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Research Paper

Effects of Small Dams on the Benthic Community of Streams in an Atlantic Forest Area of Southeastern Brazil

key words: dam, macroinvertebrates, river connectivity

Abstract

We examined the effects of longitudinal discontinuity in small rivers, produced by the construction of small dams, on the macroinvertebrate communities in a biological reserve in southeastern Brazil. Two regulated streams were sampled in the rainy and dry seasons at three sites along the river. One site was upstream of the dam/abstraction and two were below the dam. Our results indicate that there was a difference in the communities between the dry and rainy periods even though water physicochemical parameters of the water were not significantly different. The biotic richness at sites 500 m below the dam were similar to those above the impoundment (control), indicating that the fauna recovered when the discharge values found before water abstraction were reestablished. We concluded that the dam did induce changes in the composition of benthic comunities, especially in the dry period. However, overall, the fauna seemed to be able to persist during periods when the flow was absent.

1. Introduction

Water removal in large reservoirs have implications for flow regimes and discharges along longitudinal gradients of rivers (Castela *et al.*, 1995). Alterations in these two hydrological components may induce modifications in the distribution of the substrates, as well as altering food and reproductive strategies of the species. The flow regime is important in regard to diversity of benthic communities (Milhous *et al.*, 1989). These factors are considered the main conditioners of structural and functional alterations in the aquatic biota. In general, the effects of the impoundment on fish assemblages are well documented, but less is known about that influence on aquatic invertebrates (Statzner *et al.*, 1988; Cobb *et al.*, 1992; Ward *et al.*, 1999; Bunn and Arthington, 2002).

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Furthermore, the maintenance of the longitudinal (along the river) and lateral (riparian zone) connectivity is essential to the ability of populations to move freely through the microhabitats. Consequently, the construction of dams may cause the isolation of some populations, the local extinction or fostering of some species, and promote the invasion and the success of exotic species (BAXTER, 1977; WARD and STANFORD, 1983; MUNN and BRUSVEN, 1987; ARMITAGE and BLACKBURN, 1990; POFF *et al.*, 1990; IMBERT and STANFORD, 1996; FLEITUCH, 2003).

In Brazil, hydroelectric dams produce 75% of the energy produced in the country (Ministério de Minas e Energia, 2007). Most of the studies associated with the impacts caused by large reservoirs also address the modifications in the structural and functional communities of phytoplankton, fishes and macroinvertebrates (BRANDIMARTE and SHIMIZU, 1996; RIBEIRO *et al.*, 2005; HENRY *et al.*, 2006). However, even in temperate regions, there is little information concerning the effects of small dams on biota (GORE and HAMILTON, 1996; FLEITUCH, 1992; 2003; GORE *et al.*, 2001). Such latter studies are even more important in rainy tropical areas where the precipitation regime is less delimitated than in temperate regions.

The objective of the present study was to evaluate the effects of longitudinal discontinuity of the stream discharge, derived from water removal in small dams, on macroinvertebrate communities. To test possible effects of discontinuity of the discharge we considered four hypotheses:

1. There are significant alterations in the values of the physicochemical water parameters between the dry period (winter) and the rainy period (summer) and also between parts of the rivers below the dams during the dry period when a severe reduction of the discharge occurs.
2. During the dry period, when the longitudinal discontinuity of the discharge occurs, there are modifications in the macroinvertebrate community and corresponding declines in the richness and abundance of some taxa.
3. Microhabitats in riffle areas, as regards the decrease in richness, composition and abundance, are most affected.
4. There will be differentiation in functional feeding groups (FFGs) between the dry period (winter) and the rainy period (summer) and between river stretches above and below the small dams.

2. Methods

The D'Ouro and Santo Antônio rivers, both third order steams, are located within the Biological Reserve of Tinguá. This is an area of environmental preservation of Atlantic forest, about 26,000 ha in area. It is located 70 km from the city of Rio de Janeiro, State of Rio de Janeiro, in southeastern Brazil (22°21′00″S; 42°27′00″W). The region is under the climatic regime of the Cf type (KÖPPEN), *i.e.*, mesothermic and rainy. The dams of both rivers are 12 m in width and around 2 m in height. They are located at 150 m of altitude in a region of steep slopes and well preserved forest. The canopy cover in the rivers is approximately 50%.

Both dams capture all water of the rivers during the dry period (winter) and release only excess water during the rainy period (summer). Three sampling sites were established in each stream in order to assess the ecological effcts of longitudinal discontinuity provoked by water abstraction: D'ouro river (S1, S2 and S3) and Santo Antônio river (S4, S5 and S6). Control sites (S1 and S4) are the preserved parts, located upstream of the respective dams, and thus represent the natural regime of discharge. Sites S2 and S5 are located immediately below the dams, where longitudinal discontinuity of the discharge occurs in winter. About 500 m below the dam, the river begins to increase its discharge owing to contributions of a few first order tributaries and also from ground water. Then the flow becomes similar to that found upstream of the impoundment. With these conditions, sites S3 and S6 were selected (Fig. 1). Sample collections were carried out in August 2003 (dry period) and in January 2004 (rainy period).

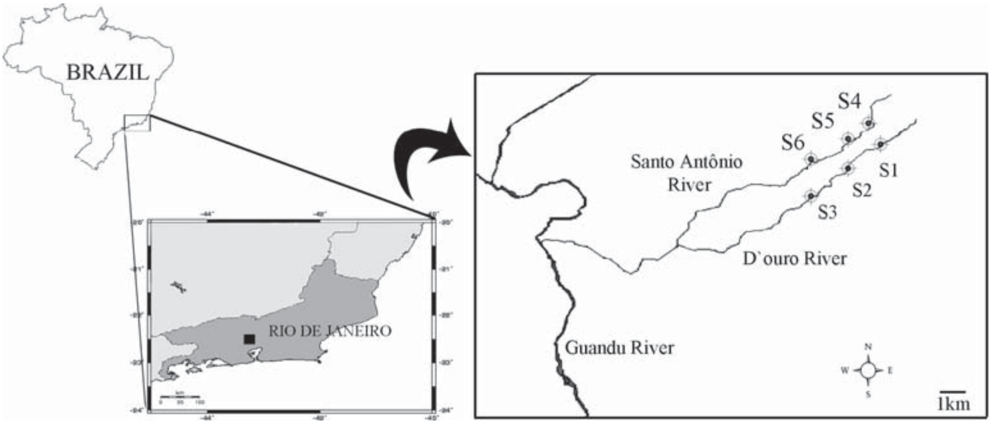

Figure 1. Sites sampled at Santo Antônio and D'ouro rivers, Rio de Janeiro, southeastern Brazil.

The samples were obtained with a Surber sampler (area of 900 cm^2 and 125 μm mesh size). Sample substrates were of four types: (1) non consolidated sediment (sand), (2) rocky (stone), (3) litter retained in rapid riffle areas, and (4) litter retained in pool areas. The field sample design was randomly stratified. Three pseudoreplicates were taken in a transect. Each sample was preserved with 80% alcohol. This procedure generated a total of 144 samples (*i.e.*, 3 samples X 4 substrates X 3 sites X 2 rivers X 2 seasons of the year).

At the laboratory, samples were washed in water on a 125 μm mesh sieve. The material retained in the sieve was put in plastic trays that contained a supersaturated aqueous sugar solution (300 g/l) for removing the macroinvertebrates. The identification and counting of the macroinvertebrates were carried under a stereoscopic microscope with a range of amplification up to 45 X.

The identification was done to the lowest possible taxonomic level by using taxonomic keys (Leech and Chandler, 1968; Benedetto, 1974; Froehlich, 1984; De Marmels, 1990; Dominguez *et al.*, 1992; Angrisano, 1995; Trivinho-Strixino, 1995; Merritt and Cummins, 1996; Wiggins, 1996; Nieser and Melo, 1997; Carvalho and Calil, 2000; Olifiers *et al.,* 2004; Salles *et al.*, 2004) and the help of experts. During the identification, each resulting taxon (family, genus and species) was considered an Operational Taxonomic Unit (OTU).

The hydrological parameters measured at all sites were: mean width, substrate composition, mean depth, current flow and mean discharge. The following physical and chemical water analyses were performed in the field: temperature, dissolved oxygen (mg $O_2\,L^{-1}$) and oxygen saturation (%sat) with a portable oxymeter (Handylab OX1/set – Schott-Geräte, Hofheim, Germany). Three water samples were taken at each sampling site and transported in plastic vials of 500 ml, under refrigeration. Analyses of the following chemical variables were carried out in the laboratory: total hardness and also Ca and Mg hardness (all as mgL^{-1}); total alkalinity (mgL^{-1} $CaCO_3$); chloride (mgL^{-1} Cl^-); bicarbonate alcalinity (mgL^{-1} $CaCO_3$); silicate (μgL^{-1} $Si(OH)_4$) – silicomolybdic method; TDS (total dissolved solids) (mgL^{-1}) – the reading was done by a conductivimeter (Orion model 150); ammonia (μgL^{-1} $N{-}NH_3$/NH_4^+) – by the indophenol blue method; Nitrite (μgL^{-1} NO_2^-) and Nitrate (μgL^{-1} NO_3^-) – diazotation method; orthophosphate (μgL^{-1}) – phosphomolybdic method. The colorimetric methods were performed with a double beam Perkin-Elmer Lambda 20 UV-Vis spectrophotometer, and 10 cm cuvettes were used. More details of the methods are described in Grasshoff *et al.* (1983), Parsons *et al.* (1984) and Paranhos (1996). The quantification of the numbers of total and fecal coliforms was conducted by a membrane filtration method, resulting in a Colony Forming Unity (CFU).

The analysis of the abiotic components was directly related to the first hypothesis of this work which considered that there would be a temporal and spatial variation in the selected environmental variables.

In order to verify the temporal-spatial variation in the macroinvertebrate community, the composition, abundance and taxa richness were analyzed in each substrate type. The macroinvertebrates were also classified in different functional feeding groups (FFGs), such as gathering-collectors, filtering-collectors, shredders, predators and scrapers, according to MERRITT and CUMMINS (1996), BAPTISTA *et al.* (1998) and SILVEIRA (2001). In the OTUs represented by more than one functional feeding group, quantification was conducted by determining proportionality among the FFGs.

In order to verify the degree of differentiation between the two seasonal periods (summer and winter), a canonical correspondence analysis (CCA) was carried out (statistical software package PCORD), using the biological data of the OTUs and data of the environmental variables (VALENTIN, 2000). For this analysis, the data were log 10(x + 1) transformed.

3. Results

We observed that total water removal by the dams occurred during the dry period. We verified that a basal flow below the dams formed small pools which, in turn, helped maintain a subtle interconnectivity among the pools along the river bed. Immediately below the dams, streams did not have a measurable discharge during the dry period. The discharge values in the rainy period increased in sites S2 and S5 but the discharge continued to be less than that of the control sites (S1 and S4). The physical and chemical water parameters measured in the dry and rainy periods are presented in Tables 1 and 2, respectively.

During the period of the study, 29,094 specimens were collected. The highest abundance of benthic macroinvertebrates was found in the dry period (Table 3). Of the 116 Operational Taxonomic Units identified, 99 were in the dry period and 89 were in the rainy period.

Table 4 indicates the richness values of OTUs found in the sample sites in the dry and rainy periods. Values of taxonomic richness found in sites S2 and S5 were slightly lower in both climatic periods. Richness values in sites S3 and S6 were similar to those found in control sites S1 and S4. This suggests a recovery of the fauna as the quantity of discharge approaches that found before the dams were reestablished.

Table 1. Values of physical and chemical variables measured in the sample sites (S1, S2, S3, S4, S5 and S6) of the D'Ouro and Santo Antônio rivers during the dry period (August 2003). * Values under the limits of sensitivity of the equipment.

	D'ouro river			Santo Antônio river		
	S1	S2	S3	S4	S5	S6
Orthophosphate (µg P–PO_4^{3-})	4.03	4.48	7.17	2.69	10.75	8.06
Ammonia (µgL^{-1} N–NH_3/NH_4^+)	11.37	37.52	*	*	10.80	11.37
Nitrite (µgL^{-1} NO_2^-)	3.20	2.51	3.65	3.65	5.82	5.48
Nitrate (µgL^{-1} NO_3^-)	831.45	748.39	662.58	367.17	856.9	436.15
Silicate (µgL^{-1} $Si(OH)_4$)	3328.90	3363.20	4044.30	5070.40	7038.90	5831.70
TDS (mgL^{-1})	10.00	10.00	13.00	14.00	20.00	17.00
Total Hardness (mgL^{-1} $CaCO_3$)	15.91	13.79	13.79	13.79	13.79	17.73
Hardness Ca (mgL^{-1} $CaCO_3$)	3.94	5.91	5.91	5.91	5.91	5.91
Hardness Mg (mgL^{-1} $CaCO_3$)	11.97	7.88	7.88	7.88	7.88	11.82
Chloride (mgL^{-1})	8.87	8.87	8.87	8.87	10.84	11.83
pH	6.40	6.40	6.60	6.80	6.60	6.80
Total alkalinity (mgL^{-1} $CaCO_3$)	10.00	10.00	10.00	8.57	8.57	8.57
Alk. Bicarbonate (mgL^{-1} $CaCO_3$)	10.00	10.00	10.00	8.57	8.57	8.57
Dissolved oxygen (mgL^{-1} O_2)	8.50	7.50	7.00	7.30	5.30	6.50
Water Temperature (°C)	17.00	19.00	18.50	17.00	17.00	18.00
Outflow ($m^3 \cdot s^{-1}$)	157.14	0.00	113.28	58.20	0.00	33.80

Table 2. Values of physical and chemical variables measured in the sample sites (S1, S2, S3, S4, S5 and S6) of the D'Ouro and Santo Antônio rivers during the rainy period (January 2004).

	D'ouro river			Santo Antônio river		
	S1	S2	S3	S4	S5	S6
Orthophosphate (µg $P–PO_4^{3-}$)	5.57	3.40	4.33	4.64	5.57	6.50
Ammonia (µgL^{-1} $N–NH_3/NH_4^+$)	6.58	8.40	3.64	8.12	5.74	8.82
Nitrite (µgL^{-1} NO_2^-)	2.38	1.40	1.40	1.82	1.54	2.38
Nitrate (µgL^{-1} NO_3^-)	463.21	452.98	503.13	466.15	489.26	555.23
Silicate (µgL^{-1} $Si(OH)_4$)	143.47	146.34	218.86	300.51	429.37	428.59
TDS (mgL^{-1})	9.00	9.00	12.00	12.00	12.00	13.00
Total Hardness (mgL^{-1} $CaCO_3$)	11.82	11.82	17.73	9.85	9.85	9.85
Hardness Ca (mgL^{-1} $CaCO_3$)	7.88	5.91	9.85	5.91	5.91	7.88
Hardness Mg (mgL^{-1} $CaCO_3$)	3.94	5.91	7.88	3.94	3.94	1.97
Chloride (mgL^{-1})	7.88	7.88	8.87	9.85	7.88	9.85
pH	6.64	6.38	6.93	6.65	6.59	6.69
Alk. Bicarbonate (mgL^{-1} $CaCO_3$)	8.57	7.14	5.71	7.14	8.57	7.14
Dissolved oxygen (mgL^{-1} O_2)	9.21	8.00	7.50	6.85	6.50	6.51
Water Temperature (°C)	20.60	20.70	20.00	20.50	21.00	21.40
Outflow ($m^3 \cdot s^{-1}$)	386.50	191.55	292.38	197.01	139.62	178.83

Table 3. Abundance of macroinvertebrates in the sample sites at the upstream and downstream of the dam for water abstraction of the D'ouro and Santo Antônio rivers (Biological Reserve of Tinguá, RJ, Brazil) in the dry and rainy periods.

	D'ouro river			Santo Antônio river			Total	OTU
Period	S1	S2	S3	S4	S5	S6		
Dry	2,044	1,383	6,173	2,304	2,621	3,722	18,247	99
Rainy	1,606	1,553	1,409	1,850	1,991	2,438	10,847	89
Total	3,650	2,936	7,582	4,154	4,612	6,160	29,094	116

Table 4. Total values of taxonomic richness in the different sampling sites (S1, S2, S3, S4, S5 and S6) in the dry and rainy periods in the D'ouro and Santo Antônio rivers.

	D'ouro river			Santo Antônio river		
Period	S1	S2	S3	S4	S5	S6
Dry	57	53	57	57	54	60
Rainy	52	41	47	50	49	50

As regards community composition, most orders of aquatic insects did not have significant differences in richness values between the dry and rainy periods. An exception was noted in the Odonata order but, generally, significant richness loss of OTUs in the sites below the dam was not registered. Only the Coleoptera order presented an increase in the richness after the impoundment (Table 5).

The canonical correspondence analysis (CCA) indicated differences in the macroinvertebrates community between the dry and rainy periods. In the first axis, a separation between

Table 5. Taxa richness at six sites (S1, S2, S3, S4, S5 and S6) in the D'ouro and Santo Antônio rivers based on samples taken from the dry and rainy periods.

	Dry						Rainy					
	D'ouro river			Santo Antônio river			D'ouro river			Santo Antônio river		
Taxa	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6
Coleoptera (Genus)	9	8	10	9	10	13	9	4	9	9	7	7
Diptera (Family)	7	5	6	7	5	8	7	7	6	6	6	7
Ephemeroptera (Genus)	10	10	10	9	9	10	10	9	8	10	11	13
Hemiptera (Genus)	5	3	3	4	5	5	4	3	2	5	4	2
Trichoptera (Genus)	14	10	11	12	9	8	11	6	9	8	7	9
Plecoptera (Genus)	3	2	3	4	2	2	3	3	2	3	4	1
Odonata (Genus)	3	4	5	2	3	4	3	0	2	1	1	2

the samples of dry and rainy pedriods was observed independently of the rivers (Fig. 2a). The physical and chemical water parameters, such as nitrate, total hardness, orthophosphate, TDS and silicate were variables which explained most of the separation of the dry period in Axis 1. The outflow, ammonia, dissolved oxygen and pH parameters, explained the separation of the rainy period (Fig. 2a). During the dry period, the silicate values increased around

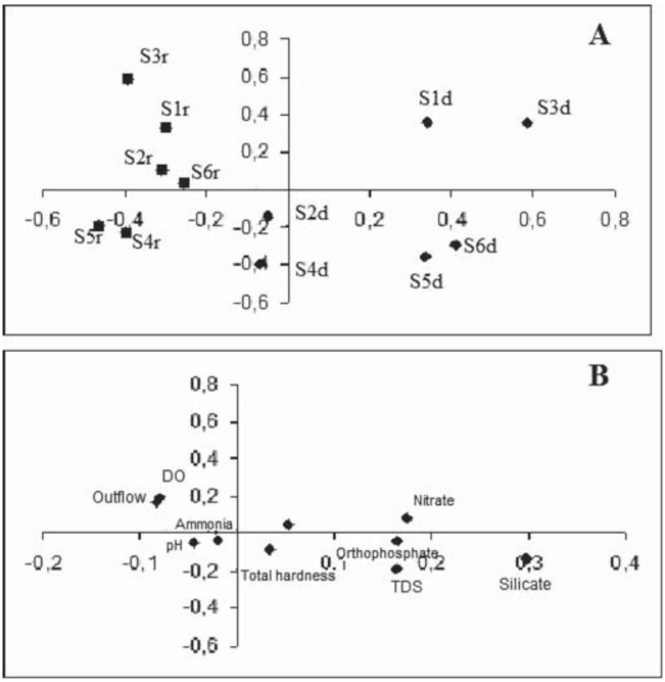

Figure 2. Canonical correspondence analysis (CCA). A – sample sites (S1, S2, S3, S4, S5 and S6) during the dry (d) and rainy periods (r) in the D'ouro and Santo Antônio rivers. B – Environmental parameters (outflow; dissolved oxygen (DO); ammonia; pH; nitrate, orthophosphate; TDS and silicate).

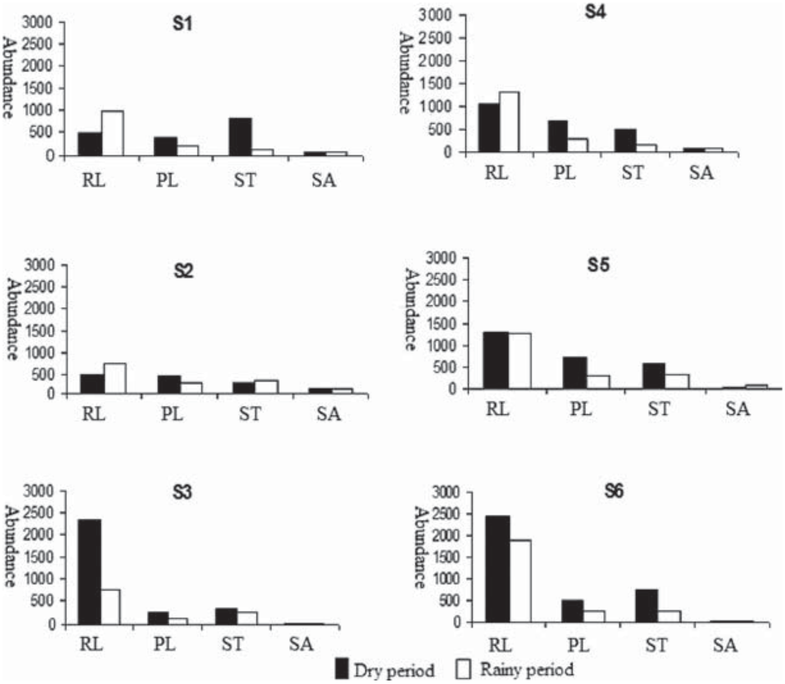

Figure 3. Abundance in different substrate types (Riffle litter (RF); Pool litter (PL); Stone – ST; Sand – SA) during the two sampling periods (dry and rainy) in the sampling sites (S1, S2, S3, S4, S5 and S6) of the D'ouro and Santo Antônio rivers.

60 times, which explains the great contribution of this element to the distribution pattern of the sample sites observed in CCA.

The numerical values of abundance in each substrate in both sampling periods, before and after water abstraction, did not clearly define any pattern. That might indicate that one or other substrate was differentially influenced. The Rifflee-Litter substrate presented the highest values of abundance of organisms, whereas the sand substrate (SS) presented the lowest values (Fig. 3).

Figure 4(a, b, c and d) shows the abundance of benthic macroinvertebrates in relation to the functional feeding groups (FFGs) in the different substrates of all the sampling sites of this study. Surprisingly, our results rejected the hypothesis that there would be a difference in the representativeness of the FFGs between the dry and the rainy period and between the sites. The FFGs presented small variations, and we can not assume that they were derived from season changes or from the discharge reduction.

The effect of the discontinuity of the water flow during the dry period on the organisms, relating them to their preferential substrates, is shown on Table 6. When the community composition was analyzed in terms of presence and absence, no significant changes were observed in stream reaches below the dam (S2 and S5). However, this discontinuity affected the abundance of some taxa, decreasing or increasing their frequencies, especially in the dry period when a higher longitudinal discontinuity occurred. The most affected genera were *Heterelmis, Rhagovelia, Leptohyphes, Baetodes, Hagenulopsis, Smicridea, Phylloicus* and *Triplectides.* This effect was clearer in the D'ouro river during the dry period. This qualitative analysis was important to verify if any substitution of species was taking place during the period of flow reduction.

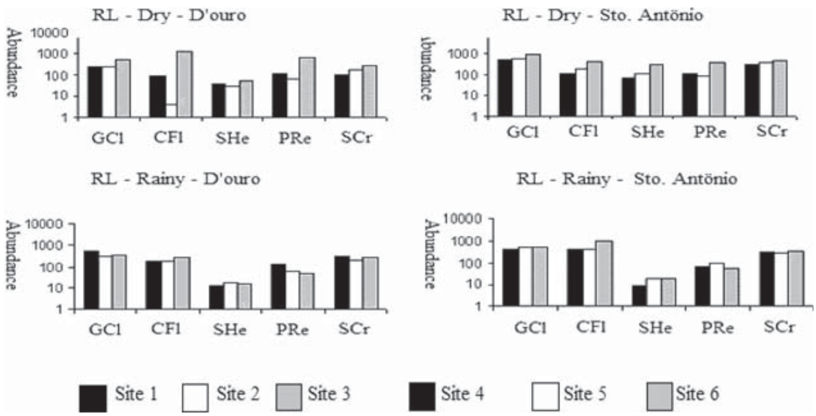

Figure 4a. Abundance of the functional feeding groups (FFGs) in the D'ouro and Santo Antônio rivers and riffle litter substrate (RL) during the dry and rainy periods. Data in logarithmic scale. Gathering-collectors (GCl); filtering-collectors (CFl); shredders (SHe); predators (PRe); scrapers (Scr).

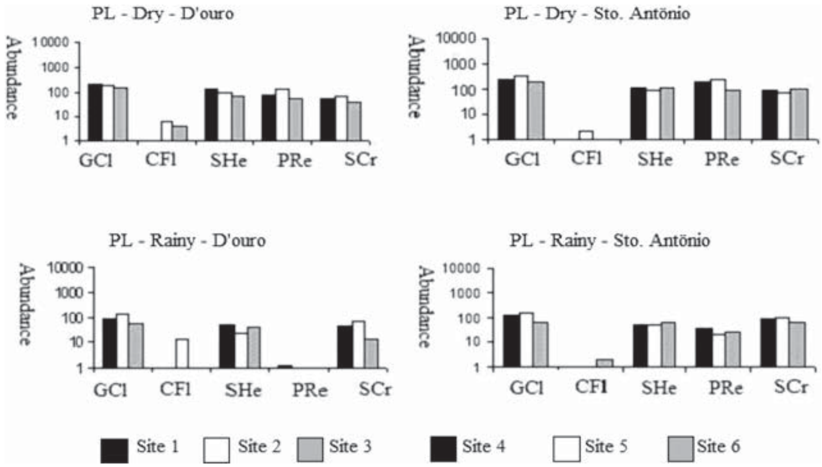

Figure 4b. Abundance of the functional feeding groups (FFGs) in the D'ouro and Santo Antônio rivers and pool litter substrate (PL) during the dry and rainy periods. Data in logarithmic scale. Gathering-collectors (GCl); filtering-collectors (CFl); shredders (SHe); predators (PRe); scrapers (Scr).

4. Discussion

Although there are many studies on the impacts associated with large reservoirs on the biota, only a few studies address the effects of alterations in flow on aquatic invertebrates (COBB *et al.*, 1992; FRUTIGER, 1992; GORE and HAMILTON, 1996; IMBERT and PERRY, 2000). Fewer still evaluate those effects during desiccation of the river bed (MCCLAY, 1968; O'KEEFE and DEMOOR, 1988; DUDGEON, 1992; CASTELLA *et al.*, 1995; RADER and BELISH, 1999).

One of the main problems associated with impoundments for irrigation or for public supply is to adjust the correct amount of water for maintaining the minimal discharge flow

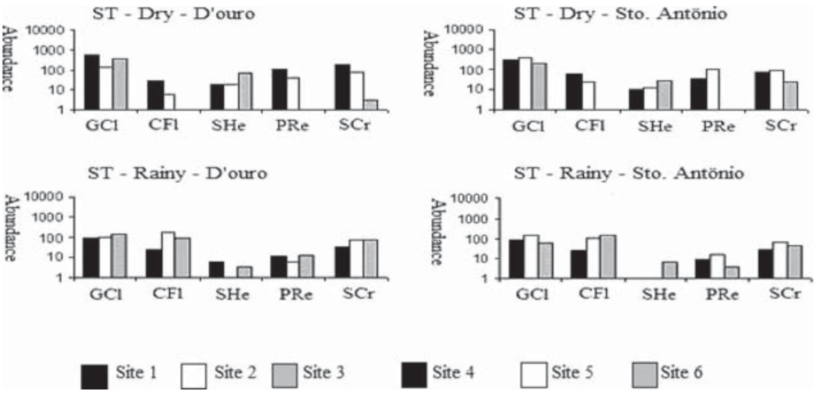

Figure 4c. Abundance of the functional feeding groups (FFGs) in the D'ouro and Santo Antônio rivers and stone substrate (ST) during the dry and rainy periods. Data in logarithmic scale. Gathering-collectors (GCl); collectors-filtering (CFl); shredders (SHe); predators (PRe); scrapers (Scr).

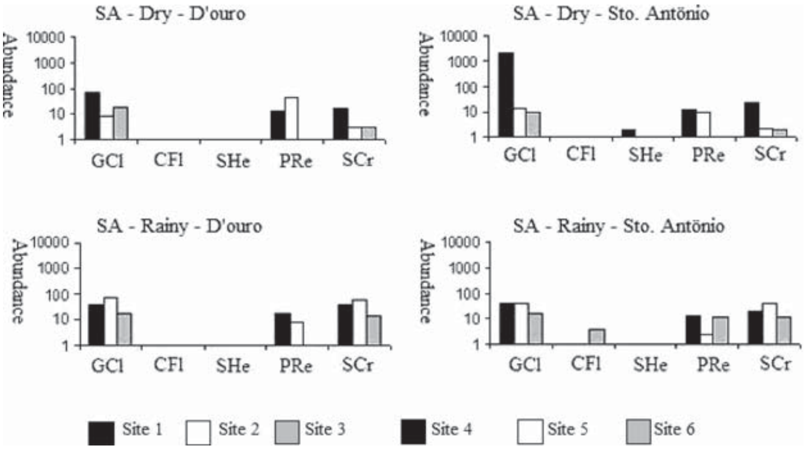

Figure 4d. Abundance of the functional feeding groups (FFGs) in the D'ouro and Santo Antônio rivers and non consolidated sediment substrate (SA) during the dry and rainy periods. Data in logarithmic scale. Gathering-collectors (GCl); collectors-filtering (CFl); shredders (SHe); predators (PRe); scrapers (Scr).

in the river. Such adjustment is important for the maintainance of aquatic life, navigation, recreation and water quality (Everard, 1996; Palau *et al.*, 1998; Dewson *et al.*, 2007). In streams, the great threat concerns the loss of the aquatic life diversity and the quality of water. Thus, in this study we wanted to analyze the potential effects of the discontinuity of the discharge produced by small dams on the macroinvertebrate community. Our first hypothesis evaluated which alterations the discontinuity of the discharge would produce in the physical and chemical characteristics of the water.

In a general way, most physical and chemical variables of the water did not differ either between the seasons of the year or below the impoundments (Table 1 and Table 2). We suspect that such stability, mainly in the dry period, was due to the upwelling of the underground water from the hyporheic zone.

Table 6. List of the most negatively or positively affected organisms in relation to their abundance and their preferential substrates due to the effect of the impoundment during the discontinuity phase of the water flow (dry period) in the D'ouro and Santo Antônio rivers (RL – Riffle Litter, PL – Pool Litter, ST – Stone).

	D'OURO – DRY PERIOD			SANTO ANTÔNIO – DRY PERIOD		
	Before the dam	After the dam	Preferential substrate	Before the dam	After the dam	Preferential substrate
Baetodes spp	86	4	RL and ST	25	11	RL and ST
Leptohyphes spp	69	24	RL	85	35	RL
Hagenulopsis spp	25	1	RL	75	13	RL and PL
Hetaerina spp	5	0	RL	0	2	PL
Rhagovelia spp	34	0	ST	3	0	ST
Heterelmis spp	54	11	RL	90	15	RL
Macrelmis spp	26	2	RL	18	24	RL and ST
Staphilinidae	35	10	RL	0	5	RL
Phylloicus spp	73	46	PL	71	9	PL
Ochrotrichia spp	50	6	ST	19	20	ST
Smicridea spp	90	18	ST	50	28	ST
Triplectides spp	17	6	PL	2	1	PL
Anacroneuria spp	58	17	RL	90	21	RL
Maruina spp	148	0	ST	0	0	ST
Simuliidae	111	17	RL and ST	170	177	RL and ST
Chironomidae	323	129	RL and PL	365	79	RL and LF
Orthocladinae	390	463	ST	502	806	ST
Tanypodinae	135	157	ST	96	178	RL

This corroborates the observations of Hynes (1983), Dumnicka (1988) and Boulton (2007) concerning such hydrological connectivity. It is important to point out that silicate values (Tables 1 and 2) were extremely high in the dry period, when there was no measurable discharge in sites below the dam. It is known that silicate concentrations are higher worldwide in groundwaters than in surface waters (Davis, 1964; Wetzel, 1981). This helps support our suposition that hyporheic groundwater is responsible for maintaining vertical connectivity and physical-chemical parameters stability during the dry period.

Armitage (1976) noted that the biological changes below dams had to be considered not only in terms of flow regulation, but also in terms of the effect that hydrological variation had on substrate stability and on the transportation of organic matter.

To these observations, Smith (2001), Fleituch (2003) and Mérigoux and Dolédec (2004) added that the alteration in the stream flow regime might be considered as the main influence on the distribution and abundance of biotic species and their communities in regulated streams. Our study partially agrees with such observations as there was a reduction in the general abundance of the organisms at all sampling sites during the rainy season and at site S2 during the dry season (Table 3).

Armitage and Petts (1992) suggested that faunal abundance is more sensitive to discharge reductions than number of taxa, but they recognized the importance of observing the overall changes in the community. Maddock (1999) and Bunn and Arthington (2002) added that the loss of biological diversity was a direct response to the impoundment which in turn led to isolated populations, loss of drift organisms, extirpated native species, and the invasion of exotic species. We did not observe a significant reduction in the richness of aquatic insects among the seasons but we did find a slight loss of richness and alterations in the abundance of some taxa below the impoundments. This reflected a loss of biological diversity caused by impoundment.

If we only compare the composition of the fauna in the control sites, there were no changes between the two sampling periods. The highest abundances of the individuals occurred during the dry period and the lowest during the rainy period. A similar composition of the species between the two periods is a recurring pattern in southeastern Brazil (BAPTISTA *et al.*, 1998; KIKUCHI and UIEDA, 1998; SILVEIRA *et al.*, 2001; BUSS *et al.*, 2002).

Coleoptera, Diptera, Ephemeroptera and Trichoptera presented the highest values of taxonomic richness. Within those orders, the highest richness was found in the Coleoptera with 27 OTUs (23.27% of the overall OTUs). According to RIBERA and VOGLER (2000), coleopterans present many strategies to survive dry periods, which might also reflect the maintenance of their richness along the gradient. BUNN and ARTHINGTON (2002) found that rivers with frequent drought periods (little to no discharge) are dominated by species which are morphologically small, physiologically tolerant, and generalists.

According to WARD (1992), the maintenance of an elevated richness, even during the river discontinuity, could be a result of the capacity of aquatic insects to migrate through the hyporheic zone and to migrate aerially through winged forms. The hyporheic zone has been proposed as a refuge for surface invertebrates from disturbances such as flood, drought, predation, extreme temperature and reduced water quality. However, a recent study (JAMES *et al.*, 2008) indicated that benthic and hyporheic macroinvertebrates are resistant to short periods (1–1.5 months) of severe flow reduction. The latter authors suspected that, in many cases, natural flood and scour events had a greater impact on aquatic macroinvertebrates in small streams than would short-term or seasonal water abstraction where at least some flow remained. Thus, invertebrate abundance and community structure may not be the most useful indicators of environmental stress caused by reduced flow.

During the rainy period, when the water flow connectivity was reestablished, colonization occurred through drift down the river. During the dry period, sites S3 and S6 were supplied by small tributaries and by faunal drift. The result was a recolonization of these sites impacted by water abstraction. The total values of fauna richness in these sites were similar to those of the control sites.

The effect of discontinuity was clearer in the dry period in the D'Ouro river which had the highest decrease in the discharge and the most desiccation. The form of the basin and the smaller size of this river were factors which favored those changes. The change from a lotic to a semilentic regime, after the impoundment, restrained the availability of the flow substrates thus making the maintainence of some species impossible or provoking a decrease in their density. According to DEWSON *et al.* (2007), the increased invertebrate abundance resulted from the concentration of invertebrates in the reduced wetted area. EXTENCE *et al.* (1999) noted that some taxa may be ideal indicators to evaluate alterations in flow conditions since they present quantitative responses. For these latter authors, most of the taxa associated with a slow flow tended to increase in abundance as the flow decreased, whereas most species associated with faster flows exhibit an opposite response.

Table 6 shows organisms with differential responses to the impoundment. The genera *Baetodes*, *Smicridea* and the family Elmidae are taxa that are restricted to stream flow areas most of the time, especially for feeding. Two genera of the Trichoptera order, *Triplectides* and *Phylloicus*, prefer little stream flow but they depend on the presence of wood and leaves, respectively. The abundance of these organisms decreased in sites below the dams (Table 6).

Some organisms, such as Ortocladinae and Tanypodinae (Chironomidae), increased their abundances in the sites just below the dams in the two rivers (S2 and S5). The Diptera order has recognized plasticity and tolerance to various environmental alterations. The organisms of this family, especially those belonging to Chironomidae, are associated with some specific substrate types (litter and sand), whereas the Orthocladinae, except those of the genus *Lopescladius* and those of the tribe Corynoneurini, prefer the rocky substrate (pebbles).

In general, there was a clear difference in the number of filterers in the riffle area substrates. This was particularly apparent in the dry period, at the sites just below the dam, mainly in the D'ouro river. This characterized an important effect derived from discontinuity (Figs. 4a and 4c). These results differed between the rivers and were clear in the dry period since the sampling stations remained connected. The decrease in the discharge was not as prominent in the rainy period.

The impact provoked by impoundment in the D'ouro and Santo Antônio rivers, and the restructuring of the community, are demonstrated by the correspondence analysis (Fig. 2). The separation of the communities by periods of the year indicates that this type of division would be linked mainly to the retention, deposition of litter, and to the heterogeneity of microhabitats during the dry period, and also to the larger homogeneity of the benthic fauna during the rainy season. Our results corroborate those of HYNES (1970) who affirmed that the heterogeneity of microhabitats was derived from the stream flow regime. According to the results obtained, water withdrawal influenced the stream flow regime and, as a consequence, negatively modified some habitats of macroinvertebrates.

We conclude that the highest alterations in the composition, abundance, and other aspects of the functional organization of the macroinvertebrate communities, occured during the dry period. The integrity of river ecosystems relies on a balance among all parameters. Nonetheless, the impact of the small dams for water withdrawal could be reduced if, during the dry period, a minimal ecological discharge were maintained thereby leaving a basal flow for the maintenance of the fluvial connectivity of the river water. Such action would offer more sustainability to the communities of aquatic invertebrates. This would let them remain structurally and functionally organized within conditions closer to the natural ones observed, *i.e.*, before the significant influence of the two dams.

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7. References

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