BIODIVERSITY ASSESSMENT OF BENTHIC MACROINVERTEBRATES ALONG A RESERVOIR CASCADE IN THE LOWER SÃO FRANCISCO RIVER (NORTHEASTERN BRAZIL)

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(With 1 figure)

ABSTRACT

In order to verify the cascade-system effect in benthic macroinvertebrate communities, and the implications for policy making and proposals for conservation and sustainable use of the lower portion of São Francisco river basin (Bahia State, Brazil), a three-reservoir cascade system including two stretches downstream were studied during dry (June, 1997) and rainy (March, 1998) periods. The dominant groups found were Mollusca (*Melanoides tuberculata)*, Oligochaeta, and Chironomidae larvae. Low Shannon-Wiener and Pielou index values were found, but with no significant difference between the sampling periods. However, density and taxonomic richness were significantly different ($t_{(0.05;\ 31)} = -2.1945$; $p < 0.05$; e $t_{(0.05;\ 31)} = -3.0600$; $p < 0.01$) between the sampling periods, with a reduction in the number of taxa and macroinvertebrate abundance during the rainy period. An increasing gradient in benthic macroinvertebrate community structures was noted along the reservoir cascade from the first reservoir (Apolônio Sales), followed by a decrease downstream from the third reservoir of the system (Xingó). Despite the negative consequences of rapid proliferation of dams, which have caused widespread loss of freshwater habitats, the reservoir cascade system promoted an increase in benthic macroinvertebrate diversity, due to water-quality improvement along the system.

Key words: benthic macroinvertebrates, reservoir, biodiversity assessment, reservoir cascade concept, São Francisco river.

RESUMO

Avaliação da biodiversidade de macroinvertebrados bentônicos ao longo de uma cascata de reservatórios no baixo rio São Francisco (nordeste do Brasil)

Com o objetivo de determinar o efeito da cascata de reservatórios nas comunidades de macroinvertebrados bentônicos e sua possível implicação para a definição de políticas e propostas para conservação e uso sustentável da porção baixa da bacia do rio São Francisco (Bahia, Brasil), amostragens foram realizadas em três reservatórios e dois trechos a jusante do último reservatório, durante os períodos de seca (junho de 1997) e chuvas (março de 1998). Os grupos dominantes foram Mollusca (*Melanoides tuberculata*), Oligochaeta e larvas de Chironomidae. Baixos valores para os índices de diversidade de Shannon-Wiener e equitabilidade de Pielou foram encontrados, contudo sem diferença significativa entre os períodos de amostragem. Entretanto, a densidade total e a riqueza taxonômica foram significativamente diferentes ($t_{(0.05;\ 31)} = -2.1945$; $p < 0.05$; e $t_{(0.05;\ 31)} = -3.0600$;

$p < 0.01$), com redução no número de taxa e abundância de macroinvertebrados durante o período de chuvas. Gradiente crescente na estrutura das comunidades de macroinvertebrados bentônicos foi observado ao longo da cascata de reservatórios desde o primeiro reservatório (Apolônio Sales), seguido por diminuição a jusante do terceiro reservatório (Xingo). Apesar das conseqüências negativas da rápida proliferação de represas, como a perda disseminada de habitats de água doce, o sistema de reservatórios em cascata promoveu aumento na diversidade de macroinvertebrados bentônicos em decorrência do aumento na qualidade de água ao longo do sistema.

Palavras-chave: macroinvertebrados bentônicos, reservatórios, avaliação da biodiversidade, conceito de cascata de reservatórios, rio São Francisco.

INTRODUCTION

Reservoirs are artificial water bodies whose dynamics and structures present a pattern of organization midway between those of rivers and lakes. The ecological processes in these ecosystems are much more complex and variable than those found in natural lakes (Agostinho & Gomes, 1997). Furthermore, reservoirs are subject to distinguishable influences of the physical, chemical, and biological components of their tributaries (Torloni, 1994), as well as those caused by the principal land uses in the drainage basins, all of which result in various changes along a reservoir cascade.

The transformation in a lentic system entail by depth increase due to river damming drastically alters the physical (e.g., subaquatic radiation, light, and temperature), chemical (dissolved oxygen and nutrient concentrations), and biological water characteristics (structure and aquatic community distribution patterns) (Júlio *et al.*, 1997). Moreover, remains of chemical fertilizers coupled with industrial effluents and untreated sewage coming from the drainage basin cause profound modifications in most reservoirs. Among these changes are increases in trophic status and aquatic macrophyte growth, and sedimentation-rate modifications (Tundisi & Straškraba, 1999).

According to Rosenberg *et al.* (2000), river diversion and large dams have contributed substantially to fishery destruction, species extinction, and overall loss of ecosystem function that is crucial for humans, with results such as water-borne disease increase. Moreover, since 1950 the number of large dams (over 15 meters in height) has increased from 5,700 worldwide to over 41,000, thus converting lotic systems into lentic ones and, according to Johnson *et al.* (2001), creating extensive habitat fragmentation in nearly 60% of the major river basins, despite the maintenance until now of a basic water flow through each reservoir.

Within the aquatic communities, benthic macroinvertebrates represent one of the groups most affected by reservoir construction (e.g., Henry, 1999). These organisms inhabit of river, lake, and reservoir bottoms, and their distribution is directly related to food availability and quantity, sediment type (organic, sandy, clay), substrate (rock, wood, aquatic macrophytes), and water quality (temperature, oxygen, and dissolved substances) (Callisto, 2000).

Data on macrobenthic community distribution and structure have been used in ecological monitoring programs, and is an important ecological tool to describe spatial and temporal changes (Callisto & Esteves, 1995; Callisto *et al.*, 1998; Leal & Esteves, 1999). Depending on the distance between the dams along the river, construction of cascade reservoir systems has the potential to increase river impoundment effects on aquatic organism composition and distribution.. This has been demonstrated recently with respect to the phytoplankton along the reservoir cascade of the upper/middle Tietê river (Barbosa *et al.*, 1999). Moreover, according to the distance involved, area is sometimes available for benthic communities, thus increasing the richness and, often, diversity of these organisms.

However, in reservoir cascades the alterations in water quality as well as in the biota composition and distribution are the results of modifications in the lateral, vertical, and longitudinal dimensions, as described in the cascading reservoir continuum concept (CRCC) by Barbosa *et al.* (1999).

Regarding the physical and chemical quality of the water, a change in the richness/diversity of benthic macroinvertebrates is to be expected along a cascade system, in accordance with the use of the drainage basin. Particularly considering the reservoir cascade formed by the three reservoirs in the lower São Francisco river, this study had as its major objective to evaluate macroinvertebrate diversity changes along the cascade, while using these organisms as water-quality bioindicators.

Study area

The São Francisco river runs 3,161 km through the states of Minas Gerais, Bahia, Pernambuco, Sergipe, and Alagoas, before reaching the Atlantic Ocean, draining a c. 670,000 km^2 basin. The river headwaters, located in Serra da Canastra National Park, in Minas Gerais State (20^{o}14'32"S; 46^{o}26'43" W) at 1,235 m a.s.l., are cold (13.4^{o}C up to 17.8^{o}C), well oxygenated (> 89% sat.), and slightly acid (pH 5.8-6.0), and have with low conductivity values (2 to 13 µS/cm) and high benthic macroinvertebrate richness (> 50 *taxa*) (Galdean *et al.*, 1999). The main economic activities in its basin are agriculture and cattle breeding, principally fruit and vegetable irrigation, especially in the Sobradinho and Itaparica reservoir stretches in Bahia State.

The hydrological regime of the São Francisco river varies according to the pluviometrical conditions in each stretch of its drainage basin. In the upper reaches, summer precipitation varies between 1,000/1,300 mm/year; in the middle reaches, decreasing to 500/800 mm/year in winter, and in the stretch near the littoral increasing to 1,000/1,200 mm/year. Water discharge ranged from 1,000 to 10,000 m^3.s^{-1}, depending on operational needs of Três Marias and Sobradinho reservoirs (IBGE, 2001).

The São Francisco river is a typical plateau river, which presents five falls. Its hydroelectrical potential resulted in the construction of several reservoirs particularly in Bahia State, and ultimately that of the Sobradinho, Itaparica, Apolônio Sales (former Moxotó), the Paulo Afonso (PA I, II, III, IV) complex, and Xingó hydroelectrical plants, thus forming a reservoir "cascade". The Apolônio Sales Hydroelectrical Plant is located c. 4 km upstream from the Paulo Afonso impoundment, which forms a 100 km^2 reservoir having a 1.2 billion m^3 water capacity. Downstream, the Xingó Hydroelectric Reservoir is inserted within the São Francisco river canyon.

In the present study, samplings were carried out in the reservoirs of Apolônio Sales, Paulo Afonso, and Xingó, as well as in two stretches of the São Francisco river downstream from the Xingó reservoir (at Entre Montes and Piranhas).

MATERIAL AND METHODS

The samplings were conducted during the dry (June, 1997) and rainy (March, 1998) periods, using an Eckman-Birge (225 cm^2) dredge for benthic fauna and a Surber sampler (10 x 10 cm; 0.250 mm mesh) for rocky substrates. At each of the sampling sites (Table 1), two samples were collected: the first, whole sediment while the second was washed using a 300 µm mesh sieve, after which both samples were fixed with buffered 40% formaline. Samples of the periphytic macrofauna on rocky substrates were collected only in the vicinity of the Adutora Nova site and downstream (Xingó reservoir) near Piranhas and Entre Montes, in the rainy period.

In the laboratory, the samples were washed using 0.125 mm mesh sieves, then sorted and identified under a stereomicroscope. The Chironomidae (Diptera) larvae were identified by a 400 X optical microscope, following the methodology used by Callisto *et al.* (1996). The recorded organisms were deposited in the Benthic Macroinvertebrate Reference Collection of the Institute of Biological Sciences of the Federal University of Minas Gerais.

In the field, depth and water transparency were measured using a Secchi disk; temperature, conductivity, dissolved oxygen, and pH were measured with a multiprobe apparatus; total alkalinity was determined in the laboratory, according to Carmouze (1994).

The diversity and evenness indices were calculated using the Shannon-Wiener and Pielou (transformed in log e) indices. Taxonomic richness was determined as the total number of taxa in each sample (Magurran, 1991).

RESULTS

Physical and chemical variables

Regarding the sampling periods, the reservoir depths did not show significant differences between dry and rainy periods ($t_{(0.05;\ 12)} = -1.8872$; $p = 0.0836$) probably due to control of water discharge by the opening and closing of the floodgates.

Using Secchi disk transparency, a significant difference ($t_{(0.05;\ 7)} = 13.1922$; $p < 0.001$) was found between the sampling periods, with lower values in the dry period. Water bottom temperature was also significantly different between the two sampling periods ($t_{(0.05;\ 11)} = 5.3269$; $p<0.001$), increasing up to 3.3°C in the rainy period (e.g., # 9).

The ecosystems presented relatively well-oxygenated waters (> 6 $mg.L^{-1}$ in the rainy season), except in Station 4, which presented low values (3.0 $mg.L^{-1}$). The pH ranged from slightly acidic (6.2, in # 1 and 2) to slightly alkaline (8.21, in # 7, in the dry period). Conductivity varied between 54.0 $\mu S.cm^{-1}$ (# 3, in the rainy period) and 159.0 $\mu S.cm^{-1}$ (# 5, in the dry period), and total alkalinity values were relatively high, reaching up to 200 $mEq.CO_2^{-1}$ (Table 2) in most sampling stations.

Structure and composition of the benthic macroinvertebrate communities

A total of 23 taxa were found in the dry period (Table 3), with evident difference in taxonomic richness between the sampling stations (from 1 *taxon* (Oligochaeta) in Station # 10, to 16 *taxa* in Station # 8. The densities varied between 889 ind/m^2 (# 10) and 37,642 ind/m^2 (# 8). The dominant groups were Oligochaeta, Chironomidae (Diptera), and the gastropod Thiaridae *Melanoides tuberculata*.

The benthic fauna in Paulo Afonso reservoir were dominated by *M. tuberculata* (67%) and Oligochaeta (29.9%). On the other hand, Xingó reservoir presented a benthic macroinvertebrate community formed mainly by Oligochaeta and Chironomidae. Oligochaeta was the dominant taxon in Station # 7 (46.4%), followed by Chironomidae (34.8%), with *Parachironomus* (42.9%) and *Djalmabatista* (28.6%); Station # 8 (73.5%); # 9 (67.4%), followed by Chironomidae (20.8%) and *Parachironomus* (59.7%); and Station # 10 (100%). In Station # 5, Chironomidae (37.9%), Oligochaeta (22.8%), and *M. tuberculata* (20.3%) were the dominant groups. The Chironomidae were composed mainly by Tanypodinae larvae (36.7%) and Chironominae (*Polypedilum* and *Fissimentum dessicatum*, 26.7% each).

During the rainy period 23 *taxa* were also found, varying between 1 taxon (# 5) to 12 taxa (# 3). The densities ranged from 44 ind/m^2 (# 5) to 7,287 ind/m^2 (# 3). The dominant groups were Gastropoda (*Melanoides tuberculata*), Oligochaeta, and Chironomidae.

The major dominant groups in Paulo Afonso reservoir were the gastropods and bivalves. *M. tuberculata* (61%) and *Biomphalaria* spp. (14%) predominate in # 3, while in Station # 4, Sphaeriidae (27.1%) and Bivalvia (20.8%) were dominant. Bivalvia was the dominant taxon in Apolônio Sales reservoir, with 100% in Station # 1, and 50% in # 2, followed by Sphaeriidae and *Cricotopus* (Chironomidae). The benthic macroinvertebrate community in Xingó reservoir was dominated by Oligochaeta and Chironomidae. However, in # 5 the only recorded taxon was the polymitarcyid *Campsurus* sp.. Oligochaeta (64.9%) predominated in # 6A, followed by Chironomidae (31.6%). The main chironomid taxa found in this station were *Tanytarsus* (38.9%) and *Djalmabatista* (27%). The periphyton-associated macrofauna in # 6B were dominated by Oligochaeta (35.5%) and Chironomidae (25.8%), represented only by *Cricotopus* larvae, and in # 7, only *Djalmabatista* and *Ablabesmyia* (Diptera, Chironomidae) were found. Sampling stations # 9 and # 10 were dominated by Oligochaeta and *M. tuberculata*. This gastropod represented almost the totality of the organisms found in # 9, with 98.8%. In Station # 10, this group represented only 28.6%, being replaced by Oligochaeta (57.1%). As well as in the benthic fauna, periphyton-associated macrofauna in Station # 10B was dominated by Oligochaeta, the only taxon identified, while in # 9B, *M. tuberculata* (57.2%) predominated, followed by Nematoda (35.7%).

Benthic macroinvertebrate diversity along the reservoir cascade

Low Shannon-Wiener indices were recorded, varying between H'= 0 (# 1, rainy period) to H'= 1.742 (# 7, dry period). In most of the sampling stations, only 1 or 2 taxa were abundant, resulting in low indices of evenness (J = 0.298, # 9, rainy period), in spite of the presence of some communities in which abundances and distributions were more homogeneous, such as # 5 in the dry period, where J = 0.902, and # 2, with the maximum evenness (J = 1) (Figure 1). No significant difference was found between sampling periods for diversity ($t_{(0.05;\ 31)} = -1.7992$; $p = 0.0817$) and evenness ($t_{(0.05;\ 31)} = -0.2374$; $p = 0.8139$) values. However, density and taxonomic richness values were significantly different ($t_{(0.05;\ 31)} = -2.1945$; $p < 0.05$; and $t_{(0.05;\ 31)} = -3.0600$; $p < 0.01$) between the sampling periods, evidencing a reduction in number of taxa and abundance of macroinvertebrates during the rainy period.

DISCUSSION

Major effects of cascading reservoirs on water quality and organism distribution

Straškraba (1990) described the major effects of temperature and chemical changes in the upstream reservoirs on reservoirs downstream. Vannote *et al*. (1980) have stressed the continuity of ecological functioning of entire river systems from 1st to 9th order rivers through the river continuum concept (RCC). The potential changes due to impoundments were recognized by Ward & Stanford (1983) in the serial discontinuity concept (SDC), which emphasizes the discontinuity caused by damns in the physical and biological characteristics of fluvial systems. More recently, Barbosa *et al*. (1999) proposed a new continuum concept: that of the cascading reservoir (CRCC), to serve as a theoretical basis for dealing with interconnected ecological processes in cascading reservoir systems. According to these authors, the presence of a reservoir cascade causes significant changes in the original continuum of a river, altering such features as thermal heterogeneity, connectivity, and coarse/fine particulate organic matter ratios, and very likely affecting the structure and distribution of the original biota.

It seems generally agreed upon that reservoir cascades promote an increase in water quality, due to water re-oxygenation through the energy-generating turbines. In addition, low water-flow promotes solid sedimentation, thus reducing water turbidity (Petrere & Ribeiro, 1994; Barbosa *et al.*, 1999). In spite of no significant differences in some water characteristics (e.g., transparency and dissolved-oxygen levels along the reservoir cascade in the lower São Francisco river), a gradient in benthic macroinvertebrate communities was recorded. An increase in taxonomic richness, diversity, and density was noticed for Apolônio Sales reservoir, with a decrease occurring for the same features in the downstream stretch of this reservoir (as in Station # 2). Regarding evenness, a decrease occurred starting from Xingó reservoir, probably due to allochthonous matter sedimentation and organic matter concentrations on the sediment, which affected the benthic macroinvertebrate communities, which were composed mainly of a few organisms adapted to these conditions.

Use and occupation of the soil and habitat diversity, distribution, and taxonomic richness of benthic macroinvertebrates

Biological community composition changes in reservoirs are imposed by pressures caused by modifications in physical and chemical characteristics. Some species change locations, while others either increase or suffer reductions (Torloni, 1994; Agostinho *et al.,* 1997; Pardo *et al.*, 1998).

Aquatic macrophytes are important components of aquatic ecosystems, offering protection against predators, serving as a food source both directly (vegetal tissue) and indirectly (organic particle accumulation and substrate for periphyton growth), and increasing substrate complexity, and therefore offering greater opportunity for benthic macroinvertebrate colonization (Ward, 1992; Humphries, 1996). Factors such as pH, hardness, total alkalinity, turbidity, humic acids, and, mainly, calcium are the main factors that determine mollusk distribution in freshwater ecosystems. Association with aquatic vegetation is also relevant for the occurrence and distribution of these organisms (Lanzer & Schafer, 1988; Costil & Clement, 1996).

Paulo Afonso reservoir presents accelerated eutrophication, due to direct input of untreated domestic sewage effluents, which results in the growth of dense stands of rooted submersed aquatic macrophytes, especially *Chara* sp. (Charophyta) and *Egeria* sp. (Hydrocharitaceae) throughout its extension. The development of a community dominated by mollusks in both dry and rainy periods was recorded, associated with certain physical and chemical characteristics (basic pH, high values of total alkalinity) and aquatic macrophytes.

Reservoirs present short-term high sedimentation potential (Nagle *et al.*, 1999), due to the impoundment of rivers and modifications in flow characteristics. As a consequence of land use and degree of human occupation in the drainage basin, these ecosystems may receive considerable amounts of fine sediment and fine particulate organic matter (FPOM). Faria & Oliveira (1994) emphasizes that reservoir tributaries are the main sources of sediments when compared with reservoir shores. Such substrate conditions favor colonization by organisms having morphological adaptations such as a worm-like body, as in Chironomidae (Diptera) larvae and Oligochaeta, which dominate the benthic communities in this study.

TABLE 1

Sampling stations of benthic macroinvertebrate samples and abiotic measurements (R: rainy; D: dry periods).

Stations	Sample type	Sampling periods	Location	Latitude (S)	Longitude (W)	Altitude (m a.s.l.)	Distance to the ocean (km)
# 1	Benthic	R	Apolônio Sales reservoir, limnetic zone	9º21’682”	38º13’900”	270	350
# 2	Benthic	R	Apolônio Sales reservoir, litoral zone	9º21’682”	38º13’900”	270	350
# 3	Benthic	R, D	Paulo Afonso reservoir, limnetic zone	9º23’598”	38º12’251”	250	290
# 4	Benthic	R	Paulo Afonso reservoir, litoral zone	9º23’598”	38º12’251”	250	290
# 5	Benthic	R, D	Xingó reservoir, close to Xingozinho stream	9º32’502”	38o01’241”	220	250
# 6A	Benthic	R	Xingó reservoir, Adutora Nova site	9º27’805”	38º01’670”	220	250
# 6B	Peryphitic	R	Xingó reservoir, Adutora Nova site	9º27’805”	38º01’670”	220	250
# 7	Benthic	R, D	Xingó reservoir, Adutora Velha site	9º27’912”	38º01’504”	220	250
# 8	Benthic	D	Xingó reservoir, close to Talhado stream	9º30’904”	37º53’830”	220	250
# 9A	Benthic	R, D	Downstream Xingó reservoir, Entre Montes municipality	9º37’085”	37º45’894”	150	248
# 9B	Peryphitic	R	Downstream Xingó reservoir, Entre Montes municipality	9º37’085”	37º45’894”	150	248
# 10A	Benthic	R, D	Downstream Xingó reservoir, Piranhas municipality	9º37’099”	37º45’760”	150	247
# 10B	Peryphitic	R	Downstream Xingó reservoir, Piranhas municipality	9º37’099”	37º45’760”	150	247

TABLE 2

Physical-chemical parameters measured in the studied ecosystems, during the dry (June 1997) and rainy (March 1998) seasons (D: dry; R: rainy periods).

Variables	Apolônio Sales reservoir				Paulo Afonso reservoir				Xingó reservoir								São Francisco river			
	# 1		# 2		# 3		# 4		# 5		# 6		# 7		# 8		# 9		# 10	
	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R
Depth (m)	–	28.6	–	15.0	–	6.5	–	14.0	5.5	3.4	8.0	8.5	–	2.5	–	20.0	15.0	20.0	47.0	32.4
Transparency (m)	–	–	–	–	–	4.4	–	4.8	0.35	6.0	0.6	–	–	6.0	–	–	0.45	5.6	0.45	–
Temperature (^{o}C)	–	28.5	–	28.4	–	28.1	–	26.7	27.0	29.2	26.1	28.7	–	29.5	–	26.4	25.6	28.9	25.6	28.8
Dissolved oxygen (mg.L^{-1})	–	7.35	–	7.63	–	7.0	–	3.0	8.1	6.67	7.36	7.71	–	8.12	–	7.49	6.1	7.17	6.11	7.14
pH	–	6.82	–	6.82	–	7.73	–	6.87	–	–	8.21	–	–	7.67	–	7.95	7.26	6.87	–	6.57
Conductivity (µS.cm^{-1})	–	68.2	–	67.9	–	54	–	83	159.0	71.7	88.0	69.3	–	68.2	–	66.4	79.0	69.5	78.0	69.6
Total alkalinity (mEq.CO_2^{-1})	–	284.3	–	291.9	–	–	–	–	–	294.8	184.6	290.8	–	286.2	–	456.0	139.1	293.1	153.8	–

According to Real & Prat (1992), usually Oligochaeta densities increase with increases in the fine-particle fraction in the sediment, and are more common in the deeper reservoir zones. In the shallower zones, Chironomidae larvae are more abundant, due to larger size of the sediment particles. In Station # 4 (Xingó reservoir, mouth of the Talhado stream), fine-particle deposition in the sediment and increase in fine particulate organic matter (FPOM) concentration are likely to influence the structure of the benthic macroinvertebrate communities. In this sampling station, high Oligochaeta density (27,689 ind/m^2) was found in the dry period. The presence of organisms typically associated with FPOM was observed in the sediment (*Polypedilum*, Chironomidae; *Campsurus*, Polymitarcyidae), or in suspension, where filtering-collectors such as Ostracoda were observed.

Apolônio Sales reservoir, despite being a relatively old reservoir, sheltered a poor and little diversified community of benthic macroinvertebrates, almost all of which were Bivalvia. These organisms feed on organic matter either in the sediment or suspended in the water (Ruppert & Barnes, 1994). Besides the downstream sampling site being inserted in an intensely cultivated area (the Itaparica region), this reservoir has received increasing domestic-sewage discharges from a growing number of villages and small towns around the reservoir (Table 4).

In both sampling stations located on the São Francisco river (downstream from Xingó reservoir), the substrate is composed of sand and FPOM, which is extremely unstable and, thus, unsuitable for benthic macroinvertebrate colonization (Allan, 1995). In lotic conditions, this kind of substrate is easily upset by water column turbulence, caused by boats or water volume and flow velocity increases during the rainy period. In these sampling stations the current increases considerably due to reservoir discharges, resulting in modifications in the reservoir bottom and highly unstable sediment.

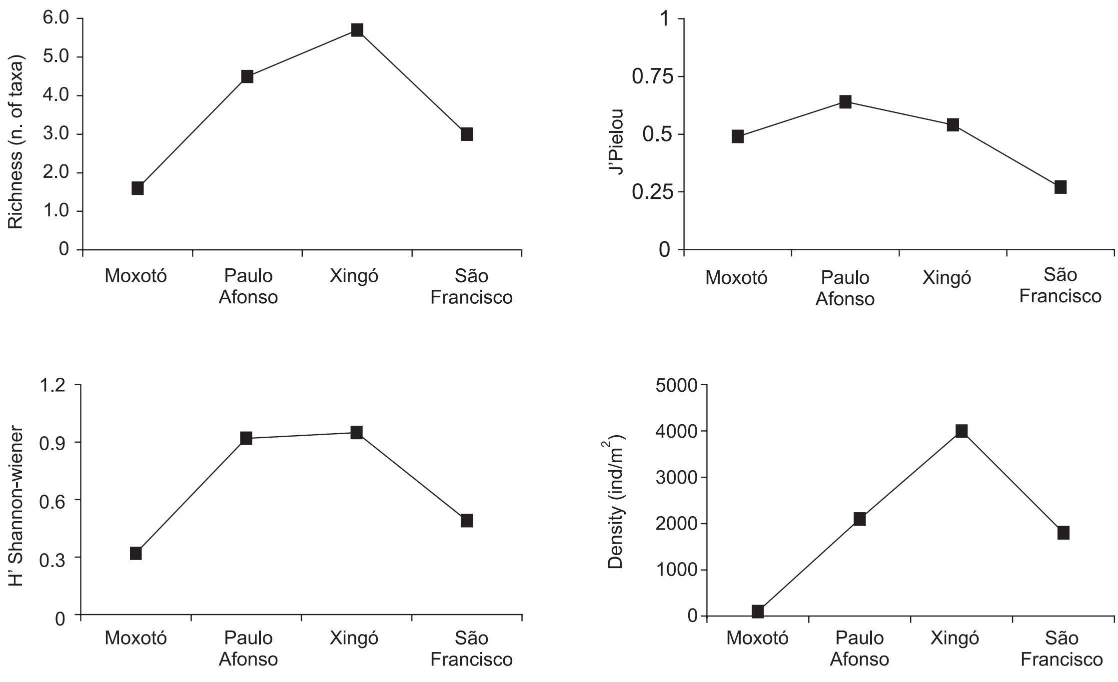

Fig. 1 — Taxonomic richness, total densities (ind/m^2), Shannon-Wiener diversity, richness, and Pielou evenness indices of the benthic macroinvertebrate communities along the reservoir cascade in the lower São Francisco river.

TABLE 3

Densities (ind/m²) of benthic macroinvertebrates and periphyton associated macrofauna in the sampling stations during the dry (D) and rainy (R) periods. In parenthesis: sieved (300 mm) sample; out of parenthesis: total sample.

Taxa	A. Sales		Paulo Afonso			Xingó							São Francisco					
	R		D	R		D			R				D		R			
	# 1	# 2	# 3	# 3	# 4	# 5	# 7	# 8	# 5	# 6A	# 6´B	# 7	# 9A	# 10A	# 9A	# .9B	# 10A	# 10B
Ephemeroptera	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polymitarcyidae *Campsurus*	–	–	–	–	–	–	44	–	(44)	–	–	–	–	–	–	–	–	–
Odonata	–	–	–	–	44	–	–	–	–	(89)	–	–	–	–	–	–	–	–
Coleoptera	–	–	–	–	–	–	–	–	–	–	44	–	–	–	–	–	–	–
Diptera	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceratopogonidae	–	–	–	–	–	(89)	–	–	–	–	222	–	–	–	–	–	–	–
Tipulidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	44	–
Chaoboridae	–	–	–	–	–	(489)	44 (44)	–	–	–	–	–	–	–	–	–	–	–
Chironomidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Orthocladiinae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cricotopus	–	44	–	–	–	–	–	–	–	–	355	–	–	–	–	–	–	–
Nanocladius	–	–	–	–	–	–	(44)	(89)	–	(44)	–	–	–	–	–	–	–	–
Tanypodinae	–	–	–	–	–	178 (311)	133	89 (89)	–	–	–	–	133 (444)	–	–	–	–	–
Ablabesmyia	–	–	–	–	–	–	–	(44)	–	–	–	–	–	–	–	–	–	–
Clinotanypus	–	–	–	–	–	–	(44)	–	–	–	–	(44)	–	–	–	–	–	–
Djalmabatista	–	–	–	44 (178)	(222)	–	(711)	133	–	44 (179)	–	(44)	(44)	–	–	–	–	–
Labrundinia	–	–	–	44	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chironominae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tanytarsus	–	–	–	–	–	44	(267)	(355)	–	(311)	–	–	(44)–	–	–	–	–	–
Chironomus	–	–	–	–	–	–	–	–	–		–	–	(44)	–	–	–	–	–
Parachironomus	–	–	–	–	(44)	44 (44)	(1067)	–	–	44 (133)	–	–	222 (1156)	–	–	(44)	–	–
Polypedilum	–	–	–	–	44	133 (222)	–	400	–	(44)	–	–	(178)	–	–	–	–	–
Fissimentum dessicatum	–	–	–	–	–	133 (222)	89 (133)	89	–	–	–	–	(44)	–	–	–	–	–
Goeldichironomus	–	–	–	–	–	–	–	44	–	–	–	–	–	–	–	–	–	–

TABLE 3 – (*Continued*)

Taxa	A. Sales		Paulo Afonso			Xingó							São Francisco					
	R		D	R		D			R				D		R			
	# 1	# 2	# 3	# 3	# 4	# 5	# 7	# 8	# 5	# 6A	# 6B	# 7	# 9A	# 10A	# 9A	# 9B	# 10A	# 10B
Oligochaeta	–	–	89 (800)	–	(711)	(800)	133 (3244)	3556 (24133)	–	581 (1072)	488	–	578 (6933)	222 (667)	–	–	–	89
Hirudinea	–	–	–	–	–	–	–	–	–	–	–	–	44 (133)	–	–	–	–	–
Nematoda	–	–	–	–	–	–	–	–	–	–	266	–	–	–	–		222	–
Bivalvia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sphaeriidae	–	(44)	(89)	(573)	(178)	–	133	89 (533)	–	–	–	–	133 (444)	–	–	–	–	–
Family "a"	–	–	–	(444)	(44)	–	–	–	–	–	–	–	–	–	(44)	133 (44)		–
Family "b"	44 (89)	44 (44)	–	(222)	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Family "c"	–	–	–	222	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gastropoda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Thiaridae *Melanoides tuberculata*	–	–	(2000)	(356)	(4355)	133 (578)	–	–	–	–	–	–	44 (444)	–	133 (3422)	(89)	356	–
Pilidae *Pomacea*	–	–	–	–	(89)	–	–	–	–	–	–	–	–	–	–	–	–	–
Planorbidae *Biomphalaria*	–	–	–	–	(1022)	(89)	–	(44)	–	–	–	–	–	–	–	–	–	–
Hydrobiidae	–	–	–	–	(444)	–	–	–	–	–	–	–	–	–	–	–	–	–
Cladocera e Copepoda	–	–	–	–	–	–	–	89 (2133)	–	–	–	–	–	–	–	–	–	–
Ostracoda	–	–	–	–	–	–	1156	89 (4444)	–	–	–	–	–	–	–	–	–	–
Decapoda	–	–	–	–	(44)	–	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 4

Consequences of benthic macroinvertebrate communities in response to modifications in the characteristics of the studied reservoirs.

Stretch	Reservoir characteristics	Consequences
Itaparica → Moxotó	Eutrophicated reservoir. Highly silted.	Poorness and low diversity of benthic communities. Filter feeders dominate (Bivalvia).
Moxotó → Paulo Afonso	In process of artificial eutrophication; high biomass of aquatic macrophytes.	Substrate diversification, increase in diversity and richness. Scrapers (Gastropoda, mainly *M. tuberculata*) dominate.
Paulo Afonso → Xingó	Young reservoir; accelerated siltation rates; increase of FPOM.	Lower sediment granulometry, increase in diversity, specially burrower forms. Collectors (Oligochaeta and Chironomidae) dominate.
Xingó → São Francisco	Unstable substrate; lotic flow; strong anthropogenic influences (villages).	Biodiversity decrease; resistant organisms (*M. tuberculata*, Tubificidae – Oligochaeta) dominate.

These factors, together with strong anthropogenic influences (in Entre Montes and Piranhas municipalities) have resulted in dense macroinvertebrate (e.g., Oligochaeta and Chironomidae) populations adapted to these substrate conditions, in addition to species resistant to organic pollution, such as *Melanoides tuberculata*, which was abundant in several sampling stations.

These organisms are very resistant, and able to survive in areas with high levels of sulfidric gases (toxic for aerobic organisms) and under oxygen depletion conditions (Heller & Ehrlich, 1995). They are also effective competitors for space and trophic resources (feeding not only on vegetal tissue and periphyton, but also on FPOM deposits), and have a long-life cycle (Pointier & Augustin, 1999). Their reproduction is mainly that of parthenogenetic polyploids (Samadi, 1999), and these organisms also present the ovoviviparous habit, thus reducing predation chances during the egg stage.

The rapid numerical increase of dams has caused widespread loss of freshwater habitats, especially waterfalls, rapids, riparian floodplains, and wetlands (Johnson *et al.*, 2001). The construction of dams can cause profound negative effects on aquatic biodiversity, because the natural seasonal pattern to which the fauna has become adapted is altered and normal seasonal migration paths are blocked (Rosenberg *et al.*, 2000). These factors, associated with aggregated distribution and the relatively little mobility of benthic macroinvertebrate communities can lead to isolation of their populations. Besides, the modification of water quality in the drainage basin results in modified chemical and physical characteristics of the reservoir, which can have significant effects in the benthic macroinvertebrate communities, causing a loss of aquatic diversity in the studied ecosystems (Table 3).

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