Effects of net cages on the vertical distribution of zooplankton in a semi-arid reservoir, northeastern Brazil

Interferência de tanques-rede na distribuição vertical do zooplâncton num açude do semi-árido, nordeste do Brasil

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Abstract: Aim: Carneiro reservoir is an aquatic environment used for net cage aquaculture activities, located in the semi-arid region of northeastern Brazil. Vertical distribution was evaluated in order to determine the effects of organic enrichment induced by aquaculture on zooplankton movements. **Methods**: three replicate samples were collected during midday and midnight at each of three depths along the water column (i.e. surface: 0 m; middle: 2 m and bottom: 4 m) at two sites (near and far from the net cages). Samples were collected using a 3 L volume capacity Van Dorn bottle. The collected individuals were preserved in a 4% formaldehyde solution saturated with sugar and, later, identified and counted on a Sedgwick-Rafter chamber under a microscope, considering a minimum of 100 individuals per subsample. **Results**: higher species richness and density were observed at the N station (nearby the net cages) compared to the F station (distant from the net cages). With few exceptions, Rotifer species did not exhibit typical vertical migration patterns, concentrating at bottom depths during daytime and at intermediate depths during nighttime. *Brachionus dolabratus* and *Hexarthra mira* were the only species to show reverse vertical migration at the N station, in opposition to patterns of the cyclopoid copepod *Termocyclops crassus*. Furthermore, vertical migration patterns were not clear for Cladocera and Copepoda species nearby the net cages, but were rather clear at the F station. **Conclusions**: the presence of fish net cages increased zooplankton species richness (mostly rotifers) and density. Vertical movements were more pronounced at sites distant from net cages, suggesting that the increased food availability reduced the need for the typical vertical movements during daytime at sites nearby the net cages.

Keywords: vertical distribution, fish net cages, semi arid region, zooplankton.

Resumo: Objetivo: O açude do Carneiro é um ambiente aquático utilizado para atividades de aquicultura em tanques-rede, localizado na região semi-árida do nordeste do Brasil. A distribuição vertical foi avaliada com a finalidade de determinar os efeitos do enriquecimento orgânico induzido pela aquicultura nos movimentos do zooplâncton. **Métodos**: três réplicas amostrais foram coletadas à meia noite (0:00 horas) e ao meio dia (12:00 horas) em cada uma de três profundidades da coluna d'água (i.e. superfície: 0 m; meio: 2 m e fundo: 4 m) em duas áreas (próximo e distante dos tanques-rede). As amostras foram coletadas utilizando uma garrafa de Van Dorn com 3 L de capacidade volumétrica. Os indivíduos coletados foram preservados em uma solução de formol a 4% saturada com açúcar e, posteriormente, identificados e quantificados com uma câmara de contagem Sedgwick-Rafter sob microscópio, considerando um mínimo de 100 indivíduos por subamostra. **Resultados**: a riqueza de espécies e a densidade foram maiores na estação N (próxima aos tanques-rede) quando comparadas com a estação F (distante dos tanques-rede). Com poucas exceções, espécies de Rotifera não exibiram padrões típicos de migração vertical, concentrando-se nas camadas mais profundas durante o dia e nas camadas intermediárias durante a noite. *Brachionus dolabratus* e *Hexarthra mira* foram as únicas espécies que mostraram padrões de migração vertical inversos na estação

N, em oposição aos padrões do copépodo ciclopóide *Termocyclops crassus*. Além disso, padrões de migração vertical não foram claros para as espécies de Cladocera e Copepoda próximos aos tanques-rede, mas foram evidentes na estação F. **Conclusões**: a presença de tanques-rede para peixes aumentou a riqueza de espécies (a maioria rotíferos) e a densidade de zooplâncton. Movimentos verticais foram mais pronunciados nos locais distantes dos tanques-rede, sugerindo que o aumento da disponibilidade de alimento reduziu a necessidade dos movimentos verticais típicos durante o dia, nos locais próximos aos tanques-rede.

Palavras-chave: distribuição vertical, tanques-rede de peixes, região semi-árida, zooplâncton.

1. Introduction

Daily cycles, including diel vertical migrations, are typical of zooplankton organisms. Several environmental factors, namely, water temperature, dissolved oxygen and water transparency may potentially induce and influence patterns of zooplankton vertical distribution (Wissel and Ramacharan, 2003). Nevertheless, predator avoidance is deemed to be a major hypothesis explaining the adaptive advantages of this periodic vertical movement (Haney, 1988; Pearre Junior, 2003; Wissel and Ramacharan, 2003). Given the metabolic costs of this behavior, location of zooplankton within the water column during daytime appears to be regulated by the level of predator risk (Bollens and Frost, 1989; Van Gool and Ringelberg, 1998a).

Typically, zooplankton individuals vulnerable to planktivory stay at deeper waters during daytime, where visual fish predators are less likely to be successful at their capture. During nighttime, however, these individuals migrate to surface waters where food quality is higher (Iwasa, 1982; Stirling et al., 1990; Ringelberg, 1991a, b).

Vertical migration is a size-dependent behavior, given that the small size of several zooplankton species constrains visual detection by predators. These species, therefore, do not exhibit periodic vertical migrations, permanently staying at nutrient-rich, surface waters, where food intake is, theoretically, more efficient than that of migrating species (Guisande et al., 1991).

Invertebrate predators, such as cyclopoid copepods may also potentially prey on small zooplankton, mostly rotifers (Williamson, 1983; Plaβmann et al., 1997), thus influencing the structure and dynamics of the overall plankton community (Haney, 1988; Karabin, 1978; Matsumura-Tundisi et al., 1990). In this way, these non-visual predators also play an important role regulating zooplankton migration processes (Haney, 1988).

Aside from predation, food availability is also an important factor influencing the vertical distribution of zooplankton. Flik and Ringelberg (1993) observed that individuals remain at surface depths with high predation pressure when food availability is very low. This comes about when the costs of periodically avoiding a depth of high predation-risk outweigh the benefits, in a so-called 'better dead than unfed' strategy (Liu et al., 2003).

Given the abovementioned, the present study aimed to evaluate the influence of net cages on the vertical distribution of zooplankton individuals at Carneiro reservoir (semi-arid northeastern region of Brazil) between two sampling stations located near and far from cultivation sites. Specifically, the following hypothesis was tested: the presence of net cages negatively affects the vertical distribution of zooplankton individuals.

2. Methodology

Carneiro reservoir is located at Jericó city, semi-arid region of Paraíba state, northeastern Brazil. The reservoir has a maximum volume capacity of 31,000,000 m^3 (Açude Carneiro, 2010) (Figure 1) where fish culture in open net cages is amongst the most common activities. The reservoir is located at an altitude of 289 m (Google Earth). Published data on limnological conditions at this site are unknown.

Water transparency was determined via Secchi disk depth.

Zooplankton samples were collected at 12:00 PM and 12:00 AM using a 3 L volume capacity Van Dorn bottle (totaling 12 L of collected water) at depths of 0 m (surface), 2 m (intermediate depth) and 4 m (bottom). The collected individuals were preserved in a 4% formaldehyde solution saturated with sugar.

Zooplankton individuals were collected at two stations. The N station was a nearby site, located 0.5 m from the net cages at coordinates (6° 31' 26" S and 37° 50' 55" W), whereas the F station was a far site located approximately 100 m from net cages at coordinates 6° 31' 21" S and 37° 50' 57" W. Individuals at the former station are most likely to be influenced by fish culture activities, the opposite being true for the latter station. Further, to evaluate day-night shifts and differences in vertical distribution patterns between stations samples were conducted at noon and at midnight.

Three replicates were collected at the surface, intermediate and bottom depths of sampling stations N and F. The average densities of the three replicates, expressed as ind.L^{-1}, were used as the representative of each depth.

The collected individuals were identified and counted on a Sedgwick-Rafter chamber under a microscope. A minimum of 100 individuals of each sample were counted. Taxonomic identification followed Ruttner-Kolisko (1974) and Koste (1978) for rotifers, El Moor-Loureiro (1997) for cladocerans, and Reid (1985) and Wright (1936) for copepods.

To evaluate differences among depths (i.e. surface, intermediate and bottom), a one-way ANOVA was conducted. In the case of significance, Tukey's test was used to assess multiple comparisons of means. Further, non-parametric Kruskal-Wallis rank test was conducted whenever ANOVA assumptions were violated. Statistical analyses were conducted on Statistica software for Microsoft Windows (Statsoft, 1998).

3. Results

Water transparency differed between stations due to lower values observed at station N compared to station F. Average values of Secchi disk depth were 0.80 m in N station (±0.00 SD) and 0.74 m (0.05) in F station.

A summary of the collected zooplankton species is shown in Table 1. In general, zooplankton composition was seemingly similar at the two stations. Nevertheless, station N (16 species) showed higher species richness than station F (12 species).

The largest crustacean species recorded during the study were the calanoid copepod *Notodiaptomus cearensis* Wright, 1936, the cyclopoid copepod *Thermocyclops crassus* Fischer, 1853, and the cladoceran *Ceriodaphnia cornuta* Sars, 1885 (Table 1). Moreover, although *Diaphanosoma spinulosum* Herbst, 1975 was recorded at Carneiro reservoir (Table 1), its very low density and frequency constrained a comparative analysis.

ANOVA results revealed that *C. cornuta* was mostly abundant at the intermediate depth of station N, during daytime. Further, *N. cearensis* and

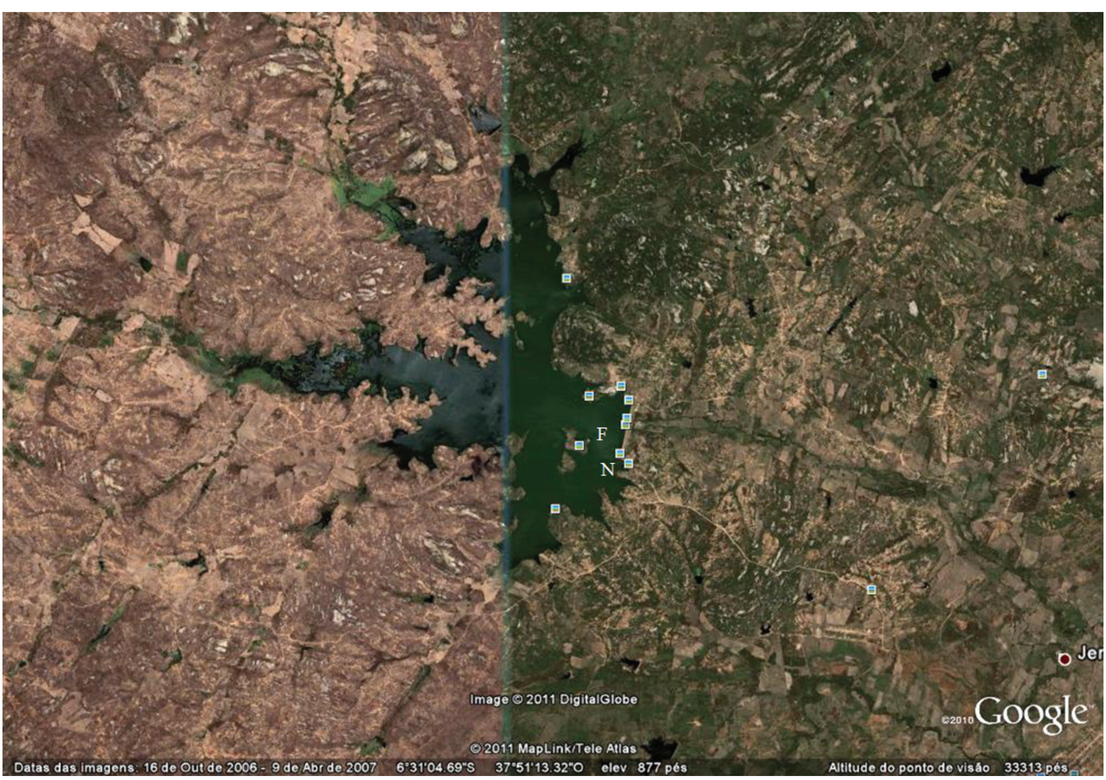

Figure 1. Location of Carneiro reservoir, Jericó, Paraíba, Brazil.

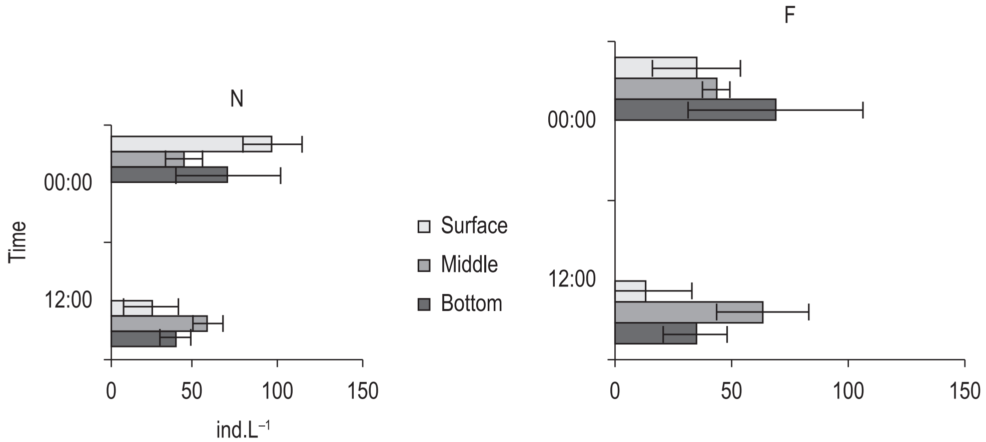

Figure 2. Density (ind.L^{-1}) of *Ceriodaphnia cornuta* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

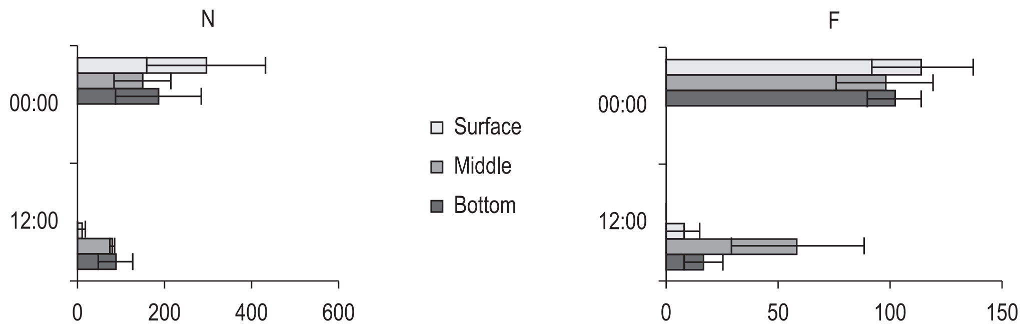

Figure 3. Density (ind.L^{-1}) of *Notodiaptomus cearensis* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

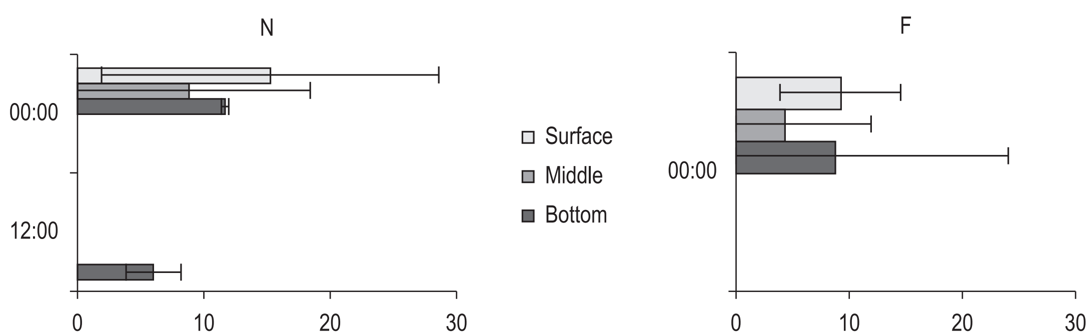

Figure 4. Density (ind.L^{-1}) of cyclopoid copepod *Termocyclops crassus* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

T. crassus were also more abundant at deeper waters (depths of 2 and 4 m, respectively) during daytime (Table 1; Figures 2-4).

At the F station, during daytime, the cladoceran *C. cornuta* was more abundant at the intermediate depth, whereas during nighttime they were significantly more abundant at the bottom (F station) and surface (N station) (Figure 1) (Table 2). Water transparency increased with distance from net cages and *C. cornuta* individuals avoided surface waters, even during nighttime, at these sites. Conversely, high turbidity nearby net cages prompted individuals of this species to feed on the surface depth, which has optimal feeding conditions. Therefore, at the N station, due to higher turbidity, this species showed periodic migration to the surface, whereas at the F station, which is not influenced by aquaculture activities, vertical migration was precluded due to the existence of clear waters even at night. A higher number of Calanoid copepods was collected during night. These individuals concentrated on the bottom during daytime and showed a somewhat homogenous distribution along the water column during nighttime. Cyclopoid copepods were not recorded at the F station during daytime. At the N station, individuals of this species were recorded solely on the bottom at night, whereas during daytime individuals were evenly dispersed throughout the water column (Figure 4).

Rotifer species such as *Brachionus havanaensis* Rousselet, 1911, *B. calyciflorus* Pallas, 1776 and *Keratella tropica* Apstein, 1907, along with cyclopoid copepodites did not reveal migration patterns at neither station. On the other hand, *Brachionus dolabratus* Harring, 1914 individuals were mostly abundant at the surface and intermediate depths of the reservoir during daytime at both stations. During nighttime, this species was recorded solely at the surface (Figure 5)

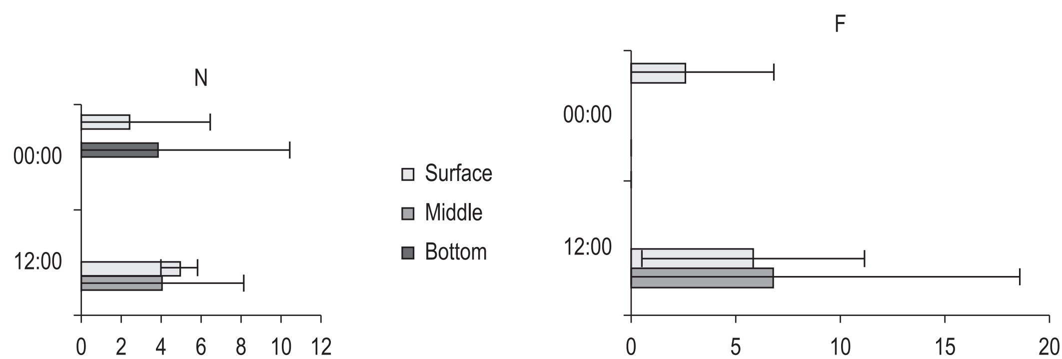

Figure 5. Density (ind.L^{-1}) of *Brachionus dolabratus* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

Table 1. Zooplanktonic species recorded at the two evaluated sampling stations (N and F) at Carneiro reservoir.

Rotifera	Stations N	F
Brachionus calyciflorus	x	x
B. dolabratus	x	x
B. havanaensis	x	x
Euchlanis dilatata	x	
Filinia longiseta	x	x
F. opoliensis	x	x
Keratella tropica	x	x
K. quadrata	x	
Keratella cochlearis	x	x
Lecane luna	x	
Hexarthra mira	x	x
Cladocera		
Alona poppei	x	
Ceriodaphnia cornuta	x	x
Diaphanosoma spinulosum	x	x
Copepoda Calanoida		
Notodiaptomus cearensis	x	x
Copepoda Ciclopoida		
Thermocyclops crassus	x	x
Total	16	12

Table 2. Results of ANOVA and Tukey's test on the differences in zooplanktonic densities among Surface (S), Intermediate (M) and Bottom (B) depths at 12:00 PM and 12:00 AM, at the N and F stations. Note that only the variables which showed significant differences (at the 5% level) are shown.

	ANOVA – 12:00 PM		
	F (2.6)	*p* value	Tukey
N			
Nauplii	6.3	0.04	S < B
Filinia opoliensis	**10.15**	**0.01**	**S < M = B**
F			
Filinia opoliensis	5.58	0.04	S < M > B
	ANOVA – 12:00 AM		
	F (2.6)	*p* value	Tukey
N			
C. cornuta	6.08	0.036	S < M = B
N. cearensis	**21.33**	**0.001**	**S < M = B**
T. crassus	21.54	0.002	S < M = B
F			
C. cornuta	5.89	0.04	S < M = B
N. cearensis	**8.1**	**0.027**	**S < M > B**

*Values in bold were log-transformed.

of the F station, and at the surface and bottom of the N station. This suggests that *B. dolabratus* avoids invertebrate predators such as the copepod *T. crassus* during daytime at both stations. During daytime, this cyclopoid copepod was restricted to the bottom at the F station and was not recorded at the N station. A similar result was obtained by Crispim (1998), which observed an inverse pattern of vertical distribution between some rotifer species and cyclopoid copepods. Furthermore, this pattern may be related to the lack of vertical movements, as commonly observed for rotifers. Due to the higher availability of food at the N station, migratory behaviors seem not to be required at this site. On the other hand, at the F station, the benefits of migrating to a depth of higher organic matter and phytoplankton concentrations outweigh the energy costs involved in their dislocation.

At the F station, *Hexarthra mira* Hudson, 1871 did not exhibit vertical migration patterns. Nevertheless, at the N station, individuals of this species were recorded exclusively at the surface during daytime and exclusively at the bottom during nighttime (Figure 6), suggesting a typical vertical reverse migration. As previously described, the higher food availability at the N station enabled this species to stay at the bottom in order to avoid copepods. In the present study, this species, along with *B. dolabratus*, were the only rotifers showing migratory behaviors in opposition to the pattern observed by *T. crassus* (Figure 4). The other rotifers did not exhibit migratory behaviors.

Within nauplii, individuals were most abundant at deeper waters (2 and 4 m depths) during nighttime, particularly at the N station (Figure 7). During daytime, however, significant vertical differences were not observed for these individuals. A similar pattern of vertical distribution was recorded for *Filinia opoliensis* Zacharias, 1898, which was mostly abundant at deeper waters (2 to 4 m depths) during nighttime at both stations (Figure 8) and concentrated at intermediate waters (i.e. 2 m depth) during daytime.

4. Discussion

The higher number of zooplankton species recorded at the N station is probably an effect of net cages providing additional surface areas for biofilm development. Phytoplankton is an important source of food for several herbivores, supporting niche diversification and, thus, increasing the complexity of trophic webs. In addition, the N station is subject to higher nutrient concentrations, as a consequence of aquaculture activities, therefore increasing food supply at this site when compared to the F station. In fact, this increase in nutrient concentration reflected on observed lower water transparency values at the former site.

Larger zooplankton species tended to concentrate at deeper waters during daytime, where predation risk by visual predators was minimized. By performing a periodic vertical movement, these individuals avoid the surface layers during periods of high predation susceptibility (Pearre Junior, 2003; Wissel and Ramacharan, 2003). Visual planktivores depend on optimal light conditions to increase prey capture efficiency, selectively picking remaining zooplankton individuals at the surface depths during daytime (Haney, 1988). Thus, diel vertical migration is an important predator-avoidance strategy employed by zooplankton individuals (Zaret, 1980; Stirling et al., 1990; Pearre Junior, 2003; Wissel and Ramacharan, 2003) regardless of the energy costs involved (Guisande et al., 1991). Given the high vulnerability of large-bodied zooplankton individuals to visual predators, migratory behaviors, concentrating individuals at deeper waters during daytime, is vital for these organisms. In the present study, selection of deeper waters during daytime was observed, particularly, for copepods.

Vertical migration is also dependent upon differences in temperature and food concentration between the surface and the bottom (Dawidovicz and Loose, 1992). Not only visual detection of zooplankton individuals by planktivores decreases with depth, but also temperature and, frequently, food availability (Van Gool and Ringelberg, 1998b).

Small zooplankton species (i.e. *Brachionus havanaensis*, *B. calyciflorus*, *K. tropica* and cyclopoids copepodites) did not exhibit migratory behavior at any of the evaluated stations due to their low visibility and, hence, lower predation risk. In fact, compared to large crustaceans and insect larvae, rotifers make up an insignificant percentage of the diet of most vertebrate predators. Given the low predation risk by planktivorous fishes, these small zooplankton individuals remain at privileged surface waters, reducing the energetic costs involved in vertical dislocations and having permanent access to high-quality food (Guisande et al., 1991). On the other hand, the rotifer *B. dolabratus*, unusually, showed a typical vertical migration pattern at the N station. Specifically, higher abundances were observed at deeper and surface waters at 12:00 PM and 12:00 AM, respectively. At the F station,

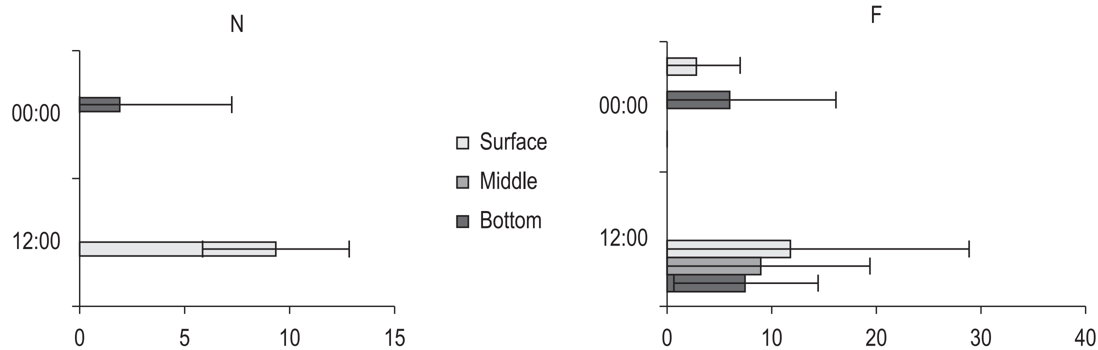

Figure 6. Density (ind.L^{-1}) of *Hexarthra mira* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

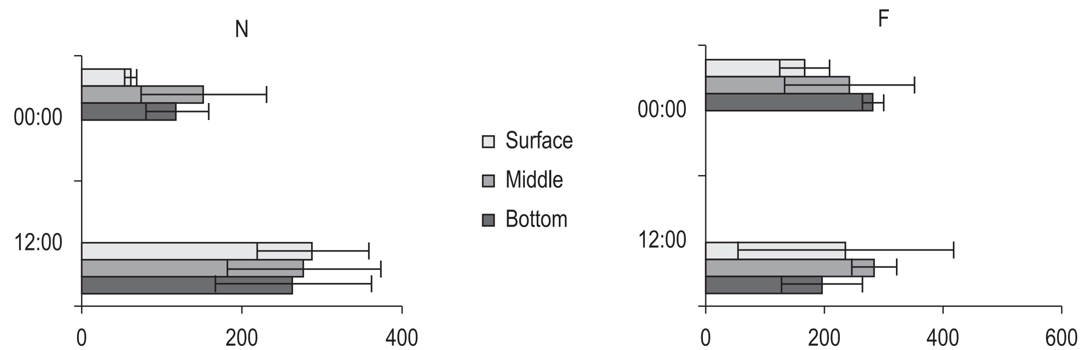

Figure 7. Density (ind.L^{-1}) of *nauplii* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

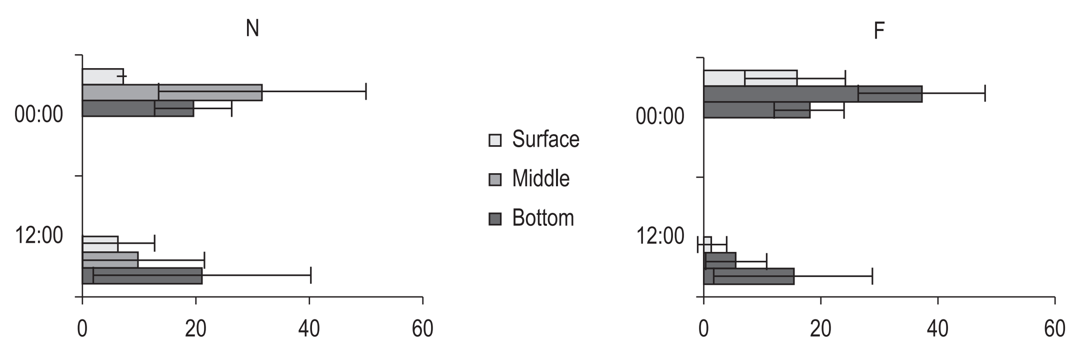

Figure 8. Density (ind.L^{-1}) of *Filinia opoliensis* at the N and F stations, during night (12:00 PM) and day (12:00 AM) at three depths (surface, intermediate, bottom). Lines at each bar represent standard deviation measures.

individuals were evenly dispersed in the water column.

Rotifers, nevertheless, make up an important proportion of the diet of invertebrate predators. Williamson (1983) showed that percent cropping rates of the cyclopoid copepod *Mesocyclops edax* Forbes, 1890 towards rotifers were approximately twice as big as the observed for adult crustaceans. This significant predation pressure probably stimulated the 'reverse' migration pattern observed exclusively by the rotifer *H. mira* at the N station. Individuals of this species were mostly abundant at deeper waters during the night and at surface waters during the day, in an opposite pattern to that of the copepod *T. crassus* (the unique invertebrate predator recorded in the present study). Similarly, *Polyarthra vulgaris* and *Pompholyx sulcata* showed reverse migration patterns, in opposition to the movements of the cyclopoid copepod *Acanthocyclops robustus* at the Maranhão reservoir (Portugal) (Crispim, 1998).

The rotifer *F. opoliensis* and nauplii were also more frequent at deeper waters (2 to 4 m) during nighttime. However, during daytime they were evenly dispersed along the water column. Crispim (1998) also observed that nauplii and juvenile copepods may show reverse vertical migrations to avoid adult copepods.

Single factors, such as predation or food availability alone, are unlikely to be the sole cause of diel vertical migration by zooplankton individuals. At most natural ecosystems, migration patterns seem to be an effect of multiple factors (Gliwicz, 1986). However, in the present study, evidence suggests that higher food availability nearby the net cages inhibited vertical movements, such as the ones observed away from the net cages. A lack of migratory behavior suggests that individuals are under a somewhat low predation pressure, thus, saving energy that would be utilized on periodic vertical dislocations. At the F station, limited food availability compelled the individuals to rise to upper layers at night. Alternatively, migratory movements observed at the N station by some rotifers are possibly the result of higher density of cyclopoid copepods, species-specific predation pressure and/or increased competition, given that some herbivores did not exhibit vertical movements.

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