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Zooplankton Abundance, Biomass and Trophic State in Some Venezuelan Reservoirs

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1. Introduction

The zooplankton community in freshwater bodies is composed principally of protozoa (flagellates and ciliates; from just a few to hundreds of micrometres), rotifers (from 30 μ m to 1mm) and crustaceans (copepods and cladocerans, some hundreds of μ m up to 1cm), as well as insect larvae (such as *Chaoborus*), freshwater jellyfish (*Craspedacusta*), ostracods (*Cypria*), aquatic mites (Hydracarina), fish larvae and even trematode cercariae (Infante, 1988; Lampert & Sommer, 1997; Rocha et al., 1999; Conde-Porcuna et al., 2004). This community represents a vital component in the food web of aquatic ecosystems (López et al., 2001). Especially in dammed rivers, information on the zooplankton community is important for the analysis of the functioning of these ecosystems and for the establishment of management policies for water use.

The density of zooplankton, expressed as the number of organisms per unit of area or volumen, does not necessarily provide exact information about the actual biomass of this community, since this consists of a huge variety of taxa with a wide size range (Matsumura-Tundisi et al., 1989). Zooplankton biomass is also an important and necessary parameter for calculating the secondary production of this community (Melão & Rocha, 2004). Thus, the estimation of the dry weight of zooplankton species is a more useful variable for the study of trophic structure in aquatic ecosystems than density, especially considering its relationship with the trophic states of the water bodies (Rocha et al., 1995).

In Venezuela, there is little data on the dry weight of zooplankton or their biomass (González et al., 2008). Although this country has over 100 operating reservoirs (MINAMB, 2007), information on the ecological aspects of zooplankton is only available for about 20% (López et al., 2001). In this study we aimed to establish the relationships between the abundance and biomass of the zooplankton with phytoplankton biomass (estimated as chlorophyll *a*) and the trophic states of reservoirs, using data collected from 13 of these water bodies.

2. Study areas

We collected plankton samples from the following reservoirs, distributed in the northeastern and north central regions of Venezuela: 1) Agua Fría, 2) Taguaza, 3) Lagartijo, 4) Clavellinos, 5) Tierra Blanca, 6) El Pueblito, 7) El Cigarrón, 8) El Cují, 9) El Andino, 10) La Mariposa, 11) La Pereza, 12) Quebrada Seca and 13) Suata (Figure 1).

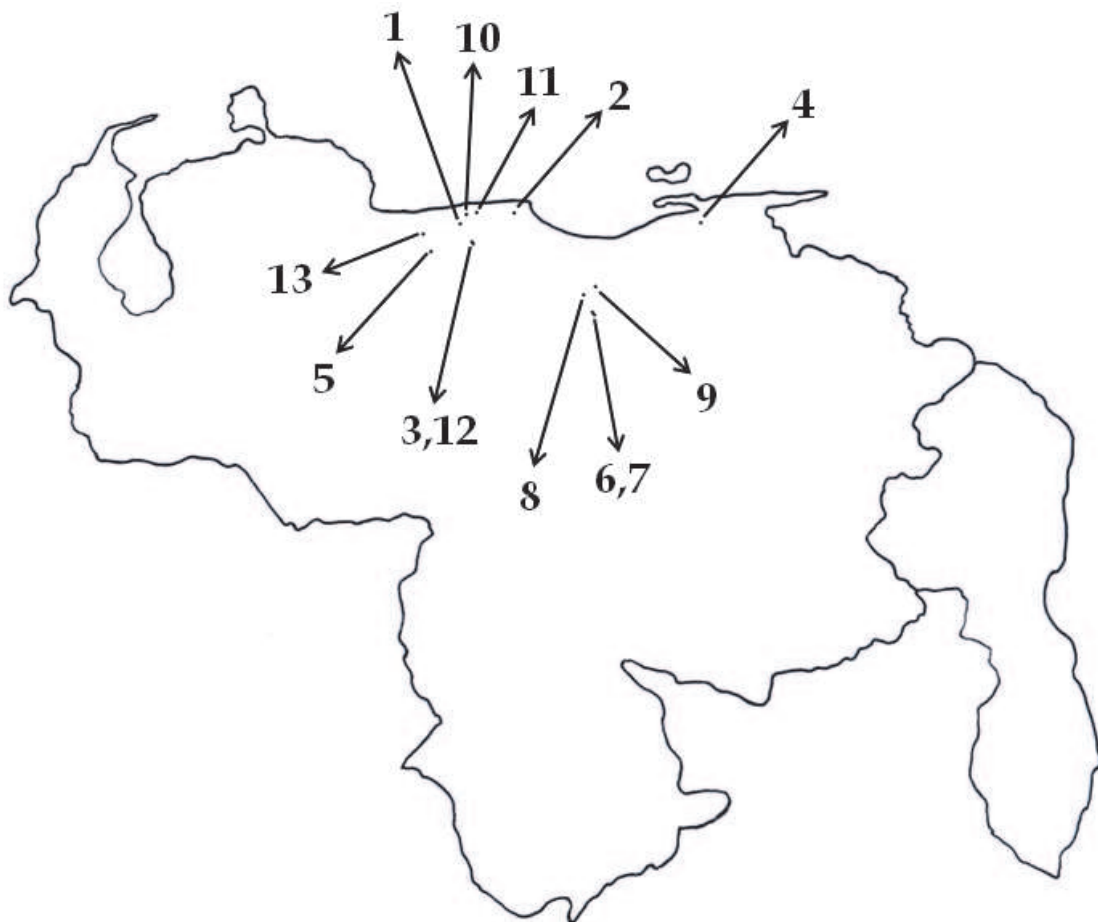


Fig. 1. Map of Venezuela, showing the relative locations of the reservoirs studied. For reservoir names, see numbers in text.

Some of the main morphometric features of the reservoirs surveyed are shown in Table 1.

Reservoir	Mean depth (m)	Area (m ²)	Volume (m ³)	Residence time (d)	Location
Agua Fría	13.2	440,000	5,800,000	38	10°23' N - 67°10' W
Taguaza	20.6	6,490,000	134,000,000	40	10°10' N - 66°26' W
Lagartijo	17.7	4,510,000	80,000,000	243	10°11' N - 66°43' W
Clavellinos	12.5	10,500,000	131,000,000	106	10°21' N - 63°36' W
Tierra Blanca	12.5	400,000	5,000,000	144	9°58' N - 67°25' W
El Pueblito	6.4	49,500,000	315,000,000	152	9°12' N - 65°34' W
El Cigarrón	4.9	50,500,000	246,000,000	158	9°12' N - 65°40' W
El Cují	3.9	12,720,000	49,310,000	375	9°37' N - 65°14' W
El Andino	7.9	1,780,000	14,000,000	167	9°32' N - 65°09' W
La Mariposa	13.0	540,000	7,000,000	12	10°24' N - 66°33' W
La Pereza	14.2	562,500	8,000,000	12	10°27' N - 66°46' W
Quebrada Seca	7.9	950,000	7,500,000	17	10°13' N - 66°43' W
Suata	5.1	8,498,00	43,540,000	84	10°12' N - 67°23' W

Table 1. Mean morphometric features of the studied reservoirs.

3. Methods

The data analyzed was taken from the results of 6-12 monthly sampling periods at each reservoir. Samples for estimating phytoplankton biomass (as chlorophyll *a*) were collected using an opaque van Dorn bottle (3 - 5 liters) from the euphotic layer of reservoirs and preserved in cold and dark conditions until their analysis in the laboratory. Chlorophyll *a* concentration was estimated by extraction of the photosynthetic pigments with ethanol after filtering with Whatman glass-fiber filters (Nusch & Palme, 1975). Zooplankton samples were obtained from the limnetic zone of the water bodies using vertical trawls in the oxygenated strata with a plankton tow net (77 μ m mesh). Samples were preserved in 4% formaldehyde (final concentration). Abundance was determined by counting animals in Sedgwick-Rafter chambers (1ml), according to Wetzel & Likens (2000) and biomass was estimated as dry weight (d.w.) after desiccation at 60°C for about 20-24 h, according to Edmondson & Winberg (1971). Parametric correlations were determined using the PAST program (Hammer et al., 2001).

4. Results

4.1 Description of reservoirs and phytoplankton biomass

- Agua Fría (AFR): Located within a protected area (Macarao National Park, Miranda State). Used to supply drinking water to the city of Los Teques (population approximately 172,000). This reservoir shows low nutrient concentrations, but the water level has declined over the years due to the increase in the demand for drinking water. Meromictic with a tendency to warm monomictic, following Lewis' (1983) criteria; shows hypolimnetic anoxia during the rainy season (González et al., 2004).
- Taguaza (TAG): Located within a protected area (Guatopo National Park, Miranda State). Used to supply drinking water to areas surrounding the city of Caracas (population approximately 4 million). Shows low nutrient concentrations. Meromictic with a tendency to warm monomictic and with permanent hypolimnetic anoxia (González et al., 2002).
- Lagartijo (LAG): Located within a protected area (Guatopo National Park, Miranda State). Used to supply drinking water to the city of Caracas (population approximately 4 million). Shows low nutrient concentrations, but due to the increasing demand for water by the metropolitan area of Caracas, water is pumped to the reservoir from the Tuy river (a highly contaminated river) after sedimentation and chlorination, although this pumped water only affects a small part of the water body. Meromictic with a tendency to warm monomictic and with nearly permanent hypolimnetic anoxia (Infante et al., 1992; Infante & O. Infante, 1994; Ortaz et al., 1999).
- Clavellinos (CLA): Located in Sucre State and used to supply drinking water to the town of Carúpano and Nueva Esparta State (population 512,366) as well as for irrigation. High nitrate concentrations were detected in its waters, possibly from the use of fertilizers on the surrounding land. Warm monomictic; shows anoxic conditions in the hypolimnion during the rainy season (Merayo & González, 2010).
- Tierra Blanca (TBL): Situated in Guárico State and used to supply drinking water to the city of San Juan de Los Morros (population 85,000); it is also used for recreational purposes. Its drainage basin is partially protected, although this is limited by free public

- access. Its water level fluctuates strongly due to demand. Meromictic with a tendency to warm monomictic and with nearly permanent hypolimnetic anoxia (González, 2006).
- El Pueblito (EPU): Located in Guárico State and used for flood control, subsistence agriculture, irrigation and recreation. Shows moderate nutrient concentrations. Classified as warm monomictic according to the criteria of Hutchinson (1957) and Lewis (1983), with hypolimnetic anoxia during the rainy season (González, 2000a).
 - El Cigarrón (ECI): Located in Guárico State and used for flood control, subsistence agriculture and irrigation. Shows high nutrient concentrations due to the use of fertilizers in the surrounding areas. Warm monomictic; with hypolimnetic anoxia during the rainy season (Unpublished data).
 - El Andino (EAN): Located in Anzoátegui State. Used for subsistence agriculture and irrigation. Shows moderate nutrient concentrations due to the use of fertilizers in the surrounding areas. Warm monomictic; with hypolimnetic anoxia during the rainy season (Infante et al., 1995; González, 2000b).
 - El Cují (ECU): Situated in Anzoátegui State and used for the supply of drinking water to the towns of Onoto and Zaraza, as well as for flood control and irrigation. Warm monomictic; with hypolimnetic hypoxia and anoxia during the rainy season (Infante et al., 1995).
 - La Mariposa (LMA): This is an urban reservoir, located 8 km from the city of Caracas (population approximately 4 million) and used to supply drinking water as well as for recreation. The catchment area is highly intervened and its waters show high nutrient concentrations, which has recently produced excessive growth of the macrophyte *Eichhornia crassipes*. In spite of low residence time, its waters show thermal stratification during the rainy season, when hypoxic conditions may also be detected in the hypolimnion (Ortiz et al., 1999).
 - La Pereza (LPE): Located in Miranda State and used for recreational purposes and the supply of drinking water to areas surrounding Caracas (population approximately 4 million). Its waters show high nutrient concentrations, which come from nearby pig and chicken farms, as well as waste waters from a galvanized steel factory. Warm monomictic; with anoxic conditions in the hypolimnion during the rainy season (Ortiz et al., 1999).
 - Quebrada Seca (QSE): Located in Miranda State and used for purifying untreated water from the Tuy river before pre treating and pumping it to the Lagartijo reservoir, from which it is used to supply drinking water to Caracas. Its catchment area is highly intervened, with surrounding rural communities that discharge their wastewaters directly into the reservoir. It mixes only once a year (warm monomictic) and shows hypolimnetic anoxia during the rainy season (Ortiz et al., 1999).
 - Suata (SUA): Located in Aragua State and used to supply water for subsistence agriculture and cattle ranching. This reservoir is fed by the Aragua river which collects the wastewaters of several populations along its course that are then deposited into the reservoir without prior treatment. It is polymictic, due to the shallowness of its waters (González et al., 2009).

The reservoirs represent a gradient of different trophic states, from ultra-oligotrophic (Agua Fría and Taguaza) to hypertrophic (Quebrada Seca, La Mariposa and Suata), according to their total phosphorus concentration following Salas & Martínó (1991), and determined by the authors cited for each reservoir description. Phytoplankton biomass, estimated as the

concentration of chlorophyll *a* in the euphotic zone of each water body, also reflects the trophic state of the reservoirs (Table 2). The mean values of both total phosphorus and chlorophyll *a* for the euphotic zone of these reservoirs varied between 4 and more than 1500 $\mu\text{g}/\text{l}$ and between 2.16 and 92.89 $\mu\text{g}/\text{l}$, respectively, for Agua Fría (the most oligotrophic) and Suata (the most eutrophicated) reservoirs.

4.2 Zooplankton abundance and biomass

The variation intervals of the abundance and biomass of the zooplankton for each of the reservoirs surveyed are shown in Table 3. The dominant zooplankton taxa for each water body are also specified.

Copepods were the dominant group in 8 of the 13 reservoirs sampled (Agua Fría, Taguaza, Lagartijo, Clavellinos, El Pueblito, El Cigarrón, El Cují and La Mariposa) and second in numeric abundance in the El Andino reservoir, where rotifers were the most dominant. Ostracods dominated in the Tierra Blanca and Suata reservoirs and protozoa showed the highest relative abundances in La Pereza and Quebrada Seca. The relative proportions of the different zooplankton taxa are shown in Figure 2. It can be appreciated that copepods were the dominant group in all of the ultra-oligotrophic and oligotrophic reservoirs, but as the trophic state of the water bodies increased other taxa became more abundant.

Reservoir	Total P ($\mu\text{g}/\text{l}$)	Chlorophyll <i>a</i> ($\mu\text{g}/\text{l}$)	Trophic state
Agua Fría	6.57	2.27	Ultra-oligotrophic
Taguaza	8.63	4.67	Ultra-oligotrophic
Lagartijo	17.08	5.78	Oligotrophic
Clavellinos	9.60	15.41	Oligotrophic
Tierra Blanca	23.11	11.66	Oligo-mesotrophic
El Pueblito	21.31	8.46	Oligotrophic
El Cigarrón	37.21	6.71	Mesotrophic
El Cují	23.58	11.05	Oligo-mesotrophic
El Andino	25.60	26.10	Mesotrophic
La Mariposa	136.83	41.92	Hypertrophic
La Pereza	94.64	44.36	Eutrophic
Quebrada Seca	121.25	62.71	Hypertrophic
Suata	1616,43	92.89	Hypertrophic

Table 2. Mean values of total P, chlorophyll *a* and trophic state in the studied reservoirs.

It can be observed that in general, as the trophic state of the reservoir increases, the mean abundances of the zooplankton also seem to increase. This can be seen from Figure 3, where the abundance and biomass of the zooplankton were ordered according to the mean concentrations of chlorophyll *a* in the water bodies. Thus, the lowest phytoplankton biomass values (as chlorophyll *a*) and the lowest abundance and biomass values of the zooplankton are found in the ultra-oligotrophic reservoirs (24 individuals/l and 48.51 $\mu\text{g d.w.}/\text{l}$ in Agua Fría, and 86 individuals/l and 28.71 $\mu\text{g d.w.}/\text{l}$ in Taguaza), whilst the highest

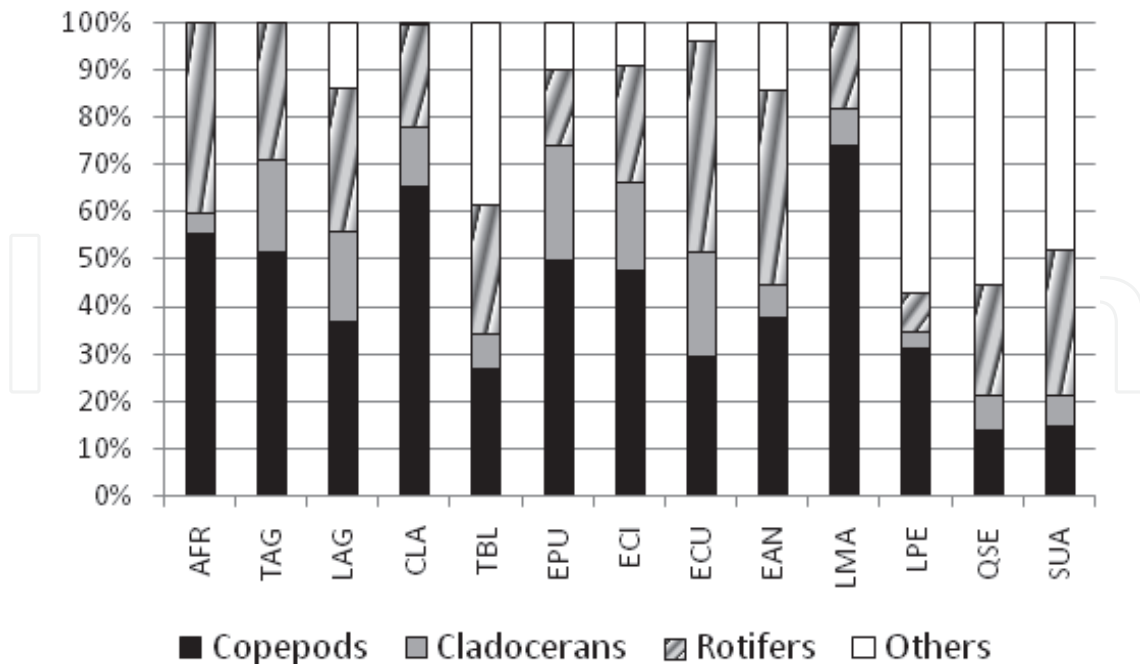


Fig. 2. Relative proportion of zooplankton groups in the studied reservoirs. AFR: Agua Fría, TAG: Taguaza, LAG: Lagartijo, CLA: Clavellinos, TBL: Tierra Blanca, EPU: El Pueblito, ECI: El Cigarrón, ECU: El Cují, EAN: El Andino, LMA: La Mariposa, LPE: La Pereza, QSE: Quebrada Seca, SUA: Suata.

phytoplankton biomass values and the highest mean abundance and biomass values of the zooplankton are found in the hypertrophic reservoirs (1130 individuals/l and 1127.26 μg d.w./l in Quebrada Seca, and 753 individuals/l and 2026.14 μg d.w./l in Suata).

Given the associations found between the phytoplankton and zooplankton, we explored the relationships between phytoplankton biomass, zooplankton abundance and zooplankton biomass in greater detail using a further set of graphs: 1) Chlorophyll *a* vs zooplankton abundance (Figure 4), 2) chlorophyll *a* vs zooplankton biomass (Figure 5) and 3) zooplankton abundance vs zooplankton biomass (Figure 6). The relationships between these parameters are presented using both the raw and logarithmically transformed data, in order to see which gives a better fit.

From Figure 4 we can see that there is a good fit between the mean chlorophyll *a* values of the water bodies and the mean abundance of the zooplankton, either when the raw data were used (Figure 4a) or after logarithmic transformation (Figure 4b). In both cases the relationship best fitted to a straight line, and the linear regression coefficients were higher than 0.60 and statistically significant ($p < 0.05$).

Figure 5 shows another good fit, this time between the mean chlorophyll *a* values and mean zooplankton biomass, either when using the raw (Figure 5a) or logarithmically transformed (Figure 5b) data. In both cases, as for the relationship between phytoplankton biomass and zooplankton abundance, the association was linear; although the linear regression coefficients were lower, they remained statistically significant ($p < 0.05$).

Figure 6 shows that the relationship between the abundance and biomass of the zooplankton can also be described linearly, both with the raw (Figure 6a) and logarithmically transformed (Figure 6b) data.

Reservoir	Abundance (Ind./l) Min. - Max. (Mean \pm S.D.)	Biomass ($\mu\text{g/l}$) Min. - Max. (Mean \pm S.D.)	Dominant zooplankton group
Agua Fría	9.68 - 39.41 (23.91 \pm 8.98)	11.56 - 123.44 (48.51 \pm 32.08)	Copepods
Taguaza	43.86 - 150.00 (85.58 \pm 29.79)	3.82 - 55.03 (28.71 \pm 15.91)	Copepods
Lagartijo	34.00 - 373.00 (155.64 \pm 128.34)	82.43 - 863.78 (251.31 \pm 218.53)	Copepods + Rotifers
Clavellinos	30.48 - 99.94 (61.84 \pm 22.33)	97.40 - 1406.29 (504.28 \pm 351.84)	Copepods
Tierra Blanca	131.80 - 688.67 (309.16 \pm 187.14)	100.08 - 2307.10 (607.21 \pm 571.54)	Ostracods
El Pueblito	73.00 - 218.00 (123.17 \pm 41.17)	69.80 - 228.10 (127.25 \pm 49.77)	Copepods
El Cigarrón	35.00 - 272.00 (130.00 \pm 69.66)	40.00 - 360.00 (164.67 \pm 103.86)	Copepods
El Cují	125.50 - 330.60 (228.05 \pm 145.03)	141.37 - 1643.14 (1092.40 \pm 546.93)	Copepods
El Andino	8.80 - 616.40 (287.89 \pm 201.36)	402.98 - 634.67 (381.72 \pm 169.46)	Rotifers + Copepods
La Mariposa	111.00 - 669.00 (423.33 \pm 182.13)	154.83 - 1297.77 (787.42 \pm 355.74)	Copepods
La Pereza	32.00 - 643.00 (278.40 \pm 262.17)	20.09 - 184.18 (121.77 \pm 79.50)	Protozoans
Quebrada Seca	98.00 - 2472.00 (1129.80 \pm 871.30)	259.46 - 1833.49 (1127.26 \pm 710.50)	Protozoans
Suata	133.76 - 2518.47 (752.93 \pm 678.60)	305.73 - 13853.50 (2026.14 \pm 3757.81)	Ostracods

Table 3. Zooplankton abundance, biomass and dominant groups in the studied reservoirs.

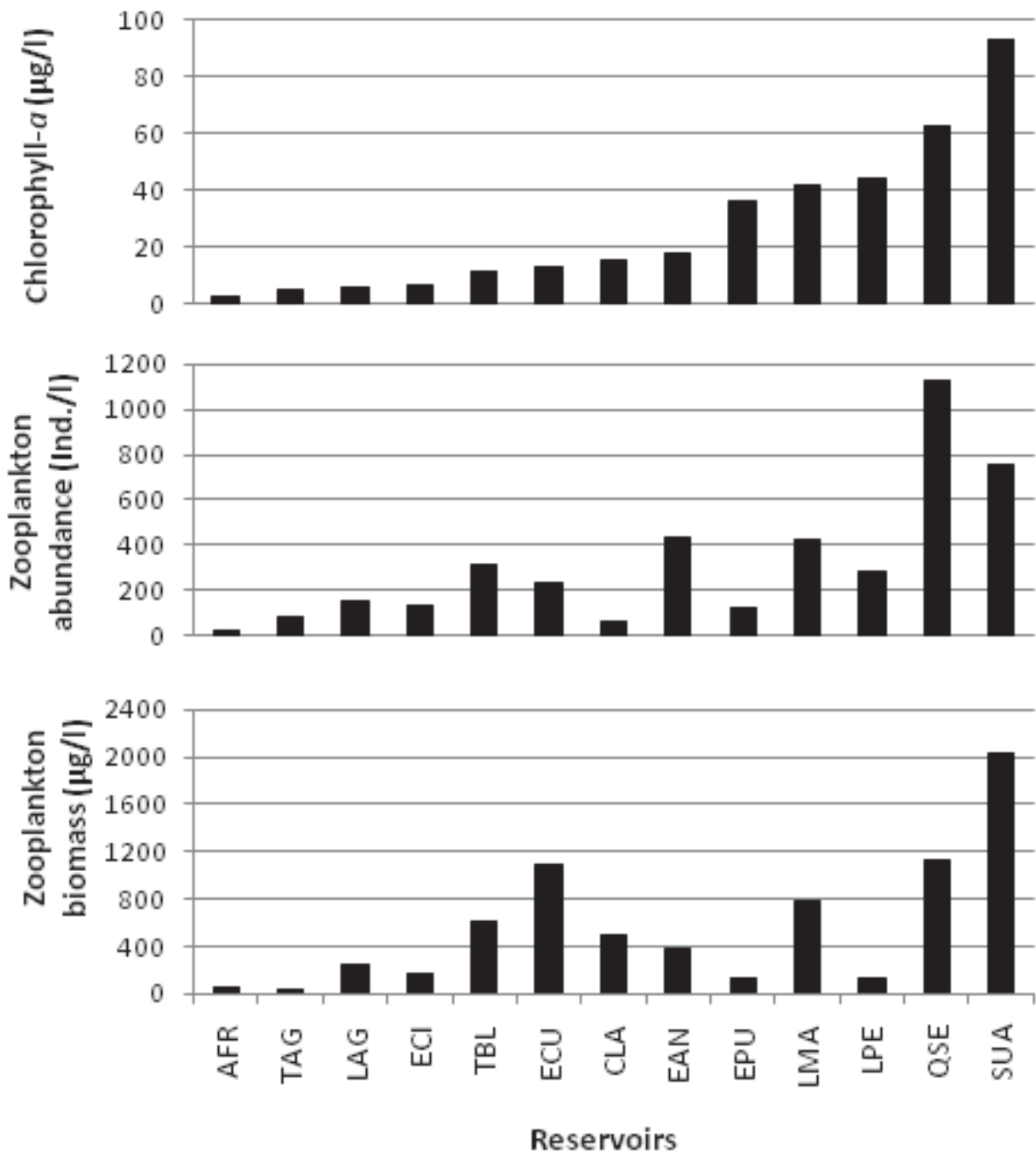


Fig. 3. Mean values of chlorophyll *a*, zooplankton abundance and biomass in the studied reservoirs. AFR: Agua Fría, TAG: Taguaza, LAG: Lagartijo, CLA: Clavellinos, TBL: Tierra Blanca, EPU: El Pueblito, ECI: El Cigarrón, ECU: El Cují, EAN: El Andino, LMA: La Mariposa, LPE: La Pereza, QSE: Quebrada Seca, SUA: Suata.

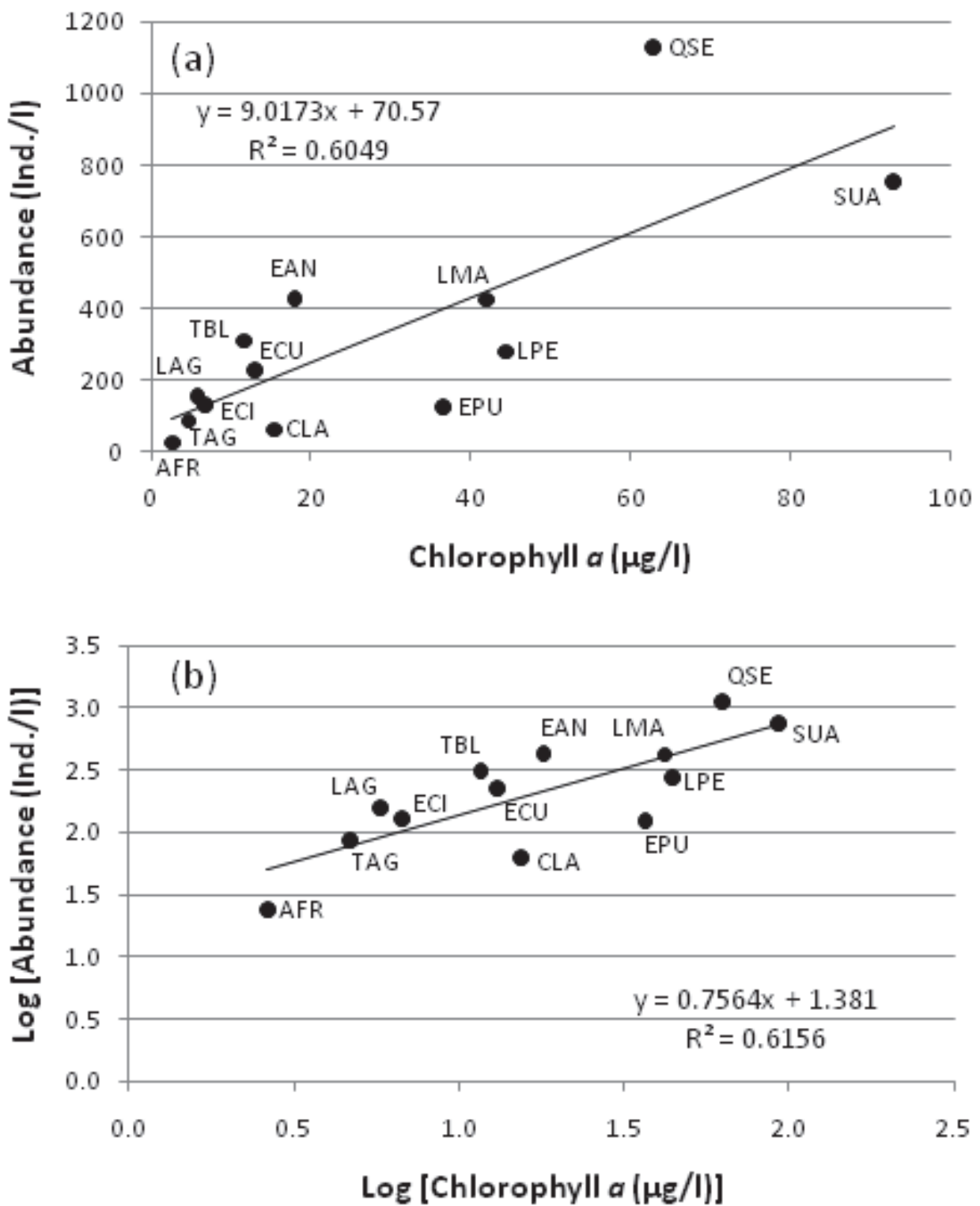


Fig. 4. Relationship between chlorophyll *a* and zooplankton abundance: a) Raw data, b) logarithmically transformed data. For reservoir names, see Figures 2 & 3.

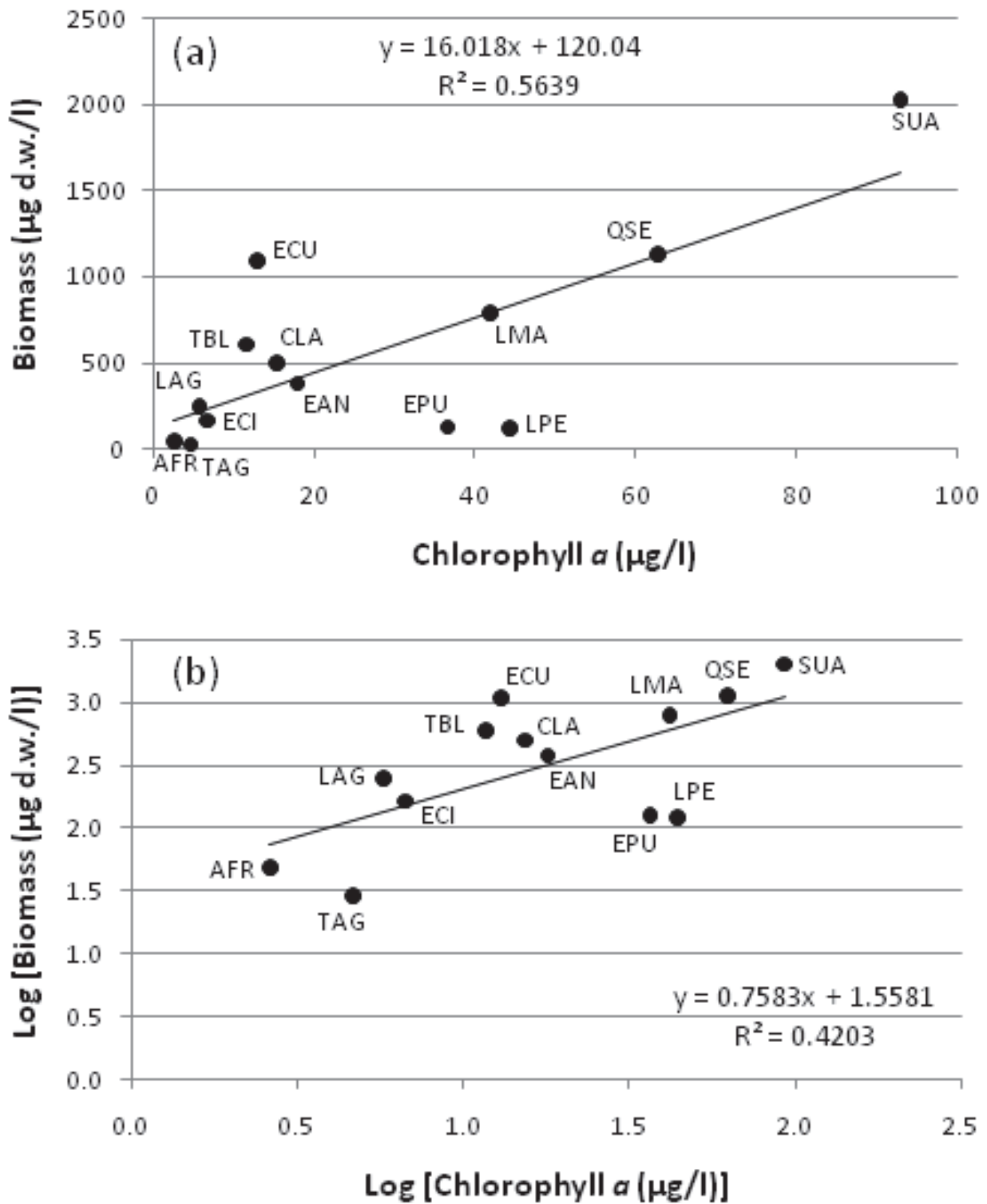


Fig. 5. Relationship between chlorophyll *a* and zooplankton biomass: a) Raw data, b) logarithmically transformed data. For reservoir names, see Figures 2 & 3.

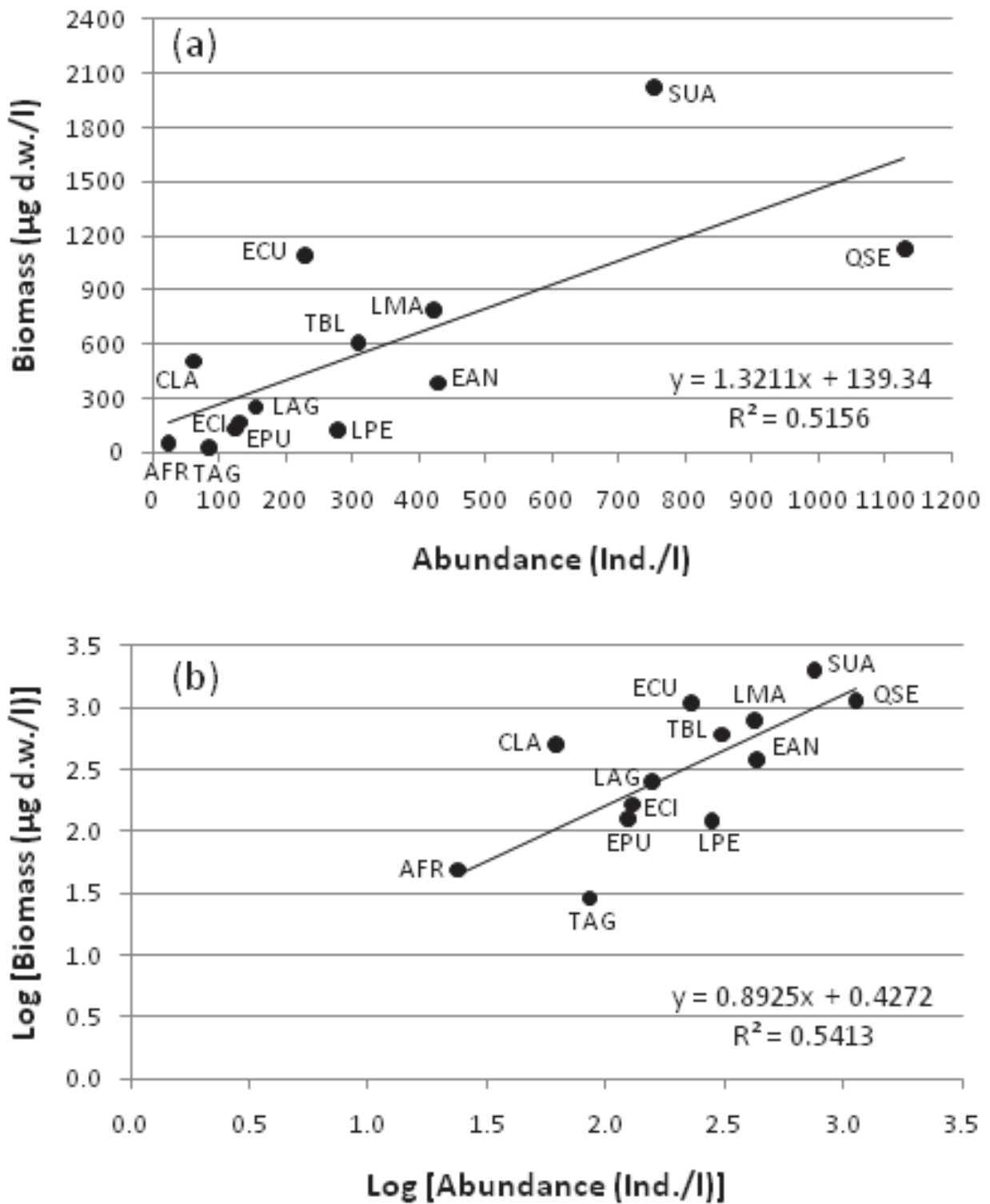


Fig. 6. Relationship between zooplankton abundance and biomass: a) Raw data, b) logarithmically transformed data. For reservoir names, see Figures 2 & 3.

As for the associations shown in Figures 4 and 5, the linear regression coefficients for zooplankton abundance vs biomass were also statistically significant ($p < 0.05$) and higher than 0.51.

The linear correlation coefficients (r) between these variables were also calculated and were also statistically significant ($p < 0.05$), as was to be expected from the linear regressions obtained:

- Chlorophyll *a* vs. zooplankton abundance; $r = 0.778$.
- Chlorophyll *a* vs. zooplankton biomass; $r = 0.718$.
- Zooplankton abundance vs. zooplankton biomass; $r = 0.751$.

5. Discussion and final considerations

The majority of the reservoirs included in this study show a tight linear relationship between total phosphorus and the concentration of chlorophyll *a*; thus these variables are good predictors of their trophic state (González, 2008; González & Quirós, submitted). Reservoirs whose drainage basins are protected or in areas with low anthropogenic impact show the lowest total phosphorus and chlorophyll values, whilst those found in degraded catchment areas give the highest values.

As regards the zooplankton, Matsumura-Tundisi (1997) suggests that an understanding of the population dynamics of the different groups constitutes a useful tool for the management of reservoirs, since the composition, abundance and spatial distribution of the zooplankton communities are strongly related to their trophic state and the degree of biological interactions that occur within them, and that furthermore, the prevalence of certain species could indicate of the trophic state of the ecosystem.

According to Esteves (1998), an increase in phytoplankton primary production due to eutrophication has immediate effects on heterotrophic organisms, considerably increasing their production. As for phytoplankton, the specific composition of zooplankton and the relative density of each species changes with eutrophication (Esteves, 1998; Pinto-Coelho et al., 2005; Leitão et al., 2006; Landa et al., 2007; Tundisi et al., 2008). Thus many species either reduce in abundance or disappear completely, and are substituted by others that take over as the dominant zooplankton taxa. For example, Infante & Riehl (1984) suggested that pelagic cladocerans, such as *Ceriodaphnia cornuta*, *Diaphanosoma* sp. and *Moina micrura*, may be more susceptible to the proliferation of cyanobacteria than copepods and rotifers in highly eutrophicated systems. In most cases, cyanobacteria negatively affect zooplankton (Zhao et al., 2008).

As far as we are aware this is the first comparative analysis of the relationships between the abundance and biomass of the zooplankton and phytoplankton biomass in reservoirs with different trophic states in Venezuela that takes into account the mean annual cycles of these three variables. Several previous studies only consider fluctuations in the abundance and biomass of zooplankton with respect to physicochemical changes and phytoplankton abundance and biomass (Infante, 1993; Infante et al., 1995; Mendoza, 1999; Carrillo, 2001; González et al., 2002; Gavidia, 2004; González, 2006; Cabrera, 2009; Merayo & González, 2010). In some of these investigations, statistically significant correlations between phytoplankton and zooplankton were not found, especially in eutrophic systems, where links between the two communities may be weakened by the proliferation of microalgae that are not the preferred food of zooplankton (McQueen et al., 1986). In these cases, zooplankton dynamics were registered as being principally determined by environmental

fluctuations, although some of the abundance and biomass peaks coincided with peaks of chlorophyll *a* concentrations. In contrast, in several oligotrophic systems, such as the Agua Fría and Taguaza reservoirs in this study (González et al., 2002; González, 2006) and the Jucazinho reservoir in Brazil (Mélo-Júnior et al. 2007), significant correlations between phyto- and zooplankton have been reported.

From the analyses done in this study, it seems common that in water bodies with a higher degree of eutrophication, zooplankton abundance and biomass are higher compared to oligotrophic reservoirs. This relationship has been reported in other comparative studies of these variables in water bodies with contrasting trophic states in both Venezuela and Brazil (González et al., 2002; González, 2006; Sendacz et al., 2006; Blettler & Bonecker, 2007), the only countries in which these types of investigations have been done within the South American tropics (González et al., 2008).

From this study it can be observed that the association between phytoplankton biomass and the abundance and biomass of the zooplankton is not perfect (see Fig. 3). The explanation for this is indicated by Fig. 2, however, which gives the relative proportions of the different zooplankton groups, as well as the information given in Tables 2 and 3.

As has already been mentioned, copepods dominate in the oligotrophic environments considered in this study, but as the trophic state increases, the relative abundances of other groups also increase. Thus, the lack of association between the variables could be due to the dominance of zooplankton taxa with small sized species, which contribute little in terms of weight to the total zooplankton biomass. In contrast, copepods contribute more to total zooplankton biomass in many fresh water bodies due to their larger sizes and heavier dry weights (Infante, 1993; Infante et al., 1995; Castilho-Noll & Arcifa, 2007; González et al, 2008; Merayo & González, 2010).

Sendacz et al. (2006) affirm that rotifers tend to dominate zooplankton communities in tropical and sub-tropical lakes and reservoirs, independently of their trophic state, but due to their small size and light weight, often contribute little to total zooplankton biomass. This could explain the lack of a perfect association between zooplankton abundance and biomass in the Venezuelan reservoirs studied.

In contrast to that indicated by Sendacz et al. (2006), the zooplankton community in most Venezuelan reservoirs seems to be dominated by copepods (López et al., 2001). This agrees with our results where copepods were the dominant group in 8 out of the 13 Venezuelan reservoirs studied. This could be promoted by high water residence times that favor species with relatively long development cycles (Santos-Wisniewski & Rocha, 2007). The dominance by groups other than copepods in Venezuelan systems could be related to factors such as temperature, the quantity and quality of available food, species genotypes, climatic periods and differences in habitat conditions, among others (Gavidia, 2004; Sendacz et al., 2006; Mustapha, 2009; Merayo & González, 2010).

In spite of the lack of a perfect fit between phytoplankton biomass and the abundance and biomass of zooplankton, strong linear relationships between the annual means were found. Thus, in the same way as for the strong linear relationships found between nutrients and phytoplankton biomass in Venezuelan reservoirs (González, 2008; González & Quirós, submitted), a strong linear association was also found between zooplankton abundance and biomass, between each of these and phytoplankton biomass (estimated as chlorophyll *a*), and between all these variables and the trophic state of the reservoirs.

Due to the fact that zooplankton dynamics are associated with the effects of anthropogenic activities in the drainage basins of these fresh water bodies (Infante, 1993), the identification of the dominant taxa (composition), and estimates of their abundance and biomass provide us with valuable tools for the determination of the trophic state, and thus should be taken into account when designing policies for the adequate management of reservoirs in Venezuela.

6. Acknowledgments

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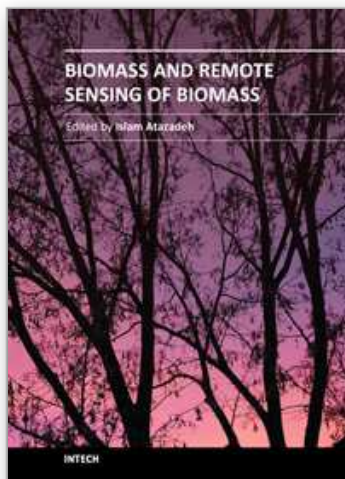
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