Spatial and seasonal variation of microcrustaceans (Cladocera and Copepoda) in intermittent rivers in the Jequiezinho River Hydrographic Basin, in the Neotropical semiarid

Variação espacial e sazonal de microcrustáceos (Cladocera e Copepoda) nos rios intemitentes da Bacia Hidrográfica do Rio Jequiezinho, no semi-árido Neotropical

Simões, NR.[1], Sonoda, SL.[2] and Ribeiro, SMMS.[3]

[1]Departamento de Biologia, Laboratório de Zooplâncton,
Programa de Pós-graduação em Ecologia de Ambientes Aquáticos Continentais,
Universidade Estadual de Maringá – UEM,
Avenida Colombo, 5790, Bloco G-90, CEP 87020-900, Maringá, Paraná, Brazil,
e-mail: nadsonressye@yahoo.com.br

[2]Departamento de Ciências Biológicas, Laboratório de Limnologia,
Universidade Estadual do Sudoeste da Bahia – UESB,
Avenida José Moreira Sobrinho, s/n, CEP: 45200-000, Jequié, Bahia, Brazil,
e-mail: sonodasl@terra.com.br

[3]Departamento de Ciência Biológicas, Laboratório de Oceanografia Biológica,
Universidade Estadual de Santa Cruz – UESC,
Rodovia IIhéus-Itabuna Km 16, CEP 45662-000, Ilhéus, Bahia, Brazil,
ssusini@uesc.br

Abstract: Intermittent rivers are environments that show a dynamic hydrology, with a period of water flow and subsequent drought, which leads to extreme environmental variation. This study investigated spatial and seasonal influence on Cladocera and Copepoda in the Jequiezinho River Hydrographic Basin (Brazil) from September/2002 to August/2003. The JRHB is formed by intermittent rivers and is located in the Brazilian semiarid region. Sampling was carried out monthly in three sampling sites located in the upper region and other three, in the lower region of the Jequiezinho River Hydrographic Basin. Microcrustaceans were collected with a plankton net (70 µm) and preserved in formaline 4%. Twenty-eight taxa were recorded: 10 Cladocera species, 3 Calanoida species, and 15 species of Cyclopoida. The spatial differences in microcrustaceans assemblage were more pronounced than temporal ones. Only nauplii density showed significant differences between dry and rainy seasons, with high density during the rainy season. Species richness, nauplii, Cladocera and Cyclopoida densities showed differences between upper and lower regions of the hydrographic basin, with high values in the upper region. These results suggest better conditions for development of Cladocera and Copepoda in upstream than downstream stretches, likely because in the headwaters the limnological features and greater availability of niches contributes to a better organism's development. The high similarity between close stretches and the interruption of upstream-downstream longitudinal links provide aspects of the river continuum, river discontinuum and patch dynamics concepts. The hierarchical patch dynamics perspective links these concepts, providing a flexible conceptual framework for intermittent fluvial landscape ecology.

Keywords: Cladocera, Copepoda, temporary stream, semiarid.

Resumo: Rios intermitentes são ambientes que apresentam uma hidrologia dinâmica, com um período de fluxo de água e outro subseqüente seco, conduzindo o ambiente a variações extremas. Este estudo investigou a influência espacial e sazonal sobre os microcrustáceos (Cladocera e Copepoda) na Bacia Hidrografica do Rio Jequiezinho (Bahia, Brasil) de setembro/2002 a agosto/2003. A Bacia Hidrografica do Rio Jequiezinho é formada por rios intermitentes e está localizada na região semi-árida brasileira. As amostragens foram realizadas mensalmente em três locais da região superior e três locais da região inferior da bacia. Os microcrustáceos foram coletados com uma rede de plâncton (70 µm) e conservados em formalina 4%. Um total de 28 taxa foram registrados: 10 espécies de Cladocera, 3 de Calanoida e 15 de Cyclopoida. Os microcrustáceos apresentaram maiores diferenças espaciais que temporais. Apenas a densidade de náuplios apresentou diferenças significativas entre as estações seca e chuvosa, com maior densidade durante a estação chuvosa. Riqueza de espécies, densidade de náuplios, Cladocera e Cyclopoida apresentaram diferenças significativas entre as regiões superior e inferior da bacia hidrográfica, com valores mais elevados nos locais a montante. Estes resultados sugerem melhores condições para o desenvolvimento de Cladocera e Copepoda nas regiões a montante do que a jusante, provavelmente porque os fatores limnológicos e a maior disponibilidade de nichos contribuiram para o melhor desenvolvimento dos organismos. A maior similaridade entre pontos próximos e a interrupção do fluxo longitudinal de água contemplam aspectos dos seguintes conceitos: rio continuo (river continuum), rio discontinuo (river discontinuum) e dinâmica de manchas (patch dynamics). A perspectiva hierárquica de dinâmica de manchas reúne as três abordagens anteriores, fornecendo uma estrutura conceitual flexível para a ecologia de rios intermitentes.

Palavras-chaves: Cladocera, Copepoda, rios temporários; semi-árido.

1. Introduction

Half of the countries in the world exhibits a portion or all their territory in arid or semiarid regions (Ffolliott et al., 2002), and temporary rivers are broadly distributed in these environments (Pires et al., 2000; Medeiros and Maltchik, 2001; Junk, 2002; Townsend, 2002; Arab et al., 2004). Intermittent or temporary rivers are environments characterized by two extremes of dynamic hydrology of water flow: a period with water flow and another one, without it, promoting the fragmentation of the river into isolated pools (Williams, 1987; Stanley et al., 1997). The dynamics of these rivers are related to the local and regional influence of seasonality, such as, precipitation, evaporation, runoff, infiltration, hydroperiod and exchanges with the groundwater (Boulton and Lake, 1992; Williams, 1997; Schwartz and Jenkins, 2000).

Streams are hydrologically diverse and dynamic ecosystems (Stanley, 1997), that have been studied according to different ecological concepts: river continuum concept (Vannote et al., 1980), serial discontinuity concept (Ward and Stanford, 1995), nutrient spiraling concept (Newbold et al., 1983), flood pulse concept (Junk et al., 1989), hyporheic corridor (Stanford and Ward, 1993); patch dynamics concept (Townsend, 1989). These concepts are strongly oriented to the direction of downstream water movement and by connectivity (longitudinal, lateral and vertical) within of the system.

The concept that "every stream is likely to be individual" was clearly explained by Hynes (1975). Poole (2002) organized the ideas from Hynes (1975) into the hierarchical patch dynamics perspective to develop the concept of uniqueness within the river discontinuum as a framework for visualizing interactions between structure and function in fluvial landscapes. The hierarchical patch dynamics perspective describes each river as a unique system, with a patches discontinuum from headwaters to mouth (Poole, 2002).

In intermittent rivers, water shortage disrupts hydrological connectivity (Gasith and Resh, 1999; Pires et al., 2000) and fragments the environment into sub-systems with their own functional dynamic and structural characteristics (Lake, 2003; Grim, 1994). These sub-systems play an important role in the maintenance of diversity, since they constitute a temporary refuge (patches) for very different communities (Humphries and Baldwin, 2003).

In these environments, fauna presents morphological, physiological, and behavioral adaptations, which promote a high diversity and endemism (Williams, 1997). Microcrustaceans (for example) are organisms that respond quickly to changes in the physical characteristics of the habitat and can be used as ecological indicators, promoting the understanding of the interaction between physical and chemical processes. Moreover, they are important for the application and development of ecological models, since they play a primordial role in the dynamic of aquatic ecosystems, especially in nutrients turnover and in the food web, by linking primary producers to consumers (Lampert, 1997).

In Brazil, about 10% of its territory is located in semiarid regions, characterized by variable, irregular, and scarce precipitation, which may undergo from one to eleven months per year of dry period, and the fauna from intermittent environments have been scarcely studied (Crispim and Watanabe, 2000; Maltchik, 1999; Medeiros and Maltchik, 2001).

In this study, we evaluated spatial and seasonal variation on Cladocera and Copepoda assemblages in temporary rivers. The initial hypothesis was that there are spatial differences in the species richness and density of microcrustaceans between the upper and lower regions of the Jequiezinho River Hydrographic Basin, JRHB, investigating if the microcrustaceans' distribution occurs in function of these longitudinal zones (upstream and downstream stretches). Moreover, we assessed if this distribution was influenced by dry and rainy seasons.

2. Material and Methods

The Jequiezinho River Hydrographic Basin, JRHB, (Figure 1) occupies 1,339 km^2 of drainage area and is located in the Brazilian semiarid region, between 13° 40'-13° 50' S and 40° 17'-41° 06' W. The main rivers of JRHB are: Jequiezinho, Conceição and Patí streams. The vegetation of this region is called 'Caatinga', is characterized by arboreal to shrubby deciduous plants, and presents species of xerophytes. Mean precipitation varies from 50 mm in the dry season (May to October) to 95 mm in the rainy season (November to April) and due to the hydrologic variability, rivers compounding its drainage area show a high degree of intermittence. In these circumstances, pools of different sizes are frequently formed along the stream bed.

Sampling was carried out monthly (September/2002 to August/2003) in six sampling sites (Figure 1 and Table 1) distributed over the Jequiezinho River Hydrographic Basin

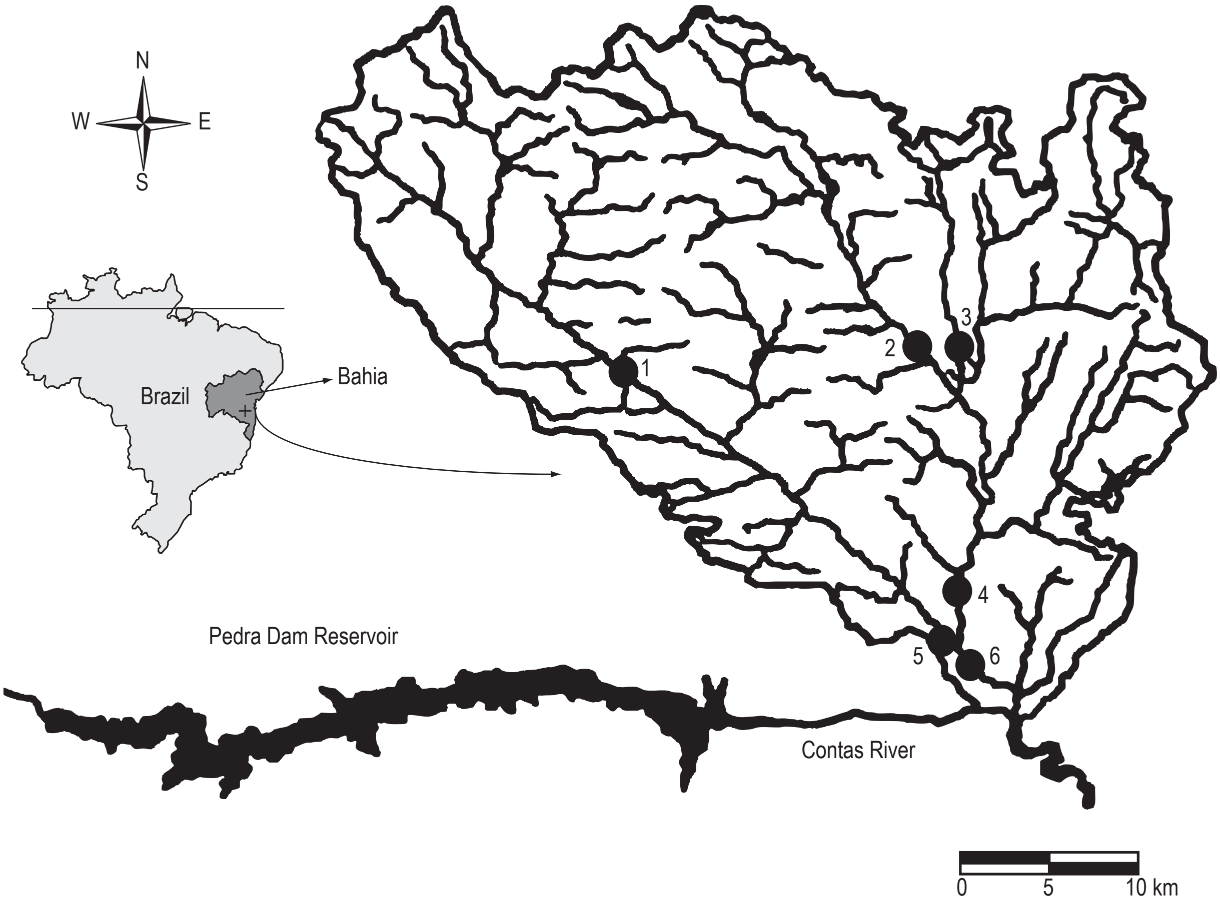

Figure 1. Sampling sites in Jequiezinho River Hydrographic Basin, Bahia, Brazil.

Table 1. Geographical position (altitude, latitude and longitude) of sites sampled in the Jequiezinho River Hydrographic Basin.

Sites	Altitude	Latitude	Longitude
1 (upstream)	481 m	13° 40' 13,2" S	40° 17' 32,5" W
2 (upstream)	348 m	13° 39' 25,3" S	40° 07' 47,1" W
3 (upstream)	375 m	13° 39' 33,8" S	40° 06' 10,9" W
4 (downstream)	244 m	13° 47' 57,4" S	40° 06' 24,5" W
5 (downstream)	239 m	13° 49' 03,8" S	40° 07' 01,9" W
6 (downstream)	222 m	13° 50' 00,0" S	40° 06' 13,1" W

(JRHB). These sites presented few riparian plants and low frequency of aquatic macrophytes throughout the year. Meanwhile, upstream sites presented more ecological types of aquatic macrophytes (emersed, free-floating, submersed, and floating-leaved) than downstream pools, which presented only one ecological type (submersed). During the samplings, 3, 4 and 5 sites dried up at some moment of the study. The water flow was observed at 2, 4 and 6 sampling sites only during October, November and December. The other sampling sites do not showed water flow.

The following environmental variables were analyzed: depth, water temperature, pH, total alkalinity (Golterman et al., 1978), dissolved oxygen (Winkler modified by Golterman et al., 1978), electric conductivity, and total suspended solids (TSS) (Tundisi, 1969).

Microcrustaceans' samples for qualitative analyses were collected through horizontal tows using plankton net (70 µm). For quantitative analyses, 100 L of water were taken in a plastic bucket, filtered in the plankton net, and preserved in 4% formalin. The organisms were identified at genus or species level using an optical microscope and specialized bibliography.

Principal Component Analysis was performed to characterize the spatial variations and to express the relationship between abiotic variables and sections of the basin. Data were standardized using a correlation matrix and to select the significant axes, we used the Kaiser-Gutman rule.

The density data were transformed in Log_2 (x + 1) to adjust them to normality and to stabilize the variance. Analysis of Variance (two-way) was carried out to test temporal (dry and rainy periods) and spatial differences (upstream and downstream section) in microcrustaceans assemblages. Species richness, nauplii, Copepoda, Cyclopoida and Cladocera density were considered. Copepoda Calanoida density was not included in the analysis since it did not reach normality assumption.

The association between the most representative axis derived from Principal Component Analysis and the individuals' density was evaluated by using the Pearson Correlation Coefficient.

3. Results

The Figure 2 presents the temporal variation of physical and chemical water features. Only the total alkalinity presented great range (min-max) in upstream sites, whereas the other variables presented high ranges at downstream sites. Seasonal trends were observed regarding pH and total alkalinity (higher values during periods with precipitation) and electric conductivity (higher values during the dry conditions).

The two first axes of the Principal Component Analysis presented an accumulative percentage of 64.38% (axis 1 and 2, 44.53 and 20.85%, respectively). The sampling units' ordination (Figure 3) associated the upstream sites positively to depth and total alkalinity, and negatively to dissolved oxygen, total suspended solids, electric conductivity, and water temperature. On the other hand, in downstream sites, high values of dissolved oxygen, electric conductivity and total suspended solids were registered (Figure 3).

Twenty-eight taxa of microcrustaceans were identified: 10 Cladocera species, 3 Copepoda Calanoida and 15 species of Copepoda Cyclopoida (Table 2). The species of Copepoda Harpacticoida were not identified. Twenty-six species were recorded in upstream stretch, while eighteen were recorded downstream. The most frequent species (70%, or more of ocurrence) in the sampling sites were: *Ceriodaphnia cornuta*, *Latonopsis australis*, *Notodiaptomus iheringi*, *N. cearensis*, *Microcyclops anceps*, *M. alius* and *Halicyclops venezuelaensis*. Over time, *L. australis* (10-460 ind.m^{-3}) and *M. alius* (10-120 ind.m^{-3}) were more frequent in the upstream stretch, whereas in the downstream one, *M. alius* (10-50 ind.m^{-3}) and *H. venezuelaensis* (10-90 ind.m^{-3}) were the species with more occurrences. Only *Notodiaptomus* species presented seasonal incidence, occurring only after the highest precipitations.

The organisms' density did not show a clear pattern over time. Total density of organisms was low towards the downstream stretch, ranging from zero (downstream, dry season) to 48,090 ind.m^{-3} (upstream, rainy season) (Figure 4), and nauplii and copepodids were more abundant than adults. Adult density also showed a decrease from upper region to lower region (Figure 5).

ANOVA results did not evidence any significant interaction between spatial and temporal variations in microcrustaceans assemblage (Table 3). However, the spatial differences (upstream and downstream) were more pronounced, than temporal ones (dry and rainy seasons).

Species richness, nauplii, Cladocera and Copepoda Cyclopoida density showed significant differences between the lower and upper sections of the basin (Table 3), and the highest values were found in the upper region of the basin. Only nauplii showed significant difference (Table 3) between the dry and rainy seasons, with highest values during the rainy season.

Significant correlations were verified between PCA scores and Cladocera ($r = 0.42$, $N = 58$, $p < 0.05$) and nauplii densities ($r = 0.34$, $N = 58$, $p < 0.05$). Thus, high densities in upstream sites were related to high values of depth and total alkalinity, and low values of dissolved oxygen, electric conductivity, and total suspended solids.

4. Discussion

During the study period, the dynamic of rivers from JRHB was characterized by the absence of constant and prolonged water flow, favoring the lentic conditions. In this period, a high drought in the region was observed, which may be influenced by El Niño climatic phenomena (http://www.cptec.inpe.br/enos/), intensifying the absence of rains in the region. Therefore, a superficial flow was registered in some points during October, November, and December, mainly after a torrential rain event in December.

The species richness of microcrustaceans recorded in the JRHB was higher than those observed in other intermittent environments (Fahd et al., 2000; Akin-Oriola, 2003; Krylov, 2004; Eitam et al., 2004). However, the abundance of microcrustaceans at JRHB was lower than those observed by Cottenie et al. (2001), Thorp and Mantovani (2005), Crispim and Watanabe (2000) and Crispim et al. (2000).

The predominance of young individuals and the high frequency of ovigerous females indicate a great reproductive effort and a high mortality rate, since very few organisms had reached the adult stage. A high number of young stages is one of the adaptive strategies in highly unstable environments (Cole, 1966). Moreover, the production of resting stages characterizes such unstable conditions of the environment (Alekseev and Starovogatov, 1996) and may compose an important source of colonization when there is improvement of environmental conditions.

High number of individuals and species richness in the JRHB occurred in sampling sites located upstream, while low values were observed in the downstream stretch. In intermittent rivers studied by Krylov (2004), Mwebaza-Ndawula et al. (2005) and Thorp and Mantovani (2005),

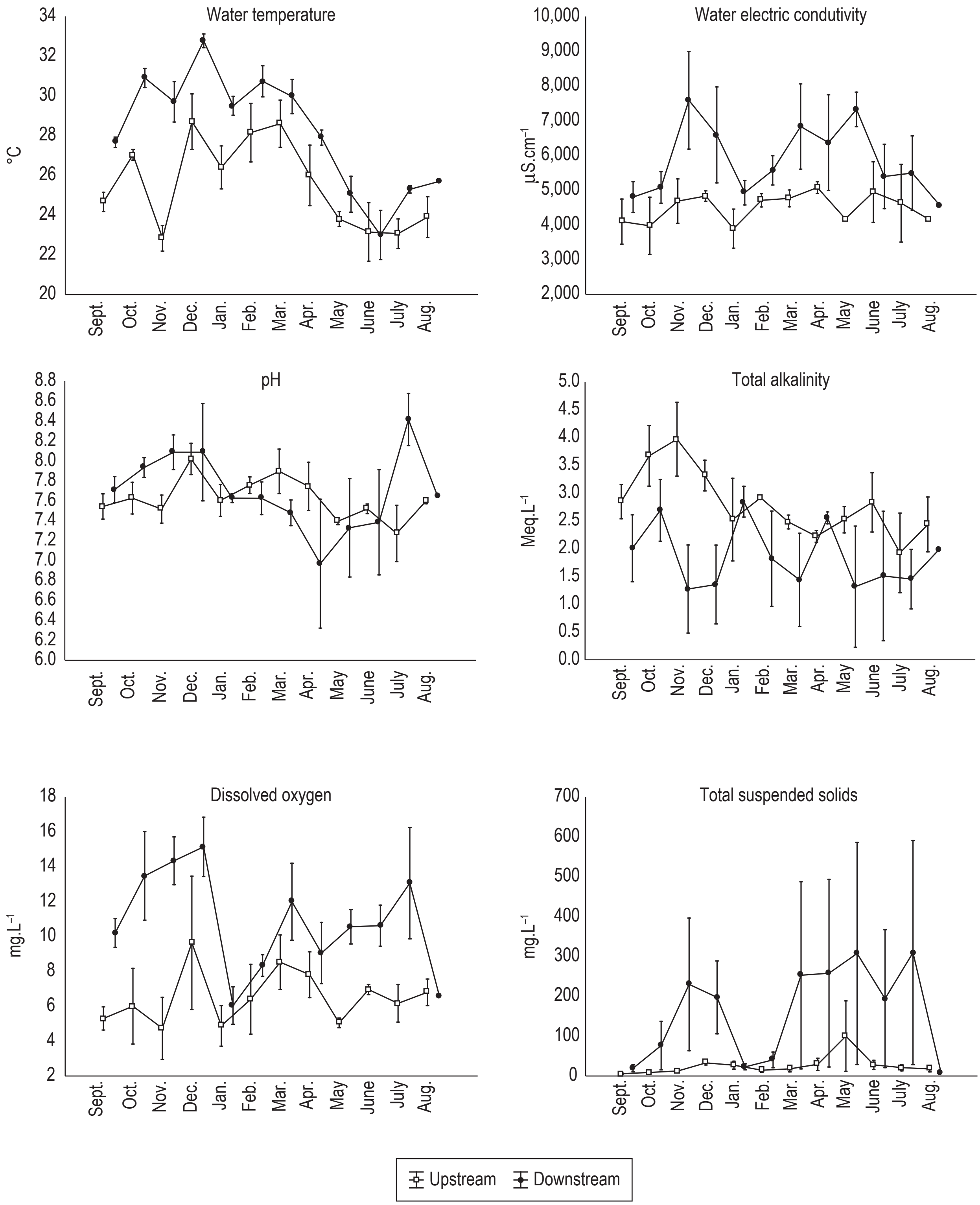

Figure 2. Temporal variation of limnological factors in the upstream and downstream Jequiezinho Hydrographic Basin (Sept./2002 at Aug./2003) (symbol = mean; bar = standard error).

similar results were observed, and these authors associated them to the environmental quality. This observation is also supposed in this study, since the upstream sites presented low values of electric conductivity and total suspended solids, high depths (representing the availability of aquatic environment) and great variety of ecological types of aquatic macrophytes, characterizing a high availability of habitats and refuge.

The presence of aquatic macrophytes increases the diversity patterns (species richness and abundance) in shallow

Table 2. Microcrustaceans (Cladocera and Copepoda) species registered in Jequiezinho River Hydrographic Basin (from September 2002 to August 2003).

Copepoda
DIAPTOMIDAE
Argyrodiaptomus azevedoi (Wright,1935)
Notodiaptomus cearensis (Wright, 1936)
Notodiaptomus iheringi (Wright, 1935)
CYCLOPIDAE
Ectocyclops cf. *rubescens (*Brady, 1904)
Eucyclops sp.
Mesocyclops cf *ellipticus* (Kiefer, 1936d)
Mesocyclops longisetus longisetus (Thiébaud, 1914)
Mesocyclops meridianus (Kiefer, 1926)
Metacyclops sp.
Microcyclops alius (Kiefer, 1935a)
Halicyclops cf. *venezuelaensis* (Lindberg, 1954a)
Microcyclops ceibaensis (Marsh, 1919)
Microcyclops anceps (Richard, 1897)
Microcyclops anceps anceps (Richard, 1897)
Thermocyclops inversus (Kiefer, 1929)
Thermocyclops minutus (Lowndes, 1934)
Thermocyclops cf. *tenuis* (Marsh, 1910)
Thermocyclops cf. *brehmi* (Kiefer, 1927)
Cladocera
CHYDORIDAE
Alona cf. *verrucosa* (Sars, 1861)
Alona davidi (Richard, 1895)
DAPHIIDAE
Ceriodaphnia cornuta (Sars, 1886)
Simocephalus latirostris (Stingelin, 1906)
Daphnia gessneri (Herbst, 1967)
MACROTHRICIDAE
Macrothrix triserialis (Brady, 1886)
Macrothrix laticornis (Jurine, 1820)
Macrothrix superaculeata (Smirnov, 1992)
MOINIDAE
Moinodaphnia macleayi (King, 1853)
SIDIDAE
Latonopsis australis (Sars, 1888)

Table 3. ANOVA results for microcrustaceans assemblages in the Jequiezinho River Hydrographic Basin.

	F- interation	F- Season	F- Spatial
Species Richness	2.31	0.01	13.01*
Cladocera	0.28	0.64	7.46*
Cyclopoida	0.37	0.29	6.42*
Nauplii	0.10	6.50*	13.40*

F = Statistic; * = Significant values ($p < 0.05$).

aquatic environments (Scheffer et al., 2006), providing high niches availability (Fahd et al., 2000; Cottenie et al., 2001), and for zooplankton they represent refuge from predation and decrease the disturbances pressure in the system (Scheffer, 1998).

Lower densities observed downstream, in JRHB, also may be a consequence of discharge variation. The discharge variation (occurring only during October, November and

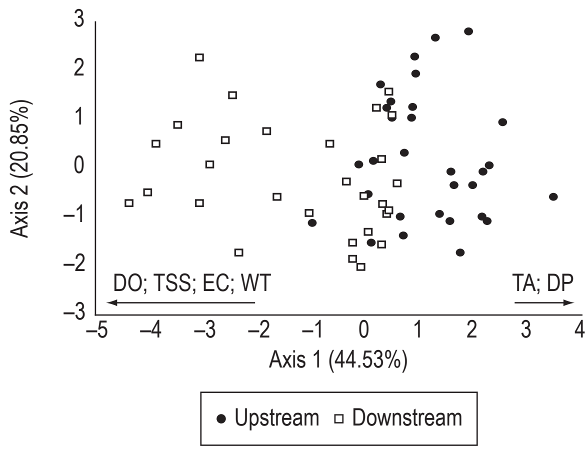

Figure 3. Principal Component Analysis showing the ordination of the sampled unities in the Jequiezinho River Hydrographic Basin (WT – Water temperature; EC – Electric conductivity; TA – Total alkalinity; DO – Dissolved oxygen; TSS – Total suspended solids; DP – Depth).

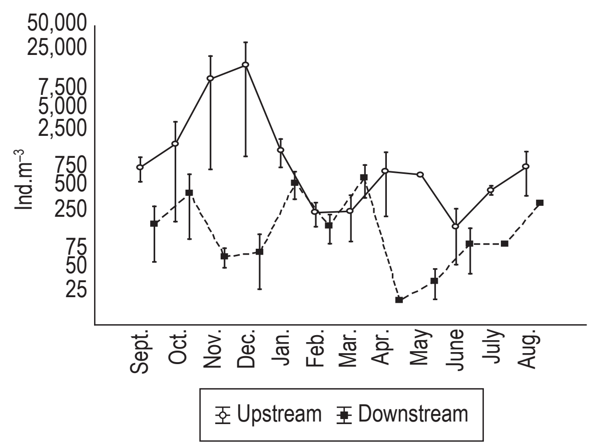

Figure 4. Spatial and seasonal variation of microcrustaceans density (adults + young) in the Jequiezinho River Hydrographic Basin, from September 2002 to August 2003 (logarithmic scale) (symbol = mean; bar = standard error).

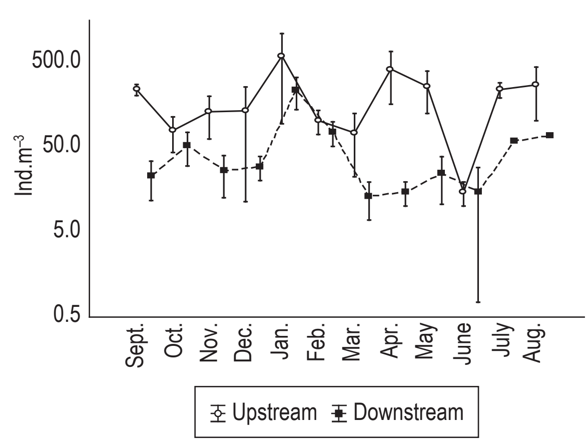

Figure 5. Spatial and seasonal variation of microcrustaceans density (adults) in the Jequiezinho River Hydrographic Basin, from September 2002 to August 2003 (logarithmic scale) (symbol = mean; bar = standard error).

December, at 2, 4 and 6 sampling stations), in spite of sporadic was enough to modify zooplankton densities, decreasing the number of individuals in the downstream sites. This can be explained by the fact that the downstream areas receive a greater volume of water coming from the watershed, promoting an increase in the flow, which does not favor the turnover of zooplankton generations. According to Sendacz and Monteiro-Jr. (2003), the discharge variations in downstream regions suppress growth and reproduction of filtering microcrustaceans.

Despite of the great proportion of adult Calanoida copepods, observed during rainy season, and adult Cyclopoida, in the dry season, only nauplii densities showed significant differences between seasons. Angeler et al. (2000) and Freitas and Crispim (2005) also recorded the impact of dynamic hydrology on the zooplankton abundance in temporary environments. In the JRHB, the rains contributed to the increase of organisms' density, significantly to young stages, and it might be related to the increase in resource availability due to the input of nutrient in the systems (Quitana et al., 1998) and with the interruption of limiting conditions caused by drought. The periodic events of drought and rain play an important role on the biota of temporary aquatic systems, with direct and indirect impacts on these organisms. Direct impacts are those caused by loss of water and flow, and habitat reduction and reconfiguration, whereas indirect impacts are those associated with changes in phenomena such as interspecific interaction, especially predation and competition, and the nature of food resources (Lake, 2003).

The differences found in this study suggest that upstream sites in the Jequiezinho River Hydrographic Basin presented better conditions (depth, aquatic macrophytes and water flow absent) for assemblages of Cladocera and Copepoda than the downstream ones. It happens, probably, because in the headwaters these conditions improve the quality of the habitat (suggesting greater availability of niche), contributing to a better development of organisms, whereas the downstream sites are more influenced by fluvial discharge during rainy season becoming less favorable to the development of planktonic organisms.

However the connectivity have been disrupted by the interruption of upstream-downstream longitudinal links, a picture of longitudinal zoning (Vanote et al., 1980) jointly with environments distributed in patches (Townsend, 1989), seem to generate pools of potential colonist for the development of organisms (Lake, 2000) in the upstream regions. The hierarchical patch dynamics perspective (Poole, 2002) provides a flexible conceptual framework for fluvial landscape ecology because it views lotic ecosystems as a discontinuum of hierarchically nested and interactive elements, linking concepts of river continuum, serial discontinuity, flood pulse, hyporheic corridor and patches dynamics. These concepts can be employed in intermittent rivers, emphasizing that their theories do not entirely consider the patterns and processes occurring in these ecosystems.

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