Effects of flow reduction and spillways on the composition and structure of benthic macroinvertebrate communities in a Brazilian river reach

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Abstract

Dams are a major threat to aquatic biological diversity. By altering the natural flow of rivers, dams modify fluvial habitats, making them unsuitable for the growth and reproduction of many aquatic species. The aim of this study was to evaluate the effects of a reduced flow reach (RFR) on benthic macroinvertebrate communities. Benthic macroinvertebrates were collected at six sites downstream of the Amador Aguiar Power Plant I before (lotic phase) and after (semi-lentic phase) Araguari River mean flow was reduced from 346 to 7 $m^3.s^{-1}$. Changes in macroinvertebrates richness, diversity and total biomass were not observed. *Ablabesmyia*, *Tanytarsus* (Chironomidae, Diptera), Leptoceridae and Polycentropodidae (Trichoptera) densities significantly increased the first year after flow reduction and the construction of spillways (*t*-test; $p < 0.05$). An analysis of similarity (ANOSIM) showed statistical differences in taxonomical composition despite considerable overlap in communities between the lotic and semi-lentic phases ($R = 0.3$; $p < 0.01$). In both phases, the macroinvertebrates were characterised by the dominance of groups tolerant to human disturbance (e.g., Chironomidae, Ceratopogonidae and Oligochaeta) and by the presence of the alien bivalve species *Corbicula fluminea* (Veneroidae), suggesting that the river was already degraded before the hydraulic modifications. Since the 1980s, the Araguari River has been continuously subjected to human pressures (e.g., cascade dams, urbanization and replacement of native vegetation by pasture and crops). These activities have led to impoverishment of biological communities and have consequently altered the ecosystem.

Keywords: spillways, reduced flow, dams, benthic, anthrophic impacts.

Efeitos da redução de vazão e construção de soleiras vertentes sobre a composição e estrutura de comunidades de macroinvertebrados bentônicos em um trecho de rio brasileiro

Resumo

As represas constituem uma das principais ameaças à diversidade biológica. Ao alterarem a vazão natural de um rio, modificam os habitats fluviais tornando-os inadequados para o crescimento e reprodução de diversas espécies aquáticas. O objetivo deste estudo foi avaliar os efeitos de um trecho de vazão reduzida sobre as comunidades de macroinvertebrados bentônicos. Os organismos foram coletados em seis estações amostrais à jusante da UHE Amador Aguiar I antes (fase lótica) e após (fase semilêntica) a vazão média do rio Araguari (MG) ter sido reduzida de 346 para 7 $m^3.s^{-1}$. Não foram registradas mudanças na riqueza, diversidade e biomassa total dos macroinvertebrados. As densidades ($ind.m^{-2}$) de *Ablabesmyia*, *Tanytarsus* (Diptera), Leptoceridae e Polycentropodidae (Trichoptera) aumentaram significativamente no primeiro ano após a redução da vazão e construção das soleiras vertentes (*t*-test; $p < 0,05$). Uma análise de similaridade (ANOSIM) apontou diferenças significativas na composição taxonômica, porém houve sobreposição das comunidades entre as fases lótica e semilêntica ($R = 0,3$; $p < 0,01$). Em ambas as fases a macrofauna caracterizou-se pela dominância de grupos tolerantes a distúrbios antrópicos (p. ex. Chironomidae, Ceratopogonidae e Oligochaeta) e pela presença do bivalve invasor *Corbicula fluminea*, sugerindo que o rio já estava degradado antes das modificações hidráulicas. Desde a década de 1980 o rio Araguari tem sido continuamente submetido a impactos antrópicos (barramentos em cascata, urbanização e a substituição da vegetação por pastagens e cultivos agrícolas). Essas atividades têm levado ao empobrecimento das comunidades biológicas e, consequentemente, alterado o funcionamento do ecossistema.

Palavras-chave: soleiras vertentes, vazão reduzida, represas, bentos, impactos antrópicos.

1. Introduction

The construction of reservoirs is one of the oldest forms of human intervention in aquatic ecosystems (Tundisi and Matsumura-Tundisi, 2008). Currently, all continents but Antarctica have dams in their major basins (Nilsson et al., 2005). In Brazil, there are over 600 dams, which were constructed mainly for hydropower (Agostinho et al., 2005). Although they aid social and economic development (Tundisi et al., 2008), dams alter natural flow regimes (Agostinho et al., 2008), including production of reaches with residual flow that reduce water quality and disturb biological communities (Cortes et al., 2002).

Benthic macroinvertebrates are one of the aquatic communities most affected by reduced flow (Dewson et al., 2007a). Low and constant flows alter benthic communities by altering sediment texture, temperature, and dissolved oxygen (Cortes et al., 2002). The availability of habitats for the growth and foraging of many species is also altered (James et al., 2007), especially for taxa with morphological adaptations (e.g., dorsally flattened body) to better resist high velocities, which include Ephemeroptera and Plecoptera (Merritt and Cummins, 1996).

By changing the current velocity and limiting the species distribution to residual pools, reduced flow accentuates predation and competition (Dewson et al., 2007b). As the water volume decreases, the local density of predators may increase, forcing prey to escape through drift ((Dewson et al., 2007a). During laboratory tests, it was confirmed that larvae of Simuliidae (*Simulium vitattum*) are easily captured by flatworms (*Dugesia dorotocephala*) in sites where the water speed is low (Hansen et al., 1991). Predation impacts are altered if habitats with high current velocities are present where preys are less accessible to potential predators (Malmqvist and Sackmann, 1996). Hydropsychidae larvae live clustered in rapids where their filtration feeding habit is favored (Georgian and Thorp, 1992). When the water volume decreases these larvae can move to areas where flows are greater, increasing the competition for space and food resources (Dewson et al., 2007a).

In river reaches with reduced flows, it is common to detect declines in density, diversity through the disappearance of taxa susceptible to flow regime changes (McIntosh et al., 2002; Kinzie et al., 2006). Disturbances may consequently affect ecological processes. The ability of macroinvertebrates to convert plant and microbial food bases into animal tissue is a vital process in aquatic food webs, and loss of macroinvertebrates community structure (e.g., elimination of gatherer or shredder populations) can alter the supply of matter and energy for the entire ecosystem (Graça, 2001).

A strategy employed in some European countries to mitigate the negative effects of flow reduction on aquatic communities (mainly fishes and macroinvertebrates) is the construction of small dams in regulated reaches (Cortes et al., 2002). These structures, called spillways (*soleiras vertentes* in Brazil, CCBE (2007)), may benefit the biota by forming backwaters that maintain a continuous water surface in the river (Brittain and L'Abée-Lund, 1995). However, the spillways should be constructed in small numbers and interspersed by rapids; otherwise, they could degrade the environment, retain large quantities of debris, and prevent the drift of aquatic macroinvertebrates (Fjellheim and Raddum, 1996).

The aim of this study was to assess the taxonomic composition, structure and biomass of benthic macroinvertebrate communities in a reach with reduced flow before and after spillway (RFR) construction. In Brazil, the effects of small dams on the benthic community have received little attention and were recently examined by Almeida et al. (2009). These authors compared upstream sites (references) with those downstream the impoundments (impaired) in two third order streams of Rio de Janeiro whereas the present research evaluated changes in a large river reach prior and after its damming. Together with the study above, this represents one of the first Brazilian ecological approaches to assess macroinvertebrate community responses to an artificially reduced and constant flow, as well as the spillways construction. This is an important study considering the susceptibility of benthos to habitat changes (Ogbeibu and Oribhabor, 2002), their role as bioindicators of the impacts caused by altered flow regimes (Dewson et al., 2007a), and the increased number of dewatered rivers in Brazil.

The hypothesis tested was that conversion of a lotic habitat into a semi-lentic habitat resulting from reduced flow and construction of spillways would alter the composition and structure of the macroinvertebrate communities. Under lotic conditions, it was expected to find higher taxa richness and a predominance of collector-filter organisms, which obtain food by filtering fine organic particles transported by the water flow. Under semi-lentic conditions, it was expected to find an increase in the abundance of taxonomic groups associated with calm water and a higher proportion of collector-gatherer organisms resulting from the accumulation of fine organic matter in the sediment and reduced current velocities.

1.1. Study area

The study was carried out in a reach of the Araguari River, with residual flow located downstream of Amador Aguiar I Reservoir (MG), between 18° 20' S and 46° 00' W and 20° 10' S and 48° 50' W (Figure 1). This 9 km long reach is 90 m wide and drains areas of sandstone and basalt; the valley bottom is in weathered granite and gneiss (Rodrigues, 2002). The average annual rainfall is 1,555 mm/year with a rainy season from October to March and a dry season from May to September. The mean annual temperature is 22 °C (Rosa et al., 2006). Pasture is the dominant vegetation around the reduced flow reach, representing 39% of the basin. The remaining land uses are preserved Cerrado (17.8%), annual crops (17.5%), temporary crops (15.4%), urban areas (7.5%) and others (2.1%) (J.F. Silva, pers. com).

After the Amador Aguiar I Reservoir was filled (Table 1), the mean flow of the downstream reach was reduced from 346 to 7 $m^3.s^{-1}$ (the minimum value recorded for the river

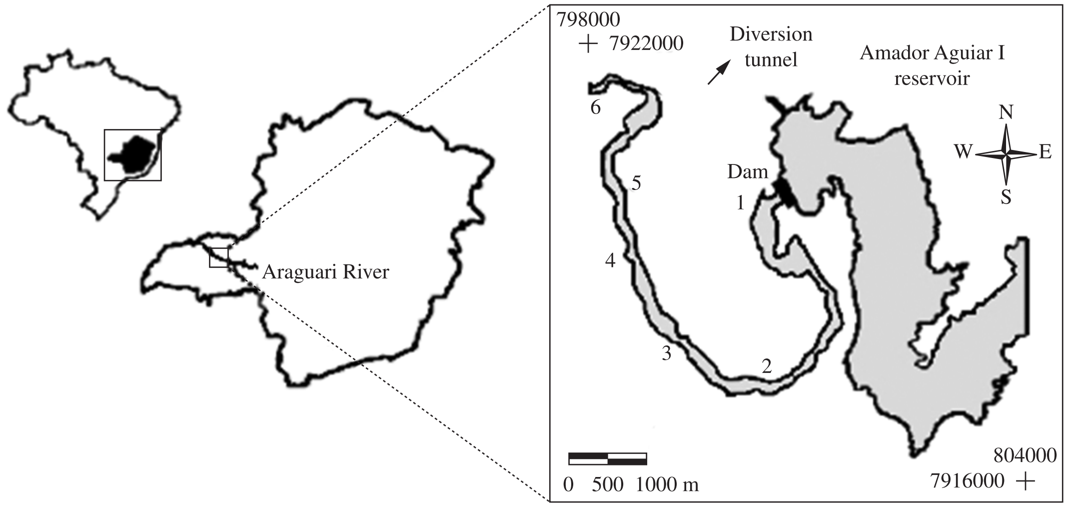

Figure 1. Study area showing the sampling stations (Minas Gerais, Brazil).

Table 1. Technical, morphometric and limnological characteristics of the Amador Aguiar I Reservoir (Minas Gerais, Brazil).

Characteristics*	Amador Aguiar I reservoir
River diversion	July 2004
Filling period	December 2005
Start of reservoir operation and reduction in downstream flow	May 2006
Flooded terrestrial area (km^2)	18.66
Volume of water (million m^3)	241
Reservoir depth at the dam (m)	52
Length of the dam (m)	610
Length of the reservoir (km)	75
Installed capacity (MW)	240
Trophic status	Ultraoligotrophic
Chlorophyll-a (mg.L^{-1})	2.14-4.28$^+$
Electrical conductivity (µS cm^{-1})	30-32$^+$
pH	5.8-6.2$^+$
Total alkalinity (meq.L^{-1} CO$_2$)	0.19
Dissolved oxygen (mg.L^{-1})	6.0-7.2$^+$
Total phosphorus concentration (µg.L^{-1})	8.10-11.78$^+$
Total nitrogen concentration (µg.L^{-1})	276.95-355.20$^+$

*Data according to CCBE (2007) and Valadares (2007). $^+$(Minimum – Maximum value).

in the 10 years preceding plant construction). To reestablish the water level, five small dams (spillways) were built in the reduced flow reach. The spillways are 3 to 10 m high and produced a series of semi lentic reservoirs.

2. Methods

This study was conducted in two stages: the first (lotic phase) was characterised by natural reach conditions, with well-developed riffles and pools free from the reservoir and spillway influences. The second stage (semi-lentic phase) occurred after dam construction when the reach was altered by reduced flow and fragmented by spillways. The predominant aquatic habitats under this condition were composed of large backwaters and pools.

Six sites were random sampled along the reduced flow reach averaging 1.5 km apart (Table 2; Figure 1). All of them were visited four times: once during the lotic phase in both June and October 2005 and once during the semi-lentic phase in both June and December 2008 (the first year after spillways). Thus, for each phase studied (lotic and semi-lentic) data were collected in dry and rainy seasons, representing a complete seasonal cycle. The total rainfall was 5 mm in July and 130 mm in October 2005, and 5 mm in June and 260 mm in December 2008 (Simge, 2010).

Table 2. Characterisation of sampling stations in the stretch downstream to the Amador Aguiar I Reservoir (Minas Gerais, Brazil) in lotic (2005) and semi-lentic phases (2008).

Characteristics	Phases	
	Lotic	Semi-lentic
Depth (m)	2.0-9.0^{+}	1.10-2.10^{+}
Width (m)	50-100^{+}	58-90^{+}
Average flow ($m^3.s^{-1}$)	346	7
Predominant habitat type*	Riffles	Pools
Aquatic plants*	Absent	Absent
Proportion of fine sediment fractions (< 0.25 mm) (%)**	83-100^{+}	18-96^{+}
Organic matter content of sediment (%)	0.7-5.9^{+}	0.5-16.9^{+}
Trophic status	Oligotrophic	Ultraoligotrophic

*Evaluated according to Callisto et al., (2002a); **Determined according to Callisto and Esteves (1996); $^{+}$(Minimum – Maximum value).

Water temperature (°C), pH, electrical conductivity ($\mu S.cm^{-1}$) and turbidity (NTU) were measured in situ with an HORIBA multiprobe (model U-10) and air temperature with a conventional thermometer. Concentrations of dissolved oxygen, total phosphorus and total nitrogen concentrations were determined at the UFMG laboratory according to the Standard Methods for the Examination of Water and Wastewater (Apha, 1992).

At each sampling station, three sediment samples were collected with a van Veen dredge (0.045 m^2). Due to the rocky nature of the central axis of the river, the material was only collected along the margins. A total of 72 van Veen sample units were obtained (six sites x three samples/site x two visits/site x two phases = 72). The sediment samples were washed through 1.0 and 0.5 mm sieves and all remaining organisms were identified according to Pérez (1988), Trivinho-Strixino and Strixino (1995), Epler (2001), Costa et al. (2006) and Roque and Trivinho-Strixino (2008). After identification, organisms were dried in a stove at 60 °C for 48 hours and weighed on a precision scale to determine their biomass ($mg.m^{-2}$). Mollusks were burned in a muffle furnace at 550 °C for 4 hours to estimate the weight of mineral parts.

To determine benthic macroinvertebrate community structure, taxonomic richness, Pielou's evenness index, and Shannon-Wiener diversity index (Magurran, 2004) were calculated from the total number of taxa found per van Veen sample, and the densities of organisms were estimated ($individuals.m^{-2}$). Classification into functional feeding groups was based on Merritt and Cummins (1996), Fernández and Dominguez (2001), and Cummins et al. (2005).

2.1. Data analysis

Firstly, previous analyses were done to evaluate the significance of differences between the sampling sites and seasons (each phase apart). The values of richness, total density, relative density, total biomass, relative biomass, taxonomic composition and Shannon-Wiener diversity were compared trough ANOVA one-way (sites) ANOSIM and the *t*-test (seasons) ($\alpha = 0.05$). There were no significant differences in these variables. As a consequence, for the following analyses, the variation in community structure among sites or seasons was disregarded.

Changes in limnological characteristics and in the structure of benthic macroinvertebrate communities between the two phases were tested through the *t*-test ($\alpha = 0.05$) using STATISTICA 7.0 software. For these analyses, the three sampling units (van Veen) for each site were pooled, resulting in 12 samples in lotic phase (six sites x one pooled sample/site x two visits/site) and 12 samples in semi-lentic phase.

Data were compiled at each site to derive a single value because the three sampling units (van Veen) per site were not independent; this was done to ameliorate the problem of spatial pseudoreplication, recurrent in ecological studies (Hargrove and Pickering, 1992). Each one of the 12 samples per phase was considered one replica. In this study, real replicas (spatial and temporal replication) were virtually impossible to obtain because until now, there is no other regulated river reach in Brazil with similar characteristics (a reach with a constant and artificially reduced flow where benthic macroinvertebrates have been sampled before and after spillway construction). Although statistical inferences should be avoided, impact assessment studies in which replication is undesirable or logically non-existent can be valid and scientifically acceptable; this is particularl y true for field approaches that investigate large scale systems (e.g. catchments and rivers) (Hurlbert, 1984).

The abiotic (electrical conductivity, dissolved oxygen, total phosphorus and total nitrogen) and biotic (density and biomass) variables were log-transformed ($\log x + 1$) to meet assumptions of normality (Komogorov-Smirnov) and homoscedasticity (Levene) (Zar, 1996). To estimate changes in diversity values between phases, the variances of the Shannon-Wiener index were compared using a *t*-test (Magurran, 2004).

The differences in the taxonomic composition of the benthic macroinvertebrate communities between the lotic and semi-lentic phases were assessed through a non-metric MDS (NMDS) ordination technique, using a Bray-Curtis dissimilarity matrix with abundance data transformed (log x + 1) and a Sorensen similarity index with presence/absence of taxa data. Abundance data favours common species, whereas presence/absence data emphasizes rare species. The NMDS orders all samples in a bidimensional plot, grouping them according to taxonomic similarity (similar samples are close, different samples are further apart).

The statistical significance of the groupings (lotic phase vs. semi-lentic) were tested through similarity analysis (ANOSIM) ($\alpha = 0.05$). The ANOSIM provides a value for interpretation where $R > 0.75$ indicates totally distinct groups, $0.50 < R < 0.75$ indicates separated but overlapping groups, $0.25 < R < 0.50$ indicates separated but strongly overlapping groups, and $R < 0.25$ represents groups that cannot be distinguished (Clarke and Green, 1988; Michelland et al., 2010). A randomisation process using Monte Carlo testing with 10,000 interactions was conducted to validate the R values observed. A value of $p < 0.05$ indicated that the R value observed was not randomly obtained. Analysis of NMDS and ANOSIM were performed with PRIMER 6.0 software.

3. Results

3.1. Physical and chemical variables in the water column

In both study phases the reach water had near neutral pH; high dissolved oxygen concentrations; and low levels of electric conductivity, turbidity, total-P and total-N (Table 3). Nevertheless, the values for electric conductivity (*t*-test; $t = 5.71$, df = 22, $p < 0.01$), turbidity ($t = 22.97$, $p < 0.01$), total-P ($t = 2.23$, $p < 0.05$) and total-N ($t = 4.64$, $p < 0.01$) were significantly lower in the semi-lentic phase, while temperature was significantly higher ($t = -2.41$, $p < 0.05$). Dissolved oxygen and pH did not vary significantly between the two phases.

3.2. Structure and composition of benthic macroinvertebrate communities

A total of 4,891 benthic macroinvertebrates were found in the 72 sediment samples. The organisms belonged to 50 operational taxonomic units (OTU, 2 Mollusca, 2 Annelida and 46 Arthropoda), 36 OTU were collected in the lotic phase and 45 in the semi-lentic phase. Taxonomic richness did not differ significantly between the two phases (Figure 2a) nor did Shannon-Wiener diversity (Table 4). Chironomidae was the dominant group, accounting for over 69% of the individuals (Figure 2f), with *Polypedilum* (18.2%) and *Aedokritus* (16.5%) the dominant genera in the lotic phase and *Tanytarsus* (23.2%) and *Aedokritus* (16.4%) in the semi-lentic phase (Table 4). Groups (no Chironomidae) with relative abundances greater than 2.5% were Oligochaeta (14.4 and 6.4%, lotic and semi-lentic phase, respectively), Ceratopogonidae (8.0 and 2.8%) and the alien bivalve *Corbicula fluminea* (Müller, 1774) (4.2 and 3.5%).

The organisms were grouped into five feeding guilds: collector-gatherers, collector-filterers, predators, scrapers, and shredders. During the lotic phase, collector-gatherers (53.7%) predominated numerically, but collector-filterers (38.9%) predominated in the semi-lentic phase. Shredders were proportionately more abundant during the lotic phase than the semi-lentic (18.2 vs. 6.5%), while scrapers were virtually absents (< 0.2%) (Figure 2d).

Total density was significantly greater during the semi-lentic phase (*t*-test; $t = -2.71$, df = 22, $p < 0.05$) (Figure 2b). The OTU with significant density increases were *Ablabesmyia* ($t = -3.57$, $p < 0.01$), *Tanytarsus* ($t = -3.65$, $p < 0.01$), Leptoceridae ($t = -2.27$, $p < 0.05$), and Polycentropodidae ($t = -8.94$, $p < 0.01$) (Table 4). Total macroinvertebrates biomass did not differ significantly between the two phases (Figure 2c); however, *Ablabesmyia* (*t*-test; $t = -3.56$, df = 22, $p < 0.01$), *Tanytarsus* ($t = -5.27$, $p < 0.01$), Leptoceridae ($t = -2.20$, $p < 0.05$), and Polycentropodidae ($t = -4.59$, $p < 0.01$) had significantly higher biomasses during the semi-lentic phase (Table 4). Over 65% of the total biomass was *Corbicula fluminea* (Figure 2e).

The NMDS and similarity analyses showed a significant separation between samples collected during the lotic and semi-lentic phases, both for abundance data (ANOSIM; $R = 0.32$; $p < 0.01$) and for presence/absence of taxa ($R = 0.30$; $p < 0.01$). This indicates changes in the taxonomic composition of the benthic macroinvertebrate communities after alteration and fragmentation of the river habitats (Figure 2g, h). Of the total OTU recorded, 10% were

Table 3. Physical and chemical characteristics of water (mean ± SD) in the dewatered reach downstream of the Amador Aguiar I Reservoir (Minas Gerais, Brazil) in lotic (2005) and semi-lentic phases (2008).

Abiotic variables	Lotic phase (n =12)*	Semi-lentic phase (n = 12)
pH	6.87 ± 0.35	7.20 ± 0.47
Electrical conductivity ($\mu S.cm^{-1}$)	26.41 ± 3.76	15.31 ± 5.57
Turbidity (NTU)	11.82 ± 1.01	1.75 ± 1.13
Dissolved oxygen ($mg.L^{-1}$)	9.41 ± 1.25	8.70 ± 0.37
Water temperature (°C)	23.26 ± 1.60	24.74 ± 1.37
Total phosporus concentration ($\mu g.L^{-1}$)	18.63 ± 7.57	12.72 ± 5.10
Total nitrogen concentration ($\mu g.L^{-1}$)	163.04 ± 55.42	81.08 ± 26.93

* number of samples.

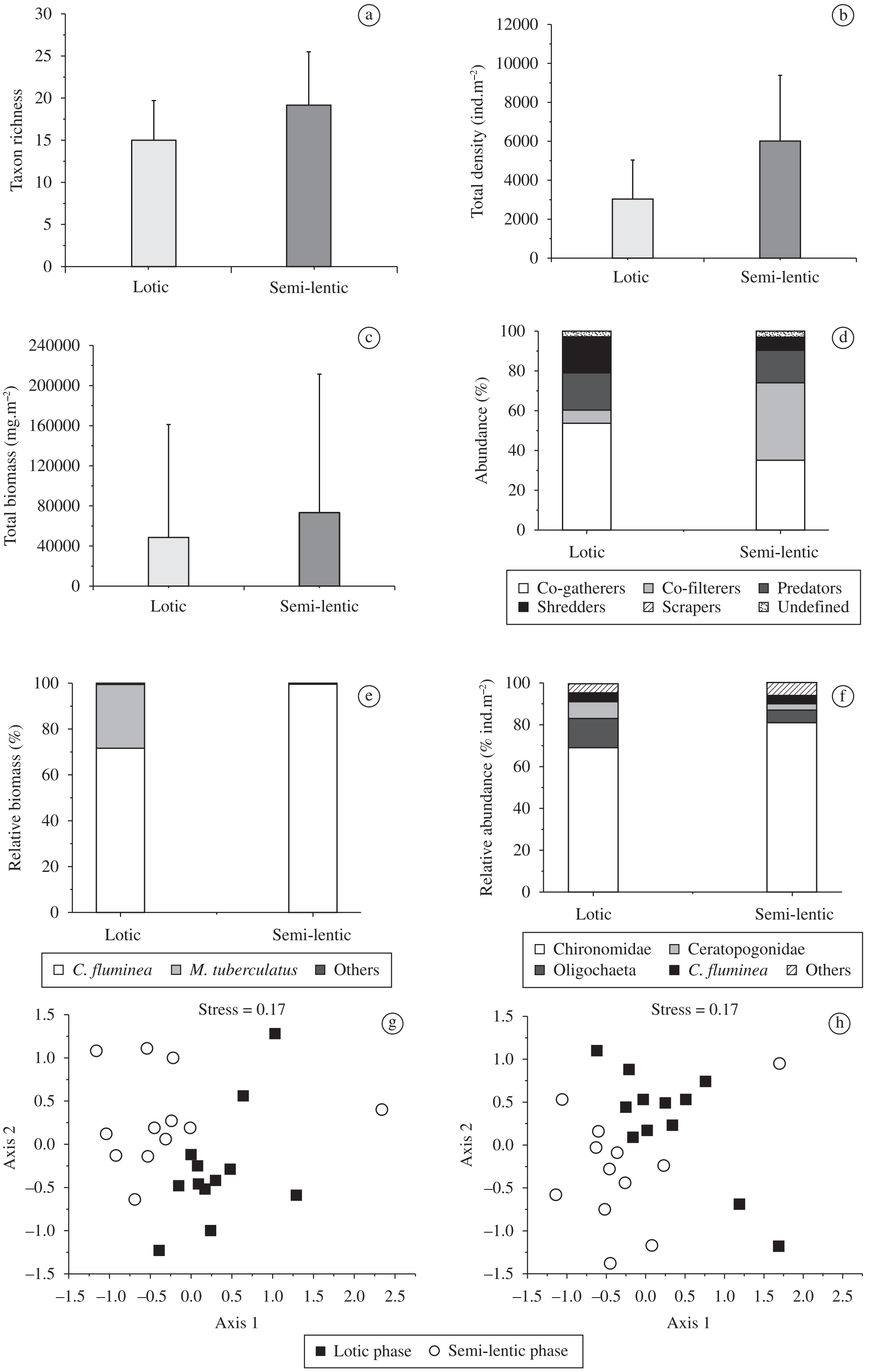

Figure 2. a) OTU richness; b) total density; c) total biomass (mean ± SD); d) functional feeding group composition %; e) relative biomass %; f) relative density %; and g) two-dimensional NMDS ordination based on relative abundance – h) presence/absence of benthic macroinvertebrate taxa sampled in the dewatered reach downstream of the Amador Aguiar I Reservoir (Minas Gerais, Brazil) in the lotic (2005) and semi-lentic (2008) phases.

Table 4. Relative abundance (% individuals.m^{-2}), density (individuals.m^{-2}) and biomass (mg.m^{-2}) (mean ± SD) of benthic macroinvertebrate taxa sampled in the reach downstream to the Amador Aguiar I reservoir (Minas Gerais, Brazil) in lotic (2005) and semi-lentic (2008) phases.

Taxa	FFG	Phases					
		Lotic (n = 12)			**Semi-lentic (n = 12)**		
		A	**D**	**B**	**A**	**D**	**B**
Mollusca							
Bivalvia							
Corbicula fluminea Müller, 1774	Co-Fil	4.2 ± 7.1	115 ± 182	34742.1 ± 81328.0	3.5 ± 5.0	170 ± 243	72941.7 ± 138114.1
Gastropoda							
Melanoides tuberculatus Müller, 1774	Co-Ga	0.8 ± 2.8	17 ± 58	13481.3 ± 46702.2	**	2 ± 6	1.3 ± 4.4
Annelida							
Hirudinea	Pr	**	6 ± 14	2.3 ± 3.5	-	-	-
Oligochaeta	Co-Ga	14.4 ± 12.3	387 ± 316	85.3 ± 122.5	6.4 ± 10.5	369 ± 664	50.2 ± 66.4
Insecta							
Ephemeroptera							
Baetidae	Co-Ga	0.1 ± 0.3	4 ± 9	0.1 ± 0.2	0.2 ± 0.4	13 ± 20	1.4 ± 4.1
Leptohyphidae	Co-Ga	0.2 ± 0.6	7 ± 20	**	-	-	-
Leptophlebiidae	Co-Ga	0.1 ± 0.3	2 ± 6	**	-	-	-
Odonata							
Coenagrionidae	Pr	-	-	-	0.1 ± 0.2	4 ± 9	3.4 ± 11.5
Gomphidae	Pr	0.3 ± 0.4	11 ± 15	66.1 ± 187.8	0.5 ± 0.5	30 ± 27	38.2 ± 87.1
Libellulidae	Pr	0.3 ± 1.0	4 ± 9	1.6 ± 5.6	0.7 ± 1.8	43 ± 101	1.6 ± 2.6
Heteroptera							
Veliidae	Pr	-	-	-	0.1 ± 0.2	6 ± 14	0.7 ± 1.8
Coleoptera							
Elmidae	Co-Ga	0.1 ± 0.3	6 ± 14	1.2 ± 3.4	**	2 ± 6	**
Trichoptera							
Hydropsychidae	Co-Fil	-	-	-	**	2 ± 6	0.2 ± 0.8
Hydroptilidae	Co-Ga	0.1 ± 0.4	2 ± 6	**	2.5 ± 7.6	146 ± 434	4.0 ± 9.9
Leptoceridae	Pr	-	-	-	0.3 ± 0.5	22 ± 46	6.7 ± 15.8
Odontoceridae	Scr	-	-	-	0.1 ± 0.3	7 ± 14	0.1 ± 2.2
Polycentropodidae	Co-Fil	-	-	-	1.8 ± 2.0	102 ± 116	11.5 ± 14.0
Diptera							
Ceratopogonidae	Pr	8.0 ± 6.3	239 ± 235	12.3 ± 9.4	2.8 ± 2.3	150 ± 136	8.3 ± 7.7
Chironomidae							
Tanypodinae							
Ablabesmyia Johhansen, 1905	Pr	0.5 ± 0.7	19 ± 39	4.0 ± 12.1	3.3 ± 3.6	215 ± 287	9.2 ± 7.0
Coelotanypus Kieffer, 1913	Pr	-	-	-	0.1 ± 0.2	6 ± 14	1.1 ± 3.9
Djalmabatista Fittkau, 1908	Pr	2.5 ± 3.2	63 ± 63	3.1 ± 4.2	2.4 ± 4.8	185 ± 450	6.4 ± 13.1
Fittkauimyia Karunakaran, 1969	Pr	-	-	-	0.5 ± 1.2	30 ± 64	2.9 ± 6.3
Labrundinia Fittkau, 1962	Pr	-	-	-	0.4 ± 1.3	20 ± 64	0.2 ± 0.8

A = abundance, D = density, B = biomass. FFG = Functional Feeding Groups, Co-Ga = collector-gatherers, Co-Fil = collector-filterers, Pr = predators, Shr = shredders, Scr = scrapers. (*) = undefined, (**) = value < 0.1, (-) = absent.

Table 4.. Continued...

Taxa	FFG	Phases					
		Lotic (n = 12)			Semi-lentic (n = 12)		
		A	D	B	A	D	B
Pentaneura Phillipi, 1865	Pr	-	-	-	**	2 ± 6	**
Tanypus Meigen, 1803	Pr	0.1 ± 0.2	2 ± 6	0.2 ± 0.6	7.2 ± 22.2	115 ± 270	12.9 ± 32.9
Chironominae							
Aedokritus Roback, 1958	Co-Ga	16.5 ± 18.7	637 ± 1001	56.9 ± 93.0	16.4 ± 22.5	943 ± 1253	73.0 ± 93.8
Chironomus Meigen, 1803	Co-Ga	1.1 ± 1.4	35 ± 47	3.6 ± 7.7	1.5 ± 3.8	93 ± 198	25.6 ± 62.3
Cladopelma Kieffer, 1921	Co-Ga	6.8 ± 5.4	265 ± 293	5.4 ± 7.0	3.5 ± 4.8	211 ± 273	4.3 ± 4.7
Cryptochironomus Kieffer, 1918	Pr	7.5 ± 5.8	211 ± 150	8.2 ± 6.2	2.2 ± 1.8	135 ± 115	8.8 ± 7.8
Demicryptochironomus Lenz, 1941	Co-Ga	1.0 ± 1.7	35 ± 48	2.1 ± 3.0	0.2 ± 0.4	13 ± 38	0.4 ± 1.2
Dicrotendipes Kieffer, 1913	Co-Ga	-	-	-	0.4 ± 0.9	19 ± 40	1.9 ± 4.8
Endotribelos Grodhaus, 1987	Co-Ga	0.1 ± 0.4	4 ± 13	**	0.2 ± 0.4	11 ± 26	0.1 ± 0.4
Fissimentum Cranston & Nolte, 1916	*	2.4 ± 3.2	67 ± 123	2.8 ± 5.7	2.1 ± 2.7	135 ± 256	8.5 ± 11.8
Goeldichironomus Fittkau, 1965	Co-Ga	**	2 ± 6	0.2 ± 0.7	0.1 ± 0.2	6 ± 10	1.3 ± 2.9
Pelomus Reiss, 1989	Co-Ga	5.3 ± 5.0	211 ± 291	5.7 ± 5.9	0.6 ± 0.1	41 ± 75	0.3 ± 0.6
Nilothauma Kieffer, 1921	Co-Ga	0.1 ± 0.3	3 ± 14	0.2 ± 0.5	0.4 ± 0.5	33 ± 60	1.0 ± 1.5
Paralauterboniella Lenz, 1941	*	0.5 ± 0.8	20 ± 32	0.7 ± 1.3	0.7 ± 0.7	43 ± 45	0.5 ± 0.9
Polypedilum Kieffer, 1913	Sch	18.2 ± 17.2	543 ± 637	12.0 ± 21.0	3.5 ± 3.3	257 ± 354	6.2 ± 8.9
Pseudochironomus Mallock, 1915	Co-Ga	0.1± 0.3	4 ± 9	0.1 ± 0.3	0.8 ± 2.2	70 ± 209	3.9 ± 9.6
Stempellina Thienemann & Bause, 1913	Co-Ga	0.1 ± 0.3	4 ± 9	0.1 ± 0.4	0.4 ± 0.8	26 ± 45	0.6 ± 0.9
Stenochironomus Kieffer, 1919	Sch	-	-	-	0.1 ± 0.3	7 ± 20	0.6 ± 1.5
Tanytarsus van der Wulp, 1984	Co-Fil	4.0 ± 4.8	89 ± 81	1.8 ± 2.9	23.2 ± 19.2	2072 ± 2585	35.2 ± 40.5
Zavreliella Kieffer, 1920	Co-Ga	0.1 ± 0.3	6 ± 14	0.1 ± 0.4	0.6 ± 1.3	39 ± 82	0.5 ± 1.5
Orthocladiinae							
Cricotopus van der Wulp, 1874	Sch	1.0 ± 2.3	17 ± 38	0.6 ± 1.1	2.0 ± 1.4	130 ± 240	3.1 ± 6.4
Psectrocladius Kieffer, 1906	Co-Ga	0.8 ± 1.4	22 ± 34	0.4 ± 0.8	7.8 ± 18.7	69 ± 68	1.3 ± 1.4
Dolichopodidae	Pr	0.4 ± 1.0	6 ± 14	0.6 ± 1.9	-	-	-
Muscidae	Pr	-	-	-	0.1 ± 0.2	4 ± 9	0.1 ± 0.3
Tipulidae	Pr	1.8 ± 4.9	17 ± 39	1.4 ± 3.2	-	-	-
Collembola	Co-Ga	-	-	-	0.1 ± 0.3	4 ± 13	0.1 ± 0.2
Hydracarina	Pr	**	2 ± 6	**	0.3 ± 0.7	17 ± 45	0.1 ± 0.3
Shannon-Wiener diversity			2.50			2.56	
Pielou's evenness			0.69			0.67	

A = abundance, D = density, B = biomass. FFG = Functional Feeding Groups, Co-Ga = collector-gatherers, Co-Fil = collector-filterers, Pr = predators, Shr = shredders, Scr = scrapers. (*) = undefined, (**) = value < 0.1, (-) = absent.

exclusively from the lotic phase (Hirudinea, Tipulidae, Dolichopodidae, Leptohyphidae and Leptophlebiidae) and 26% from the semi-lentic phase (*Coelotanypus*, *Fittkauimyia*, *Pentaneura*, *Dicrotendipes, Stenochironomus*, Muscidae, Coenagrionidae, Hydropsychidae, Leptoceridae, Odontoceridae, Polycentropodidae, Veliidae and Collembola).

4. Discussion

Lower electric conductivity, turbidity, and nutrients and increased water temperature were possible consequences of the spillways and Amador Aguiar I Dam operations because the higher precipitation in 2008 would have been expected to have had the opposite effects. Generally, dams act as settling basins, increasing water transparency by retention of fine sediments (Kondolf, 1997). Amador Aguiar I Dam, together with the upstream reservoirs (Nova Ponte and Miranda), have probably incorporated most phosphorus and nitrogen and released better quality water downstream. This pattern was initially observed in a sequence of large reservoirs in the Tietê River (SP – Southeastern Brazil) (Barbosa et al., 1999), later confirmed for the Paraná River (PR – Southern Brazil) (Roberto et al., 2009), but not necessarily for the lower São Francisco River (MG – Southeastern Brazil) (Callisto et al., 2005). As water passes through lentic ecosystems its upper layers heat; release of this layer warms downstream reaches. After water is released from dams its temperature tends to balance with the prevailing air temperature (Lessard and Hayes, 2003). The highest air temperature recorded during the semi-lentic phase was 28.3 ± 3.4 °C, vs. 26.9 ± 2.0 °C for the lotic phase, which contributed to water warming. The physical and chemical quality of the water remained within the limits established by Brazilian laws for human consumption (total-P 0.1 mg/L; total-N 3.7 mg/L; dissolved oxygen over 6.0 mg/L, pH 6.0 to 9.0; turbidity 40.0 NTU) (Brasil, 2005).

However, approaches based exclusively on physical and chemical measures do not reflect the condition of aquatic ecosystems (Karr and Dudley, 1981). Research conducted in the Cotter River in Australia, which is regulated by large hydroelectric dams, confirmed that monitoring abiotic variables was insufficient to indicate the impact of river habitat fragmentation. However, after including data about the structure of benthic macroinvertebrate communities, the negative effects became evident (Nichols et al., 2006). Aquatic fauna require specific habitat structure and flow regime conditions that are independent of water quality (Hannaford et al., 1997).

Declines in taxonomic diversity are commonly observed in benthic macroinvertebrate communities in reduced flow reaches (Cazaubon and Giudicelli, 1999; McIntosh et al., 2002; Kinzie et al., 2006). The decrease in water volume results in habitat loss and a decrease in the quantity and quality of food, leading to the disappearance of some taxa (McKay and King, 2006). This pattern, however, was not observed in this study. Because the response of benthic macrofauna during a disturbance depends on their resistance or susceptibility to the stressor agents, it is probable that changes in river habitats during the semi-lentic phase were of low impact to the local community, which was previously dominated by generalist groups (e.g., Chironomidae, Ceratopogonidae and Oligochaeta). These taxa are classified as tolerant to human modifications (Ogbeibu and Oribhabor, 2002; Brendenhand and Samways, 2009). According to Dewson et al. (2007c), the initial composition of communities controls the magnitude and direction of changes resulting from reduced flows. They emphasized that despite several species of macroinvertebrates being limited by flow, others are generalists less affected by flow alterations and therefore thrive in environments with variable hydraulic conditions. The presence of alien mollusks (*Corbicula fluminea* and *Melanoides tuberculatus*) during the lotic phase suggests that the benthic macroinvertebrate communities were already altered prior to flow reduction and spillway construction.

Since the 1990s, two large hydroelectric dams (Miranda and Nova Ponte) have operated upstream of the studied reach (Rodrigues, 2002) and their negative effects probably have spread downstream, as has been reported in the regulated Paraná river, Brazil (Stevaux et al., 2009). When rivers lose their natural flow regimes, they become homogenous (Moyle and Mount, 2007) and typically support a less diverse fauna (Poff et al., 2007). In undammed rivers, flood and drought pulses often act as selective forces, eliminating alien invaders not adapted to such conditions (Lytle and Poff, 2004). Therefore, by reducing peak flows, increasing low flows and creating semi-lentic reservoirs, dams may facilitate bioinvasion (Bunn and Arthington, 2002).

Although the categorization of benthic macroinvertebrates into functional feeding groups constitute a valuable tool for understanding food web relationships or for elaborating predictions in impact assessment studies (Vallania and Corigliano, 2007), the results obtained in this study disagreed with the proposed predictions. The collector-gatherers, feeding on fine fragmented organic matter deposited in the sediment (Wallace and Webster, 1996), were numerically dominant during the lotic phase, when the stretch of river rapids were well developed. On the other hand, the collector-filterers, feeding on drifting particles (Wallace and Merritt, 1980), dominated the community during the semi-lentic phase, when pools and backwaters were the major habitats and sources of phytoplankton production.

It is noteworthy that feeding habits of macroinvertebrates are not yet clearly defined (Motta and Uieda, 2004). During laboratory experiments, it was confirmed that some Chironomidae, typically non-scrapers, can use riparian vegetation leaf debris as a complementary food source (Callisto et al., 2007). Stomach analysis also indicated that various organisms traditionally characterised as predators in one geographical area, can feed as collectors at other sites (Silva et al., 2008). Food chains in most neotropical aquatic ecosystems are dominated by generalist feeders, with opportunistic behaviours aiding their occupation of multiple trophic positions (Tomanova et al., 2006). Filterers, for example, are not restricted to feeding on fine particulate organic matter that collects in their nets. They also capture food by direct interception or electrostatic attraction, which are important strategies in low flow conditions (Wallace and Merritt, 1980).

Macroinvertebrates exhibited higher density during the semi-lentic phase. Increased densities occur when reduced flows concentrate individuals in residual pools (Cortes et al., 2002; Dewson et al., 2007c). However, in the semi-lentic phase, the spillways restored water volumes to levels similar to those in the lotic phase. Thus, the increased total density was unlikely a result of reduced habitat availability. Two genera of Chironomidae (*Ablabesmyia* and *Tanytarsus*) and two families of Trichoptera (Leptoceridae and Polycentropodidae) increased densities in the semi-lentic phase. *Ablabesmyia* feeds on Chironomidae larvae and other smaller macroinvertebrates (Epler, 2001; Callisto et al., 2002b). Considering that the abundance of predators depends directly on prey availability (Vannote et al., 1980), the increase in the total number of macroinvertebrates and Chironomidae may have contributed to the increased numerical density of this genus. *Tanytarsus* inhabits sand substrates and is commonly found in environments with low water flux (Roque et al., 2004; Takahashi et al., 2008). The Leptoceridae and Polycentropodidae also include taxa that inhabit ponds and backwaters (Pérez, 1988; Martins-Silva et al., 2008). Their increased densities probably resulted from additional semi-lentic habitats.

Total biomass did not vary significantly between the two phases and was predominantly represented by the alien bivalve *Corbicula fluminea*. This is a filtering species, and its biomass consists basically of carbon from phytoplankton (Vaughn and Hakenkamp, 2001). This species lacked natural enemies (e.g., parasites and predators) in the invaded areas and can filter huge amounts of water (Sousa et al., 2008), which probably explains its high biomass even in an environment with limited productivity.

Significant changes in faunal composition occurred following flow reduction and formation of semi-lentic habitats; however there was overlapping of communities (ANOSIM R value = 0.3). In dammed environments, the replacement of river species by lentic species may take several years (Voshell and Simmons, 1984). When studying the succession of benthic macroinvertebrates in a newly formed lentic environment, Bass (1992) noted that the initial colonisers were species that already inhabited the river before the dam and were resilient to the new hydraulic situation. Afterwards, species arrived from adjacent areas probably by dissemination from winged adults. At the end of three years, the author observed that 80% of the original taxa disappeared and new ones were established in the area. Published data suggests that a period ranging from 20 to 36 months is needed for new communities of macroinvertebrates to stabilise in a newly formed lentic system (Solomini et al., 2003; Williams et al., 2008). During research downstream of Flaming George Dam (USA), Vinson (2001) observed small changes in the invertebrate fauna during the first years after damming: large changes were detected five years after damming.

Another possible explanation for this pattern (overlapped communities) could be derived from the taxonomic resolution used in this study (mainly Family). According to Bailey et al. (2001) the responses of aquatic communities to environmental gradients are adequately discriminated when organisms are identified to species; higher taxonomic levels seem to be disadvantageous in detecting transitional impairments. This is an important aspect to be considered; however, species-level identification in Brazil is difficult because of insufficient taxonomic knowledge and lack of comprehensive taxonomic keys (Buss and Vitorino, 2010). Family identification appears to be good for assessing variation in benthic macroinvertebrate community structure, particularly in impact assessment studies (Melo, 2005; Corbi and Trivinho-Strixino, 2006). Moreover, Bowman and Bailey (1997) also suggested that multivariate characterizations of community composition are not strongly affected by taxonomic resolution. They analyzed ten data sets from published studies of freshwater benthic macroinvertebrates and concluded that genus-level identification did not usually add distinct information to the description of community patterns than higher levels (e.g, Family).

Communities colonising homogeneous habitats with little environmental variation tend to be fragile and susceptible to physical disturbance (Armitage, 2006). One way to minimise these problems would be to establish a flow regime in the reach that reflects the hydrometeorological variations of the basin, and is not confined to a constant minimal value of 7 $m^3.s^{-1}$. In this study, the sampling regime was similar to conventional methods (the sediment samples were collected along six random sites in the same reach and used as replicas because there is no other regulated river reach with similar characteristics in Brazil). Moreover, the sampling period was relatively short (1 year/phase), which may be difficult to reveal seasonal variations – atypical years. Therefore, the results obtained should be interpreted carefully and critically, considering these shortcomings. Currently, predicting how artificially flows affect lotic biota and assessing how much water a regulated river reach below a dam needs to preserve its ecological sustainability have been a challenging task for many water managers (Bunn and Arthington, 2002). In fact, they have properly applied instream flow incremental methodology (IFMI) for some fish groups (e.g. salmonids) (Dewson et al., 2007a), but its development and use for benthic macroinvertebrates have still been limited by restrictions in collection of adequate samples (large numbers), accurately taxonomic identification of species and construction of habitat suitability curves (Gore et al., 2001).

In summary, significant changes in taxonomic composition and total density of macroinvertebrates were detected after flow reduction and spillway construction. Statistically differences in richness, total biomass, and diversity were not observed. The macroinvertebrate assemblages were characterised by the numerical dominance of tolerant organisms and by high biomasses of an alien species, suggesting that this reach of the Araguari River was already impaired before its conversion to semi-lentic conditions. Since the early 1990s, the Araguari River basin has experienced dam construction and the replacement of native vegetation by pasture and crops, leading to altered biological communities and have altered ecosystem function. Because the restructuring of benthic fauna in dammed rivers is gradual, a periodic biomonitoring programme of this regulated reach is needed to assess the long-term biotic effects of altered flows.

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