INFLUENCE OF USE AND OCCUPATION OF LAND IN ZOOPLANKTON COMMUNITY OF A LARGE TROPICAL RESERVOIR – SÃO SIMÃO

INFLUENCIA DEL USO Y OCUPACIÓN DE LA TIERRA EN LA COMUNIDAD DE ZOOPLANCTON DEL GRAN EMBALSE TROPICAL SÃO SIMÃO

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Abstract

Catchment basins are importants study units for establishment of policies of management and conservation for aquatic ecosystems. Reservoirs are artificial environments directly influenced by physical, chemical and biological processes to which these catchment basins are submitted. These influences determines biological communities in reservoirs. Many studies have established the relationship between zooplankton community as bioindicator of water quality. In this context, the aim of this study was to evaluate the effects of physical and chemical variables of water and the use and occupation of land in zooplankton community of São Simão Reservoir (MG/GO). Samples were collected in two seasons (dry and rainy), in stations located in arms at left margin (Minas Gerais State), right margin (Góias State) and in main channel - limnetic zone of São Simão Reservoir. Most of physical and chemichal parameters did not exceed limits of water quality and Trophic State Index showed values between 39 and 48, classifying São Simão Reservoir as ultraoligotrophic or oligotrophic. Zooplankton community was dominated by Rotifera and Copepoda with higher densities in stations at right margins of reservoir. Calanoida/Cyclopoida ratio classified 18 of 22 sampling stations as oligotrophic in the dry season, however only 7 in the rainy season. The first Principal Component Analysis, considering the physical and chemical parameters, showed no correlation with main zooplankton groups. However, in the second one, considering the use and occupation of land, it was possible to verify the effects of human activities around the reservoir on zooplankton community (74.3% of explanation), where higher densities of microcrustaceans were observed in stations with more fishery structures, macrophyte beds and drowned original vegetation, in addition to extensive areas of agriculture, cattle ranching or human occupation, predominant on the right margin of São Simão Reservoir in Goiás State. Although they may be spurious, these correlations can not be ignored because they reflect, even if indirectly, the eutrophication process which this environment is submitted.

KeyWords: Catchment Basin, Water Quality, Eutrophication, Bioindicators

Resumen

Las cuencas de captación son importantes unidades de estudio para el establecimiento de políticas de manejo y conservación de ecosistemas acuáticos. Los embalses son ambientes artificiales directamente influenciados por procesos físicos, químicos y biológicos a los que se someten estas cuencas hidrográficas. Estas influencias determinan las comunidades biológicas en los embalses. Muchos estudios han establecido la relación entre la comunidad del zooplancton como bioindicadora de la calidad del agua. En este contexto, el objetivo de este estudio fue evaluar los efectos de las variables físicas y químicas del agua y el uso y ocupación de la tierra en la comunidad de zooplancton del embalse de São Simão (MG/GO). Las muestras fueron recogidas en dos períodos (sequía y lluvia), en estaciones en los brazos del margen izquierdo (Estado de Minas Gerais) y margen derecho (Estado de Góias) y en el canal principal - región limnética del embalse de São Simão. La mayoría de los parámetros físicos y químicos no superaron los límites de calidad del agua y el Índice de Estado Trófico presentó valores entre 39 y 48, clasificando el embalse de São Simão como ultraoligotrófico u oligotrófico. La comunidad del zooplancton caracterizase por la dominancia de Rotifera y Copepoda con densidades más altas en las estaciones a los márgenes derechos del embalse. La razón Calanoida/Cyclopoida clasificó 18 de 22 estaciones de muestreo como oligotróficas en la estación de sequía, pero sólo 7 en la época de lluvias. El primer Análisis de Componentes Principales, considerando los parámetros físicos y químicos, no presentó correlación con los principales grupos de zooplancton. Sin embargo, en el segundo, considerando el uso y ocupación de la tierra, se pudo verificar los efectos de las actividades humanas alrededor del embalse en la comunidad de zooplancton (74,3% de la explicación), donde se observaron densidades más altas de microcrustáceos en estaciones con más embarcaderos, bancos de macrófitas y la vegetación original ahogada, además de extensas áreas de cultivos, ganadería u ocupación humana, predominando en el margen derecho del embalse de São Simão, en el Estado de Goiás. Aunquepueden ser espúrias, estas correlaciones no pueden ser ignoradas porque reflejan, aunque sea indirectamente, el proceso de eutrofización que este embalse se somete.

Palabras clave: Cuenca de captación, Calidad del agua, Eutrofización, Bioindicadores

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1. INTRODUCTION

The importance of considering the catchment basins as study units for establishment of management and conservation policies to aquatic ecosystems has been emphasized by several authors (Barbosa, 1994; Wishart, 2000; Tundisi, 2006). These environments are recipients of substances resulting from physical, chemical and biological processes, as the result of the interactions that occurs in the basin. On this assumption, considering the influence of human activities and the characteristics of geo-environmental unit, which determine the dynamics between input and output of matter and energy; the analysis of the catchment basin as integrative landscape unit may reveal the *status quo* of the river system, allowing to identify and assess the environmental impacts, managing preventive and mitigation actions (Sacramento & Rego, 2006).

Reservoirs consist in artificial ecosystems characterized by a complex interactive network between organisms (species, populations, communities), their physical and chemical environment and many human activities that occur both on its margins and its various watersheds. This network is dynamic and results from an constant process of response to climatic forcing functions and effects produced by the outflow management (Henry, 1999). Eutrophication is a increasing problem in Brazilian reservoirs since urbanization and industrialization (point sources) and the intense use of land in agropastoral activities (diffuse sources) have compromised the quality of waters. In the long term, it leads to the loss of biological diversity, reduced life of reservoirs and fish stocks (Straškraba Tundisi, 2000).

The physical and chemical characterization of water bodies allows not only to know the environment itself, as well as to characterize its trophic state, to understand the composition and spatial distribution of organisms, and contribute to decision making regarding the management of water resources (Esteves, 2011). Variables such as temperature, pH and dissolved oxygen, determine the physical and chemical structure of the environment (such as thermal stratification, ion balance and nutrient availability at the water-sediment interface) as well as influence metabolic, growth, reproduction and survival rates of organisms. The availability of organic matter, cations and anions (measured by electrical conductivity) and nutrients (especially nitrogen and phosphorus in their various forms) determine the levels of environmental productivity and consequently their trophic state. However, several researchers believe that only physical and chemical parameters are not sufficient to evaluate effectively the environmental quality, since they often represent ephemerous conditions of ecosystem (Karr et al., 1986, Metcalfe, 1989, Callisto et al. 2005). For this reason, the use of organisms, which spend all or part of their lives in aquatic environments, is recommended because they are submitted to the conditions and impacts that ecosystems are subjected.

The zooplankton community shows temporal and spatial heterogeneity due to environmental conditions and food availability (Kozlowsky-Suzuki & Bozelli, 2002; Bozelli & Huszar, 2003). Although zooplankton not depend directly of nutrients for their survival, the trophic state may influence richness, structure, body size and productivity of this community (Sladecek, 1958, McCauley & Kalff, 1981, Lathrop & Carpenter, 1992; Pinto-Coelho et al., 2005). Furthermore, in transitional zone of reservoirs (lotic-lentic transition), zooplankton can respond more strongly to physical factors than the variation of the phytoplankton (Mieczan et al., 2013). According to several authors (Gannon & Stemberger 1978; Ferdous & Muktadir 2009), if an aquatic environment does not exhibit clear oligotrophic or eutrophic conditions, zooplankton may be considered an indicator of its intermediate trophic characteristics. Therefore, patterns as observed by Matsumura-Tundisi et al. (2006), in the cascade system of the middle and lower Tietê River (state of São Paulo), wherein rotifers dominated over copepods in eutrophic reservoirs and the inverse occurred on those oligo-mesotrophic, have been used to improve knowledgement of this community.

Aiming to increasing fish production, the project Sustainable Planning of Aquaculture in São Simão Reservoir – Minas Gerais/Goiás, of which this study is a part, was proposed to select oligotrophic areas to install cage systems for tilapia farming. Abiotic and biotic variables were measured to estimate the support capacity of these areas, with the objective of minimizing water quality impacts. The knowledge generated regarding the zooplankton will guide the use of these organisms in the future as a food source for fish, as well as serving as possible bioindicators for monitoring water quality, thereby mitigating the impacts of fish production on aquatic communities.

In this context, the aim of this study was to evaluate the effects of physical and chemical variables of water, and use and occupation of land in zooplankton community of São Simão Reservoir (MG/GO). Therefore, three hypotheses have been proposed: (a) the zooplankton in São Simão Reservoir shows wide temporal and spatial variations; (b) the zooplankton in São Simão Reservoir is affected by physical and chemical conditions of water, particularly by variables related to eutrophication (water transparency, concentrations of chlorophyll-*a*, phosphorus and nitrogen); (c) the zooplankton in the São Simão Reservoir presents quantitative relationships with different patterns of land uses around the reservoir.

2. METHODOLOGY

2.1 Study Area

São Simão Reservoir (Table 1) (19°01’05”S, 50°29’57”W) is located at Paranaíba River, its catchment basin covers 71 municipalities in

Goiás State (81,659 km²) – South region, and 14 municipalities in Minas Gerais State (31,408 km²) - Mesoregions of Triângulo Mineiro and Alto Paranaíba (Pinto-Coelho & Castellanos-Solá, 2003). It was completed in 1978, being the penultimate of the cascade system. Its largest tributaries are Meia Ponte River - which drains the region of Goiânia City, Prata and Tijuco Rivers - which drain adjacent areas of main citites of Triângulo Mineiro, as Uberaba, Uberlândia and Ituiutaba (Fonseca, 2010). According to Köppen, the weather in region is predominantly Awi: which A indicates the group Tropical; w indicates rainy summer, predominant in tropical savannah regions with dry winter; and i indicates isothermal, with no well defined seasonal variations of temperature throughout the year. Lower altitudes are found through main channel of Paranaíba River and its tributaries (240 m). Higher steepness are concentrated in the Eastern portion of the basin, where dominate the modeled dissection of tabular type with very poor deepening density of drainage (CPRM, 2016). Lower steepness lands are along the stretches of Verde, Turvo and Bois Rivers.

Soils of the catchment basin are basically formed by dark Rhodic Ferralsols in undulated relief, and other soils of flat relief class, for example the red-yellow Podzolic, purple Ferralsols and Cambisols, overall being very weathered and deep (Collischonn et al., 2006). Because of the natural low fertility, these soils were considered problematic for agriculture, however, with the technologic and agricultural advances this scenario was reversed. Currently, these soils areas are highly demanded, especially in the Cerrado's region where the predominant texture is relatively uniform in entire profile, ranging from medium to very clayey (Lepsch, 2010).

According to IBGE (2014) main economic activities in municipalities around the reservoir are predominantly cattle ranching and agriculture: 24.8% of cattle and 18.1% of agriculture in Minas Gerais State are in Mesoregions of Triângulo Mineiro and Alto Paranaiba (semi-permanent and annual crops, especially the sugarcane and soybean). And 35.9% of all cattle and 24.2% of agriculture of Goiás State (in semi-permanent and annual crops as soy, corn and sugarcane) are concentred in South region.

Sampling stations were located at arms in left margin (M1 to M7) and right margin (G1 to G7); and main channel - limnetic zone (L1 to L8) of São Simão Reservoir (Figure 1).

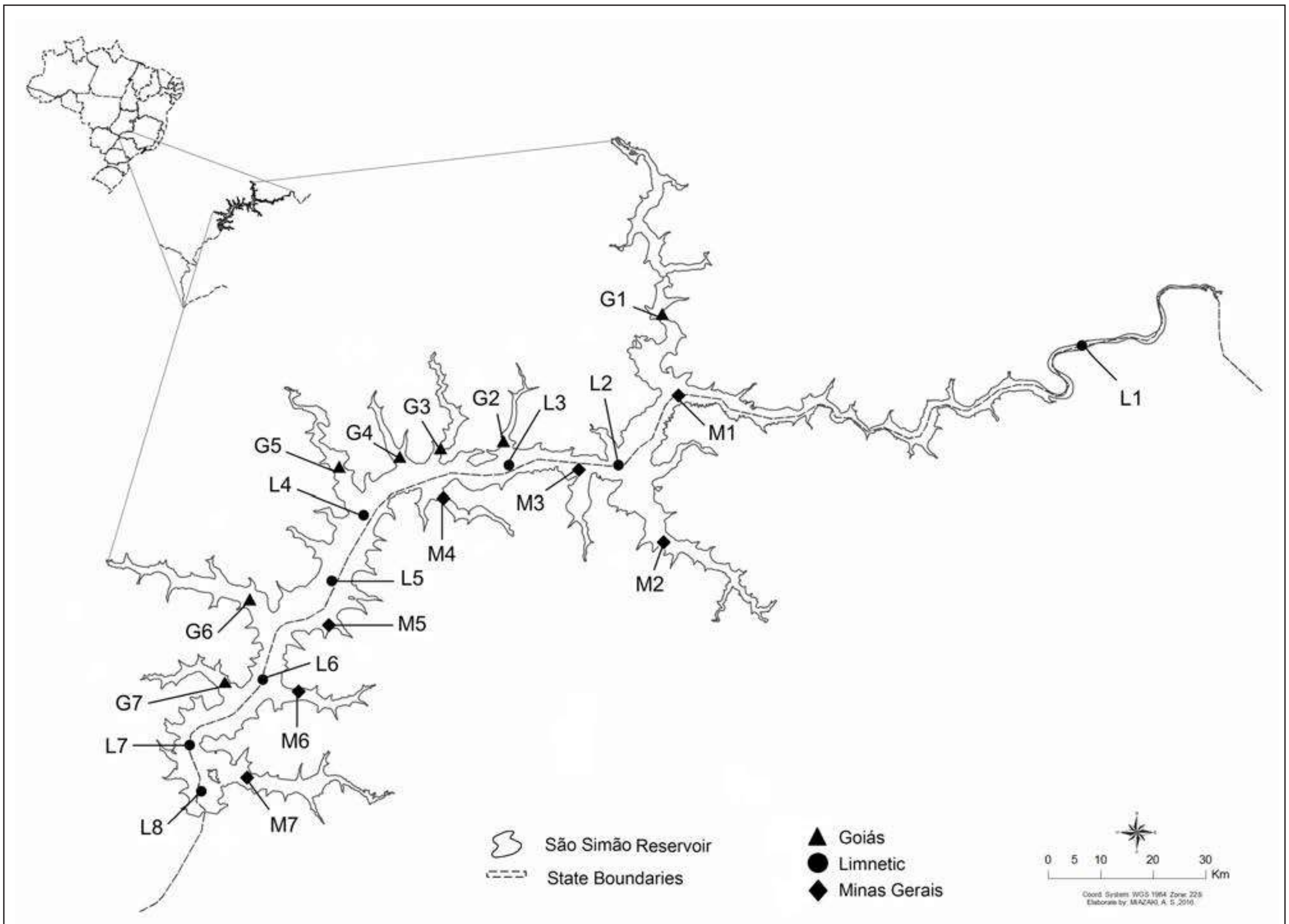

Figure 1. Sampling stations at São Simão Reservoir (MG/GO). M1 to M7 = stations at left margin, G1 to G7 = stations at right margin, L1 to L8 = stations at main channel/limnetic zone

2.2 Data Collection

Considering that São Simão Reservoir is located in a tropical area with well defined seasons, samples were collected in August 2011 and May 2012 (end of dry and rainy seasons, respectively). These periods were considered most representative of variations in temperature and precipitation for this region. On left and right margins, all samples were taken in limnetic zone of each arm, aiming to deep areas, as well as in main channel of reservoir.

In all stations were measured temperature, dissolved oxygen, pH, electrical conductivity and turbidity with Hidrolab DS5 multiprobe. Water transparency was measured with a Secchi disc. Water samples were collected in order to determine: chlorophyll-*a* (Lorenzen, 1967), nitrate, ammonium and total nitrogen (Koroleff, 1976; CONCO Labs., 2012 – modified Kjeldahl method), total phosphorus (Mackereth *et al.*, 1978), inorganic and organic dissolved solids (APHA, 1998). To evaluate water quality, Carlson's modified Trophic State Index (TSI), was calculated according to Lamparelli (2004).

For zooplankton samples, vertical hauls of 10 meters were made with a plankton net (68 µm mesh size), because of the presence of drowned original vegetation ("paliteiros") at the sampling sites, especially in the arms. Organisms were preserved with 4% buffered formalin. Subsamples of 1.0 mL were counted in a Sedgewick–Rafter chamber at optical microscope. The data are presented as organisms per cubic meter. The Calanoida/Cyclopoida ratio (Tundisi et al., 1988) was estimated in order to relate the zooplankton structure and trophic state of reservoirs, which values above 1 indicate oligotrophic environments and below 1, meso-eutrophic ones.

To characterize the use and occupation of land it was determined a 2 km buffer, considering as reference the limit of surface water of reservoir (according to Pinto-Coelho et al., 2013). Within this buffer area were recorded and georeferenced all activities through direct observation of sampling staff: water supply, ferry crossings, areas of agriculture, cattle ranching, riparian vegetation, soil exposed (erosion), human occupation (urban areas or condominiums), recreation and touristic resorts. In addition, during the samplings in the reservoir, they also recorded all the characteristics of the sampling stations: the presence of macrophyte beds, "paliteiros", fish farming cages, fishery structures (e.g. piers). The characterization of the surroundings of the reservoir was also complemented by a search in databases, satellite images and public records (Landsat, Embrapa, Soma-Brazil, IBGE, CPRM, DNPM, Google Earth) for data such as steepness, irrigation pivots, concession areas of mines, conservation units.

2.3 Data Analysis

Differences in physical, chemical and zooplankton data between stations (Minas Gerais, Goiás and Limnetic) and periods (dry and rainy seasons) were tested with two-way analysis of variance – ANOVA. The first column of ANOVA determines the spatial variation and the labels were: 1 – Minas Gerais stations; 2 – Goiás statios and 3 – Limnetic stations. The second column determines temporal variation and the labels were: 1 – dry season and 2 – rainy season. The ANOVA was followed by a Tukey's *post hoc* comparison test, to determine diferences between spatial and temporal variations. To evaluate the influence of water quality in zooplankton community, Principal Components Analysis (PCA) were performed with limnological variables and use and occupation of land. After preliminary analysis by correlation matrix, variables with low range variation or informative redundancy in the data were not employed in the PCA. All analyses were performed using Statistica software version 13.0 (StatSoft, 2016).

Table 1. Morphometric and hydrographic characteristics of São Simão Reservoir (MG/GO)

Characteristics	Values
Flooded area	722.2 km²
Drainage area	113,067 km²
Maximum depth	127 m
Volume	5.54×10^9 m³
Maximum outflow	24,000 $m^3.s^{-1}$
Altitude	404 m
Installed capacity	1,710 MW

Source: CEMIG, 2016; Pinto-Coelho & Castellanos-Solá, 2003.

3. RESULTS

3.1 Limnological Variables

Mean values and standard deviation of physical and chemichal variables are provided in Table 2. Only seasonal variation was observed for dissolved oxygen ($F = 649.3$, $p < 0.0001$), organic dissolved solids ($F = 74.6$, $p < 0.0001$) and total phosphorus ($F = 13.3$, $p = 0.001$) with higher values in dry season. In rainy season, variables with higher values were: water temperature ($F = 189.8$, $p < 0.0001$), electrical conductivity ($F = 164.8$, $p < 0.0001$), turbidity ($F = 20.9$ $p = 0.0002$), inorganic dissolved solids ($F = 70.3$; $p < 0.0001$), ammonium ($F = 178.8$, $p < 0.0001$) and chlorophyll-*a* ($F = 26.6$, $p < 0.0001$).

Spatial and temporal variation was observed for water transparency ($F = 26.4$, $p < 0.0001$) and nitrate ($F = 11.9$, $p = 0.002$) with higher values in the dry season and Limnetic zone. Total nitrogen showed higher values during the rainy season and stations located at right margins - Goiás State ($F = 15.3$, $p = 0.0001$). Values of pH were slightly alkaline, ranging between 7.24 and 7.85 with no significant differences between seasons or stations ($F = 2.02$, $p = 0.16$). Mean TSI (based in Secchi disk depths and concentrations of chlorophyll-*a* and total phosphorus) calculated for all sampling stations, showed values between 39 and 48, classifying São Simão Reservoir between ultraoligotrophic and oligotrophic.

Table 2. Mean values ± standard deviation of physical and chemichal variables measured to São Simão Reservoir (MG/GO). MG – stations at left margin (M1 to M7), GO – stations at right margin (G1 to G7), LI – stations at main channel/limnetic zone (L1 to L8)

Season	Dry – August/2011			Rainy – May/2012		
Variables	**MG**	**GO**	**LI**	**MG**	**GO**	**LI**
Secchi disc (m)	4.10 ± 1.10	3.80 ± 1.24	5.74 ± 1.01	3.26 ± 0.55	3.05 ± 0.49	3.38 ± 0.44
Temperature (°C)	24.63 ± 0.29	24.80 ± 0.30	24.84 ± 1.17	26.82 ± 0.44	26.77 ± 0.20	26.70 ± 0.35
Dissolved Oxygen (mg.L^{-1})	7.78 ± 0.16	7.82 ± 0.25	7.84 ± 0.34	6.21 ± 0.21	6.33 ± 0.21	6.24 ± 0.23
Electrical Conductivity (µS.cm^{-1})	43.84 ± 3.34	42.26 ± 2.15	42.66 ± 3.24	50.84 ± 2.76	52.47 ± 3.82	50.20 ± 2.24
Turbidez (NTU)	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	1.40 ± 1.23	1.51 ± 1.87	1.50 ± 1.40
Inorganic Dissolved Solids (mg.L^{-1})	0.21 ± 0.15	0.20 ± 0.18	0.30 ± 0.46	1.06 ± 0.32	1.23 ± 0.34	1.05 ± 0.20
Organic Dissolved Solids (mg.L^{-1})	0.51 ± 0.16	0.59 ± 0.15	0.64 ± 0.18	*	0.06 ± 0.17	0.13 ± 0.27
Nitrate (µg.L^{-1})	48.34 ± 53.49	6.84 ± 12.00	100.18 ± 43.58	13.89 ± 1.80	13.45 ± 1.43	13.73 ± 2.81
Ammonium (µg.L^{-1})	*	*	*	26.31 ± 10.30	34.04 ± 2.02	19.88 ± 7.01
Total Nitrogen (µg.L^{-1})	408.00 ± 127.1	728.00 ± 199.3	360.50 ± 60.7	592.67 ± 145.2	684.73 ± 97.6	630.06 ± 205.1
Total Phosphorus (µg.L^{-1})	106.43 ± 135.14	57.86 ± 9.01	93.38 ± 45.19	25.14 ± 18.24	19.43 ± 5.83	28.63 ± 8.96
Chlorophyll-a (µg.L^{-1})	0.08 ± 0.10	0.04 ± 0.05	0.06 ± 0.09	0.20 ± 0.10	0.24 ± 0.13	0.17 ± 0.12

* under detection limits of method

3.2 Zooplankton Community

Table 3. Species list identified in São Simão reservoir (MG/GO) during sampling periods of August 2011 and May 2012

Cyclopoida	Rotifera
Thermocyclops minutus	*Ascomorpha ecaudis*
Thermocyclops decipiens	*Collotheca* cf *pelagica*
Calanoida	*Collotheca* sp.
Notodiaptomus henseni	*Conochilus coenobasis*
Scolodiaptomus corderoi	*Conochilus hippocrepis*
Cladocera	*Conochilus unicornis*
Daphnia gessneri	*Euchlanis* sp.
Ceriodaphnia cornuta	*Filinia longiseta*
Ceriodaphnia silvestri	*Hexarthra intermedia*
Moina minuta	*Hexarthra mira*
Bosmina hagmanni	*Keratella americana*
Bosminopsis deitersi	*Keratella cochlearis*
Diaphanosoma birgei	*Lecane curvicornis*
Diaphanosoma spinulosum	*Macrochaetus sericus*
Ostracoda	*Sinantherina* sp.
Diptera - *Chaoborus* sp.	*Sinantherina* cf *verrucosa*
Hydracarina	*Synchaeta* cf *stylata*
Turbellaria - *Mesostoma* sp.	Bdelloidea

For zooplankton community, 32 species were identified belong to Copepoda (4 species), Cladocera (8) and Rotifera (18) as showed in Table 3. Other groups were also identified as Ostracoda, and zooplankton predators as: *Chaoborus* sp. (Diptera), *Mesostoma* sp. (Turbellaria, Rhabdocoela) and Hydracarina (Acari).

Spatial and temporal variation of main zooplankton groups to the right and left margins are provided in Figures 2 (dry season) and 3 (rainy season). For limnetic zone, the variation is provided in Figure 4 for both seasons. Rotifera was the most abundant group mainly during dry season (Figure 2) at margins of Goiás (mean density: 21,322 org.m^{-3}) and Minas Gerais States (mean density: 20,710 org.m^{-3}). This group was mainly represented by *Conochilus hippocrepis*, *Sinantherina* cf *verrucosa* and *Sinantherina* sp.; being the latter two have presented in colonial forms, with large numbers of individuals. Another abundant group was Copepoda, especially in rainy season (Figure 3) at margins of Goiás State (mean density: 20,750 org.m^{-3}). The most abundant species of Copepda were *Thermocyclops minutus* and *Notodiaptomus henseni*. This seasonal pattern was similar in the limnetic zone, however the predominance of Copepoda in the rainy season was most evident. For Cladocera, in dry season, the predominants species were *Daphnia gesnerii* and *Diaphanosoma spinulosum*. In rainy season, in addition of these two species, *Diaphanosoma birgei* was also abundant. Although ANOVA indicated significant difference between the zooplankton groups ($F = 23.1$, $p < 0.0001$), Tukey's test showed that this difference was related to Rotifera and Copepoda compared to Cladocera.

No significant difference was observed between dry (mean density: 46,717 org.m^{-3}) and rainy seasons (mean density: 35,639 org.m^{-3}) however the same analysis showed significant difference between the stations collected at the margins of reservoir (Goiás – mean density: 53,588 org.m^{-3}; Minas Gerais – mean density: 45,595 org.m^{-3}) compared to those collected in the limnetic zone (mean density: 26,455 org.m^{-3}) ($F = 4.29$; $p = 0.0221$). Calanoida/Cyclopoida ratio classified 18 of 22 sampling stations as oligotrophic in the dry season, however only 7 in the rainy season (Figures 2, 3 and 4).

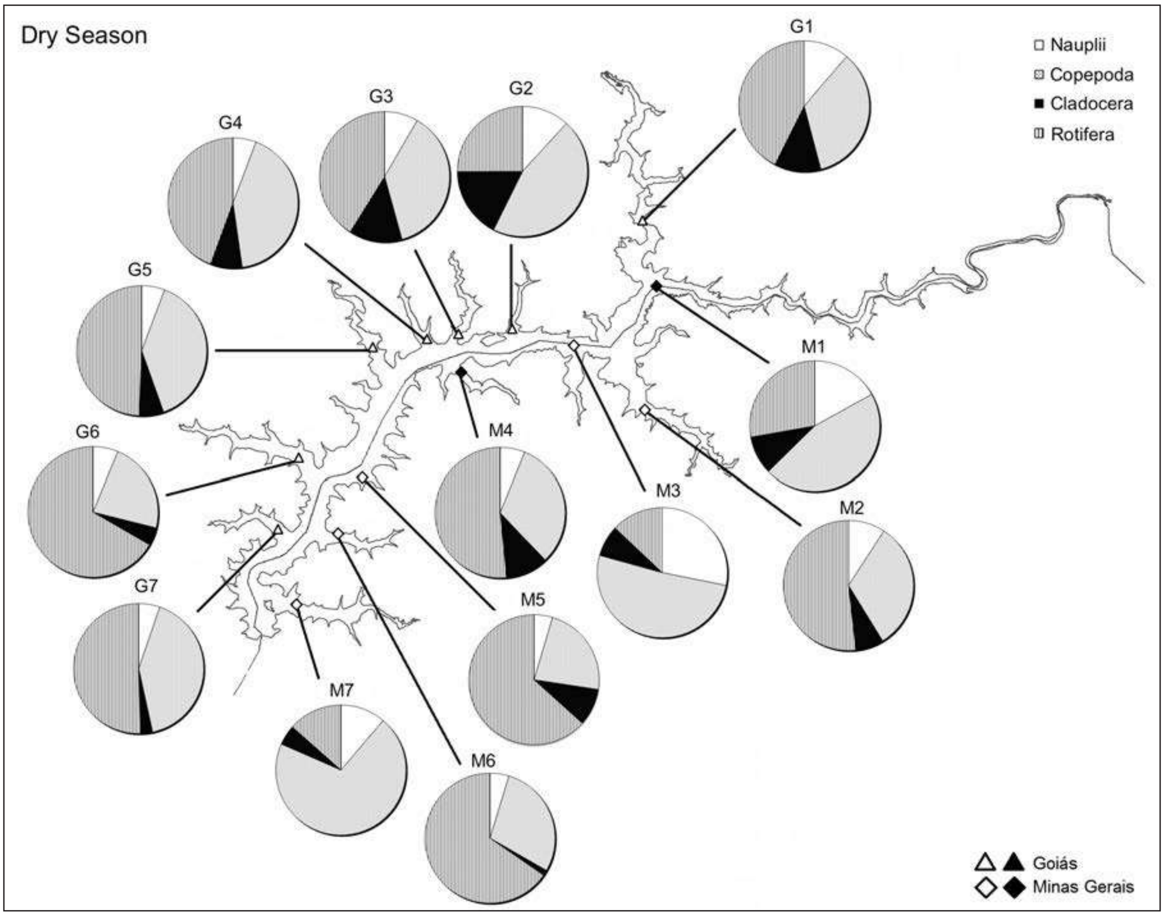

Figure 2. Relative abundance (%) of nauplii and main zooplankton groups in left (M1 to M7) and right (G1 to G7) margins of São Simão Reservoir in dry period (August 2011). Open icons represent oligotrophic state of stations and closed icons represent meso-eutrophic state according to Calanoida/Cyclopoida ratio

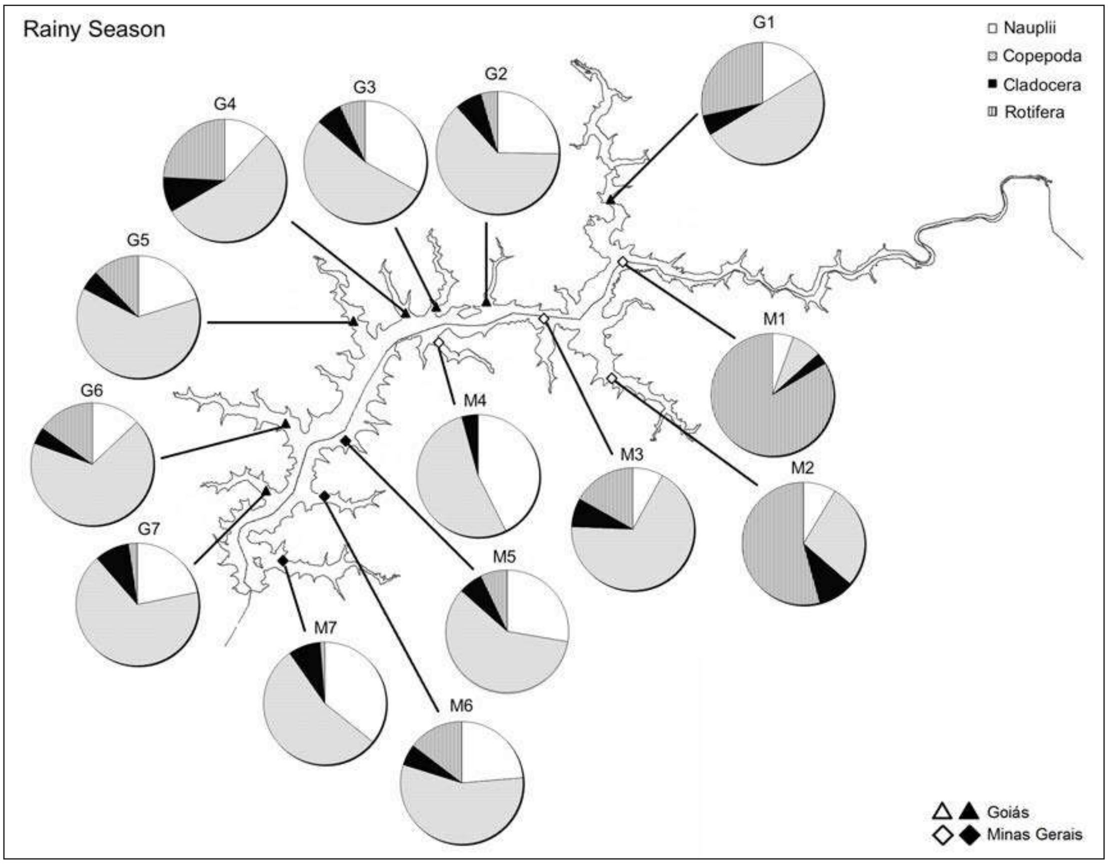

Figure 3. Relative abundance (%) of nauplii and main zooplankton groups in left (M1 to M7) and right (G1 to G7) margins of São Simão Reservoir in rainy period (May 2012). Open icons represent oligotrophic state of stations and closed icons represent meso-eutrophic state according to Calanoida/Cyclopoida ratio

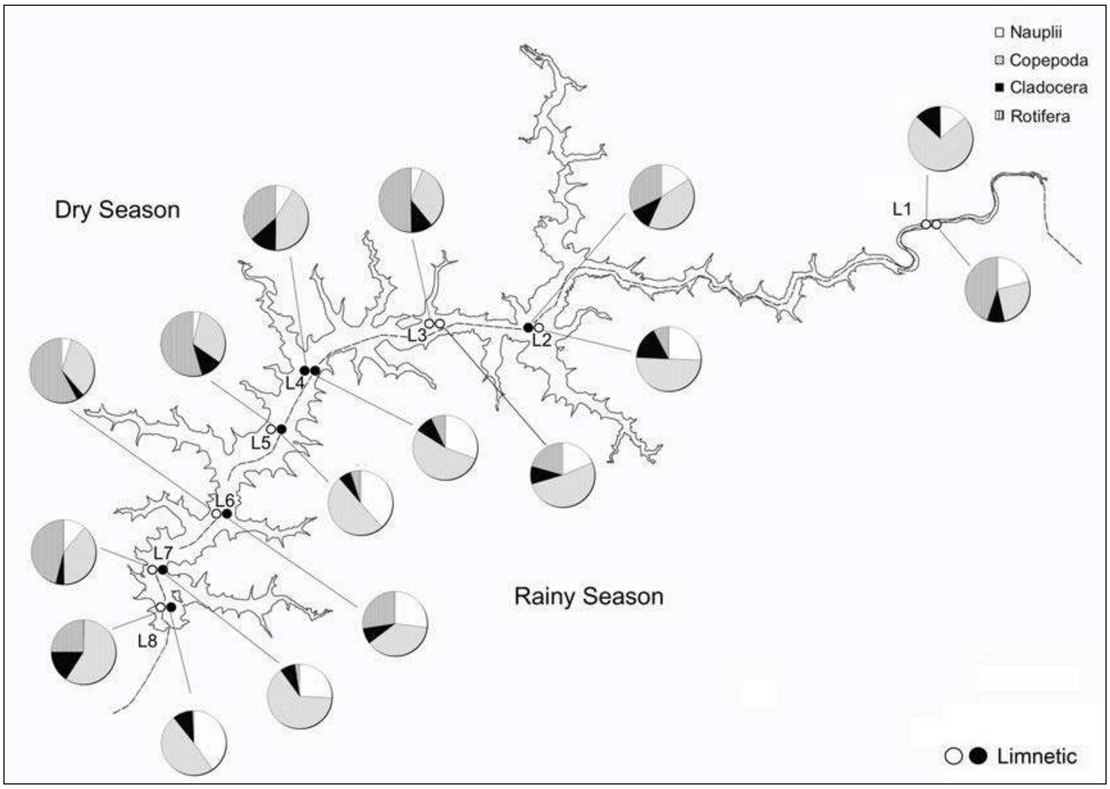

Figura 4. Relative abundance (%) of nauplii and main zooplankton groups in limnetic zone (L1 to L8) of São Simão Reservoir in dry (above) and rainy (below) periods. Icons on left represent trophic state in dry season, icons on right represent rainy season. Open icons represent oligotrophic state of stations and closed icons represent meso-eutrophic state according to Calanoida/Cyclopoida ratio

3.3 Influence of Limnological Variables and Use and Occupation of Land

Data of caractherization of use and occupation of land in São Simão Reservoir are showed in Table 4. Analysing the table it is possible to realize that all stations in Goiás State presents higher numbers of fishery structures, "paliteiros" (drowned original vegetation), areas of agriculture, cattle ranching and human occupation (urban areas or condominiums). As exception, only stations M2 and M7 in Minas Gerais State showed higher numbers of these activities and structures.

Table 4. Use and occupation of land in São Simão Reservoir (MG/GO) determined in a 2 km buffer, considering as reference the limit of surface water (according to Pinto-Coelho et al., 2013)

Stations	Fish Farm Cages	Fishery Structures	Erosion	Macrophyte Beds	Riparian Vegetation	"Paliteiros"	Cattle Ranching	Agriculture	Human Occupation	Irrigation Pivots
G1	1	9	2	9	8	11	11	23	16	3
G2	0	2	1	0	0	3	4	4	3	0
G3	0	2	0	0	0	3	4	3	3	2
G4	0	1	0	0	0	2	2	1	1	0
G5	1	10	1	1	0	4	6	5	10	0
G6	0	0	0	0	3	9	11	7	8	1
G7	1	0	0	0	1	0	2	6	0	0
L1	0	5	3	0	0	0	1	6	4	9
L2	0	0	3	0	0	2	2	2	1	2
L3	0	3	2	0	0	2	4	1	5	0
L4	0	0	0	0	0	0	3	1	1	0
L5	0	0	1	0	0	0	0	0	2	0
L6	0	0	4	0	0	0	0	1	1	0
L7	0	0	3	0	0	0	2	0	0	0
L8	0	0	0	0	5	0	0	0	0	0
M1	0	0	2	1	1	0	1	3	0	0
M2	0	6	3	1	0	1	11	6	12	0
M3	0	2	1	0	0	0	4	0	3	0
M4	0	0	0	0	0	1	0	1	1	0
M5	0	1	1	0	0	1	4	1	1	0
M6	0	0	0	0	1	1	3	0	3	0
M7	0	5	1	1	0	9	10	2	9	2

PCA considering the physical and chemical parameters (Figure 5, Table 5), despite a considerable percentage of explanation of data (63.5% combined the first two factors) showed no correlation with main zooplankton groups (Copepoda, Cladocera and Rotifera). In Figure 5, it is possible see two distinct groups in factor 1: the first is observed in samples of dry season with more transparent waters (Secchi disk), higher concentrations of dissolved oxygen and organic dissolved solids. In the second group are samples of rainy season with higher values of water temperature, electrical conductivity and concentrations of ammonium. A third group is formed by the rotifers and microcrustaceans that significantly correlated with the factor 2, however with no limnological variable.For this reason, a second PCA was performed considering the use and occupation of land and zooplankton (Figure 6, Table 6). In this second analysis (74.3% of explanation) it was possible to verify the effects of human activities around the reservoir on this community. Higher densities of microcrustaceans (Cladocera and Copepoda) were observed in stations with more fishery structures, macrophyte beds and "paliteiros", in addition to extensive areas of agriculture, cattle ranching or human occupation, predominant on the right margin of São Simão Reservoir, in Goiás State.

Table 5. Factor loadings of Principal Component Analysis for physical and chemical parameters and zooplankton main groups of São Simão Reservoir (MG/GO). Values in bold represent significant correltions with factors ($p < 0.05$)

	Factor 1	Factor 2
Copepoda	-0.049	**-0.888**
Cladocera	0.137	**-0.899**
Rotifera	0.316	**-0.788**
Organic dissolved solids	**0.804**	-0.242
Chlorophyll-*a*	-0.681	-0.126
Total phosphorous	0.622	-0.159
Ammonium	**-0.917**	-0.012
Nitrate	0.560	0.464
Total nitrogen	-0.496	-0.220
Secchi	**0.706**	0.169
Turbidity	-0.599	-0.206
Temperature	**-0.884**	0.047
Electrical conductivity	**-0.843**	-0.116
Dissolved Oxygen	**0.914**	-0.156

Table 6. Factor loadings of Principal Component Analysis for use and occupation of land and zooplankton main groups of São Simão Reservoir (MG/GO). Values in bold represent significant correltions with factors ($p < 0.05$)

	Factor 1	Factor 2
Copepoda	**-0.8370**	0.2980
Cladocera	**-0.7264**	0.3960
Rotifera	-0.5044	0.6005
Fishery structures	**-0.7287**	-0.4252
Macrophyte beds	**-0.9000**	0.1531
Riparian vegetation	-0.6862	0.2877
"Paliteiros"	**-0.8113**	-0.2781
Cattle ranching	**-0.7722**	-0.4363
Agriculture	**-0.8920**	0.0152
Human occupation	**-0.8974**	-0.3525

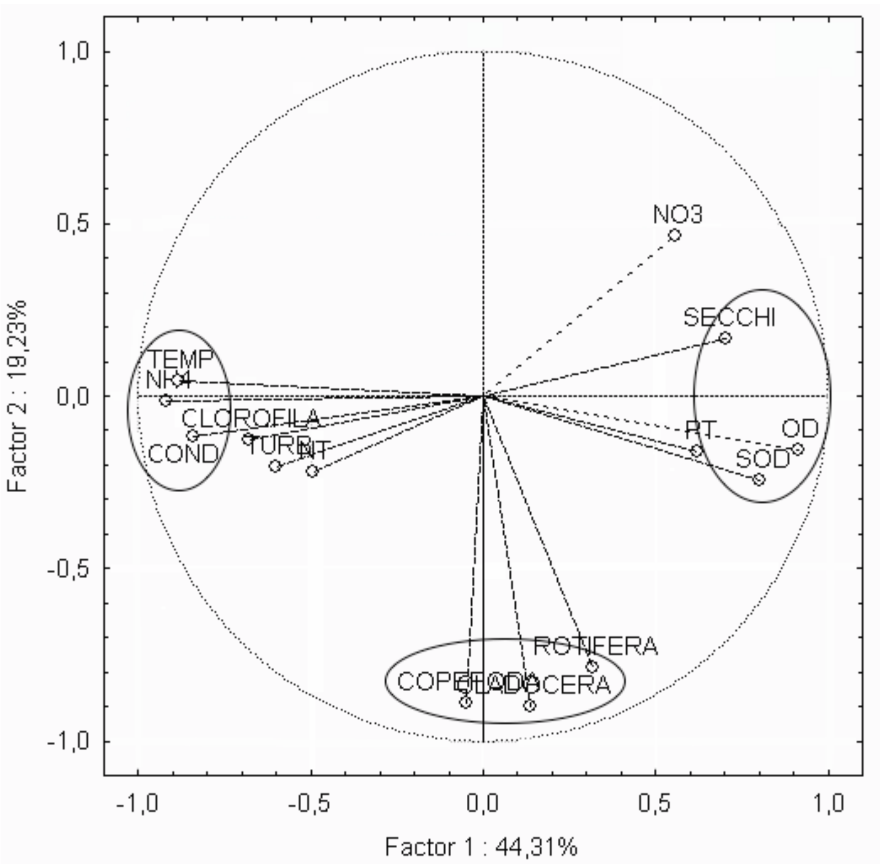

Figure 5. Principal Component Analysis for physical and chemical parameters and zooplankton main groups of São Simão Reservoir (MG/GO). COND = electrical conductivity; OD = dissolved oxygen; SOD = organic dissolved solids, SECCHI = water transparency; TEMP = temperature; TURB = turbidity; NT = total nitrogen; NO3 = nitrate; NH4 = ammonium and PT = total phophourus

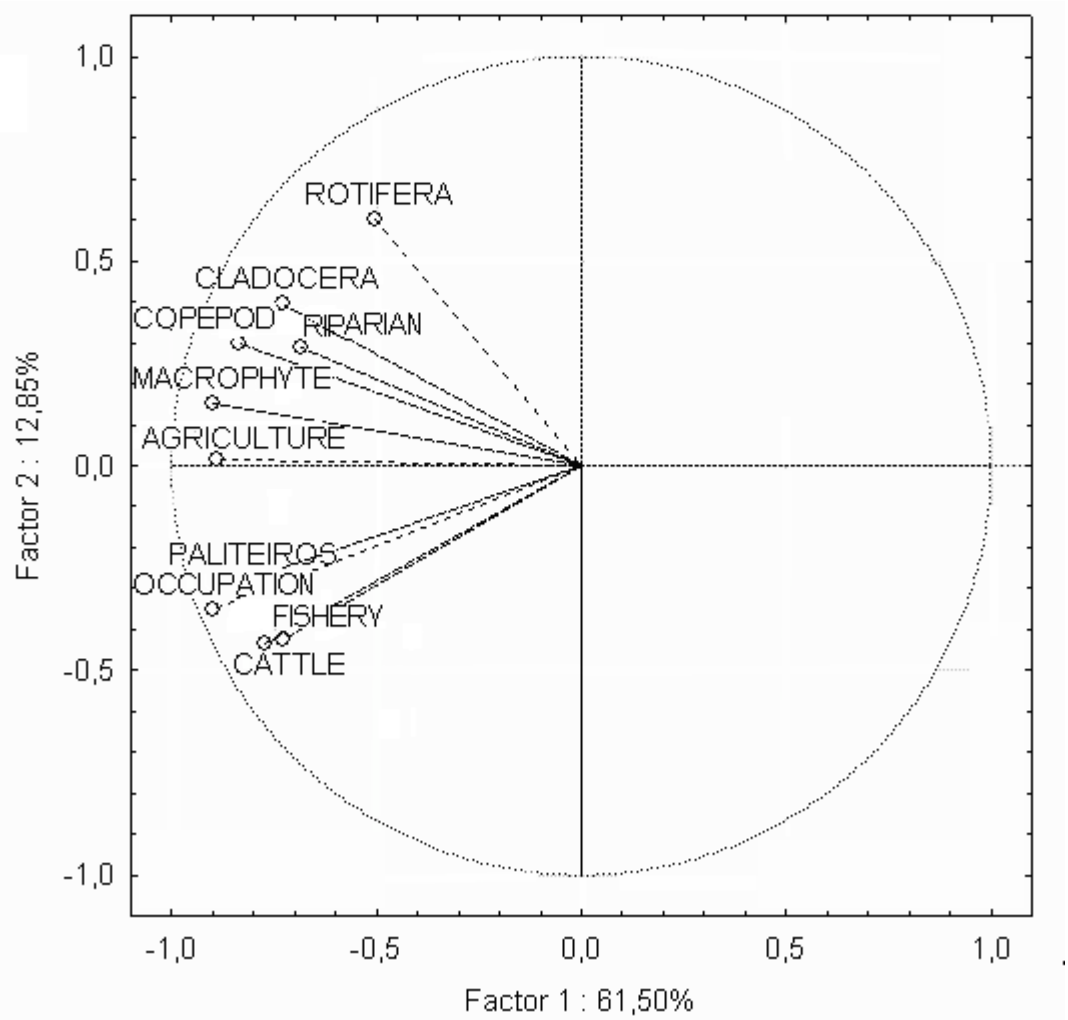

Figure 6. Principal Component Analysis for use and occupation of land and zooplankton main groups of São Simão Reservoir (MG/GO)

4. DISCUSSION

4.1 Limnological Variables

In an earlier study, performed a decade before (samplings between 2002 and 2004), it was observed the same seasonal pattern in limnological variables (Pinto-Coelho et al., 2006). In rainy season, there was a decrease in water transparency and increase of turbidity values and concentrations of chlorophyll-*a* and dissolved solids. In absolute values, current means of electrical conductivity and dissolved oxygen do not differ from those observed in the previous study. Current values of turbidity and concentrations of dissolved solids, ammonium and chlorophyll-*a* are smaller. Conversely, Secchi disk depths and total phosphorus concentrations increased recently, although when calculating mean TSI, higher water transparency and lower chlorophyll-*a* concentrations compensate the increase of this nutrient, and São Simão Reservoir is still considered oligotrophic according to calculation of this index. However, calculated separately, total phosphorus concentrations classify the stations sampled between mesotrophic and hypereutrophic, especially in the dry season, when they exceed the water quality limits of 50μg.L^{-1} (Class II - CONAMA, 2005).

Concentrations of nitrate and total nitrogen, as in previous study, showed irregular distribution between the sampled stations. Since nitrate is the predominant form of nitrogen, evidences long-term polluting sources, through runoff from diffuse sources of adjacent crops to São Simão Reservoir, as the main contribution to the input of this nutrient in the environment (CETESB, 2014). In fact, to characterize the use and occupation of land in surroundings of São Simão Reservoir, Pinto-Coelho et al., (2013) indicate a large number of fishery structures, macrophyte beds, "paliteiros" and areas with cattle ranching, agriculture and human occupation in the stations collected at margins in Goiás State, where the total nitrogen concentrations were higher in the two sampling periods.

Seasonality effects was similar to that observed by Brito *et al.* (2011) in Três Marias Reservoir (São Francisco River, MG) and Furnas Reservoir (Rio

Grande, MG), with higher water transparency and dissolved oxygen concentrations in the dry periods, while temperature and chlorophyll-*a*, total and organic suspended solids concentrations in the rainy periods. Zanata & Espíndola (2002) also observed higher total phosphorus concentration and water turbidity values in rainy periods in Salto Grande Reservoir (Paranapanema River – SP/PR). Electrical conductivity and solids showed the same variation range to the values observed in others reservoirs of cascade system in Paraná River basin, specially in Tietê River (Sendacz *et al.*, 2006) and Paranapanema River (Feitosa, *et al.*, 2006).

The increase in concentrations of inorganic solids during rainy season reflect the erosion caused by aggressive practices of extensive agriculture in the surroundings of São Simão Reservoir. Soils in this region are characterized by medium and clayey textures (Embrapa Solos, 2006) whose sandstones are mainly responsible for the input of inorganic material through silting in aquatic ecosystems. Clays, due to its high capacity of cation exchange, may transport nutrients, ions and pesticides adsorbed by them (Merten e Minella, 2002). Supression of riparian vegetation of São Simão Reservoir is also an worsening factor, since its presence can retain up to 80% of nitrogen and phosphorus from runoff of adjacent areas (Davide et al., 2000).

Studies in cascade reservoirs (Tundisi et al., 1988; Matsumura-Tundisi et al., 2006) show an improvement of water quality in reservoirs downstream, with sedimentation of solids and nutrients in reservoirs upstream. However, Espíndola et al. (2002) observed increasing toxicity to *Ceriodaphnia dubia* the last reservoirs of the cascade. According to the authors, the activities in the surrounding area of reservoirs and wastewater dumped from surrounding cities can significantly affect the quality of water, even in reservoirs downstream. Despite being the penultimate of a nine reservoirs cascade, São Simão is located between two of the most productive regions of Brazil: Triângulo Mineiro and South of Goiás, heavily exploited by cattle ranching and extensive agriculture. In fact, reservoirs upstream as Nova Ponte, Emborcação, Miranda, Capim Branco I and II are classified by WQI as “good” ($70 \leq IQA \leq 90$) while those downstream as Itumbiara, Cachoeira Dourada and São Simão, during the collections of this project, rated as “medium” ($50 \leq IQA \leq 70$) (IGAM, 2011 and 2012).

4.2 Zooplankton Community

The hypothesys of spatial and temporal variation of zooplankton community was confirmed to São Simão Reservoir. The dominance of Rotifera in reservoirs is usually attributed to the instability of these environments as well as its opportunistic and r-strategist life cycles (Matsumura-Tundisi, 1999) associated to generalist food habits (Pourriot, 1977). However, different from several authors (Arcifa, 1984; Rocha et al., 1995; Nogueira, 2001; Almeida et al., 2009), in São Simão Reservor, Rotifera was dominant only in the dry season. According to Velho et al. (2005) its dominance in reservoirs should not be considered a general rule, due to the wide variety of reservoirs in Brazil, with different sizes, ages and trophic states.

With respect to Copepoda, to several authors (Gannon & Stemberger, 1978; Pace, 1986; Tundisi et al., 1988, and Rocha et al., 1995) calanoids are associated with more oligotrophic ecosystems (especially low conductivity and neutral pH), while cyclopoids and small cladocerans are associated with more eutrophic lakes and reservoirs. However, species of the genus *Notodiaptomus* (Calanoida) are often associated to eutrophic environments (Rietzler et al., 2002; Sampaio et al., 2002; Matsumura-Tundisi & Tundisi, 2003). Among the Cyclopoida, *T. minutus* is considered typical of oligotrophic-mesotrophic environments while its congener *T. decipiens* dominates in more eutrophic environments (Reid, 1989; Landa et al., 2007).

Despite concentrations of organic dissolved solids, nitrate and total phosphorus decreased during the rainy season, probably due to dilution effect; the ratio Calanoida/Cyclopoida indicate a significant loss of water quality in this period with 15 of the 22 sampling stations classified as meso-eutrophic. Furthermore, most of the sampling stations are not locate the main channel, yet in the arms of reservoir, the predominance of Copepoda in rainy season can also be explained by reduced interference of outflow on these species, which need more constant habitats to complete their longer life cycle and are less opportunistic than the Rotifera (Velho *et al.*, 2001; Takahashi *et al.*, 2009).

Although Cyanobacteria are dominant in São Simão Reservoir (Fonseca, 2010; Oliveira, 2010), Chlorophyceae is the second most abundant group, allowing the herbivorous zooplankton, represented by large filter-feeders as Calanoida and Caldocera (daphniids and sidids) still occur in this environment. A similar situation was observed by Brito et al. (2011) in Furnas reservoir (Grande River, MG), where the phytoplankton of better nutritional quality and typical from oligotrophic environments favors larger-bodied microcrustaceans.

4.3 Influence of Limnological Variables and Use and Occupation of Land

PCA revealed the effect of surroundings activities on microcrustaceans (Cladocera and Copepoda) of São Simão Reservoir. Activities such as fish farming cages substantially affect organisms, as observed by Dias et al. (2011) in Rosana Reservoir (PR), where rotifers were significantly favored by installation of the structures, while cladocerans and copepods were negatively influenced. There was also a reduction of richness at the beginning, with a tendency to increase at the end of study period. The input of nutrients caused by agricultural activities in surroundings favors the growth of bacterias and protozoans, an essential food source for filter-feeders as nauplii, rotifers and small cladocerans (Coelho-Botelho, 2003).

Figure 6 also indicates a relatively weak correlation (coefficient below 0.70), between Rotifera and use and occupation of land. Probably, for this group, another factor not measured should be more important in determining its abundance. Climatic and hydrologic factors may be an answer to these relationships. Rodríguez-Tundisi & Matsumura (2000) studied changes in dominant Rotifera species associated with an increase in wind speed in Broa Reservoir (SP). According to the authors, due to turbulence, there was higher availability of food through the resuspension of bottom material, which led to the change in behavior and metabolism of organisms.

Even PCA have shown no relationship between zooplankton community and limnological variables in the São Simão Reservoir, changes in water quality due to human activities in the catchment basin can drastically affect the environment. Thus, the second hypothesis was rejected in part because it is widely known that the physical and chemical variables influence this community, even though the data of this work indicate the opposite. Even in catchment areas with good agricultural potential (flat/ondulated relief and well drained by streams), excessive soil disturbance and insufficient reposition of organic matter favor its physical deterioration, which also cause increased runoff and contamination of surface water with sediment, nutrients, animal waste and pesticides that are adsorbed by clays (Merten and Minella, 2002).

Studies by Vital et al. (1999) in a watershed at São Paulo State, regarding the effect of stump cutting of *Eucalyptus* on runoff, showed significant increases in input sediments as well as values of conductivity, color and turbidity of water. Comparing two headwaters preserved and two under the influence of sugar cane crop, Donadio et al. (2005) found significant differences in temperature, color, turbidity, alkalinity and total nitrogen, being higher values in those with vegetation exploited by agriculture.

Besides agricultural activities, the largest number of fish farmig cages, fishery structures, macrophyte beds and "paliteiros" observed at margin of Goiás, offer a diversified structure for colonization by planktonic organisms, with more favorable conditions as a refuge against predators, higher food availability (periphyton, bacterioplankton, detrits) and lower water flow (Basu et al., 2000).

The results obtained by PCA allowed to accept the third hypothesis in which the zooplankton is influenced by land uses around the reservoir, especially at the margins of Goiás State, where there is larger number of agricultural areas and fish farming cages. These data emphasize the importance of the catchment basin to understand aquatic ecosystems and the limnologists increasingly need to consider them in researches. Data of use and occupation of soil, hydrology and meteorology are relatively easy to obtain: direct observation and measurement in the field or by searching on free public databases of higher education, research institutes or independent and non-governmental organizations whose are reliable. Many manuscripts are reject for publication or even not submitted because they have not found significant correlations with limnological parameters, however this fact can not be a reason to abandon these data (Cassey & Blackburn, 2003), because other patterns can be found using other data sources. Although they may be spurious, these correlations can not be ignored because they reflect, even if indirectly, the effect of variables scarcely measured among those traditionally analysed by limnologists.

5. CONCLUSIONS

Limnological variables and zooplankton community associated with the use and occupation of land in the surroundings of São Simão Reservoir reflect the eutrophication process which this environment is submitted. Although some parameters or species indicate oligotrophy, several others indicate a meso-eutrophic state in this reservoir. For this reason the integrated analysis of various parameters must be employed for the complete understanding of these ecosystems.

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