Increases in microcrustaceans (Cladocera and Copepoda) associated with phytoplankton peaks in tropical reservoirs

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Abstract: We studied the interactions between microcrustaceans and phytoplankton in storage and run-of-river tropical cascade reservoirs in Brazil by performing comparisons on a spatial-temporal scale and non-parametric correlations. Samples of zooplankton and phytoplankton were obtained quarterly over a period of two years from four sites at each reservoir. Cladocerans, such as Daphniidae and Sididae in addition to adult copepods, increased in response to seasonal phytoplankton density peaks in the storage reservoir and also in the areas close to the dam zone of the run-of-river reservoir. The abundances of filter-feeding microcrustaceans and of Cryptophyceae, Chrysophyceae, Cyanophyceae, Chlorophyceae and total phytoplankton were positively correlated. Adult cyclopoids with raptorial feeding habits were particularly correlated with Bacillariophyceae, Chlamydophyceae, Cryptophyceae and Dinophyceae. As expected, fluctuations in the abundances of the phytoplankton classes in both reservoirs could be associated with the differing responses of the filter feeders and raptorial microcrustaceans, with differences observed among the taxonomic groups.

Key words: Algal quality, correlations, Crustacea, Paranapanema River, phytoplankton, tropical impoundments.

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Introduction

Planktonic microcrustaceans (Cladocera and Copepoda) are important for energy and biomass transfer between producers (phytoplankton) and other consumers. Many microcrustacean species (e.g., large cladocerans, calanoid copepods) are considered herbivorous, feeding preferentially on phytoplankton. Von Ruckert & Giani (2008) have suggested that in tropical lakes, the abundance of food (phytoplankton) exceeds the capacity for herbivorous zooplankton to shape and modify the phytoplankton structure, and only Daphniidae has shown evidence of modifications, with top-down effects being more important.

Cladocerans have a filter apparatus that is better adapted to capture small algae (Von Ruckert & Giani 2008). Calanoid copepods have mechanical and chemical sensors in their antennae that permit the discrimination of algae by size, shape, and chemical composition to detect food quality (Huys & Boxshall 1991; Ventelã *et al.*

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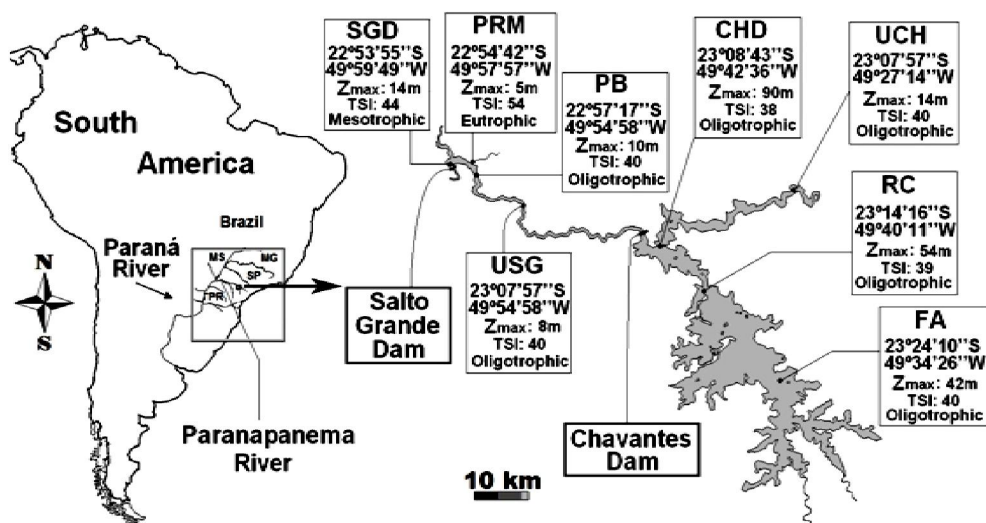
Fig. 1. Study area and sampling stations, with respectively geographic coordinates, maximum depth (Z_{max}), and trophic state according TSI of Carlson modified by Mercante & Tucci-Moura (1999). Codes: UCH - Upstream Chavantes; FA - Fartura Chavantes; RC - Ribeirão Claro Chavantes; CHD - Chavantes Dam; USG - Upstream Salto Grande; PB - Pedra Branca Salto Grande; PRM - Pardo River Mouth; SGD - Salto Grande Dam.

2002). For example, some species, such as *Notodiaptomus iheringi,* prefer to feed on small algae, while *Argyrodiaptomus furcatus* feed on larger algae (Panosso *et al.* 2003; Rietzler *et al.* 2002). Calanoid copepods are generally herbivorous filter feeders that also feed on detritus rich in bacteria (Boxshall & Defaye 2008). Cyclopoids have a raptorial feeding mode and are omnivorous; some species feed on phytoplankton and detritus, and other large species are preferentially carnivorous (Dussart & Defaye 1995), such as those from the genus *Mesocyclops* Sars 1914. A great variation in feeding occurs according to the ontogenetic developmental stage of the copepod (nauplii, copepodit, and adults), which is attributed to changes in body size as well as to alterations in the mouth apparatus (Mayer 1990).

The sizes and shapes of the mouth apparatuses of different microcrustacean species allow or prevent the manipulation and ingestion of phytoplankton (Hawkins & Lampert 1989), which also depends on the phytoplankton shape, size, composition, biochemistry, palatability, mucilaginous sheaths, and cyanotoxins (Ferrão-Filho *et al.* 2000; Perbiche-Neves *et al.* 2007; Rietzler *et al.* 2002). Caramujo & Boavida (2000) have found that zooplankton abundance is controlled by food availability, Abrantes *et al.* (2006) have observed a negative effect of Cyanophyceae on cladocerans in eutrophic lakes, and Rocha *et al.* (2002) have observed the effects of a *Microcystis* Kutz bloom on

zooplankton.

This study analyzed the relationships between microcrustaceans and phytoplankton. It was performed two reservoirs with contrasting morphometric aspects (particularly with regard to area, depth and water retention time). Considering that phytoplankton abundance is an important variable affecting the filter feeding ability of microcrustacean species (Abrantes *et al.* 2006; Darchambeau & Thys 2005; Ferrão-Filho *et al.* 2003b; Hawkins & Lampert 1989; Panosso *et al.* 2003), we tested the hypothesis that peaks in the abundances of some phytoplankton classes can be correlated with increases and peaks in some microcrustaceans, particularly the filter feeders. Positive effects should occur if the algae are palatable and negative effects should be observed if they are not.

Methods

Study area

The study focused on two reservoirs (Chavantes Reservoir (CH) at 23° 22' 09.16" S - 49° 36' 52.63" W; and Salto Grande Reservoir (SG) at 22° 57' 26.80" S - 49° 57' 09.12" W) located in the Paranapanema River, which is an important tributary of the upper stretch of the Paraná River (Fig. 1). Other limnological features of the two reservoirs can be found in Nogueira *et al.* (2008) and Perbiche-Neves & Nogueira (2010). Zoo-

plankton and phytoplankton samples were obtained from four sites in each reservoir (Fig. 1), and the sampling was repeated eight times at each reservoir over a period of two years: October 2005; January, April, July, and October 2006; and January, April, and July 2007 at the CH Reservoir, and November 2005; February, May, August, and November 2006; and February, May, and August 2007 at the SG Reservoir.

The sampling sites (Fig. 1) were distributed along different compartments of the reservoirs, which were representative of lotic (USG, PRM), river-reservoir interface (UCH, FA, PB), and lentic regions (RC, CHD, SGD).

Zooplankton sampling

Zooplankton samplings were performed using a conical plankton net with a 50 µm mesh size and a 30 cm diameter mouths hauled vertically (from the bottom to the surface). The samples were preserved in 4 % formalin solution.

In the laboratory, cladocerans and copepods (adults) were identified according to specialized literature (Cladocera: Elmoor-Loureiro 1997; Copepoda: Silva & Matsumura-Tundisi 2005) and were quantified using a stereomicroscope and binocular microscope. Immature forms of Copepoda were divided according to order level only. For the counting process, subsamples of 2 to 10 ml were obtained using pipettes and placed on acrylic gridded plates. A minimum of 200 individuals per sample was quantified under a stereomicroscope. Nauplii were quantified in a Sedgewick-Rafter chamber under an optical microscope, and a minimum of 100 individuals per sample was counted. The zooplankton abundance data were expressed as $ind.m^{-3}$.

Phytoplankton sampling

Total phytoplankton samples were obtained simultaneously with the zooplankton samples from each station at four depths of the Chavantes Reservoir (surface, middle and end of the euphotic zone, as determined with a Secchi disk, and bottom) and at three depths of the Salto Grande Reservoir (surface, middle and bottom). The means of the species observed at each depth were subjected to data analyses. We used a closing bottle to access these depths. Phytoplankton were preserved with acetic acid solution. The abundances of the phytoplanktonic classes ($ind.l^{-1}$) were quantified according to Uthermöhl (1958) using an inverted microscope at 400× magnification. The individuals (cells, colonies, coenobionts, and filaments) were counted in 150 fields, and in the case of samples with few algae, the minimum area method was employed, and the number of necessary fields was used to establish an adequate number of taxa in each field. The phytoplankton were identified according to Parra & Bicudo (1995).

Plots of the microcrustacean versus the phytoplankton classes were graphed using spatial-seasonal scales. Only those graphs with common peaks of abundance between the microcrustaceans and phytoplankton were used. The codes used for the young forms of the copepods were NCy (nauplii of Cyclopoida), NCa (nauplii of Calanoida), CCy (copepodit of Cyclopoida) and CCa (copepodit of Calanoida). Only dominant phytoplankton (> 99 % of total density) classes were used in these graphics.

Data analysis

Spearman's rank correlations (Sokal & Rohlf 1981) were performed (for the non-parametric data) among the abundances of the cladoceran families and Copepoda taxa versus the dominant phytoplanktonic classes. The adopted division (cladoceran families and copepod taxa) took into consideration the higher similarity levels of the feeding habits of the microcrustacean groups. Bonferroni correction was used to avoid type I error, and it was also used on the null hypothesis and to adjust the correlations. The data analyses were performed using R Cran Project software (2014).

Results

The same taxa of zooplankton and phytoplankton showing concurrently high values were common to both reservoirs. In the storage reservoir (Figs. 2 & 3), the peaks of total phytoplankton (77 % of total phytoplankton was dominated by Cryptophyceae) and Cryptophyceae occurred at the same time as the peaks of Daphniidae, *Notodiaptomus henseni*, Calanoida copepodits, Bosminidae, Cyclopoida nauplii, and *Mesocyclops ogunnus* (Figs. 2 & 3), which were observed in January and October 2006 at most sites. In the run-of-river reservoir (Figs. 3 & 4), common peaks of microcrustaceans and phytoplankton were observed in November 2006 at the USG, in May 2007 at the PB, and in February 2006 at all reservoirs.

For the storage reservoir, Spearman correlations were significant and positive between
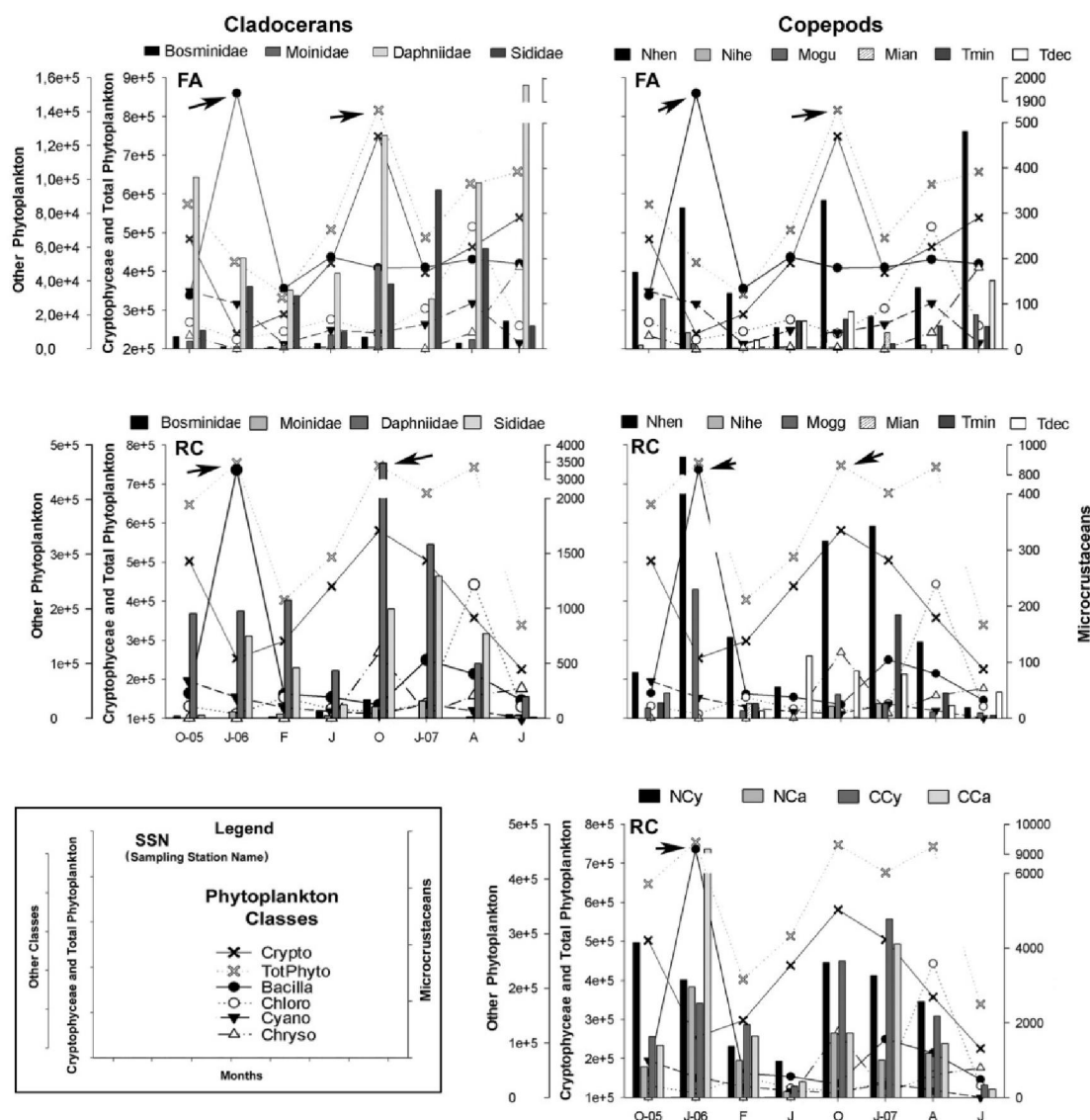
Fig. 2. Over plotted temporal variation of the abundance of cladoceran families, young copepods, adult copepods, and phytoplankton classes and total abundance among the follow sampling sites: FA and RC. Note different scales. Sampling sites codes are presented in Fig. 1. Codes for species and other taxa are present in material and methods. Arrows point common peaks of cladocerans and phytoplankton. In X axis of phytoplankton classes, "other" means Bacillariophyceae, Chrysophyceae, Cyanophyceae, Chlorophyceae, etc, except Cryptophyceae and total phytoplankton. The legend in the right corner is also valid to Figs. 3 and 4.

Daphniidae and Cryptophyceae, Sididae and Cyanophyceae, and both families with the total phytoplankton (Table 1). Chydoridae showed a positive association with Euglenophyceae, and Moinidae showed a negative association with this algal class. In the run-of-river reservoir, Sididae showed a positive association with Cryptophyceae and the total phytoplankton. Conversely, Daphniidae showed a negative association with Euglenophyceae. Moinidae was negatively corre-

lated with Chlamydophyceae and Chlorophyceae and positively correlated with Cryptophyceae (Table 1).

For the Copepods, Bacillariophyceae, Cryptophyceae and the total phytoplankton showed higher numbers of positive significant correlations (Table 1). At the storage reservoir, *Thermocyclops minutes* and calanoid nauplii presented with high numbers of positive associations with the phytoplanktonic classes. At the run-of-river reser-
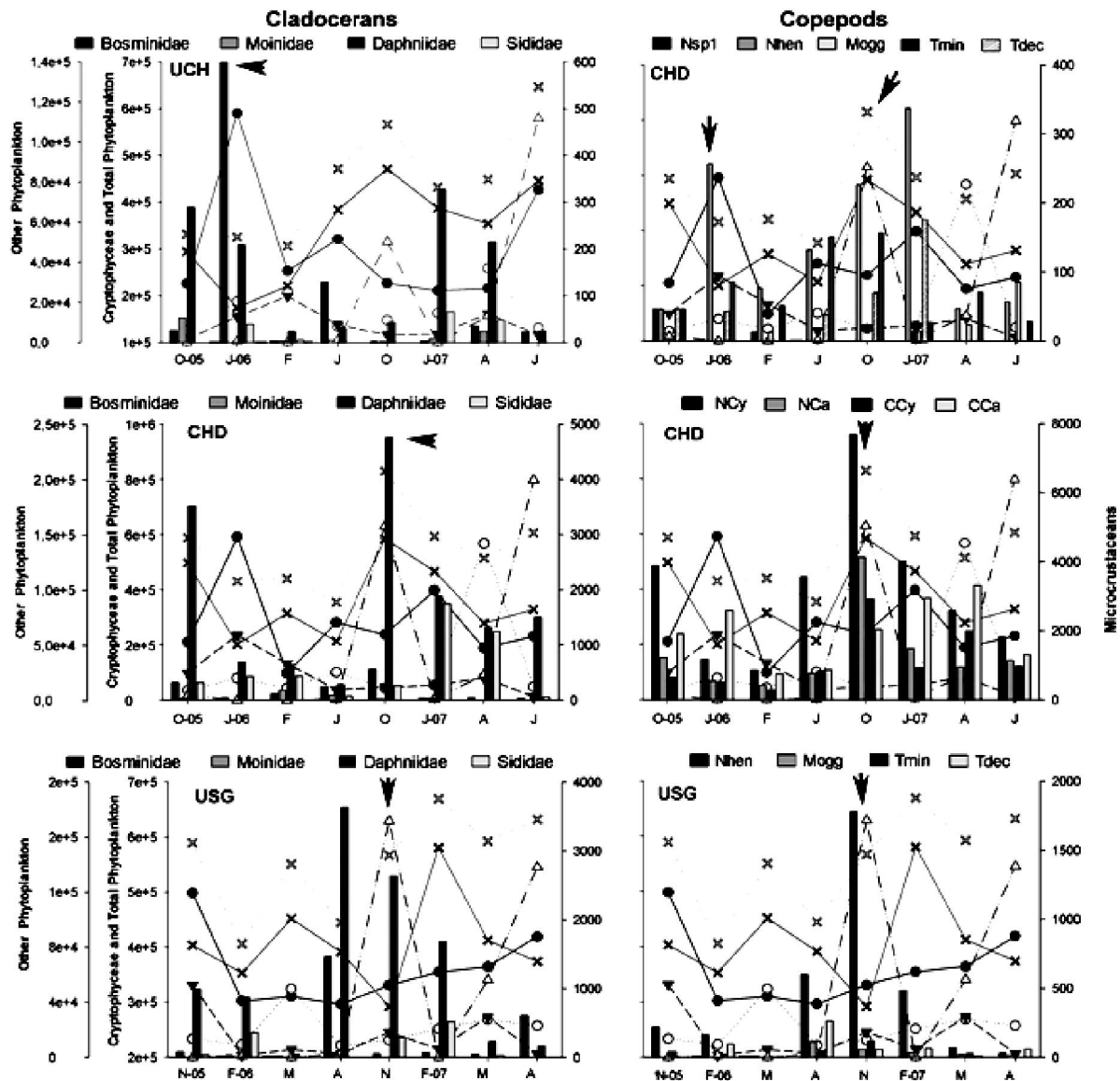
Fig. 3. Temporal variation of the abundance of cladoceran families, young copepods, adult copepods, and phytoplankton classes and total abundance among the follow sampling sites: UCH, CHD, and USG. Note different scales. Sampling sites codes are presented in Figure 1. Codes for species and other taxa are present in material and methods. Arrows point common peaks of cladocerans and phytoplankton.

voir, *Mesocyclops ogunnus*, cyclopoid nauplii and calanoid nauplii showed positive associations with Bacillariophyceae. *Notodiaptomus iheringi* showed a higher number of negative associations at the storage reservoir, and Calanoida copepodits showed a similar pattern at the run-of-river reservoir (Table 1).

Discussion

Zooplankton are greatly associated with changes in the phytoplankton community structure in lakes, indicating that microcrustacean abundance coincides with peaks in phytoplankton abundance. Many microcrustaceans are considered to be herbivorous, feeding preferentially on phytoplankton. Herbivorous zooplankton use biochemical and mechanical receptors during the feeding process, analyzing the quality (size, shape and nutritional state) and quantity of available food. It is evident the seasonal variation of phytoplankton biomass in tropical environments (Tamire & Mengistou 2014) and the presence of palatable phytoplankton is extremely important to
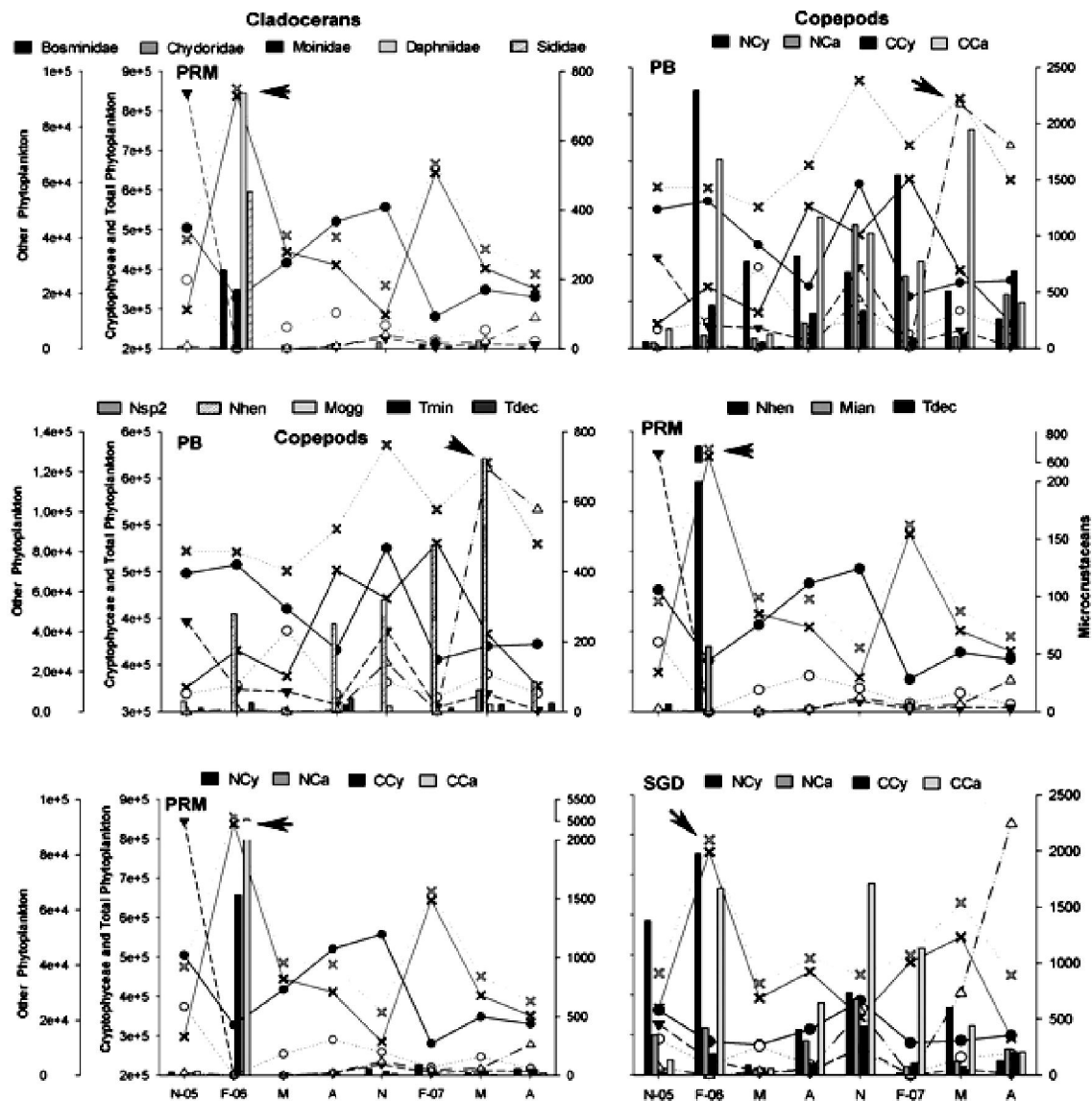
Fig. 4. Temporal variation of the abundance of cladoceran families, young copepods, adult copepods, and phytoplankton classes and total abundance among the follow sampling sites: PB, PRM, and SGD. Note different scales. Sampling sites codes are presented in Fig. 1. Codes for species and other taxa are present in material and methods. Arrows point common peaks of cladocerans and phytoplankton.

the increase of zooplankton, and the ability of zooplankton to suppress algal communities is very strongly tied to phytoplankton food quality (Danielsdottir *et al*. 2007).

Our results also demonstrated the contribution of peaks in Cryptophyceae abundance, particularly on the abundances of Daphniidae and Cyclopoida, which is in accordance with other studies involving lakes, reservoirs and fish farms (Borges *et al*. 2010; Reynolds *et al*. 2002). The small size (< 40 μm) of this class makes them susceptible to ingestion by filter-feeder microcrustaceans, such as Daphniidae

(Kagami *et al*. 2002); however, they are most likely too small to be good prey for other copepods (Sampaio *et al*. 2002), suggesting non-significant or negative relations. In addition to the faster growth of the Cryptophyceae in the systems, they tend to represent high-quality food comprising algal carbon that can be produced over a short period of time (Ahlgren *et al*. 1992).

The Bacillariophyceae class peaked in abundance in several instances near the dam, which coincided with the decreased levels of some phytoplankton, which most likely occurred due to

Table 1. Spearman correlations among the total phytoplankton classes abundance, cladocerans families and copepods in the storage and run-of-river. In bold are significant correlations (P < 0.05). Codes of phytoplankton classes: Bacci - Baccilariophyceae; Zygnem - Zygnemaphyceae; Chlamy - Clhamydophyceae; Chloro - Chlorophyceae; Cyano - Cyanophyceae; Crypto - Cryptophyceae; Eugle - Euglenophyceae; Chryso -Chrysophyceae; Dino - Dinophyceae; Tot. Phy - Total phytoplankton.

	Crypto.	Bacci.	Zygnem.	Dino.	Chlamy.	Chloro.	Eugle.	Cyano.	Chryso.	Tot. Phy.
Storage reservoir										
Chydoridae	-0.03	-0.06	-0.06	-0.07	-0.10	0.04	**0.49**	-0.21	0.21	-0.11
Daphniidae	**0.52**	0.19	-0.23	0.31	-0.22	-0.04	-0.33	0.27	0.23	**0.64**
Moinidae	0.18	-0.18	-0.10	-0.25	0.00	-0.06	**-0.38**	0.10	-0.12	0.13
Sididae	0.17	0.27	-0.29	0.11	-0.07	0.25	-0.03	**0.45**	-0.07	**0.40**
Notodiaptomus sp.	0.06	-0.23	0.25	0.19	0.06	-0.29	**-0.35**	-0.12	-0.18	-0.19
Notodiaptomus henseni (Dahl 1891)	0.25	0.14	-0.31	-0.21	-0.23	-0.18	-0.28	0.12	-0.18	**0.35**
Notodiaptomus iheringi (Wright 1935)	0.30	0.01	**-0.43**	**-0.38**	-0.20	0.03	0.23	0.23	0.21	0.20
Mesocyclops longisetus (Thiébaud 1912)	0.28	0.13	0.08	**0.41**	0.08	-0.13	0.05	-0.31	0.33	0.31
Microcyclops anceps (Richard 1897)	-0.09	-0.18	0.23	-0.01	**0.40**	0.03	0.01	0.14	-0.34	-0.21
Thermocyclops minutus (Lowndes 1934)	**0.46**	**0.46**	0.07	0.08	0.08	0.21	-0.17	0.12	0.19	**0.44**
Thermocyclops decipiens (Kiefer 1929)	0.32	0.02	0.34	**0.36**	0.31	0.13	-0.27	-0.02	0.30	0.27
Cyclopoida nauplii	**0.53**	0.34	-0.12	0.09	-0.12	0.08	-0.35	0.35	0.19	**0.65**
Calanoida nauplii	**0.40**	**0.44**	-0.13	0.29	-0.27	-0.02	-0.25	0.22	0.21	**0.66**
Cyclopoida copepodit	**0.43**	0.25	-0.15	0.12	-0.05	0.21	-0.26	0.26	0.27	**0.69**
Calanoida copepodit	0.22	**0.36**	**-0.39**	0.09	-0.25	-0.07	-0.17	0.30	-0.03	**0.47**
Harpacticoida	-0.16	0.07	0.10	-0.20	0.02	-0.17	**0.38**	-0.20	0.08	-0.23
Run-of-river reservoir										
Daphniidae	0.11	0.28	-0.02	-0.05	-0.32	0.13	**-0.42**	0.25	0.08	0.27
Moinidae	**0.38**	-0.29	0.22	0.07	**-0.36**	**-0.36**	0.07	-0.09	-0.19	0.17
Sididae	**0.39**	-0.15	-0.15	-0.05	-0.33	-0.15	-0.34	0.05	-0.16	**0.45**
Notodiaptomus sp.	-0.29	0.09	0.03	**0.35**	0.31	0.16	-0.02	0.27	**0.43**	0.05
Mesocyclops ogunnus (Onabamiro 1957)	-0.08	**0.47**	-0.25	-0.11	0.12	**0.45**	-0.16	0.34	0.34	0.25
Mesocyclops longisetus (Thiébaud 1912)	-0.11	-0.04	0.04	0.07	**0.40**	0.12	0.21	-0.07	0.12	-0.03
Microcyclops anceps (Richard 1897)	**0.39**	-0.33	-0.06	-0.04	-0.26	-0.28	-0.18	-0.13	**-0.36**	0.33
Cyclopoida nauplii	0.00	**0.37**	-0.01	-0.14	-0.25	0.34	-0.20	**0.46**	0.02	0.11
Calanoida nauplii	-0.02	**0.35**	0.02	-0.06	-0.13	0.25	-0.17	0.30	0.21	0.17
Calanoida copepodit	0.17	0.19	-0.02	-0.14	**-0.37**	0.04	**-0.36**	0.22	0.02	0.34

competition for nutrients or to the intense grazing of zooplankton on phytoplankton, particularly on the dominant palatable Cryptophyceae (Ekpenyong 2000; Perbiche-Neves & Nogueira 2010). These activities favor some phytoplankton species by reducing the numbers of competitively superior species (Danielsdottir e*t al.* 2007; Sommer & Sommer 2006). Overall, Bacillariophyceae abundance did not correlate significantly with that of microcrustacean filter feeders but did correlate with those of the juvenile life stages of Calanoida and Cyclopoida, indicating that they are not preferable food for microcrustaceans. The ability of copepods to break the filaments and more rigid structures of silica frustules are known, especially the Cyclopoida, which have a differentiated mouth apparatus due their omnivorous raptorial feeding habits (Adrian 1991).

The Class Euglenophyceae, which is favored in environments that are rich in organic matter, was positively associated with Chydoridae and Harpacticoida (littoral and benthic organisms of high turbidity and organic matter) and negatively associated with Daphniidae and Calanoida copepods (organisms of elevated transparency and those that are limnetic). All of these organisms can tolerate highly turbid waters. In such waters, these algae can use heterotrophic processes to obtain food, becoming available for ingestion by Chydoridae, which is commonly found to adapt to these conditions, and also for ingestion by aquatic macrophyte stands (Lansac-Tôha *et al.* 2004).

Cyanobacteria were positively associated only with Sididae at the storage reservoir and Cyclopoida nauplii at the run-of-reservoir. However, the effects of Cyanobacteria on zooplankton are controversial but tend to be negative (Ferrão-Filho *et al.* 2000; Ferrão-Filho & Azevedo 2003a). Cyanobacteria cause effects due their toxicities, shapes (mucilaginous colonies or filaments) and high abundances during blooms (Infante & Riehl 1984). On the other hand, Sampaio *et al.* (2002) have reported their positive associations with copepods in the Chavantes Reservoir. Perbiche-Neves *et al.* (2007) and Bini *et al.* (2008) have attributed the dominance of Cyanobacteria (especially *Microcystis aeruginosa*, Kützing 1846) to elevated zooplanktonic abundance in a eutrophic reservoir, particularly small-sized zooplankton species. Small colonies of *M. aeruginosa* can be excellent food for the three *Daphnia* species (De Bernardi *et al.* 1987). Cladocerans can also consume and/or modify the sizes or the structures of filamentous Cyanobacteria (Kâ *et al.* 2012), and they have been

observed to feed on colonial Cyanobacteria (Dawidowicz *et al.* 1988). In addition, during a cyanobacterial bloom, the abundant microcrustaceans are able to exploit other food resources, such as bacterioplankton and heterotrophic flagellates (Dias *et al.* 2011).

The abundances of other classes were less related to those of the filter feeders, such as Dinophyceae, Zygnemaphyceae, and Chrysophyceae. However, were correlated with copepods. The abundances of these algae during this study, their variable shapes and biochemical compositions may have interfered with their ingestion by most zooplankton (Panarelli *et al.* 2001). Our study suggests that the distinct food preferences most likely occurred at the specie level in some cases.

Conclusions

In conclusion, we found that some organisms with slower development times, such as Diaptomidae, increased in abundance following the increase in phytoplankton abundance and that the abundances of some phytoplankton classes were positively associated with microcrustacean abundance, depending on other characteristics, such as algal quality. Furthermore, while Von Ruckert & Giani (2008) have reported modifications in the phytoplankton community due to Daphniidae in tropical lakes in Brazil, our data suggest that the abundance of planktonic microcrustaceans, such as Cladocerans Daphniidae, Sididae and copepods, in the studied reservoirs respond positively to increases in certain classes of phytoplankton, particularly Cryptophyceae and Bacillariophyceae classes.

Acknowledgements

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