implying in adverse effects on ecosystem homeostasis in the function of environmental metabolomics, and microbial interactions, and metabolism changes, and environmental alterations that interfere in biological health and biochemical cycles (Kikuchi et al., 2018). Considering the hydric network of tropical countries in the same geographic region and the importance of the flood pulse (Lynch et al., 2016; Dalmagro et al., 2017, McInerney et al., 2017; Ramos et al., 2017; Suchara, 2018), as well as urbanization and population increase contexts, the approach proposed can be used to assess the human interference on other urban tropical wetlands.

5. Conclusions

The ecological approach that was applied was based on land use, and limnological analysis, and biotic communities, and riparian vegetation enabled the verification of the main human interferences in Sorocaba Municipality (diffuse pollution and domestic sewage) and it can be employed in other wetland ecosystems. The organic matter input was reflected on electrical conductivity, and biochemical oxygen demand, and dissolved oxygen concentrations and the organism,

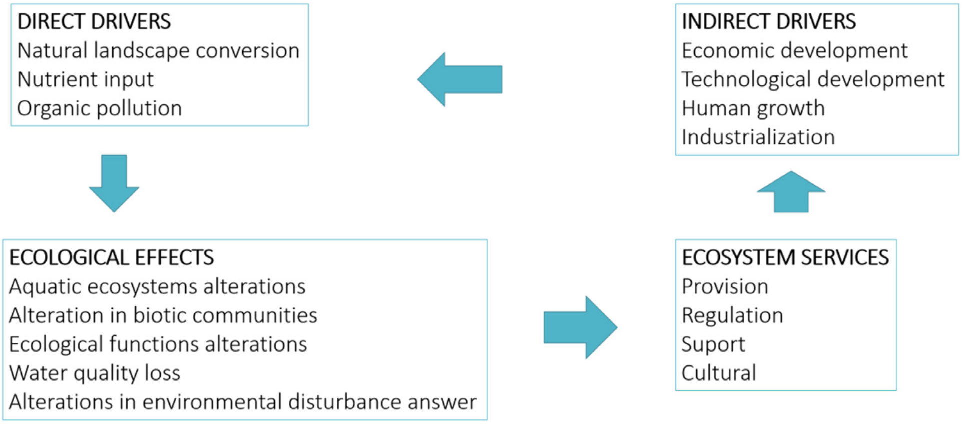


Fig. 7. The conceptual model for Sorocaba municipality drivers. Adapted from: (Galatowitsh, 2012).

indicating the water quality loss, as presented by the limnological indexes. The situation proves that the environmental planning based on strategic action is a necessary approach to deal with the incipient physical planning, besides the need of considering all hydrographic basin and activities carried out in it, which reflect on hydric bodies. The statistical analyses showed that wetlands, in general, were characterized by great similarity, but different from the Sorocaba river sampling stations. The human activities in the landscape resulted in jeopardizing the riparian in some localities, although the vegetation still contributes to water protection and have ecologic value. The situation demands the search for equilibrium between development and ecological function to meet human needs and promote wise water resources use and biological conservation. The local managers can provide normative elements that favor the ecological system maintenance and promote ecological integrity and fulfillment of public policies (e.g. Aichi Targets, Ramsar Strategic Plan 2016 – 2024). The Strategic Environmental Assessment could contribute to wetlands protection and adequate management, as well as a land-use plan that prioritizes natural areas recovery and pollution reduction. Taking into account the tropical river-wetland system observed in other regions, the bimodal pulse influence, and urbanization, and population increase, the approach can help to assess the human interference on urban wetlands and contributor river in countries located at the same geographic region.

CRediT authorship contribution statement

Fabio Leandro da Silva: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Marta Severino Stefani:** Data curation. **WelberSenteio Smith:** Supervision, Writing - review & editing, Visualization. **Daniele Cristina Schiavone:** Data curation. **Marcela Bianchessi da Cunha-Santino:** Writing - review & editing, Visualization. **Irineu Bianchini Jr:** Writing - review & editing, Visualization.

Declaration of Competing Interests

The authors declare that they have no conflict of interest

Acknowledgment

Financial support was provided by the National Council of Technological and Scientific Development(Process number: 830728/1999-6 and 158927/2018-4). The authors are grateful for the support provided by the Universidade Federal de São Carlos (Hydrobiology Department in special). We also thank Catia Cristina Teodoro, Marcos Marcilio, and André Puga, for the support during the sampling in the limnological stations. We are grateful to the anonymous reviewers, that provided valuable comments to improve the manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ecocom.2020.100852.

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