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Development of a zooplankton biotic index for trophic state prediction in tropical reservoirs

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ABSTRACT

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Reservoirs are built mainly for public supply and power generation. However, water quality is almost always compromised by discharge of domestic and industrial sewage, as well as by agricultural residues. Several ecological indices are currently used to analyze different impacts in this environment. The aim of this study was to develop a zooplankton index for tropical reservoirs. Limnological data were obtained from seven Brazilian reservoirs (Atibainha, Broa, Barra Bonita, Salto Grande, Rio Grande, Itupararanga, and Igaratá). Weighted values of ecological optimum were obtained through species response analysis (unimodal distribution) related to chlorophyll a concentration. The results obtained using the zooplankton index (ZBI) proposed had significant correlations with eutrophication indicators. Overall, poor and regular water quality were verified in most reservoirs, partially corroborating the zooplankton community index proposed for Brazilian reservoirs. For further progress, the approach presented here must be tested in other regions. In addition, the ecological indices derived from different aquatic communities should be integrated into a composite index.

Key words: zooplanktonic index, eutrophication, ecological potential, São Paulo State

RESUMO

Desenvolvimento de um índice biótico do zooplâncton para predição do estado trófico em reservatórios tropicais

Reservatórios são construídos principalmente para abastecimento público e geração de energia. No entanto, a qualidade da água é quase sempre comprometida pela descarga de esgoto doméstico e industrial além de resíduos agrícolas. Atualmente vários índices ecológicos são usados para diagnosticar impactos nesses ambientes. Este estudo teve como objetivo desenvolver um índice do zooplâncton para reservatórios tropicais. Dados limnológicos foram obtidos em sete reservatórios brasileiros (Atibainha, Broa, Barra Bonita, Salto Grande, Itupararanga e Igaratá). Os valores ponderados de ótimo ecológico foram obtidos através da análise de resposta das espécies (distribuição unimodal) relacionado com as concentrações de clorofila a. O índice do zooplâncton (ZBI) proposto apresentou correlação significativa com os indicadores de eutrofização. No geral, os reservatórios analisados apresentaram qualidade da água ruim e regular o que corrobora parcialmente com o índice da comunidade zooplanctônica de reservatórios brasileiros. Para futuros avanços, a abordagem proposta deve ser testada em outras regiões. Além disso, índices ecológicos derivados de diferentes comunidades aquáticas devem ser consolidados em um índice composto.

Palavras chave: *índice zooplanctônico, eutrofização, potencial ecológico, Estado de São Paulo*

INTRODUCTION

Reservoirs are used for different purposes, such as hydropower generation and storage of water for human consumption. At the same time, they are subject to different types of pressures that can cause loss of chemical and biological quality, thereby diminishing their ecological, economic, and cultural benefits (Breunig *et al.*, 2017; Cardoso-Silva *et al.*, 2018). Their monitoring, management, and protection requirements are essential to guarantee the best possible use (Lopez-Doval *et al.*, 2017). According to the Brazilian Environment Council and the Water Framework Directive (WFD), aquatic organisms and communities can be used as biological indicators to assess the quality of the environment. However, in Brazil, determination of classes to be used is still based on chemical analysis.

Bioindicators are living organisms such as plants, plankton, animals, and microbes that are used to assess ecosystem health. Each organic entity inside a biological system provides an indication of the health of its surroundings, such as plankton, which respond rapidly to changes in the surrounding environment and serve as an important biomarker and indicator of water pollution (Parmar *et al.*, 2016). Freshwater zooplankton communities consist mainly of protozoans, rotifers, and microcrustaceans (Pereira *et al.*, 2011; Cavan *et al.*, 2017; De-Carli *et al.*, 2018). Zooplankton play an important role in the pelagic food web as a mediator of nutrient and energy fluxes (Wetzel, 1995). Understanding factors that determine zooplankton abundance, composition, and dispersal provides information needed to improve plankton dynamic predictions and enhance effective water resource management and biodiversity conservation (Zhao *et al.*, 2017). Pollution-sensitive species are generally eliminated while more resistant species show high population growth rates (Matsumura-Tundisi & Tundisi, 2003). Furthermore, zooplankton may be considered a good indicator of environmental changes caused by impactful activities (Ferdous & Muktadir, 2009; Costa *et al.*, 2016; Hemraj *et al.*, 2017).

Biotic indices to monitor water quality are helpful tools for evaluating the health of rivers and lakes. In Brazil, water samples are analyzed

Table 1. Morphometric characteristics of the Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG), and Igaratá (IG) reservoirs. Legend: maximum depth (Mdepth); sampling depth (Sdepth). *Características morfométricas dos reservatórios Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG) e Igaratá (IG). Legenda: profundidade máxima (Mdepth); profundidade de amostragem (Sdepth).*

Sites	UTM coordinates x	UTM coordinates y	Mdepth m	Sdepth m
SG-R	271746	7484625	5.5	4
SG-C	267855	7486087	8.4	3
SG-D	265792	7487792	11.0	3
BB-R	772898	7497007	16.4	4
BB-C	767108	7502593	18.3	7
BB-D	755107	7506492	22.6	8
BR-R	203139	7540974	3.2	2
BR-C	201694	7543600	6.4	2
BR-D	200605	7545526	13.0	2
IT-R	336225	7419553	8.2	2
IT-C	329679	7418759	10.8	6
IT-D	330027	7417799	14.8	5
AT-R	318857	7370288	8.9	1
AT-C	324042	7372330	19.1	1
AT-C5	324589	7378563	17.0	1
RG-R	267375	7388420	4.4	3
RG-C	262543	7385709	7.5	5
RG-D	256208	7386044	11.7	5
IG-R	365396	7439484	28.6	5
IG-2	360537	7437729	44.0	7
IG-B	359533	7432897	24.5	7

using mainly physical and chemical attributes because most biotic indices were developed in other countries and their effective application to Brazilian ecosystems requires significant research. In this sense, the zooplankton indices have been overlooked (EC 2000; Søndergaard *et al.*, 2005; Jeppesen *et al.*, 2011), unlike other biological communities such as macrophytes, phytoplankton, benthic invertebrates, and fish.

The relationship between zooplankton and water quality has been the subject of several studies (Gannon & Stemberger, 1978; Matsumura-Tundisi *et al.*, 2002; Sousa *et al.*, 2008; Sakamoto *et al.*, 2018). A wetland zooplankton index for water quality assessment was developed In North America (Lougheed & Chow-Fraser, 2002), using weighted values to formulate equations. Similarly, Hering *et al.* (2006) and Kane *et al.* (2009) developed a biotic integrity planktonic index and Carpenter *et al.* (2006) prepared a zooplankton index of biotic integrity in an estuarine environment. Ejsmont-Karabin (2012) compiled rotifer data from temperate lakes and pointed metrics for trophic state assessment. In Brazil, the Environmental Agency of São Paulo State, Brazil (CETESB, 2006), has applied biological indices since 2003, an important advance for environmental management of reservoirs, rivers, and streams. Here, we developed and validated predictive index for water quality using zooplanktonic communities of the tropical reservoirs.

MATERIAL AND METHODS

Study area

The Atibainha Reservoir is part of the Cantareira System that supplies water to the metropolitan region of São Paulo (Andrade *et al.*, 2015). The Salto Grande Reservoir is situated in the hydrographic basin of the Atibaia River (one of the tributaries of the Piracicaba River, upstream of the upper basin of the Paraná River) (Zanata & Espindola, 2002). The Barra Bonita Reservoir is situated in the Tietê River basin and also receives water from the Piracicaba River near the cities of Barra Bonita and Iguaraçu do Tietê (SP) (Ometo *et al.*, 2000; Petesse *et al.*, 2007). The Broa Reservoir is a part of the Tietê/Jacaré basin, located in the central region of São Paulo State, and encompasses three main rivers: Tietê, Jacaré-Guaçu, and Jacaré Pepira (Tundisi *et al.*, 2008). The Itupararanga Reservoir is situated in the Alto Sorocaba basin, one of the six sub-basins of Middle Tietê (Conceição *et al.*, 2015). Rio Grande is an arm partially isolated from the Billings Reservoir, covering the municipalities of São Paulo, Santo André, São Bernardo do Campo, Diadema, Ribeirão Pires, and Rio Grande da Serra (Moschini-Carlos *et al.*, 2010) (Table 1).

Sampling and procedures

Between June and October 2015, samplings were performed in seven reservoirs (Rio Grande arm, Barra Bonita, Broa, Salto Grande, Atibainha, Itupararanga, and Igaratá) totaling 21 points. One sample per zone at each reservoir was collected considering dam, central region, water inlet, and channels (Kimmel *et al.*, 1990) (Fig. 1).

Dissolved oxygen, pH, temperature, and electrical conductivity were determined in situ using a multiparameter probe (YSI mod 556 MPS). Transparency was measured using a Secchi disk (SD). To measure inorganic dissolved nitrogen (DIN), total phosphorus (TP), suspended solids and chlorophyll *a* (CLa), water-integrated samples were collected using a hose according to the photic zone (Table 2). The hose was introduced repeatedly until it reached the appropriate volume to perform the analyzes (Becker *et al.*, 2010). Trophic state index (TSI) was calculated based on the basis of TP and CLa indices according to Carlson (1977) adapted from Lamparelli (2004) using the following equations: TSI (TP) = 10*(6- (1,77-0,42*(ln PT)/ln 2)); TSI (CLa) = 10*(6-((0,92-0,34*(ln CLa))/ln 2)); TSI = [TSI (TP) + TSI (CLa)] / 2. Sampling sites are classified into ultraoligotrophic (TSI $<$ 47), oligotrophic (47 $<$ IET $<$ 52), mesotrophic (52 $<$ IET $\leq$ 59), eutrophic (59 $<$ IET $<$ 63), supereutrophic (63 $<$ IET $<$ 67), hypertrophic IET $>$ 67.

Zooplankton samples were collected at the respective water collection sites using a plankton net (68 μm) at the limit of the photic zone (SD*2.7, Cole, 1979). Filtered volume was estimated by measuring depth trawl and radius of the net mouth. Taxonomic identification was based on Koste (1978), Elmoor-Loureiro (1997), Nogrady & Segers (2002), Silva (2008) and Perbiche-Neves *et al.* (2015). A Sedgwick-Rafter chamber with 1 mL capacity was used for density estimative (ind./m^3), with aliquots from the total homogenized sample.

Zooplankton Biotic Index

We developed a novel Zooplankton Biotic Index (ZBI) that uses data from species unimodal response analysis (Leps & Smilauer, 2003) using the response curves form a statistical model of

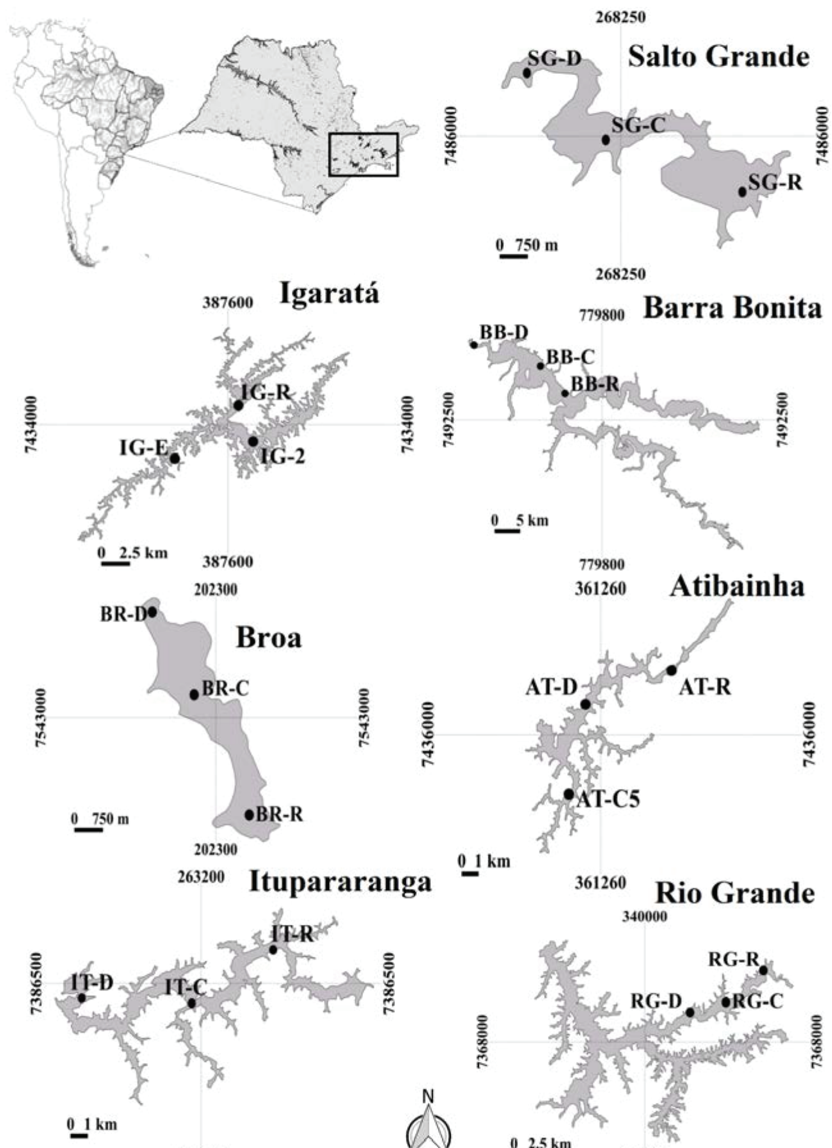

Figure 1. Map showing 21 sampling sites from studied reservoirs. Legends: Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG) and Igaratá (IG). River inlet (R), central (C, 2), dam zones (D), and water outlet (E). *Mapa demonstrando os 21 pontos de amostragem dos reservatórios analisados. Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG) e Igaratá (IG). Entrada de água (R), centro (C,2), zona de barragem (D) e saída de água (E).*

zooplankton composition in relation to CLa (Jamil *et al.*, 2014). From the model, it is calculated the probability that a particular species will be observed at a given chlorophyll *a* value. By determining this probability for a range of chlorophyll *a* value, we can select the value that gives the highest probability of observing the specific taxon. The CLa value is the maximum likelihood estimate (ter Braak & van Dame, 1989). Thus, optimum values were calculated through a Gaussian model along with CLa concentration to make up the final index as follows:

$$\mathrm{OP(sp)} = \frac{\sum_{i=1}^{n} \mathrm{Env}_i \text{ x } \mathrm{Abund}_i}{\sum_{i=1}^{n} \mathrm{Abund}_i}, \quad (1)$$

OP (sp) corresponds to the optimum value of each species, Envi represents the value of the environmental variable (CLa) in the i^{th} sample, and Abundi corresponds to the abundance of the zooplankton species in the i^{th} sample.

From this, we adapted the equation shown below, which aims to predict the trophic state:

$$\mathrm{ZBI} = \frac{\sum_{i=1}^{n} \mathrm{OP}_{sp} \text{ x } \mathrm{Abund}_i}{\sum_{i=1}^{n} \mathrm{Abund}_i}, \quad (2)$$

The following classification was adopted for ZBI: < 7.22, good; 7.23 to 11.53, regular; and 11.54 to 15.84, poor. This scale was developed using the Sturges formula for determining classes and is based on trophic state index correlation (Oliveira *et al.*, 2008).

Zooplanktonic Community Index for reservoirs (ICZ) was calculated using a water quality diagram, which links the Calanoida/Cyclopoida ratio and CLa concentrations (CETESB, 2006). This index does not present absolute values, but rather water quality classes (very poor, poor, regular, and good).

Validation

The ZBI index has been tested applying the present survey data observing the association between index and limnological variables. Spearman coefficient (r_S) was used to analyze the degree of correlation between variables. A regression analysis was used for verification as the calculated indices vary according to the environmental variables. For this, we used the first principal component axes (obtained from phosphorus and chlorophyll *a*), trophic state index, total phosphorus, chlorophyll *a* and correlated with proposed index. In order to achieve this analysis assumptions data were transformed by the ranging method (Milligan & Cooper, 1988), where the observed value less minimum is divided by maximum less minimum. All statistical analyses were carried out using PAST version 3.17 (Hammer *et al.*, 2001).

RESULTS

The Igaratá Reservoir has the deepest sites and has the highest levels of water transparency. High electrical conductivity and nutrient enrichment (TP and DIN) were observed in Salto Grande and

Table 2. Limnological parameters and methods used in Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG), and Igaratá (IG) reservoirs. *Parâmetros limnológicos e métodos utilizados nos reservatórios Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG) e Igaratá (IG).*

Variables	Method	References
Suspended solids (mg/L)	Gravimetry	Teixeira *et al*. (1965)
Total phosphorus (μg/L)	spectrophotometric	Valderrama (1981)
Nitrate (μg/L)	spectrophotometric	Mackereth *et al*. (1978)
Nitrite (μg/L)	spectrophotometric	Mackereth *et al*. (1978)
Ammonium (μg/L)	spectrophotometric	Koroleff (1976)
Inorganic dissolved nitrogen (μg/L)	$\sum NO_2^- + NO_3^- + NH_4^+$	Wetzel & Likens (1991)
Chlorophyll a (μg/L)	spectrophotometric	Lorenzen (1967)

Table 3. Limnological variables obtained from water integrated samples in São Paulo state reservoirs. Legends: Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG), and Igaratá (IG). River inlet (R), central (C, 2), dam zones (D), and water outlet (E). Temperature (T), dissolved oxygen (DO), electrical conductivity (EC), Secchi disk (DS), suspend solids (SS), inorganic dissolved nitrogen (DIN), total phosphorus (TP), chlorophyll *a* (CLa). Underlined data indicates minimum and bold maximum values. (*) Value corresponding to half detection limit (13 μg/L). *Variáveis limnológicas obtidas de amostras integradas de água nos reservatórios do Estado de São Paulo. Legendas: Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG) e Igaratá (IG). Entrada de água (R), centro (C,2), zona de barrage (D) e saída de água. Temperatura (T), oxigênio dissolvido (DO), condutividade elétrica (EC), disco de Secchi (DS), sólidos em suspensão (SS), nitrogênio inorgânico dissolvido (DIN), fósforo total (TP), clorofila* a *(CLa). Dados sublinhados indicam mínimos e valores em negrito máximo. (*) Valor correspondente a metade do limite de detecção (13 µg/L).*

Sites	T °C	DO mg/L	pH	EC µS/cm	DS m	SS mg/L	DIN µg/L	TP µg/L	CLa µg/L
SG-R	20.87	3.22	6.78	**410**	1.24	8.00	908.32	**115.30**	26.73
SG-C	20.92	3.16	7.12	363	1.07	8.14	355.78	100.19	13.75
SG-D	21.25	2.71	6.86	340	1.19	7.71	399.25	69.12	19.38
BB-R	22.23	4.01	7.01	274	1.55	3.90	**2063.54**	95.15	15.64
BB-C	20.99	3.56	6.80	258	2.50	3.10	845.29	64.93	11.63
BB-D	22.41	2.80	6.88	247	2.90	3.00	382.94	70.80	3.74
BR-R	22.57	5.69	7.11	18	0.63	7.75	66.90	28.83	30.07
BR-C	22.57	4.26	7.46	17	0.62	6.75	27.75	18.75	29.74
BR-D	21.56	4.11	7.90	17	0.62	**10.33**	38.01	27.99	**38.09**
IT-R	17.91	4.40	7.28	83	1.23	6.40	89.25	28.83	8.82
IT-C	19.38	2.97	6.59	81	1.61	2.80	60.66	13.71	5.35
IT-D	19.25	3.65	6.81	80	1.39	3.60	63.67	14.55	9.76
AT-R	**24.96**	4.08	7.51	41	1.88	2.57	244.32	7.50*	7.64
AT-C	24.33	3.52	7.85	40	2.65	2.12	102.67	7.50*	5.51
AT-C5	24.17	2.57	**7.98**	39	2.38	2.25	73.74	7.50*	2.17
RG-R	22.59	2.61	2.61	108	1.12	4.17	571.39	33.86	5.16
RG-C	22.57	3.20	3.20	104	1.52	0.50	604.83	21.27	5.12
RG-D	22.61	**5.15**	5.15	105	1.71	6.83	663.52	7.50*	9.80
IG-R	22.57	4.94	5.76	33	**5.15**	0.60	106.40	7.50*	0.40
IG-2	22.66	3.51	3.74	35	3.95	0.90	104.73	17.07	0.67
IG-E	23.44	3.18	6.80	36	2.92	2.00	73.50	7.50*	3.61

Barra Bonita reservoirs. High chlorophyll *a* concentration was recorded at the Broa Reservoir. Based on the average CLa and TP indices, most sampling stations were classified as eutrophic, except for the Atibainha and Igaratá reservoirs, which were considered mesotrophic (Table 3).

Sixty-seven zooplankton taxa were identified, divided into Phylum Crustacea (Calanoida, Cyclopoida, Cladocera), aquatic insects belonging to the order Diptera, Phylum Rotifera, Phylum Protozoa, and Phylum Nematoda (Table 4). Phylum Rotifera was considered as having the greatest richness (33 taxa) and the Brachionidae family was considered most representative (14 taxa). Nauplius of Calanoida, nauplius and copepodites of Cyclopoida, *Thermocyclops decipiens* (Kiefer, 1929), *Thermocyclops minutus* (Lowndes, 1934), *Bosmina* sp., *Asplanchna* sp. (Eckstein, 1883), *Collotheca* sp. (Harring, 1913), *Kellicottia bostoniensis* (Rousselet, 1908), *Keratella cochlearis* (Gosse, 1851), and *Difflugia* sp. (Leclerc, 1815) were most common (> 50 %). High abundances were recorded in the Itupararanga Reservoir (44 161 ind./m^3) against the Broa Reservoir (3441 ind./m^3). Species such as *Asplanchna* sp. (77 886 ind./m^3), *Kellicotia bostoniensis* (14 043 ind./m^3), nauplius (29 941 ind./m^3), and copepodites of Cyclopoida (21 658 ind./m^3) were most abundant in the seven reservoirs.

At sampling sites, ZBI values ranged from 7.2 to 15.8 (Table 5). The Salto Grande and Broa reservoirs were shown to have poor water quality conditions, while the other reservoirs were classified as regular. For the ICZ, the reservoirs were classified as having poor water quality. Regarding validation, the ZBI showed significative correlation mainly with CLa ($r_S = 0.54$; $p = 0.01$), trophic state index ($r_S = 0.45$; $p = 0.03$), total phosphorus ($r_S = 0.33$; $p = 0.13$), and first principal component axis ($r_S = 0.43$; $p = 0.04$) (Fig. 2).

Table 4. Taxonomic list and respective optimum values (OP). *Lista taxonômica e respectivos valores de ótimo (OP).*

Taxa	OP	Taxa	OP
Calanoida		**Rotifera**	
Copepodito	15.86	*Anuraeopsis* sp. Lauterborn 1900	9.29
Nauplius	12.82	*Ascomorpha* sp. Harring, 1913	9.82
Notodiaptomus cearensis (Wright, 1936)	20.63	*Asplanchna brightwellii* Gosse, 1850	5.14
Notodiaptomus conifer (Sars, 1901)	26.73	*Asplanchna* sp. Eckstein, 1883	6.88
Notodiaptomus henseni (Dahl, 1894)	15.78	*Brachionus angularis* Gosse, 1851	8.52
Notodiaptomus iheringi (Wright, 1935)	16.69	*Brachionus caudatus* Barrois & Daday, 1894	5.98
Notodiaptomus sp. Kiefer, 1936	15.49	*Brachionus falcatus* Zacharias, 1898	11.63
Cyclopoida		*Brachionus mirus* Daday, 1905	5.16
Copepodito	8.15	*Brachionus plicatilis* Müller, 1786	16.16
Nauplius	7.35	*Brachionus* sp. Pallas, 1766	5.66
Mesocyclops longisetus (Thiebaud, 1912)	17.74	*Brachionus variabilis* Hempel, 1896	11.63
Mesocyclops ogunnus Onabamiro, 1957	26.73	*Collotheca* sp. Harring, 1913	10.13
Mesocyclops sp. Sars, 1914	12.60	*Conochilus unicornis* Rousselet, 1892	18.27
Metacyclops sp. Kiefer, 1927	13.75	*Epiphanes* sp. Ehrenberg, 1832	13v.75
Thermocyclops decipiens (Kiefer, 1929)	11.20	*Euchlanis* sp. Ehrenberg, 1832	8.45
Thermocyclops minutus (Lowndes, 1934)	7.41	*Filinia opoliensis* (Zacharias, 1898)	25.38
Thermocyclops sp. Kiefer, 1927	11.63	*Filinia* sp. Bory De St. Vincent, 1824	27.55
Cladocera		*Hexarthra* sp. Schmarda, 1854	26.73
Alona sp. Baird, 1843	26.73	*Kellicottia bostoniensis* (Rousselet,1908)	18.28
Bosmina freyi De Melo & Hebert, 1994	9.09	*Keratella americana* Carlin,1943	7.60
Bosmina sp. Baird, 1845	12.84	*Keratella cochlearis* (Gosse,1851)	18.32
Bosminopsis deitersi Richard, 1895	0.86	*Keratella quadrata* (Müller, 1786)	12.34
Ceriodaphnia cornuta (Sars, 1885)	7.07	*Keratella* sp. Bory De St. Vincent, 1822	6.60
Ceriodaphnia silvestrii Daday, 1902	10.21	*Keratella tropica* (Apstein, 1907)	18.02
Ceriodaphnia sp. Dana, 1853	11.30	*Lecane* sp. Nitzsch, 1827	6.41
Chydoridae	13.75	*Lepadella* sp. Bory de St. Vincent, 1826	7.64
Daphnia gessneri (Herbst, 1967)	5.98	*Polyarthra vulgaris* Carlin,1943	10.71
Daphnia sp. Müeller, 1785	8.82	*Pompholyx* sp. Gosse, 1851	10.08
Diaphanosoma sp. Fischer, 1850	4.89	*Ptygura* sp. Ehrenberg, 1832	13.51
Diaphanosoma spinulosum Herbst, 1975	19.34	*Synchaeta stylata* Wierzejski, 1893	6.01
Moina sp. Baird, 1850	12.57	*Trichocerca capucina* (Wierzejski & Zacharias, 1893)	5.51
		Trichocerca longiseta (Schrank, 1802)	29.74
		Trichocerca sp. Lamarck, 1801	11.84

DISCUSSION

Few studies have developed reservoir quality indices using zooplankton communities. Here, the species score method was differential. A linear response is the simplest approximation, whereas a unimodal response model assumes that species have an optimum in an environmental gradient (Leps & Smilauer, 2003; Jamil *et al.*, 2014). Therefore, algae biomass may be considered a good indicator of trophic gradients, mainly in reservoirs (Boyer *et al.*, 2009). The present study represents the first instance of a zooplankton trophic index using optimum values in Brazilian reservoirs. The method allowed us to predict the trophic status and showed good prospects due to good adherence with indicator variables.

Using the ZBI index, surface waters of the Salto Grande Reservoir were considered of poor quality. The results obtained by Dornfeld *et al.* (2006) for this reservoir showed an impacted environment that can cause adverse effects to biota, mainly because of the input of organic and inorganic (industrial) pollution. Although considered of poor quality, the Broa Reservoir was considered oligotrophic some years ago (Argenton, 2004). Despite the Rio Grande arm being considered to have regular quality, Mariani *et al.* (2008) and Pompêo (2017) highlighted the problems of algal bloom and the constant use of copper sulfate.

Since 2003, the São Paulo State Environmental Agency has used an ICZ based on zooplankton data and water quality diagram (CETESB, 2006). However, despite its simplicity, this index can present some problems. The ICZ considers the presence or absence of main zooplankton groups and uses a ratio of total number of calanoids (better water quality) and cyclopoids (poor quality). For calculation, three main taxa (Rotifera, Cladocera, and Copepoda) are required, but are not always present. Except in the Rio Grande arm, all reservoirs contain the above-mentioned groups. According to the ICZ, more than 50 % of the points had poor conditions, although some sampling points had regular water quality. Therefore, the ICZ results are observed to be close to the ZBI values.

It was not possible to use other environmental quality indices such conducted by some authors (Montagud *et al.*, 2019). The use of the Wetland Zooplankton Index (WZI) must be made with modifications for tropical regions since it has been developed for wetlands in the Great Lakes. These authors confirmed that further research is required to confirm its suitability for other regions and other vegetated habitats (Lougheed & Chow-Fraser, 2002). In Spanish reservoirs, researchers used a Zooplankton Reservoir Trophic Index with tolerance values. A total of 13 reservoirs (37.1 %) was considered to have good or superior status, 14 reservoirs (40 %) have moderate status, 6 reservoirs (17 %) have deficient condition, and 2 (5.7 %) are of poor quality (CHE, 2015). As mentioned above, the index was developed for reservoirs located in temperate regions.

Through linear regression analysis, Ejsmont-Karabin (2012) and Ejsmont-Karabin & Karabin (2013) established different formulas for predicting trophic gradients in Polish lakes. Parameters were verified since abundance and richness can be used as metrics. Biomass of Cyclopoida, Cyclopoida/Calanoida ratios and percentage of cyclopoid biomass were the most significant variables to include in trophic prediction models. Rotifer numbers, percentage of species indicative of high trophic levels in the indicative group's numbers, and percentage of tecta form in the population of *Keratella cochlearis* were the most significant parameters. Although regression coefficients may be used for different types of lakes, the formulas may be

Table 5. Water quality class obtained from different zooplanktonic indices. Legends: Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG), and Igaratá (IG). River inlet (R), central (C, 2), dam zones (D), and water outlet (E). Zooplanktonic community index for reservoirs (ICZ), Zooplankton biotic Index (ZBI) e Trophic state index (TSI). *Classes de qualidade da água obtidos de diferentes índices zooplanctônicos. Legendas: Salto Grande (SG), Barra Bonita (BB), Broa (BR), Itupararanga (IT), Atibainha (AT), Rio Grande (RG) e Igaratá (IG). Entrada de água (R), centro (C,2), zona de barragem (D) e saída de água (E). Índice da comunidade zooplanctônica para reservatórios (ICZ), Índice biótico do Zooplâncton (ZBI) e, Índice de estado trófico (TSI).*

Sites	ICZ	ZBI	TSI	
SG-R	Poor	Poor (15.06)	69	Hypereutrophic
SG-C	Poor	Poor (14.39)	67	Supereutrophic
SG-D	Regular	Poor (14.05)	67	Supereutrophic
BB-R	Poor	Regular (9.59)	67	Supereutrophic
BB-C	Regular	Regular (9.18)	65	Supereutrophic
BB-D	Regular	Regular (8.49)	63	Eutrophic
BR-R	Regular	Poor (15.30)	65	Supereutrophic
BR-C	Regular	Poor (15.84)	64	Supereutrophic
BR-D	Regular	Poor (13.86)	66	Supereutrophic
IT-R	Poor	Regular (8.40)	62	Supereutrophic
IT-C	Poor	Regular (7.23)	59	Mesotrophic
IT-D	Poor	Regular (9.04)	60	Eutrophic
AT-R	Regular	Regular (9.24)	58	Mesotrophic
AT-C	Poor	Regular (8.83)	57	Mesotrophic
AT-C5	Poor	Regular (9.73)	55	Mesotrophic
RG-R	Poor	Regular (8.20)	61	Eutrophic
RG-C	Poor	Regular (8.90)	60	Eutrophic
RG-D	Poor	Regular (7.61)	58	Mesotrophic
IG-R	Regular	Regular (9.04)	50	Oligotrophic
IG-2	Regular	Regular (10.35)	54	Mesotrophic
IG-E	Regular	Regular (9.31)	56	Mesotrophic

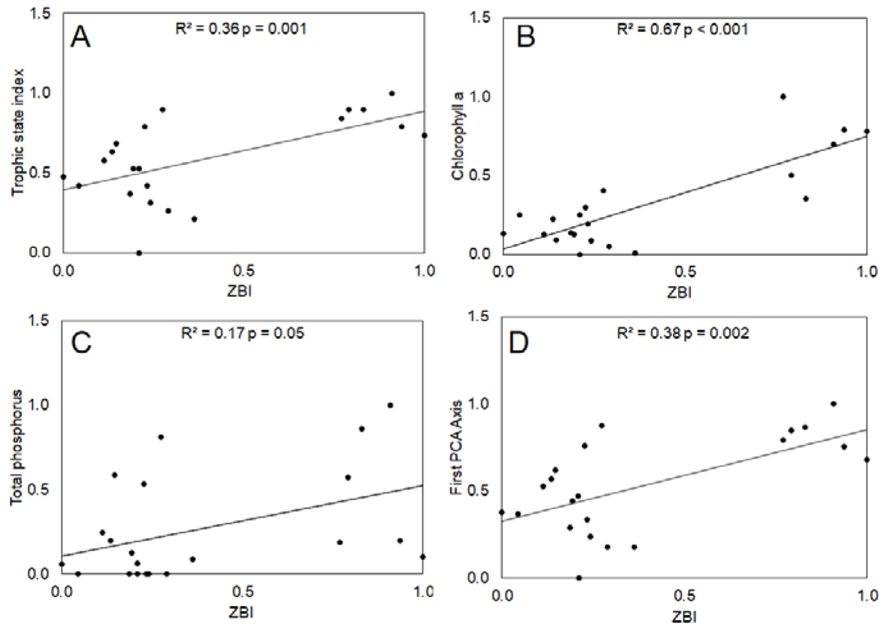

Figure 2. Relationship between standardized Zooplankton Biotic Index (ZBI) values and total phosphorus, chlorophyll a, trophic status index (TSI), and first principal component axis (PCA). Legends: Zooplankton Biotic Index (ZBI), determination coefficient (R^2), and significance values (p). All data were transformed for a better graph display. *Relação entre os valores padronizados do Índice Biótico do Zooplâncton (ZBI) e fósforo total, clorofila a, índice de estado trófico e o primeiro eixo do componentes principais (PCA). Legendas: Índice Biótico do Zooplâncton (ZBI), coeficiente de determinação (R²) e valores de significância (p). Todos os dados foram transformados para uma melhor visualização no gráfico.*

useful only in preparing similar indices for lakes in central and northern Europe.

In a German lowland river, a plankton index of biotic integrity was developed to assess effects of human disturbances on the ecosystem. From 36 original metrics, only six were chosen to compose the index. The general ecological status of the region was considered as moderate regardless of seasonal variations, which was lower than the requirement (good status) of the WFD of 2015. The relatively lower ecological status was probably caused by point sources, diffuse source emissions and artificial drainage systems of the study area (Wu *et al.*, 2012). Through historical data analysis, Kane *et al.* (2009) developed a planktonic index of biotic integrity in the Great Lakes (Lake Erie). Discriminant analysis was used one of the differentials used to determine the best impact variables; in addition, combined zooplankton and phytoplankton data were also used. The results obtained showed that the increase in water quality score from 1970 to the mid-1990s, and its subsequent decline, reflected the changing trophic status of the lake. A differential of this study was the inclusion of two biological communities, allowing a better evaluation of the environmental integrity of the ecosystem. As another example, a zooplankton index of biotic integrity was developed for estuarine waters, using data from a long-term environmental assessment program. The choice metrics were the Simpson diversity index, abundance of barnacle larvae, rotifers, cladocerans, copepods, total mesozooplankton, and predators. The composite index of biotic integrity correctly classified approximately 94 % of the impaired samples and approximately 82 % of the reference samples. Average classification efficiency was 88 % (Carpenter *et al.*, 2006).

As observed, few studies have attempted to develop biological indices mainly with zooplankton. It should be noted that most studies were based on the multimeric index method (e.g. Karr, 1981, Hering *et al.*, 2006) and weighted values for each taxon were not calculated. In the present study, these values were calculated species by species and thus the index shows greater functionality. One of the main problems related to the use of a multimetric index is that the metrics do not always correlate with environmental variables. To elaborate the index, metrics such as total richness, abundance, and biomass must be used. After selection, the scale is calculated through analysis of percentile values. Both methods have advantages and disadvantages and the choice is the responsibility of the researcher.

When applying the proposed index (ZBI), we recommend that a few steps be followed. First, it is necessary to verify which species have a relationship with the eutrophication gradient (phosphorus, CLa, etc.). This assumption can be tested with a simple test of correlation. After analysis of the unimodal peaks, optimum and tolerance values should be calculated, and values that do not always coincide should be highlighted. For example, Sousa *et al.* (2008) investigated reservoirs in northeastern Brazil and calculated optimum and tolerance values taking into account eutrophication and salinization parameters. Using the values obtained in the present study, we tested equations proposed by other authors but could not verify good adherence.

CONCLUSION

The developed index proved to be efficient in estimating parameters related to eutrophication. It should also be noted that the Salto Grande and Broa reservoirs had poor water quality, while other reservoirs were classified as regular. In addition, the present study provides environmental weighted values for each species and can be applied to, and compared with, other tropical/subtropical reservoirs. As far as possible should be adapted the indices from other continents. For a better understanding of the environmental quality, the ecological indices derived from different aquatic communities should be integrated into a composite index.

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