Differences in body size of *Thermocyclops minutus* (Lowndes, 1934) in two tropical lakes

Variação do tamanho de corpo de *Thermocyclops minutus* (Lowndes, 1934) em dois lagos tropicais

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Abstract: Aim: Body sizes of males and females of *Thermocyclops minutus* were compared, based on monthly samples, in two lakes with similar areas and depths, located in the Rio Doce State Park (Minas Gerais, Brazil). Body size may be influenced by distinct physical (temperature) and chemical (trophic state) characteristics and biotic interactions (herbivory and predation); **Methods:** Lake Carioca is mesotrophic, remains stratified most of the year, and harbors exotic species of fishes. Lake Gambazinho is oligotrophic, does not thermally stratify, and still has its native fish fauna. Each month, 30 males and 30 females of *T. minutus* were measured using an ocular micrometer; **Results:** Differences in the body size were significant between the dry and rainy periods ($p = 0.000$) and between females in both lakes ($p = 0.000$). Larger-bodied individuals were mostly observed during the dry period, and larger females were recorded in Lake Carioca; **Conclusions:** The smaller body size of individuals in Lake Gambazinho may be associated to the lack of thermal stratification and low food quality; whereas in Lake Carioca, the stable thermal structure and the greater algae diversity may have allowed for a larger body size of this copepod. The presence of vertebrate (fish) and invertebrate (*Chaoborus* larvae) predators may also be responsible for the differences in size of *T. minutus* in these environments.

Keywords: body size, zooplankton, Cyclopoid, *Thermocyclops minutus*, tropical lake.

Resumo: Objetivo: Variações mensais no tamanho de corpo de machos e fêmeas de *Thermocyclops minutus* foram analisadas para duas lagoas do Parque Estadual do Rio Doce, com áreas e profundidades semelhantes. O tamanho corporal pode ser influenciado por distintas condições físicas (temperatura), químicas (estado trófico) e interações bióticas (herbivoria, predação); **Métodos:** A lagoa Carioca é considerada mesotrófica, permanece estratificada a maior parte do ano e tem, como componentes de sua fauna, peixes exóticos. A lagoa Gambazinho é considerada oligotrófica, não apresenta estratificação térmica e ainda conserva a fauna nativa de peixes. Mensalmente, 30 machos e 30 fêmeas de *T. minutus* foram medidos com auxílio de uma ocular micrometrada; **Resultados:** Diferenças no tamanho de corpo foram significativas entre períodos de seca e chuva ($p = 0{,}000$) e entre fêmeas nas duas lagoas ($p = 0{,}000$). Indivíduos com maior tamanho de corpo geralmente foram observados no período de seca e entre as lagoas, fêmeas maiores foram registradas na lagoa Carioca; **Conclusões:** O menor tamanho de corpo dos indivíduos da lagoa Gambazinho pode estar associado à ausência de estratificação térmica e alimento de baixa qualidade, enquanto na lagoa Carioca, a estabilidade da estrutura térmica e maior diversidade de algas permitiram o maior tamanho de corpo desta espécie de copépode. A presença de predadores vertebrados (peixes) e invertebrados (larvas de *Chaoborus*) são também apontados como responsáveis pela variação de tamanho de corpo de *T. minutus* nos ambientes analisados.

Palavras-chave: tamanho de corpo, zooplâncton, Cyclopoida, *Thermocyclops minutus*, lago tropical.

1. Introduction

In terms of zoology and animal ecology, body size is frequently considered when describing species, because of its relationship to consumption, respiration, growth, and influence on the predator-prey relationship, resistance to starvation, and life history (Peters, 1986). Temperature, food availability, and predation are among the factors considered as determinants of zooplankton populations and the body sizes of community members.

Temperature influences the physiological rates of organisms, increasing or decreasing the mean body size within a population (Gilabert, 2001; Kobari et al., 2003; Azevedo and Bonecker, 2003; Savage et al., 2004). The existence of a relationship between trophic state of a waterbody and the body-size structure of its aquatic communities was suggested by Thiel (1975, apud Peters, 1986), who observed a predominance of species with smaller body sizes in environments with greater food resources. Later, Gannon and Stemberger (1978) also showed, for aquatic environments, that eutrophication favors smaller-bodied zooplankton. The role of vertebrate predators in determining body size

and community structure of zooplankton was suggested at least four decades ago by Brooks and Dodson (1965), and confirmed by Zaret and Kerfoot (1975). In the 1970s, several studies demonstrated the importance of invertebrates (mainly larvae of Chaoboridae) in predation of zooplankton in aquatic communities (Kajak and Ranke-Rybicka, 1970; Dodson, 1972; Fedorenko, 1975). Contrasting, researches in zooplankton body size and variables – abiotic and biotic – that may influence this parameter are scarce in tropical aquatic ecosystems (Azevedo and Bonecker, 2003).

The lacustrine system of Rio Doce State Park, Minas Gerais, shows water bodies with different shape, depth, thermal structure and trophic stages. In some lakes, reduction of the populations of smaller-sized native fishes has been thought to result from the introduction of species of predator fishes, such as tucunaré (*Cichla kelberi*) and piranha (*Pygocentrus nattereri*) (Godinho and Formagio, 1992). Changes in the structure of the zooplankton community in some lakes have also been considered an effect of these introductions, as well as of the presence of Chaoborid larvae in high densities (Maia-Barbosa et al., 2003). Recently, *Thermocyclops minutus* has become the most commom and abundant copepod in lakes of Rio Doce State Park (PELD, 2008). However, our knowledge about this specie is still scarce.

This study compared the variations in body size of males and females of the planktonic cyclopoid copepod *Thermocyclops minutus* in two lakes in Rio Doce State Park. Our hypothesis is: body size of *T. minutus* in lakes Carioca and Gambazinho may be influenced by distinct physical (temperature) and chemical (trophic state) characteristics and biotic interactions (herbivory and predation).

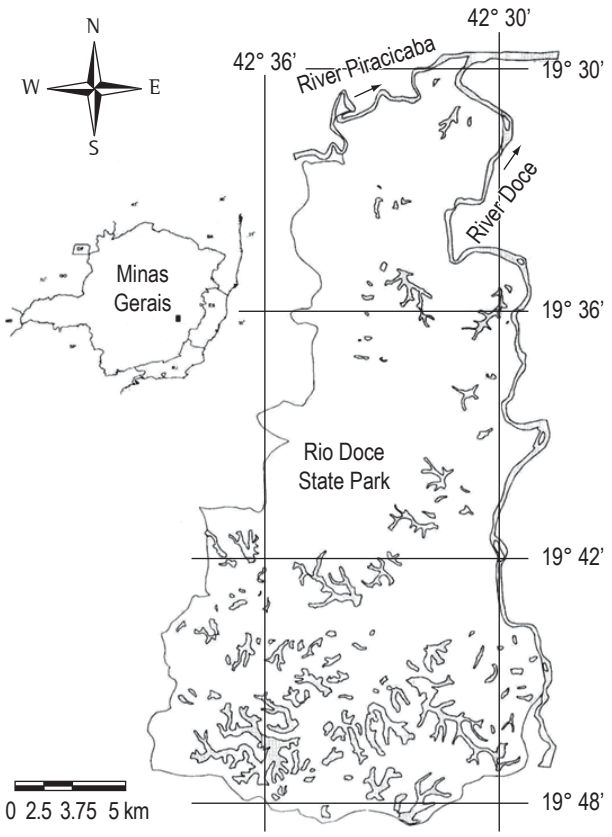

Figure 1. Rio Doce State Park lake system (Minas Gerais, Brazil), with 1 – Lake Carioca and 2 – Lake Gambazinho (modified from Godinho, 1996).

2. Material and Methods

2.1. Study area

Lakes Carioca (19° 46' 54.4" S and 42° 37' 5.8" W) and Gambazinho (19° 47' 6.5" S and 42° 34' 45.1" W) are part of the Rio Doce Lake system (Minas Gerais, Brazil). They are located in Rio Doce State Park, where they are surrounded by humid tropical forest, the largest remnant of the Atlantic Forrest in Minas Gerais (Figure 1). These lakes were selected for this study because of their similar area and depth, and different thermal structure, degrees of trophy and fish fauna composition (PELD, 2008). Although the studies in Lake Carioca started in the 1970s, Lake Gambazinho began to be monitored only in 2002, after the beginning of the Long-Term Ecological Research Program (LTER/UFMG).

Lake Carioca (13.3 ha in area and maximum depth 11.8 m) is classified as mesotrophic and has a brief period of circulation during winter (June to August) (PELD, 2008). Its fish fauna was drastically altered after the introduction of piscivorous exotic fish (tucunaré *Cichla kelberi*, piranha *Pygocentrus nattereri*, African catfish *Clarias gariepinus,* and tamboatá *Hoplosternum litoralle*) (Latini et al., 2004). Native foraging fish species disappeared after these introductions (Godinho et al., 1994), followed by an increase in densities of Chaoborus larvae, now the main predator of zooplankton community, as reported for Lake Dom Helvécio, another lake in the same system (Maia-Barbosa et al., 2003).

Lake Gambazinho (10.4 ha in area, maximum depth 10.3 m) does not show thermal stratification and is considered oligotrophic (PELD, 2008). This lake still has its native fish fauna, consisting of planktivorous species such as lambari (*Oligosarcus solitarius*, *Moenkausia doceana*, *Astyanax taeniatus*) and acará (*Cichlasoma facetum* and *Geophagus brasiliensis*) (Latini and Petrere, 2004). According to a study by Latini et al. (2004) in 42 lakes in Rio Doce State Park, this is one of only three lakes that do not yet contain exotic fish species.

In both lakes, Copepoda (mainly *T. minutus*) is the dominant group of zooplankton (means: nauplii – 49.5%, copepodids + adults – 27.7%) beside Rotifera (20.5%). Cladocera and *Chaoborus* larvae didn't represent more than 3% (PELD, 2008).

2.2. Sampling procedure

Samples were collected monthly (January/02 to January/03) at a fixed station in the limnetic zone of each lake. Temperature profiles were measured with a Horiba U-22 multi-analyzer. Water samples were collected at four different depths, defined by the Secchi disc (100, 10, 1% and aphotic zone), in order to determine the total phosphorus concentration, according to Mackereth et al. (1978). The geometric mean of the total phosphorus values was used to evaluate the lakes' trophic states, according to Salas and Martino (1991).

Zooplankton samples were obtained by filtering 10 L of water collected with a Van Dorn bottle from each depth in a plankton net of 68 µm mesh size. Samples were preserved with 4% neutral formalin. Each month, 30 males and 30 females of *T. minutus* (length from cephalothorax to abdomen, excluding the furca or caudal ramus) were measured using an ocular micrometer. Due to scarcity of individuals during research period, adults of all depths were measured aiming to reach 30 males and 30 females. Chaoborus larval were all counted in reticulated acrylic chambers in stereoscopic microscope and its densities expressed in organisms per cubic meters (org.m^{-3}).

Differences in the mean body size for *T. minutus* males and females, between the dry and rainy periods and between the lakes, were analyzed by the Mann-Whitney test. The relationships between mean water temperature, density of *Chaoborus* larvae, the lakes' trophic state (geometric mean), and the variations in the mean size of *T. minutus* in each month were tested by the Spearman correlation (Sampaio, 2002).

3. Results

3.1. Environmental conditions

Lake Carioca was thermally stratified between September and April (rainy period), and unstratified between May and August (dry period). During the period of stratification, the temperature variation range was 10.6 °C between the surface (33.4 °C) and the bottom (22.8 °C), with the metalimnion located between 3.0 and 6.0 meters. During the unstratified period, the mean water-column temperature was 24.3 °C (±1.5 °C). In Lake Gambazinho, no thermal stratification was observed; instead, a "warm mixing" period (November-April) and a "cold mixing" period (May-October) occurred, with mean temperatures of 29.4 °C (±1.02 °C) and 25.4 °C (±1.4 °C) during the rainy and dry periods, respectively (Figure 2).

According to the model of Salas and Martino (1991), Lake Carioca is mesotrophic during almost the entire year. Lake Gambazinho appears as mesotrophic only in May and July, and can be considered oligotrophic during the other periods (Figure 3). Coincidently, the lowest total mean

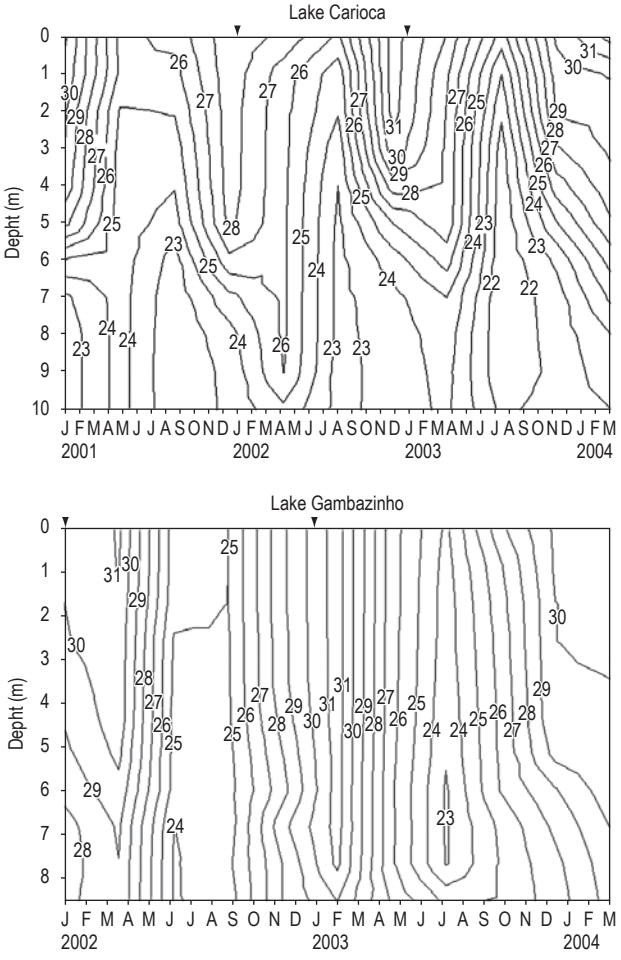

Figure 2. Thermal structure of Lake Carioca (January/01 to March/04) and Lake Gambazinho (January/02 to March/04). Arrows indicate the research period (January/02 to January/03).

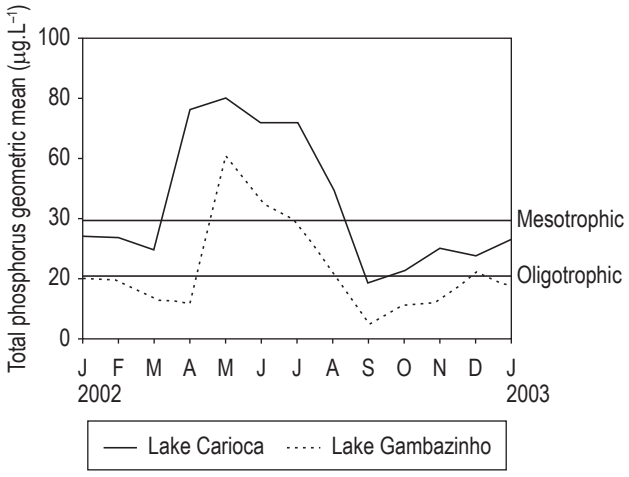

Figure 3. Total phosphorus geometric means (µg.L^{-1}) for lakes Carioca and Gambazinho from January/02 to January/03 (oligotrophic and mesotrophic levels from Salas and Martino, 1991).

phosphorus concentrations were observed in September (18.54 µg.L^{-1} for Lake Carioca and 4.76 µg.L^{-1} for Lake Gambazinho), which is the beginning of the stratification and rainy periods.

3.2. Monthly variation of the body size of Thermocyclops minutus

T. minutus males showed a mean body size of 415.6 µm (±18.7) (minimum: 350 µm, maximum: 490 µm) in Lake Carioca, and 411.4 µm (±15.6) in Lake Gambazinho (minimum: 350 µm, maximum: 460 µm) (Figure 4). These differences were not statistically significant (U = 53817.5; Z = 1.580; p = 0.1141). However, significant differences were observed between the rainy (September to April) and dry periods (May to August), with higher values recorded in the latter (U = 34677.5; Z = –8.947; p = 0.000).

For the females, the mean body size was 498.0 µm (±22.4) in Lake Carioca (minimum: 410 µm, maximum: 565 µm) and 461.2 µm (±22.6) in Lake Gambazinho (minimum: 405 µm, maximum: 560 µm). These differences were statistically significant (U = 13828; Z = 17.585; p = 0.000). Larger females were observed in Lake Carioca, especially during the dry period (Figure 5), and the differences between periods were significant (U = 49594.5; Z = –4.006; p = 0.000).

A strong negative correlation ($p < 0.05$) between temperature and mean body size of males and females was observed in both lakes. As for *Chaoborus* density, the correlation was positive ($p < 0.05$) for both genders and lakes. The relationships were not significant for the trophic state (Table 1).

4. Discussion

In general, individuals with larger body sizes were observed during the dry period in both lakes. Normally, lower temperatures increase the generation time and, consequently, the body mass of copepods (Riccardi and Mariotto, 2000; Gaudy and Verriopoulos, 2004). Some studies have mentioned temperature as one of the causes of variations in the body size of zooplankton organisms (Azevedo and Bonecker, 2003; Kobari et al., 2003). There is a clear relationship between the increase of temperature and reduction of development time and body size of zooplankton (Gillooly, 2000). In Lake Gambazinho, the lack of thermal stratification and the constant circulation of the water column make the system less stable, and consequently affect the zooplankton community. In contrast, in Lake Carioca, the water-column stratification makes the system more stable, forming strata with different conditions for the plankton.

Some authors (Matsumura-Tundisi, 1997; Panarelli et al., 2001; Rietzler et al., 2002) have associated the organisms' body size with the trophic state of the environment. Thus, species of larger body size, such as Calanoida (mostly herbivorous) would occur mainly in oligotrophic environments, whereas, Cyclopoida would occur in meso-eutrophic environments because of the ability of the individuals of this order to manipulate larger-sized food particles (Gannon and Stemberger, 1978; Pace, 1986; Harper, 1992). However, the correlations tested in this study showed no influence of the

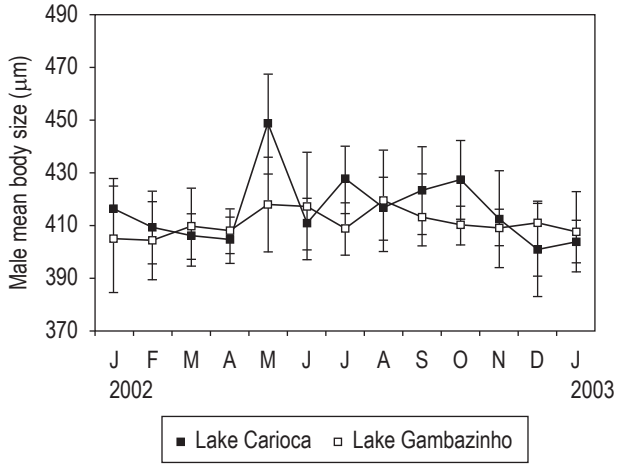

Figure 4. *Thermocyclops minutus* male mean body size (µm) during January/02 to January/03 in lakes Carioca and Gambazinho.

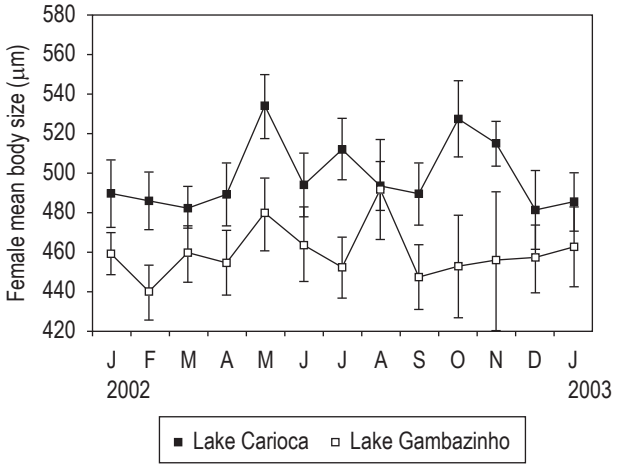

Figure 5. *Thermocyclops minutus* female mean body size (µm) during January/02 to January/03 in lakes Carioca and Gambazinho.

Table 1. Spearman correlations (r) between mean *T. minutus* body size, mean water column temperature, total phosphorus geometric mean (trophic state), and mean density of *Chaoborus* larvae for lakes Carioca and Gambazinho. Boldface indicates values with significant correlations ($p < 0.05$).

	Lake Carioca		Lake Gambazinho	
	Male	Female	Male	Female
Temperature	**–0.8729**	**–0.9963**	**–0.9388**	**–0.9485**
Trophic state	–0.6952	–0.5895	0.5998	0.3219
Chaoborus larvae	**0.9497**	**0.8171**	**0.9659**	**0.9814**

degree of trophy, as measured by the phosphorus concentrations, on *T. minutus* body size. In Lake Gambazinho, beside other food sources, the high abundance and large biomass of cyanophyceans (over 90% of the phytoplankton community) (PELD, 2008) makes this group the main food resource for *T. minutus*. In Lake Carioca, besides the cyanophyceans, other algal groups are also available (chlorophyceans and desmids) (PELD, 2008). Studies in Lake Dom Helvécio associated the high abundance of this cyclopoid with its raptorial habit and ability to manipulate particles larger than 50 µm, such as cyanophyceans (Matsumura-Tundisi et al., 1997a, Maia-Barbosa et al., 2003). However, because cyanophyceans have low nutritional value (Rietzler and Espíndola, 1998) the greater consumption of this group by *T. minutus* in Lake Gambazinho can affect its development, resulting in smaller-sized individuals. Although *T. minutus* may have its distribution associated with higher densities of cyanophyceans (Matsumura-Tundisi et al., 1997a), because of the omnivorous habits of this species (Matsumura-Tundisi et al., 1997b), other types of food are certainly being used, such as phytoflagellates, rotifers, and detritus, and possibly nauplii and younger copepodids of its own and other copepod species.

Although predation by fish and *Chaoborus* was not evaluated by experiments, its effect cannot be ignored. Studies have demonstrated that stage III and IV *Chaoborus* larvae are preferential predators of cladocerans, copepodids, and adults of copepods (Lewis, 1999; Arcifa, 2000). Thus, the larger size of *T. minutus* observed in Lake Carioca, where the density of these larvae is higher (mean density: Carioca, 1050 org.m^{-3}; Gambazinho, 745 org.m^{-3}, U = 934.00; Z = 1614.0; p = 0.0211), could be an effect of the predation by *Chaoborus* larvae, which, according to several authors (Hanazato, 1990; Mumm, 1997), would select mainly smaller-sized prey. Higher densities were observed by Bezerra-Neto et al. (2009) in recent work with *Chaoborus* larvae in Lake Carioca (means between 8.5 and 23.3 x 10^3 org.m^{-2}). In Lake Gambazinho, one of the few lakes in the Middle Doce River system where there are no exotic fish species (Latini and Petrere, 2004), the smaller body size of *T. minutus* could be an effect of predation by native fish, mainly of the larvae and young of these species (Roche and Rocha, 2005), since, in small lakes, the role of these fish in the zooplankton community structure and in determining the body size of their components is more pronounced (Jeppensen et al., 2000; Blumenshine et al., 2000; Rettig, 2003).

The smaller body size of *T. minutus* in Lake Gambazinho may be related to the predominance of cyanophycean algae and constant circulation of the water column. Lake Carioca, due to its stable water column, at least during the thermal stratification period, and greater food resource availability, may provide better conditions for body growth of the zooplankton organisms. The results of this study suggested that the body size of *T. minutus* in Lakes Carioca and Gambazinho could be influenced by the characteristics of the environment (thermal structure) and by the biotic relationships (food, predation).

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