



Effects of a small fish cage farm on zooplankton assemblages (Cladocera and Copepoda: Crustacea) in a sub-tropical reservoir (SE Brazil)

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Abstract. In Brazil, the environmental impacts of fish cage farming in water reservoirs have not been well studied. As this activity is being increasingly practiced, investigations on the impacts of this practice are strongly needed. The goal of this study was to investigate the effects of a small cage tilapia farm on zooplankton assemblages in an oligo/mesotrophic reservoir (Jurumirim Reservoir, Paranapanema River). Zooplankton, limnological variables, and water samples were obtained trimonthly during a year at two sample sites, one was located adjacent to the cage farm and the control area was located one kilometer away from it. Eighteen species were identified and Cladocera was the dominant group. The same species of microcrustaceans were identified at both sites. Among the ecological attributes studied, only evenness showed a tendency towards being higher in the control site. Significant differences between studied variables in the sites were observed only for material in suspension. The results of the study indicate that, during the studied period, the cage farm did not generate detectable changes in the zooplankton assemblages and their ecological attributes. However, small differences in some limnological variables could be an indication of some environmental changes associated with the fish farm system.

Key words: *Oreochromis niloticus*, eutrophication, environmental damage, microcrustaceans, tropical reservoir

Resumo. Efeitos de um pequeno sistema de piscicultura em tanques-rede na assembléia de zooplâncton (Cladocera e Copepoda: Crustacea) em um reservatório sub-tropical (SE Brasil). No Brasil, os impactos ambientais da piscicultura em tanques-rede em reservatórios foram pouco estudados. Como essa atividade tem sido cada vez mais praticada, investigações neste sentido tornam-se imprescindíveis. O objetivo deste trabalho foi investigar os efeitos de um pequeno sistema de tilapicultura em tanques-rede na assembléia zooplanctônica em um reservatório oligo/mesotrófico (Reservatório de Jurumirim, Rio Paranapanema). A coleta de zooplâncton, variáveis limnológicas e água foram realizadas trimestralmente durante o período de um ano em duas localidades, uma adjacente ao sistema de piscicultura e outra área controle, localizada a um quilômetro do sistema de produção. Foram identificadas 18 espécies, sendo Cladocera o grupo dominante. As mesmas espécies de microcrustáceos foram identificadas para as duas áreas estudadas. Entre os atributos ecológicos analisados, apenas a equitabilidade apresentou tendência a ser maior na área controle. Diferenças significativas entre as variáveis estudadas foram observadas apenas para o material em suspensão. Os resultados deste estudo indicam que durante o período estudado o sistema de piscicultura em tanques-rede não gerou alterações detectáveis na assembléia zooplanctônica. Entretanto, as pequenas diferenças em algumas variáveis limnológicas pode ser um indicativo das alterações ambientais resultantes da implantação de sistemas de piscicultura em tanques-rede.

Palavras chaves: *Oreochromis niloticus*, eutrofização, impactos ambientais, microcrustáceos

Introduction

Human population increases have contributed to the overexploitation of native fish stocks. Consequently, aquaculture has become the zootechnical activity with the highest growth rate. In Brazil, particularly, this activity rises by 25% per year. According to IBAMA (2002), continental aquaculture contributes to approximately 20% of the Brazilian fish production.

Currently, net cage aquaculture in large reservoirs is becoming one of the most often employed production systems in different Brazilian hydrographic basins, as the result of governmental programs and availability of public funds for the activity (Agostinho *et al.* 2007). Although the consequences of eutrophication in reservoirs are well documented, much less is known about the impact of fish cage farming in tropical waters. The Nile Tilapia (*Oreochromis niloticus* Trewavas, 1983) is the most commonly-reared species in north-western and south-western Brazil due to its commercial value and adaptability to different environmental conditions (Ostrensky *et al.* 2008).

Recent studies about the impacts of this rearing system on different aspects such as limnological variables (Alves & Baccarin 2006), the structure of phytoplankton and zooplankton (Starling 1993, Dias 2008, Santos *et al.* 2009), benthos (Menezes & Beyruth 2003) and fish (Zanatta 2007, Ramos *et al.* 2008) assemblages, indicate discrete alterations related to the rearing of fish in cages. In contrast, in Asiatic countries with a long history in aquaculture, strong environmental impacts related to fish cage farming have been reported. Guo & Li (2003) detected an increase in nitrogen, phosphorus, chlorophyll and microcrustacean biomass, due to the emission of organic matter from a fish farm in a Chinese lake. According to Beveridge (1984, 1996), each Kg of cultivated fish provides about 0.023 Kg of available phosphorus to the environment, where residual food is the main source of this waste. Landell (2007) observed that between 1000 and 1300 kg of food per year caused an increase of 500 to 650 kg in phosphorus.

Considering that increased nutrients availability is the most important impact of fish cage farming (Hankanson 2005), the changes in zooplankton assemblages caused by this activity are possibly less severe than those observed during the eutrophication process (Tundisi 2003). In general, the most affected ecological attributes are species composition, richness, diversity and species abundance of the zooplanktonic assemblages (Matsumura-Tundisi & Tundisi 2005, Tundisi & Matsumura-Tundisi 2008).

Jurumirim is the first in a cascade of 11 reservoirs in the Paranapanema River (São Paulo State, Brazil), and its limnological characteristics have been studied for 30 years. This river is considered an oligo/mesotrophic system (*sensu* Carlson modified by Toledo *et al.* 1983) with few branches in eutrophic conditions (Henry & Nogueira 1999). The zooplankton distribution is well known in Jurumirim reservoir (Nogueira 2001, Panarelli *et al.* 2001, Mitsuka & Henry 2002, Panarelli *et al.* 2003, Sartori *et al.* 2009), and alterations in its structure due to environmental changes might be detectable if compared with other studies.

The aim of this paper was to evaluate the effects of a small fish cage farm on the ecological attributes of zooplankton assemblages in the Jurumirim Reservoir. Furthermore, we investigated the correlation of these attributes with some limnological variables.

Material and Methods

The study was carried out in 2005 at a small commercial tilapia cage farm located in the Jurumirim Reservoir (Figure 1), high Paranapanema River Basin. The reservoir is of the storage type, has an approximate area of 440km², maximum depth of 40m and mean depth of 12.9m, volume of 7.9 x 10⁹m³, mean outflow of 315m³.s⁻¹, water retention time varying between 334 and 544 days, and shows a hot monomitic stratification pattern (Henry *et al.* 2006).

The fish farm studied was composed of 30 cages (18m³ volume each) spread over an area of approximately 300m². The depth at the site was over 3.5m. The cages were made of a steel frame and polyethylene net with a mesh size of 17mm.

The fish (*Tilapia – Oreochromis niloticus*) were stocked in growth cages with an initial density of 500 fish.m⁻³. Final densities in growth cages were about 120 to 220 fish.m⁻³. Feeding was performed with extruded commercial food with 36% and 32% of protein for growth and fattening phases. The amount of commercial food used during the study was about 100 to 130 tons.

The sampling of zooplankton and water initiated in December/2004, and two months later the fish cages were installed, in February/2005. Water and zooplankton were sampled every three months for a year at two sites (cage and control) between February/2005 to December/2005, totaling eight observations. One sampling site was located near the cages and the control site was located one km away from it (Figure 1). Cage and control sites were similar in depth (Cage, Z_{max}: 3.5m, Control,

Z_{\max} : 3.0m), water flow and distance to littoral zone. Aquatic macrophytes were absent at both sites.

Water and zooplankton analysis

Limnological variables (dissolved oxygen, temperature, electric conductivity, pH and water turbidity) were obtained in the water column using a

Horiba multiparameter probe, model U-22. Water transparency was obtained with a Secchi disk.

Water samples (5 L) were obtained using a Van Dorn bottle ca. one meter above the bottom and In the laboratory the variables specified in Table I were determined.

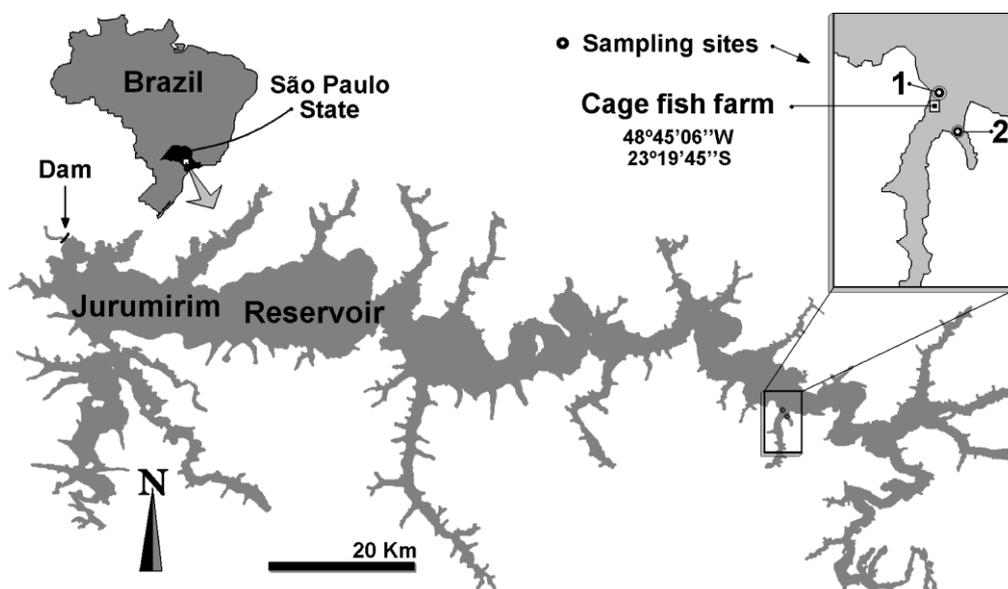


Figure 1. The study area and the sampling sites: 1 – Cage farm; 2 – Control area.

Zooplankton samples were obtained through vertical hauls of 3m in the water column - from the bottom to the surface - with a conical plankton net of 64 μ m mesh size and 30cm diameter mouth opening. The total volume filtered (through the cylinder volume formula) by the net was 240 liters. The filtered content was fixed in 4% formaldehyde (final concentration).

The identification of zooplankton adult stages was performed under an optic microscope and using specialized bibliography (Matsumura-Tundisi 1986, Reid 1985, El-Moor Loureiro 1997, Santos-Silva

2000, Silva 2003). For quantitative analysis, three sub-samples were counted in an acrylic chamber under a stereoscopic microscope. Only nauplii stages were counted in the Sedgwick-Rafter chamber, under a microscope. At least 200 individuals of adults and nauplii were counted and the abundance was expressed as individuals.m⁻³.

Based on data about zooplankton abundance, the Pielou Evenness, Shannon-Wiener diversity index (alpha diversity) and richness of species were determined using Past software (Hammer *et al.* 2001).

Table 1. Limnological variables and methods used in the laboratory.

Limnological variables	Methodology
Suspended matter	Mudroch & Macknight 1991
Chlorophyll- <i>a</i> , Reactive silicate	Golterman <i>et al.</i> 1978
Total phosphorus, Total dissolved phosphorus, Inorganic phosphorus	Strickland & Parsons 1960
Total nitrogen, Nitrite, Nitrate	Mackereth <i>et al.</i> 1978
Ammonium	Koroleff 1976

The reservoir studied has a long water retention time, and therefore we used the data from different months as replicates of the sites. Thus, to detect differences for the abundance of zooplankton and limnological variables between the sampling sites - cage and control, a t-test was used. The valid "n" was 8. Seasonal variation was not analyzed statistically, because the objective focused on spatial patterns.

The correlation of microcrustaceans

abundance with limnological variables (water temperature, dissolved oxygen, conductivity, pH, transparency, suspended matter, chlorophyll-a, phosphorus, inorganic phosphorus, total dissolved phosphorus, nitrogen, nitrate, nitrite, silicate, and ammonium) was explored using Pearson correlations. T- test and Pearson correlations were performed with Statistic 6.0 software (Statsoft 2002); a 5 % significance level was considered in all cases.

Results

Eleven species of Cladocera and six of Copepoda were identified (Table 2).

The t-test did not detect any differences in the abundance of zooplankton between sites. However, some differences could be observed for Cladocera in February (*Bosminopsis deitersi* and *Diaphanosoma spinulosum*) and August (*Bosminopsis deitersi*, *Bosmina hagmanni* and *Moina minuta*), and adult Copepoda in August

(*Thermocyclops minutus*) and December (*Thermocyclops decipiens*). In general the peaks of abundance for each zooplankton group did not occur in the same month for both sites. A similar temporal trend of abundance at both sites was observed only for Cyclopoida nauplii, Calanoida nauplii and less clearly for Cyclopoida copepodits (Figure 2). These last categories showed the least difference between the sites.

Table 2. List of zooplankton taxa found in this study.

Cladocera	Copepoda
<i>Bosminopsis deitersi</i> Richard, 1834	Cyclopoida
<i>Bosmina hagmanni</i> Stingelin, 1904	<i>Mesocyclops ogunnus</i> Onabaniro, 1957
<i>Bosmina (Sinosbosmina) freyi</i> De Melo & Hebert, 1994	<i>Mesocyclops longisetus</i> Thiébaud, 1914
<i>Ceriodaphnia cornuta</i> Sars, 1886	<i>Thermocyclops minutus</i> (Lowndes, 1934)
<i>Ceriodaphnia cornuta</i> var. <i>rigaudi</i>	<i>Thermocyclops decipiens</i> (Kiefer, 1929)
<i>Ceriodaphnia cornuta</i> var. <i>intermedia</i>	<i>Thermocyclops inversus</i> Kiefer, 1936
<i>Ceriodaphnia silvestrii</i> Daday, 1902	Calanoida
<i>Daphnia gessneri</i> Herbst, 1967	<i>Argyrodiaptomus furcatus</i> (Sars, 1901)
<i>Diaphanosoma birgei</i> Korineck, 1981	
<i>Diaphanosoma brevireme</i> Sars, 1901	
<i>Diaphanosoma fluviatile</i> Hansen, 1899	
<i>Diaphanosoma spinulosum</i> Herbst, 1967	
<i>Moina minuta</i> Hansen, 1899	

For Copepoda in December/05, the highest values of evenness were verified at the control site. Evenness was the single community descriptor which differed between control and cage sites ($t = 2.14$, $p = 0.04$). No clear patterns were observed in relation to diversity and species richness (Figure 3), with changes in major values between sites and months.

The results of the t-test showed that most of the limnological variables were similar in both studied sites (cages and control). Only the suspended matter was higher in the cage than at the control site (Table 3).

Most Pearson correlations between zooplankton abundance and limnological variables were not significant. pH was the variable that correlated with most groups, namely Sididae, Cladocera and Calanoida copepodits (negatively) and adult Calanoida (positively). Conductivity correlated positively with Cyclopoida nauplii and negatively with Cladocera. Chlorophyll-a correlated positively with Bosminidae and Cladocera and negatively with Cyclopoida nauplii (Table 4). Daphniidae and nauplii Calanoida did not correlate with any variables.

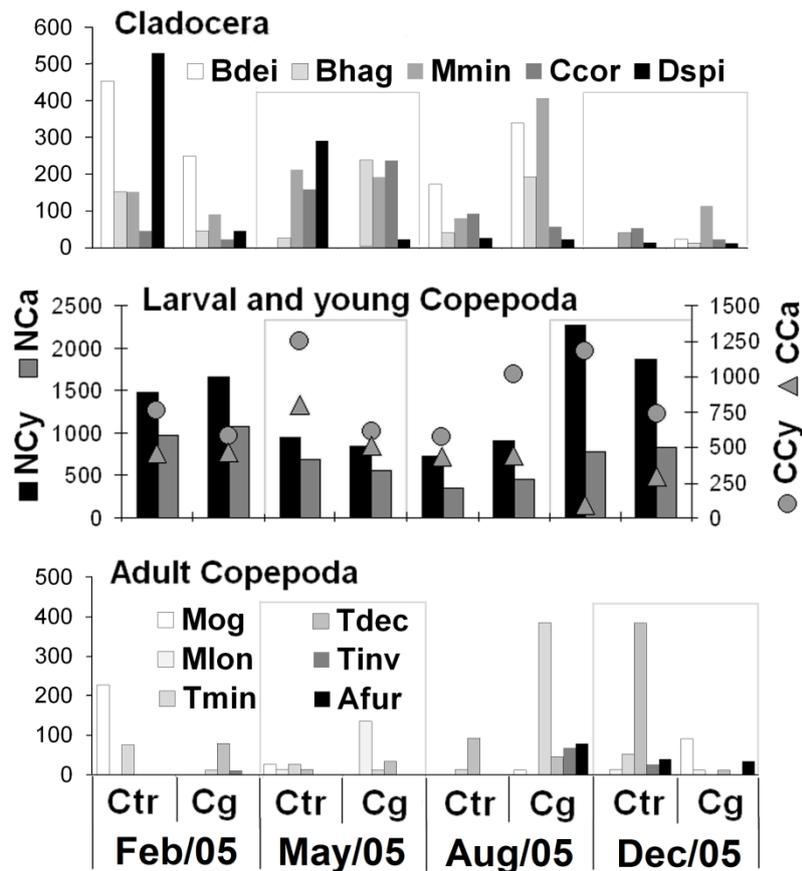


Figure 2. Spatial (Ctr= control and Cg= cage) and seasonal variation of the abundance (individuals.m⁻³) of Cladocera , nauplii and copepodits of Cyclopoida and Calanoida and adult Copepoda. (Codes: Bdei= *Bosminopsis deitersi*; Bhag= *Bosmina hagmanni*; Mmin= *Moina minuta*; Ccor= *Ceriodaphnia cornuta*; Dspi= *Diaphanosoma spinulosum*; NCy – Cyclopoida nauplii, NCa – Calanoida nauplii, CCy - Cyclopoida copepodits, CCa – Calanoida copepodits, Mog= *Mesocyclops ogunus*; Mlon= *Mesocyclops longisetus*; Tmin= *Thermocyclops minutus*; Tdec= *Thermocyclops decipiens*; Tinv= *Thermocyclops inversus*; Afur= *Argyrodiaptomus furcatus*).

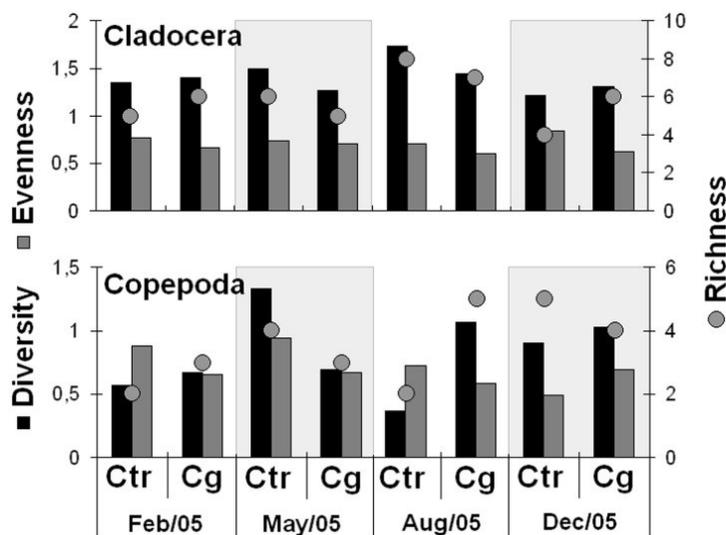


Figure 3. Ecological attributes (Pielou Evenness, Shannon-Wiener diversity and species richness) for zooplankton assemblages’ in neighboring cages and control sites. Codes: Ctr= control; Cg= cage.

Table 3. Average values, standard deviation and t-test/p values of limnological variables in the cages and control sites. Variables typed in bold show significant differences.

Limnological variables	Control	Cages	t/p values
Temperature (°C)	23.22 ± 3.18	23.58 ± 3.15	-0.28/0.78
Dissolved oxygen (mg.L ⁻¹)	8.10 ± 0.73	7.93 ± 0.91	-0.13/0.89
Conductivity (µS.cm ⁻¹)	59.50 ± 8.46	59.33 ± 9.81	-0.01/0.99
pH	6.39 ± 0.67	6.79 ± 0.56	-0.24/0.81
Transparency (m)	0.95 ± 0.24	0.94 ± 0.18	-0.00/0.99
Suspended matter	1.30 ± 0.41	3.52 ± 0.74	-5.61/0.00
Chlorophyll-a (µg.L ⁻¹)	3.23 ± 2.11	2.73 ± 1.56	0.30/0.77
Phosphorus (µg.L ⁻¹)	8.16 ± 1.98	6.59 ± 1.78	1.11/0.30
Nitrogen (µg.L ⁻¹)	593.64 ± 33.57	649.37 ± 52.17	-1.84/0.11
Inorganic phosphorus (µg.L ⁻¹)	0.66 ± 0.09	0.81 ± 0.31	-0.95/0.37
Total dissolved phosphorus (µg.L ⁻¹)	1.80 ± 0.67	1.01 ± 0.36	1.90/0.10
Nitrate (µg.L ⁻¹)	224.50 ± 62.07	199.75 ± 65.66	0.56/0.59
Nitrite (µg.L ⁻¹)	9.79 ± 2.43	8.65 ± 3.35	0.69/0.51
Silicate (µg.L ⁻¹)	11.91 ± 1.04	9.33 ± 3.06	1.57/0.16
Ammonium (µg.L ⁻¹)	0.073 ± 0.052	0.052 ± 0.052	0.50/0.63

Discussion

Fish cage farming caused very slight changes in only a few variables in this study, such as the evenness index for copepods and suspended material. The nutrient levels (nitrogen and phosphorus) did not present differences between sites, suggesting that the fish cage farm had not yet affected the water quality. Probably the short-time scale studied (just one year) was not sufficient to allow the clear detection of the effects. In Brazil, Santos et al. (2009) found that the farming of tilapias in net tanks caused only small differences in zooplankton levels; although they did point out that small alterations may signify the initial stage of alterations in this community. In our study,

during preliminary pilot sampling a small spatial variability was observed at both sites, and so only one replicate sample was subsequently taken at each site. But, lack of differences between test (cage) and control sites for most variables measured may have resulted from that limitation in the sampling design, i.e., lack of proper within-site replication, and pooling of seasonal observations instead for statistical comparison. Present results should therefore be taken as preliminary, pointing out that probably the impact is of cumulative nature over the years, given the low number of cages and characteristics of the reservoir.

Table 4. Significant Pearson correlations ($p < 0.05$) between microcrustaceans abundance and limnological variables. NS= not significant.

Zooplankton	Conductivity	pH	Chlorophyll-a
Bosminidae	NS	NS	0.71
Sididae	NS	-0.79	NS
Total Cladocera	-0.81	-0.86	0.74
Nauplii Cyclopoida	0.77	NS	-0.86
Copepodit Calanoida	NS	-0.85	NS
Adult Calanoida	NS	0.80	NS

Non-clear trends were detected for composition, abundance, species richness and diversity of zooplankton in site cage. In contrast, a

trend towards higher evenness in the control site was observed, possibly suggesting a more homogeneous assemblage than the cage site. Matsumura-Tundisi &

Tundisi (2003, 2005) reported that increased nutrients, chlorophyll-a, phytoplankton, conductivity, bacteria, and other factors can change the zooplankton structure, especially in species evenness and diversity index. These authors suggested that conductivity was responsible for the collapse of some and the growth of some Copepoda and Calanoida species in the eutrophic reservoirs of the São Paulo State during previous decades. However, the conductivity values were very low in our study, when compared with the Barra Bonita Reservoir (Matsumura-Tundisi & Tundisi, 2003).

Since the Jurumirim Reservoir shows low primary productivity (Henry *et al.* 2006), the enrichment with nutrients originated by a small aquaculture activity is difficult to perceive, as found by Borges *et al.* (2010), with small alterations for phytoplankton and zooplankton. Possibly the long water retention time and the high volume of the reservoir cause a strong dilution of the nutrients. These and other characteristics of this reservoir permit a controlled bottom-up development of phytoplankton assemblages, representing a limiting factor for zooplankton. The values of environmental variables were similar to those obtained in previous studies in this reservoir (Nogueira *et al.* 2002, 2006, 2008, Henry *et al.* 2006, Sartori *et al.* 2009). The main inputs of nutrients to this reservoir are diffuse sources (e.g domestic sewage and soil erosion) due to the occupation of the Paranapanema hydrographic basin (Henry & Gouveia 1993) by agriculture and other activities. In Chinese lakes, Guo & Li (2003) showed that the most important impacts caused by the fish cage farm are related to increased nutrient levels (phosphorus and nitrogen) in the water column and sediment layers, reflecting in biota changes.

Significant differences for suspended material may be caused by the waste from fish farm cages, such as animal feces and food residues, and eventually by local increases in phytoplankton as observed by Borges *et al.* (2010). The fecal material and the food excess are the main effluents from fish and crustacean farm cages shown by many studies (Jensen *et al.* 1990, Holmer & Kristensen 1992, Hargrave *et al.* 1993). Since these particles are deposited at the bottom near the cages, it may be postulated that the absence of nitrogen and phosphorus concentration alterations may be more important for the composition of the sediment, as supported by Guo & Li (2003) in Chinese lakes.

The Pearson correlations showed that some limnological variables (pH, conductivity and chlorophyll-a) correlated positively or negatively with abundance of particular zooplankton groups,

even though there were no statistical differences between the sites. In general, the limnological variables showed a clear seasonal variation in the Jurumirim Reservoir (Nogueira *et al.* 2008, Sartori *et al.* 2009). For example, the seasonality of water temperature is high in the Jurumirim Reservoir according to Henry & Nogueira (1999).

The negative correlations of total Cladocera with conductivity and positive correlations with Cyclopoida Nauplii occurred possibly due to the higher proportion of this second category. These organisms are more tolerant to stress conditions than Calanoida (Huys & Boxshall 1999) and possibly compared to other microcrustaceans, such as the dominant species of Cladocera.

The Calanoida presented contrasting correlations with pH. While copepodits negatively correlated with pH, the only adult species (*A. furcatus*) showed positive correlation with this variable. While this species has not been identified in the past in this reservoir (Nogueira 2001, Panarelli *et al.* 2003), the adults are probably more tolerant than copepodits.

The concentrations of chlorophyll are suggested by many authors as indicative of primary production increment, and were not found to be altered by the fish cage farming. The increase in chlorophyll favours cladocerans abundance and was positively correlated, since most cladocerans are herbivorous and feed on phytoplankton. Some studies (Panarelli *et al.* 2001) showed a clear trend for some zooplankton species when related to abundances of phytoplankton and zooplankton. The Daphniidae and Sididae families, in particular, are filter feeders with large antennas, which is an important feeding adaptation (Elmour-Loureiro 1997). Nauplii of Cyclopoida presented a lower abundance in the summer, in contrast with chlorophyll increase, and normally in this season Calanoida presents a higher abundance than Cyclopoida (Nogueira 2001, Panarelli *et al.* 2001). High water temperatures could interfere positively in the abundance of copepods Calanoida and some Cladocera (Daphniidae and Sididae families).

Even though not clearly observed in our study, the effects of cage fish farming can be detected if the culturing system was more intensive. Some effects on zooplankton assemblages were shown by Demir *et al.* (2001) for trout cage farming in a Turkish Reservoir. In Brazil, Dias (2008) showed these effects in a tilapia cage farm in Rosana Reservoir (Paranapanema River), where a higher abundance of rotifers and cladocerans were observed next to the cages, due to the nutrient enrichment and food availability. Santos *et al.* (2009) showed minor

interferences from a tilapia cage farm on zooplankton assemblages in oligo/mesotrophic conditions in the Furnas Reservoir (Grande River, MG), as did Borges *et al.* (2010) for phytoplankton and zooplankton in the Rosana Reservoir.

Moreover, no significant effect of the waste from the fish cage farm was found for limnological variables. With regard to the low productivity of the Jurumirim Reservoir, the present waste emission has a lower eutrophication potential when compared to Asian fish cage farms, for example, which use higher concentrations of animal and vegetal residues (Guo & Li 2003), causing serious eutrophication problems such as loss of water quality and alterations in the assemblage structures on a short time scale (Beveridge 1996).

Finally, this study may conclude that the fish cage farm had not yet affected the water quality and planktonic microcrustaceans assemblages in the reservoir. Still, it is important to highlight that the small differences found in limnological variables could be an indication that the environment was affected by the fish farm system to some extent, and that eventually, if accumulation of seston particles or nutrients occurs faster than the recycling capability of the system, environmental consequences may be observed.

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