# Longitudinal distribution of microcrustacean biomass in three tropical reservoirs (Paraná State, Brazil)

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**ABSTRACT.** This study evaluated the biomass distribution of microcrustaceans in three subtropical reservoirs in Brazil and the relationship among these distributions and some limnological variables in the reservoirs. The hypothesis was that the microcrustacean biomass is distributed according to Marzolf´s third model, proposed in 1990 for zooplankton density in tropical reservoirs. The planktonic microcrustacean biomass ranged from 261.5 mg DW $m^{-3}$ (Iraí reservoir, transition zone, dry season) to 0.03 mg DW $m^{-3}$ (Segredo reservoir, fluvial zone, wet season). The highest biomass values were registered in the transition zone, but this longitudinal variation was not significant. The total biomass was related to the trophic state of each reservoir, and a higher difference was observed among the reservoirs than within them. The longitudinal biomass distribution was also related with the longitudinal distribution of chlorophyll-*a* and showed the same pattern described in Marzolf´s third model. In this way, the results suggested that this model developed for density zooplankton could be employed for the longitudinal distribution of zooplankton biomass in the studied reservoirs.

**Key words:** zooplankton, biomass, longitudinal distribution, tropical reservoirs.

**RESUMO. Distribuição longitudinal da biomassa de microcrustáceos em três reservatórios tropicais (Estado do Paraná, Brasil).** Este estudo avaliou a distribuição longitudinal da biomassa de microcrustáceos planctônicos, em três reservatórios subtropicais, no Brasil, e a relação dessa distribuição com algumas variáveis limnológicas em reservatórios. A hipótese foi que a biomassa de microcrustáceos se distribui similarmente como proposto no terceiro modelo de Marzolf (1990) para densidade zooplanctônica em reservatórios tropicais. A biomassa dos microcrustáceos variou de 261,5 mg DW $m^{-3}$ (Reservatório de Iraí, zona de transição, estação seca) a 0,03 mg DW $m^{-3}$ (Reservatório de Segredo, zona fluvial, estação chuvosa). Os valores mais elevados de biomassa foram registrados na zona de transição, embora esta variação não tenha sido significativa. A biomassa total esteve relacionada com o estado trófico de cada reservatório, sendo, ainda constatado uma maior diferença de biomassa entre os ambientes do que entre cada zona dos reservatórios. A distribuição longitudinal da biomassa foi relacionada também com a distribuição longitudinal de clorofila-a e apresentou padrão conforme o terceiro modelo proposto por Marzolf. Este fato sugere que esse modelo poderia ser usado para descrever a distribuição longitudinal da biomassa nos reservatórios estudados.

**Palavras-chave:** zooplâncton, biomassa, distribuição longitudinal, reservatório.

## Introduction

Cladocerans and copepods are important groups of reservoir zooplankton, usually representing a major part of the zooplankton community biomass (De Manuel and Jaume, 1994; Rocha *et al*., 1995; Ghadouani *et al*., 1998). These microcrustaceans participate actively in the energy flow and nutrient cycling of aquatic systems since they are characterized as efficient filter feeders and predators on bacteria and phytoplankton, and also due to their importance as a food resource for other invertebrates and fishes.

Reservoirs show typically both abiotic and biotic gradients upstream towards the dam, especially on account of the progressive settlement of particles and materials transported in the inflowing river water. This process often results in the establishment of a longitudinal zonation (Thornton *et al*., 1981; Thornton, 1990) in tropical reservoirs, with three distinct regions: fluvial zone, transition zone and lacustrine zone. Based on this longitudinal gradient, Marzolf (1990) proposed three gradient models to describe the distribution of zooplankton populations in reservoirs. The third model considered resource inputs to the reservoir and water flow regime, and described maximum zooplankton density in the transition zone with lower densities close to the dam and at the upstream end of the reservoir. This pattern was also observed by Takahashi *et al.* (2005) for richness and abundance of planktonic cladocerans in a tropical reservoir in Brazil and by Velho *et al*. (2005) for zooplankton abundance in two subtropical reservoirs in Brazil.

In this study, we explored the biomass distribution of microcrustaceans in three subtropical reservoirs in Brazil, the principal limnological variables that should be related to biomass. We hypothesized that the microcrustacean biomass should be longitudinally distributed similarly to Marzolf's third model in those subtropical reservoirs.

## Material and methods

Three reservoirs were selected for this study (Segredo, Mourão and Iraí Reservoirs), which are located in different watersheds in Paraná State (Southern Brazil) and also differ in nutrient concentrations, depth, uses, area and age (Figure 1 and Table 1).

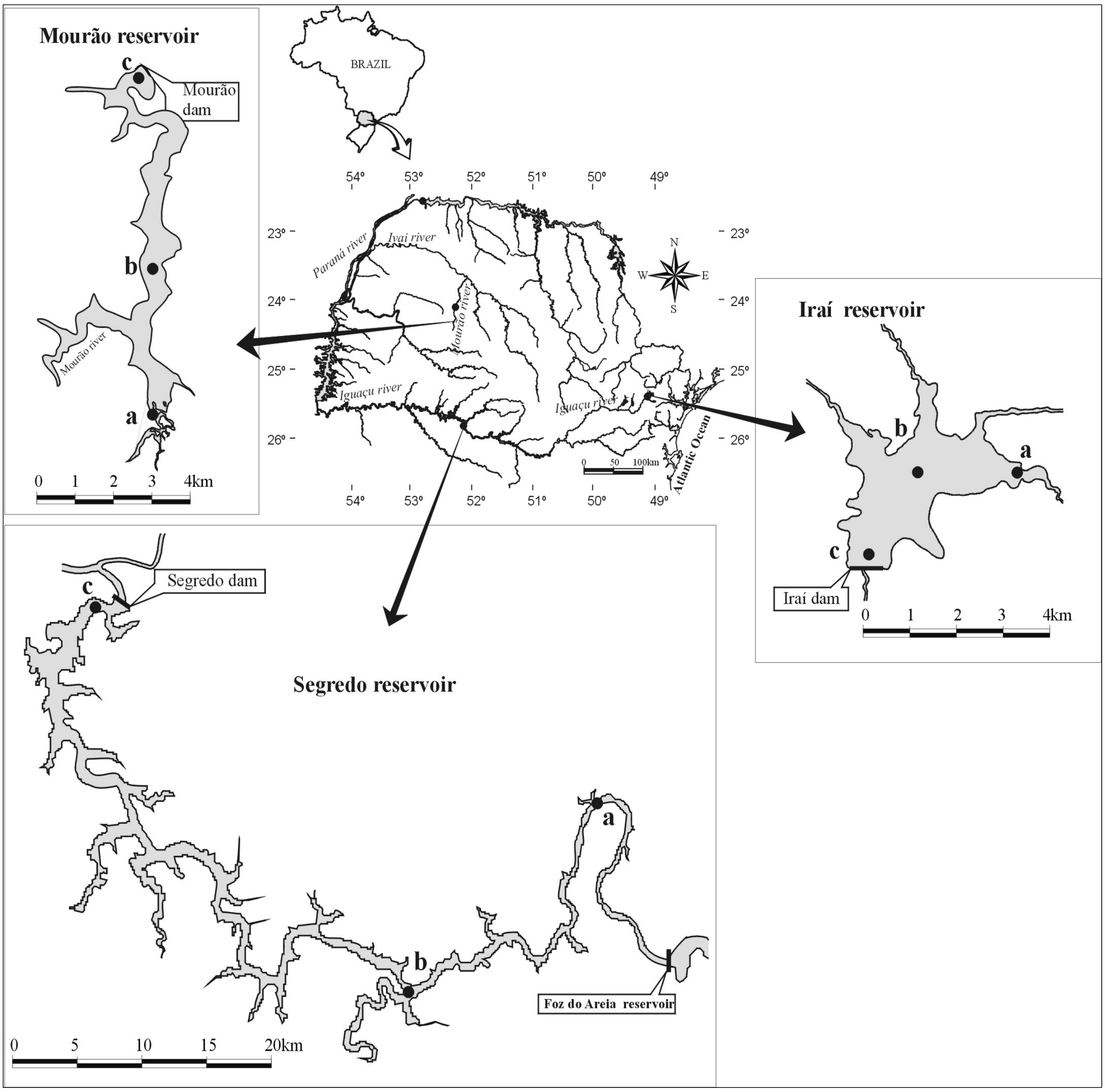


**Figure 1.** Paraná state map and the location of the three reservoirs studied in March and November 2002.

**Table 1.** Reservoirs limnological features, area, age, coordinates, watershed and main use.

| Reservoir | Segredo | Mourão | Iraí |
|---|---|---|---|
| Coordinates | 25°47'46"S; 52°08'07"W | 24°06'25"S; 52°19'45"W | 25°25'24"S; 49°06'46"W |
| Watershed | Iguaçu River | Ivaí River | Iguaçu River |
| Uses | Electric power generation | Water supply and electric power generation | Water supply |
| Area (km$^2$) | 80.4 | 11.2 | 14.4 |
| Age (year) | 12 | 5 | 40 |
| Mean depth (m) | Fluvial region = 18.5 | Fluvial region = 1.5 | Fluvial region = 0.5 |
| | Transitional region = 37.0 | Transitional region = 7.5 | Transitional region = 4.5 |
| | Lacustrine region = 105.0 | Lacustrine region = 8.0 | Lacustrine region = 7.0 |

Sampling of cladocerans and copepods was undertaken on the subsurface (0.5 m) in three pelagic sampling stations (fluvial, transition and lacustrine zones) of each reservoir, during the morning on two seasons in 2002 (wet season: March; dry season: September). Each sample consisted of 1000 L of water collected subsurface using a motorized pump and a 68 μm mesh plankton net and preserved immediately with buffered formalin (4%). Water temperature (ºC) (YSI digital portable thermistor), dissolved oxygen concentration (mg $L^{-1}$) (YSI digital portable oximeter), depth (m), water electrical conductivity (μS $cm^{-1}$) (Digimed digital portable potentiometer), turbidity (NTU) (LaMotte portable turbidimeter) and total alkalinity (mEq $L^{-1}$) (Carmouze, 1994) were measured *in situ* in the same depth and periods of the zooplankton samples. Water samples were taken with the same methodology for other laboratory analysis using a Van Dorn bottle (5 L) and kept frozen. In the laboratory, samples were filtered (Whatman GF/C membrane) to quantify the total suspended material (MTS), after drying at 105°C (Teixeira *et al.,* 1965). The total phosphorus (μg $L^{-1}$), total Kjeldahl nitrogen (μg $L^{-1}$) (Mackereth *et al.,* 1978), and chlorophyll-*a* concentrations (μg $L^{-1}$) were also determined (Golterman *et al.,* 1978).

Quantity of suspended inorganic material (calculated from suspended material concentration) was used as an indirect indicator of current flow in the reservoir. The highest suspended inorganic material concentration values could suggest a high current flow and the lowest concentration values could suggest a low current flow. This last variable and the chlorophyll-*a* concentration, as an indirect indicator of food concentration, were considered the principal variables to determine the longitudinal zooplankton distribution, according to Marzolf´s model (1990). The correlations among microcrustacean biomass and chlorophyll-*a,* and suspended inorganic material were estimated.

Microcrustacean density was estimated by counting at least 150 individuals in a Sedgwick-Rafter chamber in three subsamples (2.0 mL) taken with a Hensen-Stempell pipette under a microscope (Bottrell *et al.,* 1976). Samples with reduced number of individuals were counted per whole sample. Final density was expressed as individuals per cubic meter. Microcrustacean biomass estimation (mg DW $m^{-3}$) was based on total dry weight of the individuals (Duncan, 1975) in the three subsequent quantitative subsamples. Samples with reduced numbers of individuals were weighted in total. The individuals were dried at 60°C for 24 hours (Edmondson and Winberg, 1971; McCauley, 1984; Geller and Müller, 1985). The dry weight was estimated using a Sartory microanalytical scale (0.1 μg precision).

To evaluate if the means of zooplankton biomass were significantly among the regions along the reservoirs' longitudinal axis (fluvial, transition and lacustrine zones), we used Analysis of Variance (one-way ANOVA) (Sokal and Rohlf, 1991) for the independent factors (zones). Normality and homocedasticity assumptions were tested *a posteriori*. In order to identify the principal variables that characterized the reservoirs, we performed a Principal Components Analysis (PCA). The first two axis of this ordination analysis represent the highest explanations of their variability (Jackson, 1993). To normalize the data, log transformation, $\log_{10}(x + 1)$, *a prior* to analysis, was applied. The probability level considered as significant in correlation analysis was $p < 0.05$. All statistical analyses were undertaken using Statistica version 5.0 (Statsoft, 1996).

## Results

The planktonic microcrustacean biomass ranged from 261.5 mg DW $m^{-3}$ (Iraí reservoir, transition zone, dry season) to 0.03 mg DW $m^{-3}$ (Segredo reservoir, fluvial zone, wet season). Iraí reservoir presented the higher mean biomass value (101.5 mg DW $m^{-3}$) and Mourão and Segredo reservoirs presented lower ones (6.8 mg DW $m^{-3}$ and 7.3 mg DW $m^{-3}$, respectively) (Table 2).

**Table 2**. Values of biotic and limnological variables registered in each sampling station. B: microcrustacean biomass (mg DW $m^{-3}$); D: microcrustacean density (ind $m^{-3}$); MD: maximum depth (m); K: water conductivity (μS $cm^{-1}$); TR: turbidity (NTU); DO: dissolved oxygen (mg $L^{-1}$); WT: water temperature (°C); AL: alkalinity (mEq $L^{-1}$); CL: chlorophyll-*a* concentration ($\mu$ $L^{-1}$); SIM: suspended inorganic material ($\mu$ $L^{-1}$); TN: total nitrogen ($\mu$ $L^{-1}$); TP: total phosphorus ($\mu$ $L^{-1}$) (Pagioro *et al*., 2005); F: fluvial zone; T: transition zone; L: lacustrine zone.

| Variables | | B | D | MD | K | TR | DO | WT | AL | CL | SIM | TN | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reservoir | Zone | | | | | | Wet season | | | | | | |
| Segredo | F | 0.03 | 107 | 19.00 | 43.10 | 1.89 | 3.23 | 23.60 | 255.70 | 0.14 | 7.60 | 587.94 | 11.76 |
| | T | 4.90 | 130 | 35.00 | 41.30 | 1.75 | 4.48 | 23.90 | 256.80 | 0.96 | 5.30 | 532.84 | 10.73 |
| | L | 1.17 | 347 | 100.00 | 38.40 | 0.78 | 7.59 | 24.80 | 244.90 | 4.37 | 0.85 | 442.63 | 10.58 |
| Mourão | F | 4.40 | 571 | 2.50 | 28.50 | 6.20 | 7.57 | 22.60 | 217.80 | 0.15 | 1.86 | 208.90 | 8.52 |
| | T | 9.18 | 287 | 9.00 | 24.40 | 1.85 | 7.66 | 26.70 | 184.20 | 2.73 | 0.11 | 140.86 | 9.70 |
| | L | 0.28 | 30 | 10.00 | 24.70 | 1.32 | 7.32 | 26.40 | 182.50 | 2.28 | 0.10 | 175.99 | 10.14 |
| Irai | F | 16.99 | 7964 | 0.50 | 54.20 | 2.40 | 6.90 | 25.20 | 322.90 | 8.19 | 1.80 | 480.56 | 31.53 |
| | T | 50.51 | 20416 | 4.00 | 47.20 | 4.78 | 8.92 | 25.40 | 307.50 | 22.75 | 0.15 | 797.34 | 36.98 |
| | L | 7.14 | 30397 | 7.50 | 48.60 | 5.28 | 9.10 | 26.00 | 465.40 | 35.49 | 0.15 | 789.18 | 39.20 |
| | | | | | | | Dry season | | | | | | |
| Segredo | F | 3.02 | 3766 | 18.00 | 56.10 | 1.04 | 7.09 | 16.40 | 277.60 | 0.91 | 4.50 | 759.81 | 16.51 |
| | T | 20.26 | 8330 | 39.00 | 56.00 | 2.65 | 7.22 | 17.00 | 270.60 | 2.18 | 4.88 | 833.88 | 18.01 |
| | L | 11.66 | 3729 | 110.00 | 45.40 | 0.60 | 8.05 | 18.10 | 262.30 | 2.05 | 6.40 | 712.17 | 10.95 |
| Mourão | F | 1.10 | 441 | 0.50 | 26.60 | 15.79 | 8.08 | 16.70 | 216.20 | 0.55 | 3.00 | 267.58 | 16.21 |
| | T | 18.14 | 24824 | 6.00 | 25.70 | 13.91 | 7.61 | 22.10 | 202.50 | 1.37 | 2.35 | 184.10 | 16.21 |
| | L | 10.59 | 2129 | 6.00 | 23.20 | 2.72 | 7.66 | 20.70 | 168.90 | 3.96 | 0.98 | 167.16 | 13.35 |
| Irai | F | 104.50 | 6655 | 0.50 | 56.80 | 4.10 | 9.21 | 13.50 | 354.60 | 2.18 | 1.18 | 600.06 | 42.65 |
| | T | 261.52 | 200155 | 5.00 | 46.60 | 6.62 | 9.48 | 17.30 | 275.00 | 32.76 | 0.56 | 657.46 | 39.20 |
| | L | 168.66 | 303287 | 6.50 | 45.10 | 5.24 | 7.62 | 16.70 | 281.20 | 23.44 | 0.85 | 431.54 | 48.51 |

The first two axis of the PCA together explained 73% (PCA1 = 43%, PCA2 = 30%) of the limnological variation (Table 3).

**Table 3.** PCA results from correlations of limnological variables for the first two principal axis.

| Variables | Axis 1 | Axis 2 |
|---|---|---|
| Depth (m) | 0.162359 | 0.844884 |
| Conductivity ($\mu$S $cm^{-1}$) | -0.900169 | 0.389091 |
| Turbidity (NTU) | -0.113845 | -0.853649 |
| Dissolved oxygen (mg $L^{-1}$) | -0.299967 | -0.580709 |
| Water temperature (°C) | 0.483167 | 0.219156 |
| Alkalinity (mEq $L^{-1}$) | -0.910134 | 0.119941 |
| Total nitrogen ($\mu$ $L^{-1}$) | -0.855452 | 0.456587 |
| Total phosphorus ($\mu$ $L^{-1}$) | -0.838337 | -0.400266 |
| % explanation | 43 | 29 |

Considering the longitudinal gradient in each reservoir formerly mentioned during the two seasons, the higher biomass values occurred in the transition zone; however, the biomass showed no significantly difference among the zones ($F_{(2,15)}$ = 1.2437; p = 0.316) (Figure 2).

The reservoirs remained separated into three groups, suggesting that the limnological variation was higher among the reservoirs than within them. Iraí reservoir was characterized by higher values of conductivity, alkalinity, total nitrogen, total phosphorus (axis 1), dissolved oxygen, and turbidity (axis 2), lower water temperature (axis 1), and depth values (axis 2). Mourão reservoir also showed higher turbidity and dissolved oxygen values and lower depth values (axis 2), but lower total phosphorus, total nitrogen, conductivity and alkalinity and higher water temperature values (axis 1). Finally, Segredo reservoir was characterized by higher total nitrogen, conductivity, alkalinity, water temperature and lower total phosphorus values (axis 1), and higher depth and lower dissolved oxygen and turbidity (axis 2) (Figure 3).

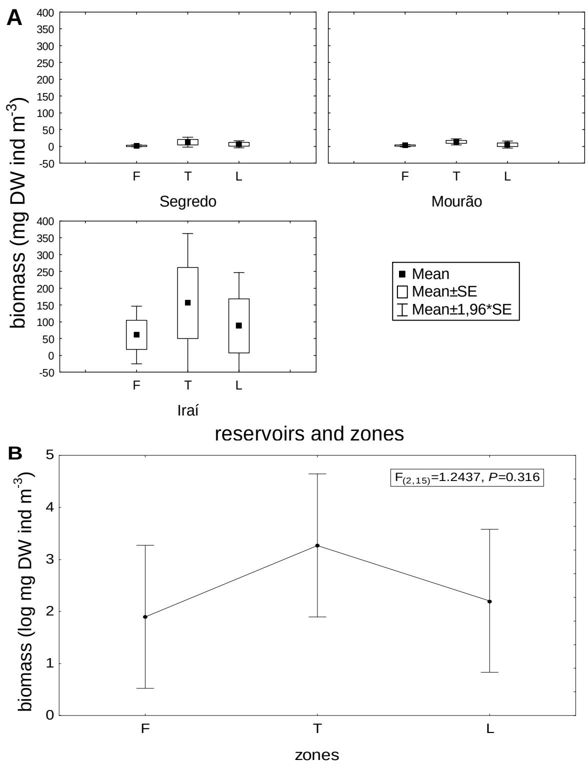


**Figure 2.** Biomass of planktonic microcrustaceans registered in different regions (F = fluvial, T = transition and L = lacustrine) from each reservoir (A) and ANOVA results (B) (symbol = mean; vertical bar = 0.95 confidence intervals).

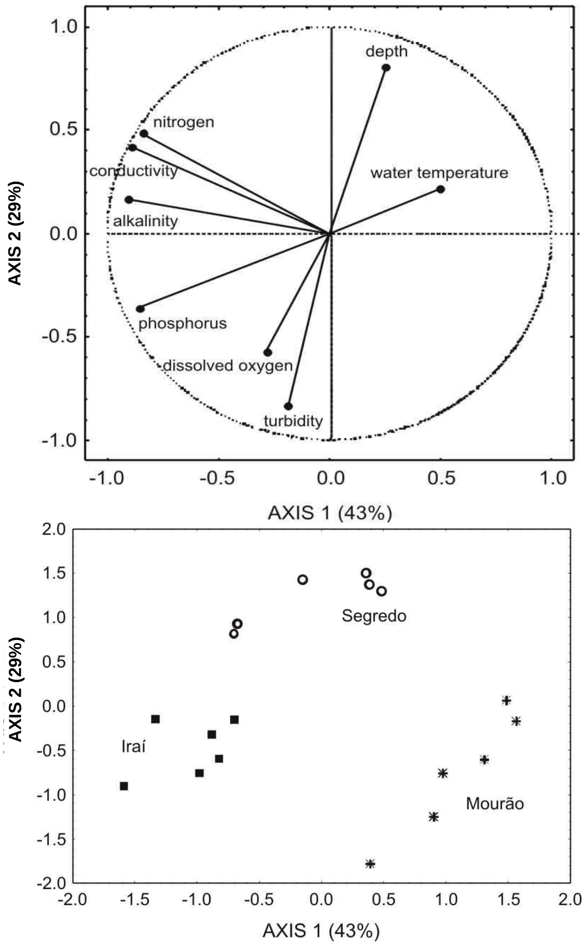


**Figure 3.** Scores distribution along PCA axis according to the limnological variables registered in the reservoirs (zone and season).

In general, the chlorophyll-*a* concentration showed an increase of values from the fluvial to lacustrine zone. On the other hand, the suspended inorganic material showed a clear decreasing tendency downstream towards the dam (Figure 4). However, in both cases those diferences were not significant.

The microcrustacean biomass was significant and positively correlated with the chlorophyll-*a* concentration (r = 0.64, $p < 0.05$), but was not correlated with suspended inorganic material. The Pearson correlation suggested that the biomass increased with the increase of the phytoplankton biomass, and was observed mainly at the Iraí reservoir (Figure 5).

The higher mean microcrustacean density values were registered in the transition zone of Segredo and Mourão reservoirs, and in the lacustrine zone at Iraí reservoir. This variable and microcrustaceans biomass were significant and positively correlated (r = 0.85; $p < 0.05$) (Figure 6).

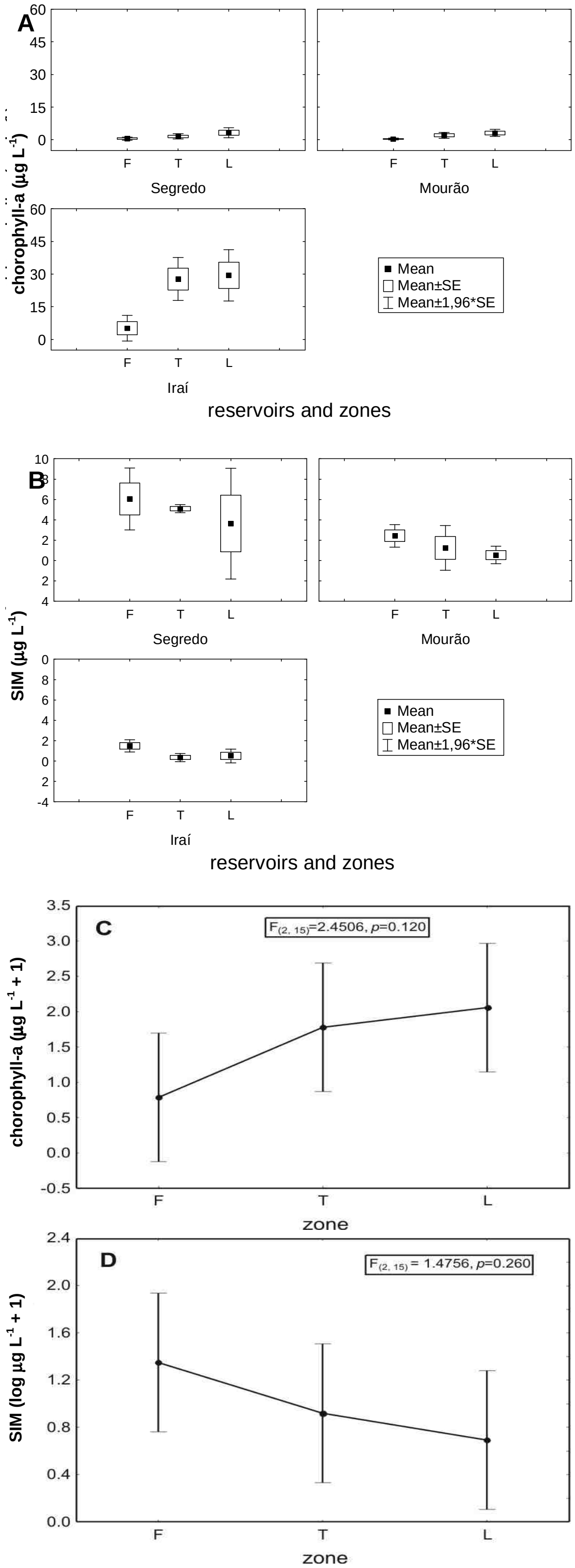


**Figure 4.** Chlorophyll-*a* and suspended inorganic material concentrations registered in different zones (F = fluvial, T = transition and L = lacustrine) from each reservoir (A e B) and ANOVA results (C e D) (SIM = suspended inorganic material) (symbol = mean; vertical bar = 0.95 confidence intervals).

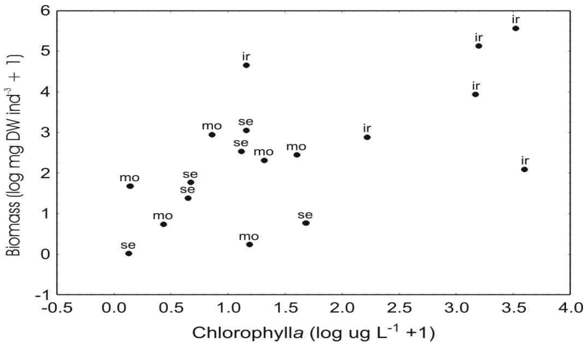


**Figure 5.** Significant correlation between microcrustacean biomass and chlorophyll-*a* concentration (ir = Iraí reservoir, mo = Mourão reservoir, se = Segredo reservoir).

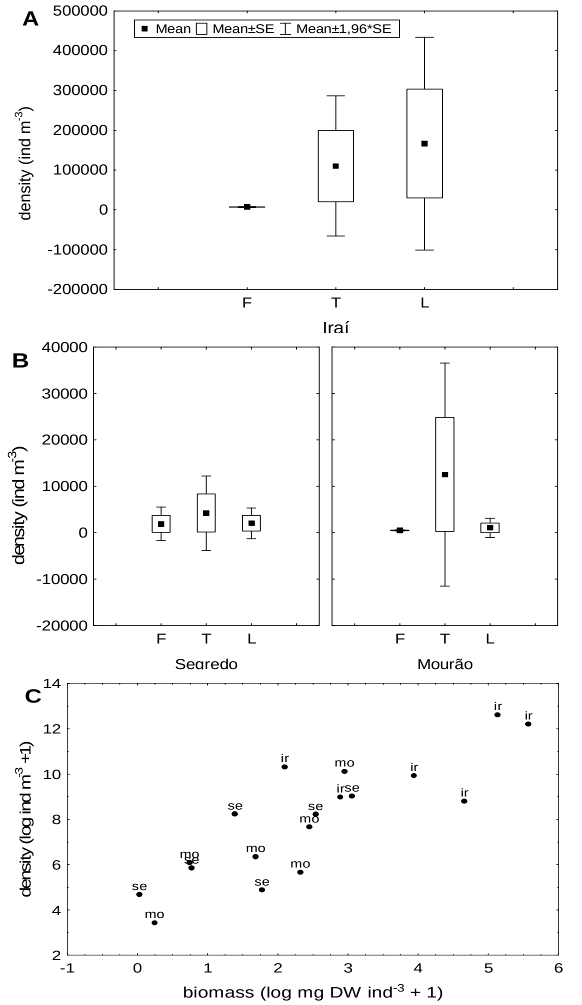


**Figure 6.** Microcrustacean density registered in different regions (F = fluvial, T = transition and L = lacustrine) from Iraí (A), Mourão and Segredo (B) reservoirs, and significant correlation between density and microcrustaceans biomass (C) (ir = Iraí reservoir, mo = Mourão reservoir, se = Segredo reservoir) (symbol = mean; vertical bar = 0.95 confidence intervals).

## Discussion

According to the PCA results, the reservoirs show different limnological features. In this sense, Iraí reservoir has typical characteristics of a eutrophic environment, while Segredo reservoir is a mesotrophic one, and Mourão reservoir is an oligotrophic one. In this way, the microcrustacean biomass values recorded for these reservoirs (Iraí reservoir = 101.5 mg DW $m^{-3}$, Mourão reservoir = 6.8 mg DW $m^{-3}$, Segredo reservoir = 6.8 mg DW $m^{-3}$) were also relatively similar to values obtained by other authors for tropical reservoirs with similar trophic status (Infante, 1993; González *et al.*, 2002; Pinto-Coelho *et al.*, 2005). Specifically, in Brazilian oligotrophic reservoirs, Melão and Rocha (2000) registered 0.5-63 mg DW $m^{-3}$ microcrustacean biomass (Dourada lake), and Sendacz *et al.* (2006) 13 mg DW $m^{-3}$ (Ponte Nova reservoir). In a eutrophic reservoir, Sendacz *et al.* (2006) registered 381 mg DW $m^{-3}$ microcrustaceans biomass.

The microcrustacean biomass was influenced by the trophic features of the reservoir and this is clearly shown at the Iraí reservoir, where the higher biomass values were registered with the highest values of water conductivity, alkalinity, total nitrogen and total phosphorus. In this way, the microcrustacean biomass was related with the trophic state of the reservoirs and the results showed a higher microcrustacean biomass difference among the reservoirs than within them.

According to the longitudinal axis of the reservoirs, the longitudinal distribution of biomass was positively and significantly related to the chlorophyll-*a* concentration ($p < 0.05$). Strong correlations between microcrustacean biomass and chlorophyll-*a* have been found in other lakes and reservoirs. The phytoplankton production was highest at Iraí reservoir, in concordance with Train *et al.* (2005). This correlation was also observed by Amarasinghe *et al.* (1997) in three reservoirs in Sri Lanka, and Hanson e Peters (1984) observed similar ones in two African lakes.

However, is important to remark that the Figure 7 shows the highest values of chlorophyll-*a* in the lacustrine zone and Figure 2 shows the highest values of microcrustacean biomass in the transition zone. This fact could be explained because the water flow is lowest in the lacustrine zone, and therefore sediment the majority of organic material into the flow, which is a food resource to filtered zooplankton, but also sediment the inorganic material, which hinders phytoplankton development. Consequently, by combination of these factors, the zooplankton biomass is highest in the transition zone. On the other hand, Kimmel *et al.* (1990) announced that a higher phytoplankton biomass is frequently observed in transition regions of reservoirs.

Our results are concordant with the third Marzolf model (1990), which shows that the depreciating tendency of water flow and the crescent tendency in food concentration downstream toward the dam explain the highest values of zooplankton density in the transition zone in tropical reservoirs. Hence, the longitudinal distribution of microcrustacean biomass, food resource and water flow showed the same pattern described in this model. In this way, the results suggested that this model, which was developed for zooplankton density, could be employed in the prediction of longitudinal distribution of zooplankton biomass in the studied reservoirs; however new studies are necessary to support this point.

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