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POTENTIAL USE OF CYCLOPOIDA (CRUSTACEA, COPEPODA) AS TROPHIC STATE INDICATORS IN TROPICAL RESERVOIRS

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ABSTRACT

The pelagic zones of fifty three São Paulo State reservoirs were sampled as a part of the project "Diversity of zooplankton in relation to conservation and degradation of aquatic ecosystems in the State of São Paulo", within the Biota/Fapesp Program (1999 – 2003). The trophic state index (TSI) was calculated, using total phosphorus and chlorophyll a. The Cyclopoida (Copepoda) populations were analyzed, and richness and relative abundance of the dominant species determined. Most values of the TSI ranged from oligotrophic to mesotrophic. The species richness did not present linear relationships with the TSI values. Nine species of Cyclopoida were dominant. *Thermocyclops decipiens* was the most frequently dominant species, followed by *T. minutus*, *Mesocyclops ogunnus, T. inversus, T. iguapensis, Microcyclops anceps, Tropocyclops prasinus*, *Microcyclops alius* and *Mesocyclops longisetus.* Correlations between the abundances of different species were highly negative, with values over 85%, especially between the *Thermocyclops* species. The species that are potential bioindicators due to the relationship between their dominance and reservoir trophic state are the following: *Thermocyclops decipiens* and *Tropocyclops prasinus* as indicators of mesotrophic/eutrophic systems; *Thermocyclops inversus* and *Microcyclops anceps* as indicators of oligotrophic/mesotrophic systems, *Thermocyclops minutus* and *T. iguapensis* as indicators of oligotrophic systems and *Mesocyclops ogunnus* as indicator of eutrophic systems.
Keywords: Bioindicators; zooplankton; water quality.

RESUMO

USO POTENCIAL DE CYCLOPOIDA (CRUSTACEA, COPEPODA) COMO INDICADOR DE ESTADO TRÓFICO EM RESERVATÓRIOS TROPICAIS. Cinquenta e três reservatórios do estado de São Paulo foram amostrados, em suas regiões pelágicas, no projeto "Diversidade de zooplâncton em relação à conservação e degradação dos ecossistemas aquáticos do estado de São Paulo" vinculado ao programa Biota/Fapesp (1999-2003). Estes reservatórios tiveram seus índices de estado trófico (IET) calculado com base nos valores de fósforo total e clorofila a, e suas populações de Copepoda Cyclopoida foram calculadas, considerando-se a riqueza e a abundância relativa para as espécies dominantes. A riqueza de espécies não apresentou relação com o estado de trofia dos reservatórios. Nove espécies de Copepoda Cyclopoida foram dominantes em algum reservatório onde a espécie *Thermocyclops decipiens* foi a que dominou o maior número de reservatórios, seguida por *T. minutus*, *Mesocyclops ogunnus, T. inversus, T. iguapensi, Microcyclops anceps, Tropocyclops prasinus*, *Microcyclops alius* e *Mesocyclops longisetus*. As espécies mostraram uma alta correlação negativa entre si, acima dos 85%, principalmente entre as espécies congenéricas de *Thermocyclops*. As espécies mostraram um grande potencial como bioindicadores com a seguinte relação entre TSI e espécie: *Thermocyclops decipiens* e *Tropocyclops prasinus* indicam sistemas mesotrófico/eutróficos; *Thermocyclops inversus* e *Microcyclops anceps* indicam sistemas oligotrófico/mesotróficos; *Thermocyclops minutus* e *T. iguapensis* indicam sistemas oligotróficos e *Mesocyclops ogunnus* indica sistemas eutróficos.
Palavras-chave: Bioindicadores; zooplâncton; qualidade de água.

INTRODUCTION

Brazil is poor in perennial natural lakes and rich in rivers, floodplain areas and marginal lakes (Tundisi & Matsumura 2008) and the planktonic populations are adapted to the cyclic flooding pulse. Moreover, beginning in the seventies, many hydroelectric power plants have been built by the damming of large rivers, with the formation of large reservoirs (Tundisi 1989). These reservoirs created a new environment for planktonic populations, composed mainly of Rotifera, Cladocera and Copepoda (Esteves 1998); these communities respond differently to disturbance, such as climatic changes and anthropogenic interventions. The capacity to quickly respond to environmental changes makes the zooplankton a good bioindicator for water quality (Ferdous & Muktadir 2009).

Studies on biological communities in reservoir systems are very important because the distribution and abundance are usually quite different for each species, some of them having a widespread distribution but a variable abundance which depends on particular characteristics of the system, such as residence time, construction time and trophic state (Matsumura-Tundisi 1999, Matsumura-Tundisi & Tundisi 2003). These studies allow us to identify some species as indicators of environmental disturbances or of water quality.

Among freshwater zooplankton communities, the cyclopoid copepods constitute a very important group, inhabiting lakes, ponds, reservoirs, temporary ponds, etc. (Huys & Boxshall 1991). In tropical reservoirs, this group is one of the most important components of plankton biomass (Rocha *et al*. 1995). The use of Cyclopoida as a bioindicator of water quality of tropical reservoirs was traditionally carried out by comparing the abundances of Calanoida populations with that of Cyclopoida populations, the so called Calanoida/Cyclopoida ratio (Tundisi & Matsumura-Tundisi 1990, Nogueira *et al*. 2006) or using specific Cyclopoida species composition, mainly regarding the species of *Thermocyclops* and *Metacyclops* genera (Sendacz & Kubo 1982, Arcifa 1984, Reid 1989, Matsumura-Tundisi *et al*. 1990, Tundisi & Matsumura-Tundisi 1994, Rocha *et al.*, 1999, Silva & Matsumura-Tundisi 2002, Sampaio *et al.* 2002, Silva & Matsumura-Tundisi 2005 and Landa *et al*. 2007).

The aim of this work was to relate the dominant Cyclopoida species with the trophic state of São Paulo State reservoirs, in order to identify potential indicator species of trophic level and water quality.

METHODOLOGY

STUDY AREA

Figure 1 shows the location of São Paulo State in Brazil, the limits of São Paulo Hydrographic Units for Hydric Resources Management (UHGRH), and the locations and names of the 53 sampled reservoirs.

MATERIAL AND METHODS

The data utilized in this study were obtained from the project "Diversity of zooplankton in relation to conservation and degradation of the aquatic ecosystems in the State of São Paulo", which formed part of the BIOTA/FAPESP program. The water bodies were sampled between 1999 and 2003 in the 19 of the 22 UHGRHs that contain reservoirs. Total phosphorus concentration was determined by persulfate digestion, according to Valderrama (1981), and chlorophyll a concentration determined by hot ethanol extraction (Nusch 1980). Planktonic organisms were sampled using a plankton net with 68µm mesh size, by vertical hauls from bottom to surface at a site near the dam. These samples were preserved in formaldehyde to a final concentration of 4%. The Cyclopoida populations were quantified using a stereoscopic microscope and identified with an optical microscope, using Reid (1985), Van de Velde (1984), Matsumura-Tundisi & Silva (2002), Silva (2003) and Silva & Matsumura-Tundisi (2005). The relative abundances of the dominant (most abundant) and co-dominant (second most abundant) species were computed.

The Trophic State Index (TSI) values were estimated according to Carlson (1977), modified by Toledo Jr. (1990) for tropical reservoirs, with Secchi transparency not being utilized. The equations are presented below:

$$TSI(P) = 10\{6-[\ln(80.32/P)/\ln 2]\}$$
Equation 1

$$TSI(Chl) = 10\{6-[(2.04-0.695)\ln Chl/\ln 2]\}$$
Equation 2

Where:

P is total phosphorus in $\mu g.L^{-1}$
Chl is chlorophyll a in $\mu g.L^{-1}$

The average value for the TSI is given by the arithmetic mean:

TSI (X) = (TSI (P) + TSI (Chl))/2
Equation 3

The trophic classification adopted was: Ultra-oligotrophic (<24), oligotrophic (≥24 and <44), mesotrophic (≥44 and <54), eutrophic (≥54 and <74) and hypertrophic (≥74).

For data analysis, the Pearson Correlation was used when n>4.

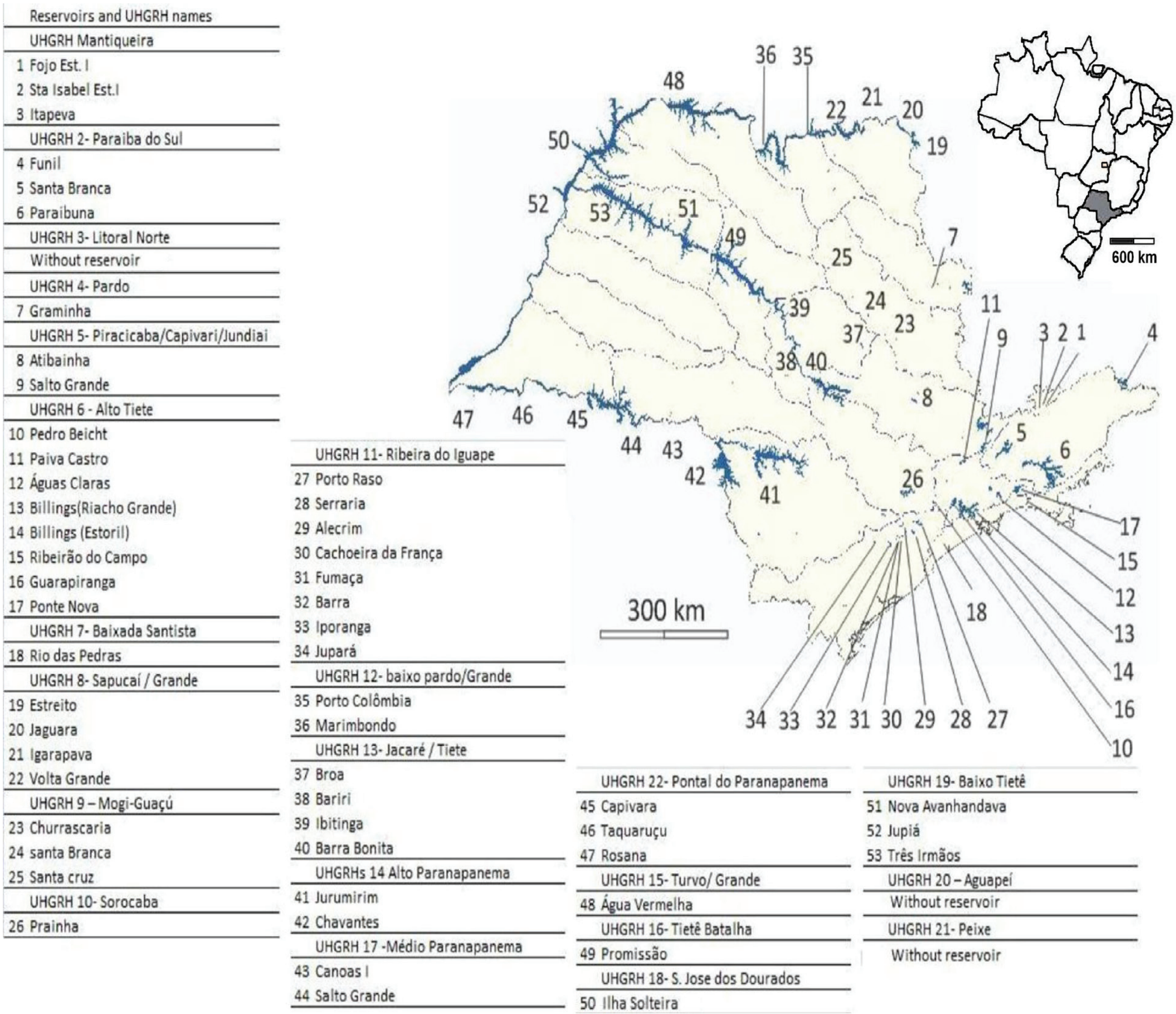

Figure 1. Location of São Paulo State in Brazil, its Hydrographic Management Units (UHGRH) and the sampled reservoirs.
Figura 1. *Localização do Estado de São Paulo no território brasileiro e as suas Unidades de gerenciamento dos Recursos Hídricos (UHGRH) e a localização dos reservatórios amostrados e seus nomes.*

RESULTS

Table 1 shows the number of the São Paulo State reservoirs in relation to the TSI classification, for the different variables used to calculate the TSI values. The majority of values for TSI (P) are in the range of oligotrophic and mesotrophic; for TSI (Chl), values are concentrated in the mesotrophic to eutrophic range, and for TSI (X), values are concentrated in the oligotrophic and mesotrophic range. Figure 2 shows the species richness along the range of TSI (X) values. Maximum richness was seven species, recorded in four reservoir. There was no correlation about richness and trophic state.

Table 1. Number of reservoirs in São Paulo State classified according to the Trophic State Index of Carlson, modified by Toledo *et al.* (1984). TSI (Cl) = TSI (Chl), Oligotrophic = Oligotrophic.
Tabela 1. *Classificação e numero de reservatórios do Estado de São Paulo com base nos Indices de Estado Trófico propostos por Carlson e modificados por Toledo* et al. *(1984), para reservatórios tropicais.*

Class/ (%)	TSI (P)	TSI (Cl)	TSI-(x)
Ultraoligotrophic	8	0	0
oligotrophic	50	14	40
Mesotrophic	34	50	36
Eutrophic	8	28	26
Hipereutrophic	2	8	0

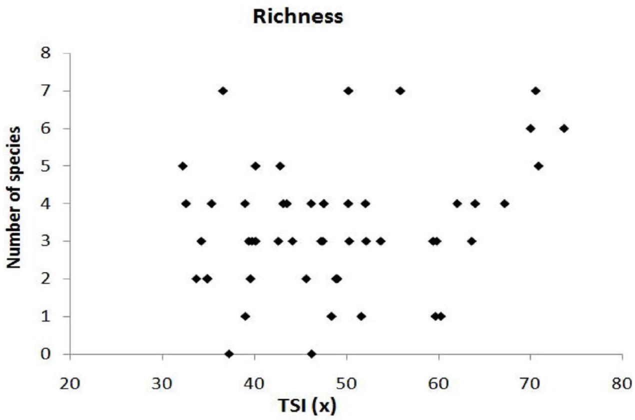

Figure 2. Relationship between cyclopoid copepod species richness and the Trophic State Index (TSI) for 53 reservoirs of São Paulo State.
Figura 2. *Riqueza das espécies de Copepoda Cylopoida para 53 reservatórios do estado de São Paulo ao longo de um gradiente de Índice de Estado Trófico (IET).*

Table 2 shows the species which were dominant and co-dominant in the reservoirs. Nine species were dominant or co-dominant. *Thermocyclops decipiens, T. minutus* and *Mesocyclops ogunnus* were the species that dominated the largest number of reservoirs. *Mesocyclops longisetus* and *Microcyclops alius* were dominant/co-dominant in less than five reservoirs.

Table 2. Cyclopoida species and the number of reservoirs they were dominant or co-dominant among the 53 reservoirs analyzed for São Paulo State. *Total =sum of Dominant + Co-dominant .*
Tabela 2. *Espécies de Copepoda Cyclopoida e o numero reservatórios em que foram dominantes ou co-dominantes entre 53 reservatórios analisados em São Paulo. Total = a soma de Dominante + Co-dominate.*

Species / Dominace	Dominant	Co-dominant	Total
Thermocyclops decipiens	18	15	33
Thermocyclops minutus	8	4	12
Mesocyclops ogunnus	2	11	13
Thermocyclops inversus	4	2	6
Thermocyclops iguapensis	4	2	6
Tropocyclops prasinus	3	2	5
Microcyclops anceps	4	1	5
Microcyclops alius	2	1	3
Mesocyclops longisetus	1	0	1

Table 3 shows the results for the Pearson correlation analysis among species that dominated in at least five reservoirs (n>4) and between TSI values and species for *T. decipiens* and *T. minutus*. *Thermocyclops minutus* and *T. inversus* presented high negative correlations with TSI (P) and TSI (X), whereas *Mesocyclops ogunnus* presented a weak positive correlation with TSI (Chl) and TSI (X). The correlations between species were highly negative (<-85%, p=0.01) mainly between *Thermocyclops* species (<-95%, p=0.01). On the other hand, the correlations between *Thermocyclops* species and *Macrocyclops* and *Tropocyclops* species were zero, due to rare co-existence between these species.

Table 3. Correlations between TSI of São Paulo State reservoirs and Cyclopoida species abundances, and correlations between *Thermocyclops decipiens* and *T. minutus* and the other species abundances, where: Td= *Thermocyclops decipiens*, Tm= *T. minutus*, Tin= *Thermocyclops inversus,* Tig= *Thermocyclops iguapensis*, Mog= *Mesocyclops ogunnus*, Tp= *Tropocyclops prasinus* and Man= *Microcyclops anceps.*

Tabela 3. *Valores da correlação entre os estados tróficos dos reservatorios do estado de São Paulo e abundãncia das espécies dominantes e a correlação entre a abundãncia das espécies Thermocyclops decipiens e T. minutus com a abundãncia das demais espécies. Onde Td= Thermocyclops decipiens , Tm= T. minutus, Tin= Thermocyclops inversus, Tig= Thermocyclops iguapensis, Mog= Mesocyclops ogunnus, Tp= Tropocyclops prasinus e Man= Microcyclops anceps.*

	Td	Tm	Tin	Tig	Mog	Tp	Man
TSI (Chl)	0,02	-0,24	-0,56	0,41	0,59	0,19	-0,01
TSI (P)	0,27	-0,65	-0,74	-0,44	0,38	-0,02	-0,57
TSI (x)	0,17	-0,67	-0,66	-0,27	0,52	0,10	-0,47
Td	1,00	-0,99	-0,97	-0,99	-0,88	0,00	0,00
Tm	-0,99	1,00	0,00	0,00	-1,00	0,00	0,00

Figure 3 shows the species relative abundances distributed along the reservoir TSI(X) gradient. There were two types of distribution, one composed by species with a large spectrum of abundance, occurring along the entire oligotrophic to eutrophic gradient, and the other with a smaller spectrum, being restricted to the oligotrophic to mesotrophic gradient. The abundances of the three most frequent species, *T. decipiens, T. minutus* and *Mesocyclops ogunnus,* are plotted in Figure 4, showing the different patterns of dominance along the trophic state gradient. All had different relative abundance distributions with peaks in different range of values of the TSI(X). These frequent species were correlated at sites where they were respectively dominant and co-dominant (Figure 5). In the reservoirs where TSI(X) values were in the range between oligotrophic and mesotrophic, the relative abundance was greater than in reservoirs classified as eutrophic; in the latter environment, the dominant species usually had less than 50% of dominance.

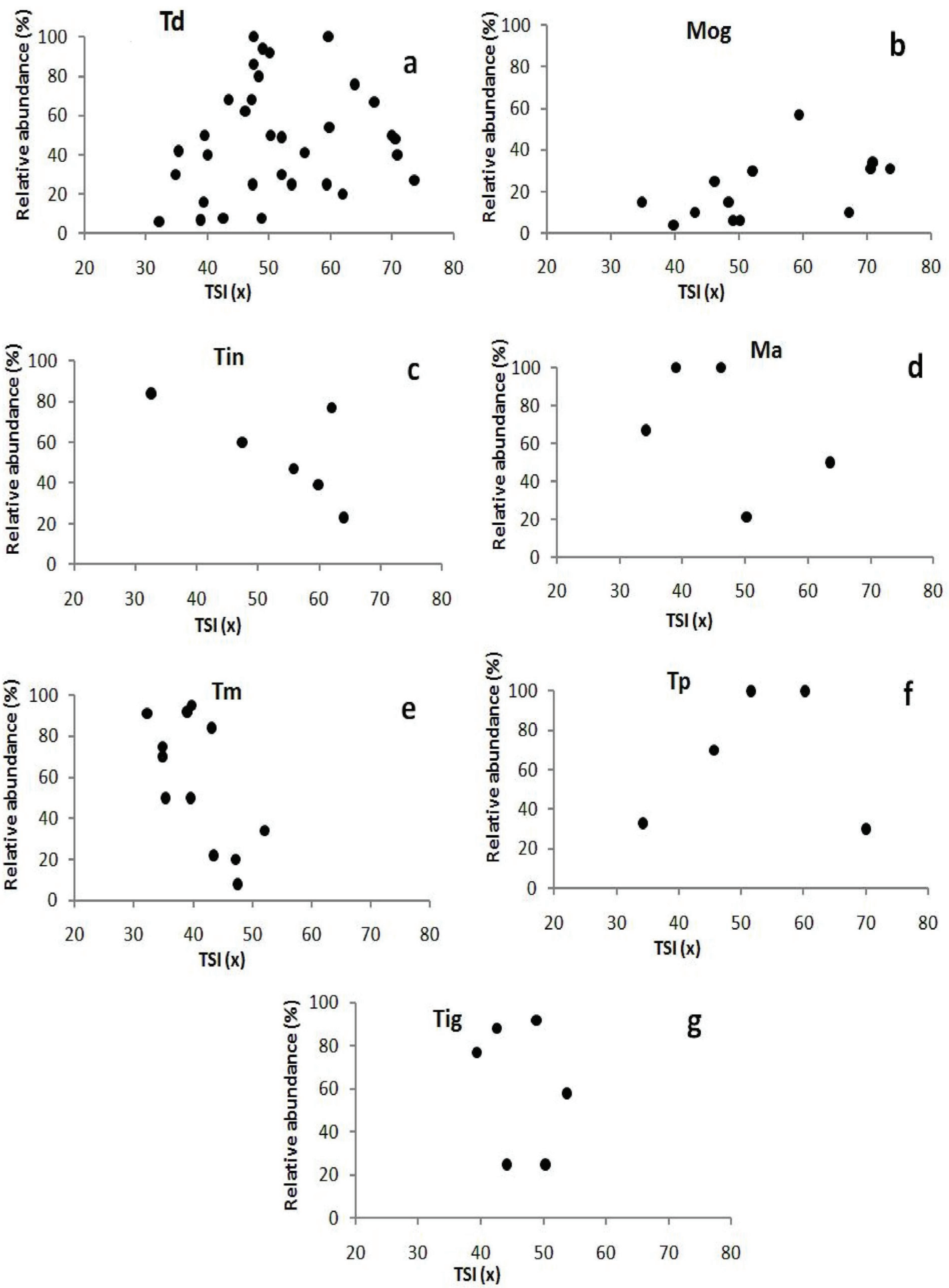

Figure 3. Relationship between the relative abundance of cyclopoid species and the TSI for reservoirs of São Paulo State: a: *Thermocyclops decipiens,* b: *Mesocyclops ogunnus,* c: *Thermocyclops inversus* , d: *Microcyclops anceps*, and: *Thermocyclops minutus*, f: *Tropocyclops prasinus*, g*: Thermocyclops iguapensis.*

Figura 3*. Valores da abundãncia relativa das espécies de Cyclopoida ao longo do gradiente do IET para reservatórios do estado de São Paulo. a :Thermocyclops decipiens, b: Mesocyclops ogunnus, c: Thermocyclops inversus , d: Microcyclops anceps, e: Thermocyclops minutus, f: Tropocyclops prasinus, g: Thermocyclops iguapensis.*

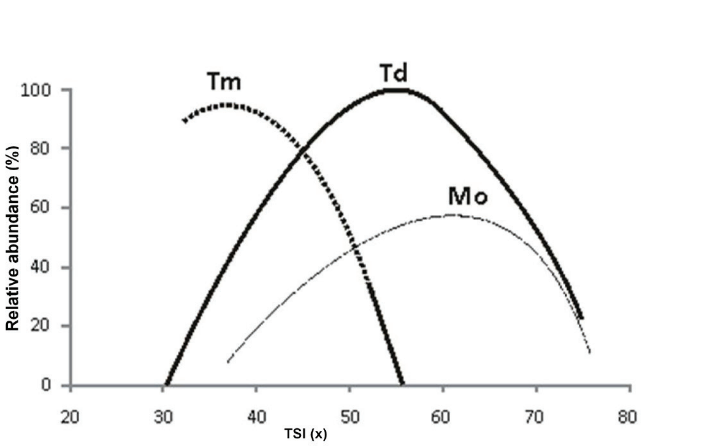

Figure 4. Distributions of relative abundance of Thermocyclops decipiens (Td), Thermocyclops minutus (Tm) and Mesocyclops ogunnus (Mo) along a trophic state gradient for São Paulo State reservoirs..

Figura 4. *Representação das distribuições dos valores de abundancia relativa das espécies Thermocyclops decipiens (Td), Thermocyclops minutus (Tm) and Mesocyclops ogunnus (Mo) ao longo do um gradiente de estado trofico dos reservatórios do estado de São Paulo.*

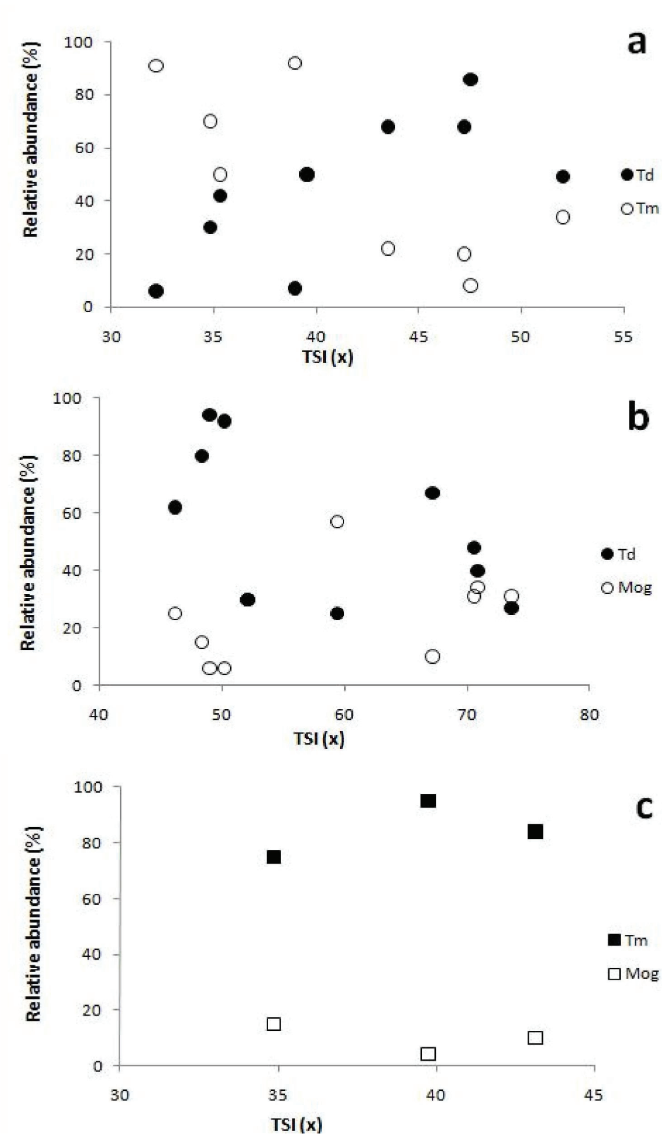

Figure 5. Relationship between the relative abundance of the three most frequent dominant or co-dominant cyclopoid species and the TSI for reservoirs in São Paulo State: a) *T. decipiens* and *T. minutus* b) *T. decipiens* and *Mesocyclops ogunnus,* c) *T. minutus* and *Mesocyclops ogunnus.*

Figura 5*. Abundâncias relativas das três espécies mais frequentes e dominantes ou co-dominantes de copépodos ciclopóides nos reservatórios do estado de São Paulo ao longo do gradiente de estado trófico representado pelos valores do índice de estado trófico (IET): a) T. decipiens e T. minutus b) T. decipiens e Mesocyclops ogunnus, c) T. minutus e Mesocyclops ogunnus.*

Table 4 summarizes the TSI (X) classification and the Cyclopoida species with relative abundances higher than 50% of total Cyclopoida numbers. Three species had dominance restricted to just one level in the trophic state gradient: *Thermocyclops minutus, T. iguapensis* and *Mesocyclops ogunnus*. The other species, *Thermocyclops decipiens, T. inversus, Tropocyclops prasinus* and *Microcyclops anceps* were dominant in two sequential trophic state levels, either occurring in the oligotrophic-mesotrophic or in the mesotrophic-eutrophic range.

Table 4. Dominant (relative abundance > 50%) Cyclopoida species in relation to reservoir Trophic State Classification.
Tabela 4. *Espécies de Cyclopoida e a Classificação do Estado Trófico dos reservatórios em que elas são dominantes.*

Species	TSI (x)
Thermocyclops decipiens	Mesotrophic and Eutrophic
Thermocyclops minutus	Oligotrophic
Mesocyclops ogunnus	Eutrophic
Thermocyclops inversus	Oligotrophic and Mesotrophic
Thermocyclops iguapensis	Oligotrophic
Tropocyclops prasinus	Mesotrophic and Eutrophic
Microcyclops anceps	Oligotrophic and Mesotrophic

DISCUSSION

The results show that planktonic Cyclopoida species dominate in specific ranges of the trophic state gradient and that co-existence and co-dominance between species have negative relationships. Reid (1989) suggested that environments occupied by congeneric species of *Thermocyclops* are those undergoing changes in trophic state; Silva & Matsumura-Tundisi (2005) demonstrated this relationship in Barra Bonita reservoir with the congeneric species *Thermocyclops decipiens* and *T. minutus*. The co-existence of two or more Cyclopoida species in the same environment depends on the capacity of these species in maximizing their abilities in exploring resources and occupying their niches. Rocha & Matsumura-Tundisi (1997) showed the capacity of Cyclopoida species to inhabit different water compartments in a natural lake with a thermocline and metalimnetic anoxia. In São Paulo State, most reservoirs are polimictic, with no long-lasting thermoclines (Tundisi 1981, Matsumura-Tundisi *et al*. 2006). In such cases, the co-existence of Cyclopoida species probably depends on other factors such as meteorological events and changes in residence time, causing disturbances.

According to Connell (1978), some kinds of disturbances promote diversity and Tundisi & Matsumura-Tundisi (1994) verified that, in reservoirs, disturbances are greater and more frequent than natural lakes, and these disturbances could promote increases in diversity in the plankton communities. Changes of trophic state promote changes in plankton populations (Wetzel 1975, Barbosa *et al*. 1999), including changes in Cyclopoida species. In the present study, the greatest similarity in cyclopoid population abundances occurred at the limits of oligotrophic to mesotrophic and mesotrophic to eutrophic transition. In other conditions, one species had higher abundance than the others.

The negative relationship among species co-existing in one reservoir shows that with changes of trophic state, the species show different competitive abilities, and that one species or a group decreases in population abundance whereas another increases, thus creating a successional pattern analogous to ecological succession (Margalef 1983). Of the 39 species of Cyclopoida recorded in São Paulo State (Silva & Matsumura-Tundisi 2011) only nine were dominant in any reservoir (in the pelagic zone) and of these, only seven were dominant in more than five reservoirs. It should, nevertheless, be pointed out that some authors have recorded other species not observed in the present work, such as *Metacyclops mendocinus,* as dominant, in eutrophic systems (Sendacz & Kubo 1982, Arcifa 1984, Tundisi & Matsumura-Tundisi 1990). Nevertheless, the species recorded here as dominant and co-dominant provide a strong tool for bioindicaton of trophic state in tropical reservoirs.

The three most frequent species, *Thermocyclops decipiens, T. minutus* and *Mesocyclops ogunnus*, indicate different degrees of trophic state. *T.*

decipiens appears as indicator for mesotrophic and eutrophic environments; *T. minutus* as indicator of oligotrophic environments and *M. ogunnus* as indicator of eutrophic environments. These results are corroborated by ecological studies made by Reid (1989), Silva & Matsumura-Tundisi (2002), Silva & Matsumura-Tundisi (2005) and Landa *et al*. (2007). The widespread distribution and dominance of *T. decipiens* in the São Paulo State reservoirs is due to the fact that most of the latter are presently mesotrophic/eutrophic. *T. decipiens* competes with *T. minutus* and *M. ogunnus*, in oligotrophic to mesotrophic and mesotrophic to eutrophic reservoirs, respectively.

Silva and Matsumura-Tundisi (2002), studying the cascade of reservoirs in the Tietê River, observed that the size of Cyclopoida could explain their dominance, with the small ones dominating the oligotrophic systems perhaps because the phytoplankton in these environments are usually smaller, while in the eutrophic environments the Cyanophyta colonies dominate and large species of Cyclopoida are best adapted to eat them. In São Paulo State reservoirs, the Cyclopoida species distribution corroborates this fact with regard to the species of the genera *Thermocyclops* and *Mesocyclops* where the smaller species had higher abundances in oligotrophic systems and the larger ones in those more eutrophicated. The other two *Thermocyclops* species, *T. inversus* and *T. iguapensis,* were restricted to oligotrophic/mesotrophic water bodies, but these species co-occurred only with *T. decipiens*. Silva & Matsumura-Tundisi (2005) analyzed the distribution of *Thermocyclops* species in São Paulo State reservoirs and observed that *T. minutus* did not occur in the Atlantic costal basin, where it was replaced by *T. iguapensis*, a species of similar size that probably occupies a similar niche.

The last two species that dominated in São Paulo reservoirs were *Microcyclops anceps* and *Tropocyclops prasinus*, the first being dominant in oligotrophic/mesotrophic and the last being dominant in mesotrophic/eutrophic systems. In this case, co-occurrence with another species was rare, although these two species are common in São Paulo water-bodies (Rocha & Botelho 1999, Silva 2003). Unlike the species of *Thermocyclops* and *Mesocyclops* for which the body size was directly related to the trophic state, for *M. anceps* and *T. prasinus*, the large body size was related with oligotrophic conditions and the small size with eutrophic systems. Matsumura-Tundisi *et al*. (1997) showed that *T. prasinus* is adapted to anoxic environments, rich in detritus. Therefore, this species can indicate systems with oxygen depletion. Also, Melão & Rocha (2004) found a high abundance of *T. prasinus* in the summer (rainy season), a period of large inputs of allochtonous material.

In conclusion, the present study shows that some species were good bioindicators of reservoir trophic level in São Paulo State, corroborating and expanding previous observations in the tropics (Reid 1989), in São Paulo State (Silva and Matsumura-Tundisi 2002, 2003) and in Minas Gerais State (Landa *et al*. 2007). *Thermocyclops decipiens* and *Tropocyclops prasinus* indicate mesotrophic/eutrophic systems; *Thermocyclops inversus* and *Microcyclops anceps* indicate oligotrophic/mesotrophic systems, *Thermocyclops minutus* and *T. iguapensis* indicate oligotrophic systems and *Mesocyclops ogunnus* indicates eutrophic systems.

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