Zooplankton composition in aquatic systems of semi-arid Brazil: spatial variation and implications of water management

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Abstract. This study compares major taxa of zooplankton (Rotifera, Cladocera and Copepoda) between natural (intermittent streams) and artificial (reservoirs) aquatic systems in semi-arid Brazil to evaluate spatial variation of taxa abundance according to habitat type and the implications of water management on zooplankton composition. The zooplankton fauna recorded was composed of 42 species distributed across 21 families. Assemblage richness was dominated by Rotifera, which presented 13 families and 32 species. Brachionidae was the richest taxon (13 species), followed by Lecanidae (4 species) and Filiniidae (3 species). Cladocera were represented by 5 families and Chydoridae was the richest with 2 species. Copepoda presented three families with 4 species. Zooplankton composition did not vary between the study areas. However, segregation among sites (managed and natural) was observed within each study area. Results indicate that the modification of natural patterns of water flow and promotion of lentic conditions has the potential to interfere with zooplankton communities by favoring groups with slower growth rates such as Cladocera and Copepoda. Given the notion that factors affecting the structure and composition of the zooplankton community lie at several levels of the river watershed, decision-makers must identify the parts of the riverine ecosystems that are vital to maintaining its health, in order to propose (or re-evaluate) management and conservation policies for dryland streams.

Keywords: Rotifera, Cladocera, Copepoda, intermittent stream, reservoir, semi-arid

Resumo. **Composição do zooplâncton em ecossistemas aquáticos do semiárido brasileiro: variação espacial e implicações do manejo.** Este estudo compara a riqueza e densidade do zooplâncton (Rotifera, Cladocera e Copepoda) entre ambientes aquáticos naturais (rios intermitentes) e artificiais (reservatórios) do semiárido brasileiro com o objetivo de avaliar a variação espacial dos taxa de acordo com o tipo de habitat e comentar as implicações do manejo desses sistemas na composição do zooplâncton. A fauna foi composta por 42 espécies distribuídas entre 21 famílias. As comunidades foram dominadas, em termos de riqueza de espécies, pelos Rotifera, que apresentaram 13 famílias e 32 espécies. Brachionidae foi o taxon mais rico com 13 espécies, seguido por Lecanidae (4 espécies) e Filiniidae (3 espécies). Cladocera apresentou 5 famílias dentre as quais Chydoridae foi a mais rica com 2 espécies. Copepoda apresentou 3 famílias e 4 espécies. A composição do zooplâncton não variou entre as áreas de estudo. Contudo, observou-se segregação entre os locais de estudo (artificiais e naturais) dentro de cada área estudada. Os resultados do presente estudo indicam que modificações nos padrões naturais de fluxo pela implementação de condições lênticas tem o potencial para interferir na composição do zooplâncton e favorecer grupos com taxas de crescimento mais lentas como Cladocera e Copepoda. Tendo em vista que fatores que afetam a estrutura e composição das comunidades de zooplâncton podem ser determinados em escalas diferentes da bacia hidrográfica, deve-se identificar que partes dos sistemas ribeirinhos são vitais para manutenção da integridade biológica antes de propor (ou reavaliar) as políticas de manejo de ecossistemas e conservação de espécies em ambientes aquáticos de áreas secas.

Palavras chave: Rotifera, Cladocera, Copepoda, rios intermitentes, reservatórios, semiárido

Introduction

Drylands cover approximately 48% of the Earth´s land surface and are inhabited by 38% of the total global population (some 6.5 billion people) (Reynolds *et al.* 2007). Even though these areas include deserts, arid and semi-arid lands and dry sub-humid regions, semi-arid regions alone comprise almost 18% of drylands (Kassas 1999). Drylands are usually associated with (1) high and variable degrees of aridity which reflect low ratios between precipitation and evapotranspiration; and (2) unevenly distributed (frequently sparse) and temporally variable vegetation cover (Tooth 2000). According to Tooth (2000) water resource issues, such as catchment management, are rapidly assuming major environmental, economic and political importance in drylands of both developed and developing countries.

In Brazil, about 11% of the territory is classified as semi-arid land, some 925000 km^2. The Brazilian semi-arid encompasses most of the northeastern region of the country, and is inhabited by approximately 19 million people (IBGE 2000). An extensive area in the northeast receives precipitation lower than 1000 mm per year, with areas receiving less than 500 mm per year, and evaporation rates are generally 1150 mm per year. This area is also characterized by irregular precipitation and frequent droughts that can last up to 11 months (Nimer 1977).

Not surprisingly, streams and rivers exert an important role in the survival strategies of human populations in this region (Maltchik *et al.* 2009), with the intermittency of the surface water flow being recognized as the principal hydrological characteristic of rivers and streams in semi-arid Brazil (Steffan 1977, Medeiros & Maltchik 2001a, Maltchik & Medeiros 2006). Intermittent streams in semi-arid Brazil represent distinctive landscape features within the dry shrubby deciduous open forest called 'Caatinga'. For much of the time these streams exist as networks of dry courses of sand and/or pebbles, with occasional strings of temporary and ephemeral pools. In their natural state these rivers are characterized by the extremes of flooding and total absence of water which contribute to a high degree of spatial variation and habitat heterogeneity (Maltchik & Medeiros 2006).

Water resource development and management in semi-arid Brazil has been increasing since the mid 1900s and has been a threat to the natural flow regimes and the ecological integrity of the intermittent streams and rivers of the region. Nevertheless, efforts to manage stream flow and at the same time maintain ecological integrity are hampered by limited scientific information on the ecological processes driving the biota. Furthermore, current water resource development policies for the semi-arid region of Brazil have been emphasizing the construction of large dams, barrages, artificial channels and inter-basin water transfers, at the expense of loss of biological integrity (Simpson 1998, Vieira 1998, MIN 2004).

The responses of biota to changes in flow regime and their spatial dynamics in semi-arid streams of Brazil are largely unknown. However, studies in other temporary habitats have shown that the zooplankton is sensitive to local variation in flow regime, since the succession of taxa is interrupted by the seasonal absence of water, and that the extent of water permanence and the length of the dry phase vary spatially in temporary habitats (see Tavernini 2008). Such dynamics is associated with the emergence of rotifers, cladocerans and copepods from the inundated dry river beds leading to a complex pattern of succession of these microinvertebrates within days of flooding (Jenkins & Boulton 2003). In order to understand the effects of artificially imposed lentic conditions on the highly variable semi-arid intermittent streams, this study compares major taxa of zooplankton (Rotifera, Cladocera and Copepoda) between natural (intermittent streams) and artificial (reservoirs) aquatic systems in semi-arid Brazil, evaluating spatial variation of taxa abundance and discussing the implications of the water management on zooplankton composition.

Study area

The semi-arid region of Brazil is characterized by complex climatic patterns (Moura & Shukla 1981, Liu & Juárez 2001) that lead to irregularly distributed and scarce rainfall and low thermal amplitude. This low thermal amplitude is the main climatic difference between Brazilian and other semi-arid lands (Nimer 1977). It has been recognized that the intermittency of surface water flow is the principal hydrological characteristic of rivers and streams in the semi-arid region of Brazil (Maltchik & Medeiros 2006).

The present study was performed in two different areas of the Brazilian semi-arid region: Seridó/Borborema and Buíque/Vale do Ipojuca (sensu Tabarelli & Silva 2005) (Figure 1). These areas are classified as being of extreme biological importance and were identified as priority areas for biodiversity conservation in the Caatinga biome by Silva *et al.* (2003), because they have high species diversity and endemism.
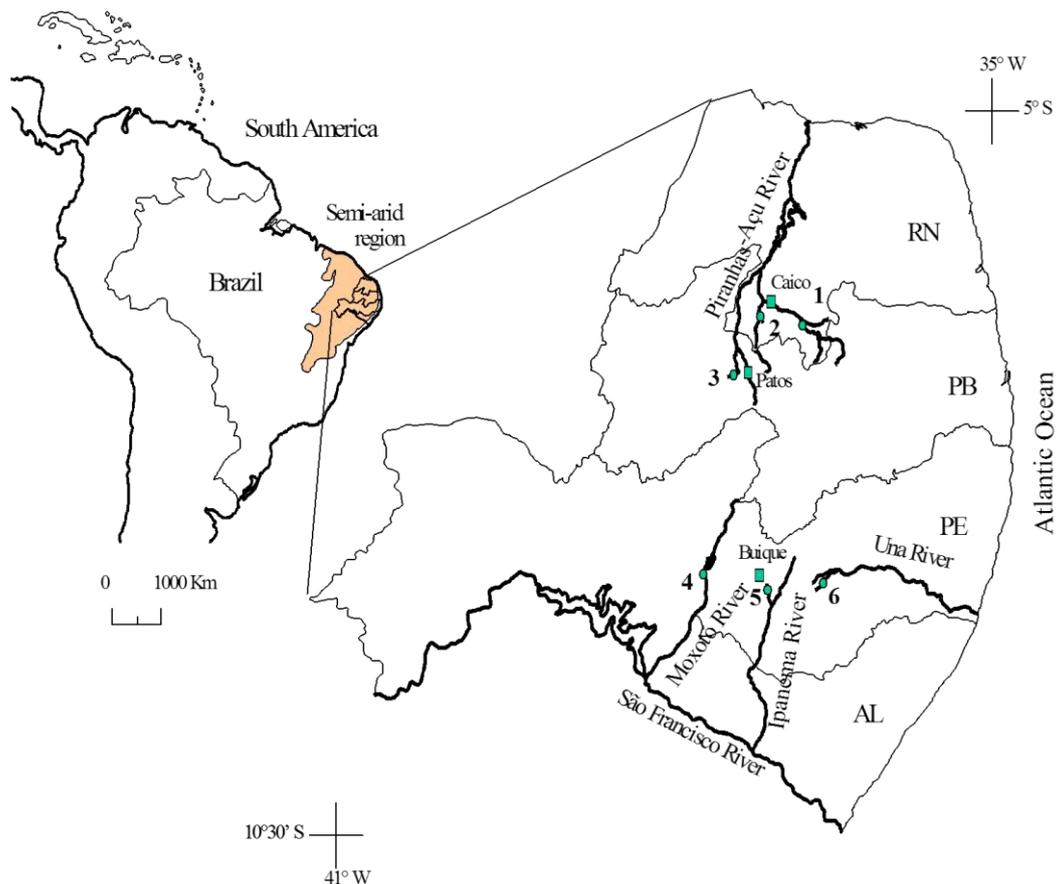
Figure 1. Study area in the semi-arid region of Brazil showing the states of Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE) and Alagoas (AL), major river systems and sampling sites. Sites 1 (in the Seridó River), 2 (Cipó Stream), and 4 (Escama-Peixe Stream) are intermittent streams and sites 3 (Recanto Reservoir), 5 (Mulungu Reservoir), and 6 (Gurjão Reservoir) are man-made impoundments on intermittent streams. Numbered circles indicate sampling sites and squares show major towns in the study area.

The Seridó area is located in the south of the state of Rio Grande do Norte (RN), between the towns of Caicó and Patos. Average annual temperature is 30.7°C, with the maximum monthly average in October (31.0°C) and the minimum average in February (29.3°C). Precipitation is concentrated between January and April, with 350 to 800 mm per annum and an annual average of 600 mm (Amorim *et al.* 2005). Altitude in Seridó reaches between 100 and 800 m (Governo do Estado da Paraíba 1985). The Buíque area is located around the town of Buíque in central-east of the state of Pernambuco (PE). Average annual temperature and precipitation are 25°C and 1095.9 mm, respectively. Rainfall is concentrated between April and June. Altitude ranges between 800 and 1000 m (Rodal *et al.* 1998). The Seridó area is drained mostly by the Piranhas-Açu River Basin, with the Seridó River as the main affluent. The Buíque area is drained mostly

by affluents of the São Francisco River (e.g. Moxotó and Ipanema Rivers). In the state of Pernambuco, this study spanned further than the Buíque area with a sampling site at the headwaters of the Una River, which drains east to the Atlantic Ocean. Aquatic systems in the study areas comprise heterogeneous habitats (littoral grass, aquatic macrophytes, overhanging and submerged vegetation, and submerged wood debris) and substrate composition (mud, sand and cobbles) (see Medeiros *et al.* 2008 for further detail).

Materials and methods

Six sites were selected across the study areas to represent typical artificial (reservoirs) and natural temporary and semi-permanent environments (intermittent streams) (Figure 1). Sites consisted of stream reaches, usually 100 to 500 m long, and small artificial reservoirs created from stream

impoundment. Sampling was conducted during one year on four occasions during the wet (April and June 2006) and dry (September and December 2006) seasons. Site 4 was not sampled on April 2006.

Zooplankton was collected quantitatively using a plankton net (opening diameter 30 cm, 70 cm long and mesh size 60 μm). The net was towed for a distance of 10 m on the surface of the water at dusk or dawn. Three replicate samples were taken from each site per sampling occasion, representing different pools (during dry season) or reaches (during flooding) for intermittent streams; or different littoral areas for reservoirs. During the dry season when pool size was small or in cases where underwater structures were observed, the 10-m sampling transect was broken up into two or more sub-transects which were later pooled together to a length compound of 10 m. This also allowed a better characterization of microhabitats in the study sites, since the distribution of plankton is usually non-homogeneous (depending on exposure to sunlight, submerged macrophytes, wind action, etc.) (Seminara *et al.* 2008). To minimize variation in sampling efficiency across sites and replicates, velocity and length of tow were similar and the net was washed between each tow to prevent clogging.

The zooplankton collected was anesthetized with commercial sparkling water and preserved in 4% formalin. Sucrose was added to the preserved sample to prevent female cladocerans from losing eggs and to minimize carapace distortion (Haney & Hall 1973). In the laboratory, four sub-samples were taken from each replicate sample for counts in a Sedgewick-Rafter counting cell. All individuals were counted in each sub-sample, which represented 1/80 of the total sample. Only rotifers, cladocerans and copepods were considered in the present study. Number of individuals counted in each sub-sample ranged from zero to 2670, 144 and 650 for Rotifera, Cladocera and Copepoda, respectively. The resulting counts of each sub-sample were averaged to represent the mean density (±SD) for each replicate sample. Statistical analyses were performed on the mean density and the level of taxonomic resolution used for statistical analyses was family.

Water velocity was measured using the float method (Maitland, 1990). Littoral depth was measured with a staff and represented the depth of the first 3 m from the terrestrial-water interface. Width was measured using a measuring tape. Macrophyte cover and substrate composition were estimated as their proportional contribution to the wetted perimeter of each site, using a square of 1 m. Water temperature (°C) and dissolved oxygen (mg/L) were measured with an oxygen meter

(Lutron DO-5510), and transparency (cm) was measured with a Secchi disk (see Medeiros *et al.* 2008). These data are briefly described here and were used to associate the zooplankton fauna with habitat type (rivers and reservoirs) and spatial changes in habitat structure.

Assemblage structure was characterized across sites using taxa richness and density. Environmental variables and richness were compared between study sites using one-way ANOVA followed by *post hoc* multiple comparisons using Tukey's HSD test (significance level of 0.05) (Zar 1999). All environmental variables were log-transformed ($\log_{10}(x+1)$) and the richness was square-root transformed prior to statistical analyses (Sokal & Rohlf 1969). Variation in zooplankton density between sites and study areas (Seridó and Buíque) was investigated using Non-metric Multidimensional Scaling (NMS) of the standardized arcsine-square root-transformed data (Bray-Curtis similarity measure). The Multi-Response Permutation Procedure (MRPP) (McCune & Grace 2002) was then used to test for differences in density of zooplankton between the two study areas and sites. For all MRPP analyses, the chance-corrected within-group agreement (A) is presented as a measure of the degree of within group homogeneity, compared to random expectation. Where MRPP detected significant differences in zooplankton composition Indicator Species Analysis (McCune & Grace 2002) was performed to reveal which particular family taxa contributed significantly to this variation. Indicator Values (IV) were calculated using the method of Dufrene & Legendre (1997). These were tested for statistical significance (p<0.05) using a Monte Carlo technique with 1000 runs.

Results

Site morphological characteristics varied considerably and were related to the nature of the study site (that is, stream or reservoir) (Table I). Water quality variables did not vary significantly between sites, where ANOVA for temperature (d.f.=5,17; F=2.6; p=0.061) and dissolved oxygen (d.f.=5,17; F=0.5; p=0.733) yielded non-significant results. Even though ANOVA for transparency resulted in significant differences across sites (d.f.=5,17; F=3.02; p=0.039), *post hoc* Tukey HSD tests showed that the only significantly different sites were Recanto Reservoir and Seridó Stream with a *p* value of 0.049 (see Table I). Regarding the presence of aquatic macrophytes, only Recanto Reservoir showed high proportion of cover. All study sites had great amounts of mud and, to a lesser

extent, sand as substrate composition (Table I, see   Medeiros *et al.* 2008 for detailed information).

Table I. Morphology, water quality and habitat structure for the study sites along the 2006 hydrological cycle (See Medeiros *et al.* 2008 for further detail).

Site	Month	Water flow (m/s)	Littoral depth (cm)	Width (m)	Temperature (°C)	Dissolved oxygen (mg/L)	Transparency (cm)	Macrophyte cover (%)	Mud (%)	Sand (%)
Seridó River Site 1	Apr	0.17	81.3	19.6	32.9	6.5	46.0	8.3	65.0	30.0
	Jun	0.13	67.0	16.1	32.0	5.4	44.0	0.0	40.0	40.0
	Sep	0.00	32.3	6.2	28.3	6.0	17.3	0.0	65.6	23.1
	Dec	0.00	32.3	5.4	32.6	6.0	16.0	0.0	95.0	1.8
Cipó Stream Site 2	Apr	0.16	22.7	17.2	35.2	6.9	26.0	0.0	16.7	70.0
	Jun	0.00	32.7	18.5	29.0	3.0	33.0	0.0	0.7	87.7
	Sep	0.00	32.7	15.1	29.7	5.0	50.3	0.0	48.8	22.5
	Dec	0.00	45.3	10.7	27.6	4.9	60.0	0.0	5.0	60.0
Recanto Reservoir Site 3	Apr	0.10	54.7	102.0	34.0	4.8	61.0	5.8	81.7	8.3
	Jun	0.00	37.7	100.0	29.0	5.0	90.0	54.8	5.0	95.0
	Sep	0.00	22.3	88.0	34.0	9.0	51.7	44.6	46.7	40.0
	Dec	0.00	30.3	72.2	29.5	9.4	67.0	37.3	59.1	38.7
Escama-Peixe Stream Site 4	Jun	0.00	49.3	29.6	29.0	5.6	50.0	0.0	39.0	56.0
	Sep	0.00	50.0	27.3	29.0	5.0	32.3	0.0	33.7	63.0
	Dec	0.00	52.8	20.0	28.9	5.1	30.0	0.0	48.9	47.9
Mulungu Reservoir Site 5	Apr	0.00	32.7	270.0	29.8	5.7	48.0	0.0	33.3	65.0
	Jun	0.00	22.0	247.6	29.0	1.8	43.0	0.0	20.6	77.0
	Sep	0.00	25.7	234.5	26.0	5.7	63.0	0.0	65.0	35.0
	Dec	0.00	41.3	239.0	26.0	7.3	89.0	0.0	91.8	3.2
Gurjão Reservoir Site 6	Apr	0.00	8.2	330.0	29.2	5.1	25.7	46.7	96.7	3.3
	Jun	0.00	7.0	321.0	29.0	1.9	55.0	2.6	98.0	2.0
	Sep	0.00	6.8	314.2	24.0	8.8	51.7	0.0	87.8	6.7
	Dec	0.00	4.7	289.5	24.7	8.8	36.0	2.1	95.2	3.4

The zooplankton fauna recorded in the study sites was composed of 42 species distributed across 21 families. Assemblage richness was dominated by Rotifera, which presented 13 families and 32 species. Brachionidae was the richest taxon, with 13 species, followed by Lecanidae (4 species) and Filiniidae (3 species). Cladocera presented 5 families and Chydoridae was the richest with 2 species, whereas Copepoda was represented by the three orders of the group and two species of Cyclopoida (Table II).

Richness of taxa varied from 10 families in Escama-Peixe Stream to 17 families in Recanto Reservoir. Including naupliar stages of copepods, Recanto Reservoir also showed the highest richness (averaged across sampling occasions) among the study sites (13.1 ±2.2 taxa), whereas the lowest average richness was observed in Seridó Stream (6.5 ±2.0 taxa). The richness of taxa was significantly higher in reservoir sites (11.4 ±2.1 taxa on average) than in stream sites (7.5 ±2.2 taxa on average) (t-test, t=-7.5; d.f.=67; p<0.01).

Table II. Zooplankton species from semi-arid Brazil aquatic habitats and average densities (ind/L) for major taxa. Sites 1 (Seridó River), 2 (Cipó Stream), and 4 (Escama-Peixe Stream) are intermittent streams and sites 3 (Recanto Reservoir), 5 (Mulungu Reservoir), and 6 (Gurjão Reservoir) are man-made impoundments on intermittent streams.

	1	2	3	4	5	6
Rotifera						
Philodinidae	0.00	0.00	0.15	0.14	0.02	0.00
Rotaria rotatoria (Pallas, 1766)						
Conochilidae	0.00	1.08	0.00	0.00	0.00	0.35
Conochilus unicornis Rousselet, 1892						
Filiniidae	2.59	3.56	0.18	1.54	6.30	1.00
Filinia terminalis (Plate, 1886)						
Filinia opoliensis (Zacharias, 1898)						
Filinia longiseta (Ehrenberg, 1834)						
Hexarthridae	3.60	0.41	0.44	3.64	23.97	0.00
Hexarthra mira (Hudson, 1871)						
Testudinellidae	4.80	0.00	2.07	11.38	0.89	0.70
Pompholyx sulcata Hudson, 1885						
Testudinella patina (Hermann, 1783)						
Asplanchnidae	0.87	0.01	0.14	0.37	3.28	0.92
Asplanchna sp.						
Brachionidae	2.65	8.94	4.31	6.09	76.66	5.81
Brachionus quadridentatus Hermann, 1783						
Brachionus calyciflorus Pallas, 1766						
Brachionus dolabratus Harring, 1915						
Brachionus falcatus Zacharias, 1898						
Brachionus havanaensis Rousselet, 1911						
Brachionus angularis Gosse, 1851						
Brachionus caudatus Barrois & Daday, 1894						
Brachionus urceolaris Müller, 1773						
Keratella tropica (Apstein, 1907)						
Keratella americana Carlin, 1943						
Keratella lenzi (Hauer, 1953)						
Macrochaetus sericus (Thorpe, 1893)						
Plationus patulus (Müller, 1786)						
Euchlanidae	0.00	0.00	0.05	0.00	0.02	0.00
Euchlanis sp.						
Lecanidae	0.002	3.10	1.22	0.15	0.15	0.01
Lecane luna (Müller, 1776)						
Lecane bulla (Gosse, 1851)						
Lecane hastata (Murray, 1913)						
Lecane pyriformes (Daday, 1905)						
Synchaetidae	0.00	0.005	2.49	1.80	1.74	0.19
Polyarthra vulgaris Carlin, 1943						
Trichocercidae	0.00	0.00	0.08	0.00	0.00	0.00
Trichocerca grandis (Hauer, 1965)						
Trichocerca sp.						
Lepadellidae	0.00	0.00	0.47	0.00	0.00	0.00
Lepadella sp.						
Gastropodidae	0.00	0.00	0.38	0.00	0.00	0.00
Ascomorpha sp.						
Cladocera						
Chydoridae	0.00	0.10	0.03	0.00	0.005	0.00
Alonella brasiliensis Bergamin, 1935						
Chydorus sp.						
	0.01	0.20	0.005	0.00	0.06	1.38

Table II (*Cont*.)

Daphniidae						
Ceriodaphnia cornuta Sars, 1885						
Moinidae	0.01	2.44	0.01	0.00	1.14	0.23
Moina minuta Hansen, 1899						
Bosminidae	0.00	0.00	0.00	0.00	0.01	0.00
Bosmina sp.						
Sididae	0.005	1.85	0.00	0.00	0.00	0.88
Diaphanosoma sp.						
Copepoda						
Diaptomidae (Calanoida)	0.04	7.14	0.05	0.003	6.43	4.14
Notodiaptomus sp.						
Cyclopidae (Cyclopoida)	0.13	1.34	0.16	0.04	4.08	1.42
Thermocyclops minutus (Lowndes, 1934)						
Mesocyclops sp.						
Canthocamptidae (Harpacticoida)	0.00	0.00	0.00	0.00	0.00	0.11
Attheyella fuhrmanni (Thiébaud, 1912)						
Immature stages of Copepoda	0.86	11.11	3.6	0.33	4.99	4.03

A total of 102892 individuals were counted (Table III) and the values of zooplankton density varied considerably across sites, ranging from an average of 0.7 (±2.7) ind/L in Seridó River to 5.9 (±28.5) ind/L in Mulungu Reservoir (Table II). Nevertheless, rotifers were also dominant in terms of density. The most abundant rotifer taxa were Brachionidae (17.9 ±50.8 ind/L), Hexarthridae (5.4 ±19.5 ind/L), Testudinellidae (3.0 ±6.1 ind/L), Filiniidae (2.6 ±5.8 ind/L), Synchaetidae (1.0 ±1.8 ind/L), Asplanchnidae (1.0 ±2.2 ind/L) and Lecanidae (0.8 ±2.6 ind/L). Among the cladocerans, Moinidae (0.7 ±1.4 ind/L) and Sididae (0.5 ±1.5 ind/L) were the most abundant. Nauplii stages of Copepoda (4.3 ±8.4 ind/L), Calanoida (3.1 ±6.4 ind/L) and Cyclopoida (1.2 ±3.3 ind/L) were the most abundant copepods. The taxa mentioned above represented 98.1% of the total number of individuals recorded during this study.

With regard to variations in fauna composition between sites (natural and managed) and areas (Seridó and Buíque), ordination results showed that zooplankton composition was not significantly different between Buíque and Seridó areas (MRPP, A=0.002; p>0.05). However, NMS plots for each area showed clear spatial segregation in zooplankton composition across sites (Figures 2 and 3). In the Seridó area (Figure 2), reservoir samples were clearly segregated from stream site samples (MRPP, A=0.19; p<0.05). Nevertheless,

stream samples were also significantly different from each other for this area (MRPP, A=0.29; p<0.05). Clear segregation in zooplankton composition was also observed in Buíque (Figure 3), where the zooplankton composition was significantly different between reservoir and stream sites (MRPP, A=0.18; p<0.05) and both reservoir sites (MRPP, A=0.33; p<0.05).

Indicator value analysis showed that, for both areas studied, reservoirs had more indicator families than stream sites. In the Seridó area, Moinidae (IV=86.5; p=0.001), Sididae (IV=80.9; p=0.001), Diaptomidae (IV=72.2; p=0.003) and Daphniidae (IV=41.4; p=0.008) were significant indicator taxa of the Cipó Stream. The Seridó River had only Asplanchnidae (IV=56.0; p=0.009) as indicator taxon. Recanto Reservoir had only rotifers as indicator taxa, the significant ones being Gastropodidae (IV=91.7; p=0.001), Synchaetidae (IV=90.4; p=0.001), Philodinidae (IV=75.0; p=0.001), Trichocercidae (IV=50.0; p=0.002), Lepadellidae (IV=50.0; p=0.002), Lecanidae (IV=49.0; p=0.019) and Testudinellidae (IV=47.8; p=0.029). In the Buíque area the same pattern emerged, with most indicator taxa observed for reservoir sites. In this area, the only significant indicator taxon for the Escama-Peixe Stream was Testudinellidae (IV=69.4; p=0.001). For the Gurjão Reservoir the significant indicator taxa were Sididae (IV=100; p=0.001), Canthocamptidae (IV=75.0; p = 0.001), Conochilidae (IV =75.0;

p=0.001), Daphniidae (IV=66.1; p=0.001) and Diaptomidae (IV=52.0; p=0.048). Significant taxa for the Mulungu Reservoir were Hexarthridae (IV=67.0; p=0.006), Cyclopidae (IV=62.7;

p=0.011), Brachionidae (IV=61.5; p=0.001), Moinidae (IV=45.2; p=0.012) and Euchlanidae (IV=33.3; p=0.031).

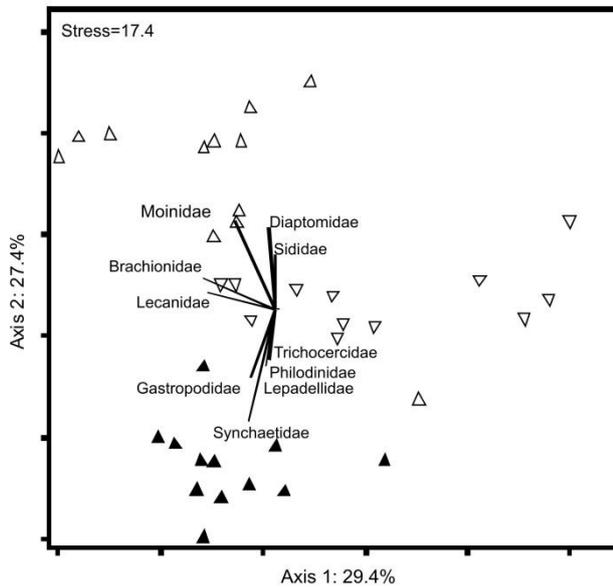**Figure 2.** NMS results for zooplankton composition across the study sites in the Seridó area ($\triangle$=Cipó Stream, $\triangledown$=Seridó River and $\blacktriangle$=Recanto Reservoir). Vectors show family taxa correlated (r^2>0.2) with sampling site replicates and sampling occasions in ordination space. The direction and length of vectors indicate strength of correlation.
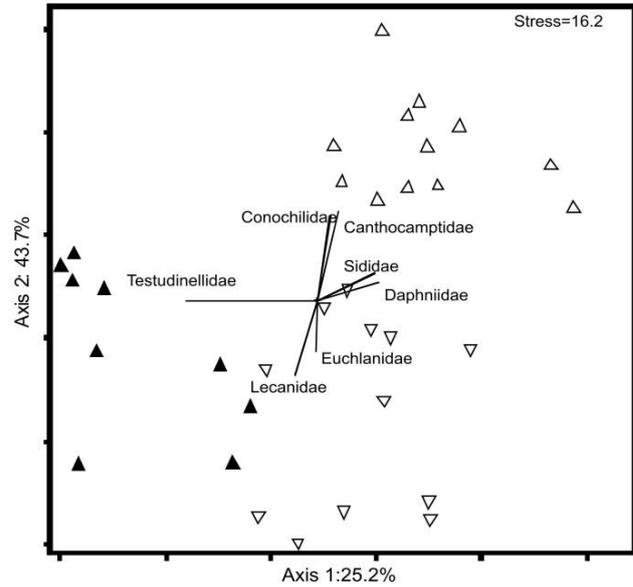

Figure 3. NMS results for zooplankton composition across the study sites in the Buíque area ($\triangle$=Gurjão Reservoir, $\triangledown$=Mulungu Reservoir and $\blacktriangle$=Escama-Peixe Stream). Vectors show family taxa correlated (r^2>0.2) with sampling site replicates and sampling occasions in ordination space. The direction and length of vectors indicate strength of correlation.

Discussion

During the study period, the dynamics of the study sites were characterized by important periods of water flow in streams, followed by habitat contraction. Even though no flow was recorded for Escama-Peixe Stream, sampling on this site started late during the wet season, and local information indicates the occurrence of flooding between March and May 2006. Reservoir sites also diminished in size, and the overall absence of water flow favored long-term lentic condition. Macrophyte cover was present mostly in reservoir sites and more importantly in the smaller one. Proportions of mud and sand were variable across sites, but in general reservoirs may be associated with muddy sediments and streams can be regarded as presenting greater importance of sand. Such differences have been associated with variation in local morphology of sites as a result of flow regime (Medeiros *et al.* 2008). It is important to bear in mind that the design of the present study was unbalanced and the effects of interaction between study areas (Seridó/ Buíque)

and environment types (stream and reservoir) on the environmental variables were not measured.

The species composition and richness of zooplankton observed in the present study are in accordance with other studies performed in semi-arid Brazil (Crispim & Watanabe 2000, Simões *et al.* 2008, Sousa *et al.* 2008) and Rotifera was the dominant group across the study sites. The dominance of rotifers in aquatic ecosystems has been well documented by several authors (e.g. Sampaio *et al.* 2002) and is generally attributed to their high fecundity, parthenogenetic reproduction and short developmental rates (Pourriot *et al.* 1997). Furthermore, the less specialized feeding makes rotifers an opportunistic r-strategist group (Allan 1976), which is favored by the typically unpredictable and seasonal nature of Brazilian semi-arid aquatic systems. Among the rotifers, Brachionidae was the predominant family in terms of species richness and densities in the present study. This family is one of the most important rotifer taxa

in tropical waters, with most species being planktonic (Almeida *et al.* 2006).

According to Allan (1976) cladocerans also fall into an r-strategist group presenting a rather unspecialized feeding behavior, short life cycles and large transitory populations. On the other hand, copepods are more likely to have species with longer life cycles and fewer generations. This could be one factor explaining the overall patterns of richness across the three major groups of zooplankton recorded in the present study, since cladocerans were richer than copepods.

Table III. Counts (minimum-maximum) per sampling occasion of major taxa of zooplankton across the study aquatic habitats in semi-arid Brazil.

	Seridó River (Site 1)				Cipó Stream (Site 2)				Recanto Reservoir (Site 3)			
	Apr	Jun	Sep	Dec	Apri	Jun	Sep	Dec	Apr	Jun	Sep	Dec
Asplanchnidae	0-9	0-1	0-28	0-56	0-1				0-8	0-3	0-6	0-9
Bosminidae												
Brachionidae	0-6	0-1	19-163	0-46	0-273	0-3	0-22	62-359	0-237	2-81	7-32	3-63
Calanoida	0-4	0-2		0-2	0-256	20-61	70-146	0-2	0-8		0-1	0-1
Chydoridae					0-2	0-9	0-1		0-1	0-2	0-1	
Conochilidae						0-132						
Cyclopoida	0-3	0-2	0-1	0-7	0-96	0-6	0-1		0-12	0-5	0-2	0-13
Daphniidae	0-1		0-1		0-5	0-36	0	0-4			0-1	0-1
Euchlanidae									0-10	0-2		
Filiniidae	0-5		37-98	3-41	0-275	0-1	0-1		0-7	0-5	0-2	0-7
Gastropodidae									0-17	0-8	0-13	0-31
Harparticoida												
Hexarthridae	0-4		93-190	0-1	0-34	0-2			0-1	0-40	0-9	0-6
Lecanidae	0-1			0	0-2	0		51-221	0-44	0-3	0-25	0-77
Lepadellidae											0-42	0-11
Moinidae			0-2	0-1	0-7	0-35	1-144	21-64	0-2			0-2
Nauplius	0-20	0-2	0-3	0-43	0-650	15-46	12-60	0-1	0-50	0-104	0-96	5-114
Philodinidae										0-3	0-5	0-13
Sidiidae		0-1	0-1		0-2	0-9	0-111	0-11				
Synchaetidae									0-58	0-63	0-78	0-112
Testudinellidae	0-1	0-2	84-332	0-24					0-13	0-88	0-37	0-110
Trichocercidae										0-3	0-11	0-1

Table III (*Cont.*)

	Escama-Peixe Stream (Site 4)			Mulungu Reservoir (Site 5)				Gurjão Reservoir (Site 6)			
	Jun	Sep	Dec	Apr	Jun	Sep	Dec	Apr	Jun	Sep	Dec
Asplanchnidae	0-8	0-9	0-23	42-153	0-7	10-31	0-1	0-52	0-1	3-38	0-15
Bosminidae				0-3							
Brachionidae	13-59	14-146	20-179	1541-2670	179-281	27-53	115-397	59-118	32-113	4-15	9-51
Calanoida		0-1		126-357	0-4	0-3	0-3	49-214	2-16	3-19	8-30
Chydoridae					0-1	0-1					
Conochilidae									0-4	2-8	2-10
Cyclopoida	0-1	0-1	0-2	68-292	2-7	0-16	1-10	16-121	0-1	0-3	0-2
Daphniidae				0-6				15-100	0-7	0-4	
Euchlanidae					0-3	0-1					
Filiniidae	0-21	0-53	1-29	14-362	1-11	0-1		0-12	0-4	4-36	7-23
Gastropodidae											
Harparticoida								0-3	0-7	0-2	0-4
Hexarthridae	21-203	0-7	1-41	478-1329	3-39	1-6	0-19				
Lecanidae	0-6	0-3	0-9	0-6	1-7	0-2	0-4		0-1		0-1
Lepadellidae											
Moinidae				7-86		0-3	0-1	0-23			
Nauplius	0-7	0-6	0-9	72-245	1-9	2-13	0-18	60-125	2-10	17-33	6-26
Philodinidae		0-38	0-3		0-1	0-1	0-2				
Sidiidae								1-46	0-5	0-8	1-7
Synchaetidae	0-41	20-43	0-3	37-89	0-4	0-2		0-9	0-2	0-1	0-3
Testudinellidae	37-437	39-149	0-8	9-37	3-37	0-3	0-1	0-45	0-8		0-18
Trichocercidae											

The low species richness of Cladocera and Copepoda recorded in this study was also observed by Sousa *et al.* (2008) in Brazilian semi-arid reservoirs. Those authors explained the overall patterns of zooplankton composition in terms of trophic status (eutrophication), siltation and salinization due to evaporation. Even though such factors may be at work in the study sites, there was

no indication of eutrophication or siltation during the present study. That is inferred mostly from the low overall turbidity, relatively high rates of dissolved oxygen and low macrophyte growth at most sites.

Alternatively, we propose that the inadequacy of water residence time for the Cladoreca and Copepoda in the study sites, mostly during the wet period (with unpredictable flooding), contributed significantly to their low richness and overall paucity. In environments with periods of high flushing rates, due to the short residence time, only organisms with rapid growth and high renewal rates can increase their populations (Pourriot *et al.* 1997). As exemplified by Recanto Reservoir, even larger water bodies are subject to flow during the wet season in semi-arid Brazil. Similarly, the longer life cycles attributed to Cladocera and Copepoda (compared to Rotifera) may have been an important factor explaining their low numbers in streams during the dry season, when the rapidly contracting aquatic habitat are associated with increasingly dense fish populations (Brooks & Dodson 1965, Medeiros & Maltchik 2001b), more significantly so in small remnant pools in the stream bed than in the larger reservoirs. Nevertheless, low numbers of planktonic Cladocera have also been observed in the more stable reservoirs during the dry season, thus more information is needed on resource use and availability, and population dynamics of zooplankton as well as the dominant fish assemblages in order to fully explain this phenomenon in those water bodies.

Despite low richness, Copepoda showed high densities across study sites (mostly reservoirs). The longer residence time of such environments is the most likely factor explaining this observation. Nevertheless, Copepoda was also present in high densities in Cipó Stream. Some groups of Copepoda have been reported as first colonizers in temporary environments (Frisch & Green 2007). This early colonization has been associated to their ability to store sperm and capacity to survive drought. This is corroborated in the present study where large densities of juvenile stages of Copepoda were observed, indicating that early colonization may be in use as an adaptive strategy in these highly variable environments (see also Cole 1966). Despite that, some studies have shown copepods to be late colonizers in other semi-arid regions (Hancock & Timms 2002). This is an indication that the local pool of species must also be taken into account in the present study, given that other groups of zooplankton have also been reported to be able to withstand dry periods and are quick colonizers

(Crispim & Watanabe 2001, Hancock & Timms 2002, Frisch & Green 2007).

In order to identify patterns of occurrence of family taxa, grouping was carried out and species groups were associated with study areas (Buíque and Seridó) and habitat type (stream and reservoir). On a larger spatial scale (study areas), grouping was not possible and the zooplankton fauna was not discriminated between the Seridó and Buíque regions. However, within each area grouping was easily performed, separating not only reservoir from stream sites but also reservoir sites and stream sites between themselves. Similar results were observed by Medeiros *et al.* (2008) when characterizing the structure of the habitat in the study sites. Those authors observed that at larger spatial scales (between the Seridó and Buíque areas) the structure of the habitat could not be distinguished, despite some segregation between sites within study areas. This pattern was explained as the result of a nested hierarchy (Poff 1997) where various levels of catchment- and stream-reach variables are correlated with the habitat structure. Data from the present study indicate that the composition of zooplankton may be influenced by aspects related to spatial hierarchical levels, where a common large-scale pool of species is broken into more specific community traits at local scales (e.g. Tomanova & Usseglio-Polatera 2007), the latter being likely regulated by local-scale physical and biological processes, such as competition, predation and grazing patterns. That being the case, catchment-scale processes, such as climate and geomorphology, are important to define higher levels of organization of the plankton fauna and overall species pool of the river ecosystem. These higher levels of organization will then influence factors at a variety of lower spatial reach-scale characteristics such as morphology, flow and water variables, and consequently the local species pool, which may be particularly relevant to semi-arid systems.

Management policies for aquatic semi-arid systems in Brazil are based on reservoir and weir construction and different degrees of flow regulation (but see Leal *et al.* 2005, Maltchik & Medeiros 2006). These alterations greatly modify the hydrological characteristics of the highly variable intermittent streams, which have been reported to have the extremes of flooding and drought as the driving forces organizing biotic communities (Maltchik & Florin 2002). Implications of such modifications in dry lands have been summarized by Bunn & Arthington (2002) and include changes on macrophyte assemblages structure, nutrient

dynamics and longitudinal connectivity, all of which are associated with the conversion of lotic to lentic systems. Rotifera was fairly widespread across streams and reservoirs during the present study, which is most likely the result of their opportunistic characteristic. However, some groups of zooplankton, mostly some species of Copepoda and Cladocera, have been associated to littoral vegetated areas in many dryland aquatic systems (Shiel 1995). The trophic position of the zooplankton makes this group highly associated with the dynamics of nutrients of the aquatic systems where they live (Sampaio *et al.* 2002, Medeiros & Arthington 2011). Therefore, the modification of natural patterns of water flow and promotion of lentic conditions has the potential to interfere with zooplankton communities by favoring groups with slower growth rates such as Cladocera and Copepoda.

Results presented have implications not only for the management of aquatic systems on semi-arid Brazil, but also to their conservation. Since zooplankton has been regarded as an important trophic link between primary production and other consumers (Medeiros & Arthington 2008, 2011) changes in their composition may have a cascading effect up and down the food web (Jones *et al.* 1999). Furthermore, given the notion that factors affecting the structure and composition of the zooplankton community, as well as the potential mechanisms that maintain their diversity lie at several levels of the river watershed, decision-makers must identify the parts of the riverine ecosystems that are vital to maintaining its health, in order to propose (or re-evaluate) management and conservation policies for Brazilian semi-arid streams.

Acknowledgements

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