Downstream impact of Mogi-Guaçu River damming on the benthic invertebrates (São Paulo State, Brazil).

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ABSTRACT: Downstream impact of Mogi-Guaçu River damming on the benthic invertebrates (São Paulo State, Brazil). Effects of damming the Mogi-Guaçu River (São Paulo State, Brazil) on the downstream invertebrate community were examined. Samplings were conducted at a site downstream of the dam prior to, during and after reservoir filling. In the pre and post-filling phases, taxa richness tended to increase during periods of low surface current velocity. This fact could be associated with higher organic matter availability and/or a lower remotion of organisms. Density and richness values remained in the range observed before damming whereas taxa composition changed after filling. However, the impact over taxa composition was not severe because extreme changes of similarity were not observed between pre and post-filling periods.

Key-words: benthic invertebrates; reservoir filling; post-filling phase, downstream impact.

RESUMO: Impacto do represamento do Rio Mogi-Guaçu sobre os invertebrados bentônicos a jusante da barragem (SP, Brasil). Foram examinados os efeitos do represamento do Rio Mogi-Guaçu (SP, Brasil) sobre a comunidade de invertebrados bentônicos a jusante da barragem. A amostragem foi realizada antes, durante e após o represamento. Tanto na fase pré-enchimento como na pós-enchimento, a riqueza de taxa tendeu a aumentar durante períodos de menor fluxo superficial. Este fato poderia estar associado com uma maior disponibilidade de material orgânico e/ou menor perda de organismos por arraste. Tanto os valores de densidade total como de riqueza continuaram a oscilar dentro da mesma amplitude observada no período anterior ao enchimento do reservatório, enquanto que a composição da comunidade mudou após o enchimento. No entanto, o impacto sobre a composição não foi severo, pois não ocorreram mudanças extremas nos valores da similaridade entre as fases pré- e pós-enchimento.

Palavras-chave: invertebrados bentônicos, represamento, fase pós-represamento, impacto a jusante.

Introduction

Mankind has modified lotic environments by reservoir construction for many centuries. Regardless of their purpose, all dams trap sediment to some degree and most alter the flood peaks and seasonal distribution of flows (Kondolf, 1997). Consequently, the longitudinal continuum of physical and biological features of these environments is disrupted (Armitage, 1984; Johnson et al., 1995). The resulting changes in water flow and transport of sediments, nutrients and energy, and in the biota alter most of the ecological processes (Ligon et al., 1995).

Benthic invertebrates are crucial elements to the functioning of freshwater ecosystems, representing a link between detritus and grazing food chains (Gore, 1989; Munn & Brusven, 1991). These organisms have long been used to evaluate the upstream and downstream alterations induced by reservoir construction (Petr, 1971; McLachlan, 1974; Armitage, 1978). The structure and/or function of the invertebrate community may be altered locally and downstream the dam (Munn & Brusven, 1991).

Most studies on impacts of reservoirs use upstream sites and tributaries to compare with downstream features induced by the reservoir. In this case, the choice of one or more reference sites for the study area is a fundamental task. In fact the use of just one reference site can be troublesome. If a real impact results in a decrease in the abundance of organisms it may not be detected when a similar decrease occurs by chance in the single control site. So the use of several, randomly chosen reference sites is appropriate (Underwood, 1992). However, to choose reference sites is very difficult when the study area is already heavily impacted. Although the knowledge of conditions existing prior to the reservoir is advisable and may be an alternative to the reference sites, studies using this approach are rare (Petr, 1978; Petts, 1984; Bass, 1992).

In Brazil, besides the great number of reservoirs built, studies following the abiotic and biotic parameters pre-, during and post-filling are relatively recent and rare. Their beginning coincided with the 1986 establishment of federal legislation related to environmental impact studies (CONAMA, 1986). Our study is the first in Brazil using the benthic invertebrate community to evaluate the effects of stream regulation. It is based on the comparison of the conditions prior and after a man-made lake creation.

Material and methods

Study Area

The Mogi-Guaçu River has its origin in the Mantiqueira mountain range, Minas Gerais State, SE Brazil (26º16'S, 46º42'W; 1,650 m a.s.l.). It reaches Pardo River at São Paulo State after 473 km (377.5 km of which in São Paulo State) and at about 490 m a.s.l. (Maier et al., 1978) under influence of the Köppen Cwa type climate (mesotermic with a dry winter, from June to September) (CESP, 1993a). Its catchment of 17,560 km² embodies 44 cities (37 in the São Paulo State), many of them unloading raw sewage and wastewaters into the river. Significant industrial load is mostly released as effluents in the Mogi-Guaçu tributaries (CETESB, 1995; CESP, 1993a). The original vegetation in the catchment was primarily Semideciduos Latifoliate Tropical Forest and also some "cerrado" (Brazilian savannah). Furthermore, there were large areas with riparian forest and wetlands in its floodplain. Nowadays small and sparse fragments remain (CESP, 1993a) and sugar cane culture and pasture dominate the landscape of the study area.

São Paulo State Energy Company (CESP) dammed the Mogi-Guaçu River, originating the Mogi-Guaçu Multipurpose Reservoir, an on channel run-of-the-river reservoir, with four gated spillways and power generation of 7.2 kW (Fig. 1). Initially (14 November 1995), the reservoir was filled up to the volume required for water supply. Filling for the generation of electric power occurred in December, 28-29th 1995. The morphometric characteristics of the reservoir are as follow: length - 8 km, surface area - 5.73 km², volume - 12.56 million m³, altitude - 598.5 m a.s.l., dam height - 13.5 m, dam length – 170 m, spillway level - 594.3 m a.s.l. (CESP, 1993b), and calculated mean retention time - 74 hours.

Sampling site

Reference sites are virtually absent in the study area as it is under the heavy influence of human activities. So the alternative sampling design was the comparison between the conditions prior and after impoundment. Moreover, the choice of sampling sites was difficult due to the hard access and navigability. Consequently only one sampling site was established about 2 km downstream the dam (Fig. 1). Its substrate was basaltic bedrock (Comitê da Bacia Hidrográfica do Rio Mogi-Guaçu, 1999) with stony and sandy patches in minor quantity, a feature that did not change after filling. The mean depth was 3.41 m (range: 2.86-4.16 m) in the pre-filling and 4.13 m (range: 3.00-5.00 m) in the post-filling phase.

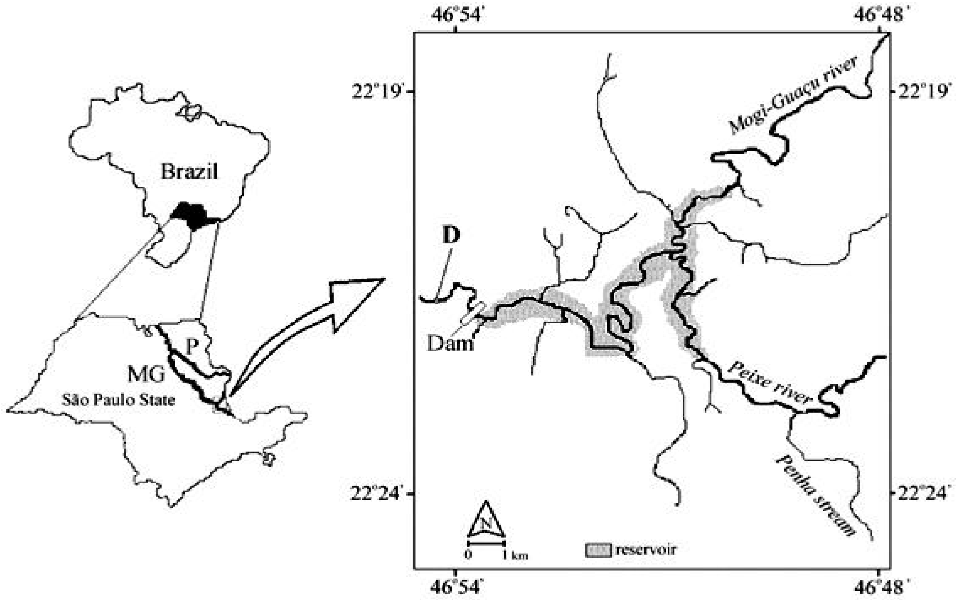

Figure 1: Mogi-Guaçu River with reservoir and sampling site location (D) (São Paulo State, Brazil). (MG: Mogi-Guaçu River; P: Pardo River)

Surface current velocity measure

The surface current velocity was estimated using a float (an orange) by measuring the time for its passage over a measured distance (Wetzel & Likens, 1991).

Benthic fauna sampling and analysis

Sampling was conducted bimonthly from February/94 to August/94 before river damming (Pre-Filling Phase), in November/95 during the initial filling (Filling), trimonthly from February/96 to November/96, quadrimonthly from March/97 to November/97 and, finally, in May/98 and November/98 (Post-Filling Phase).

Using a simple random scheme, three sampling units of substrate were taken in the main channel with a modified Petersen grab (325 cm^2). A sampling unit was accepted only if it has sampled a stony or sandy patch. Stones and small boulders were individually washed for attached individuals removal. Samples were floated with saturated NaCl solution (Brandimarte & Anaya, 1998). The remaining material was sieved through a 250 mm mesh. Organisms were preserved in 4% neutral formalin and stained with phloxine-B.

Organisms were identified to the family level, when possible, or to a superior taxonomic level. Bryozoa was counted by zooids.

The mean total density of organisms per square meter and the standard error of the mean (Elliott, 1977) were calculated. The richness of taxa was considered as the simple sum of taxa in the sampling units. Relative abundance of each taxon (as percentage) was calculated as abundance in relation to the total abundance of all taxa.

The Spearman rank correlation coefficient (r_s) (a = 0.05) (Zar, 1999) was applied in order to search for correlation between: 1) total density of organisms and taxa richness; 2) total density and surface current velocity; 3) richness and surface current velocity; 4) surface current velocity and mean daily effluent discharge; 5) total density and the mean of daily effluent discharges of the two days prior to the sample date and 6) richness and the mean of daily effluent discharges of the two days prior to the sample date.

Analyses involving effluent discharges (data provided by the Energy Company) were limited to the period when this data was available, from November/95 to November/98. Considering the mean monthly values of effluent discharges, we observed three value ranges. In each discharge range, three samplings were conduced: range £ 40 $m^3.s^{-1}$

(August/96, July/97 and November/98); range 60 to 70 $m^3.s^{-1}$ (May/96, November/97 and May/98); range 80 to 130 $m^3.s^{-1}$; (February/96, November/96 and March/97). Since the datum of July/97 was an outlier it was excluded from the tests using effluent discharge.

The similarity between successive samples was qualitatively evaluated by the Jaccard index (Jongman et al., 1987). The quantitative analysis of similarity between communities of pre- and post-filling phases, involving 36 pairs of samples, was calculated by the Renkonen index or percentage of similarity (PS) (Wolda, 1981).

Results

The mean surface current velocity was 0.57 $m.s^{-1}$ (range: 0.36-0.67 $m.s^{-1}$) during pre-filling and 0.85 $m.s^{-1}$ (range: 0.61-1.28 $m.s^{-1}$) in the post-filling phase, decreasing in the coldest and driest months (Fig. 2A).

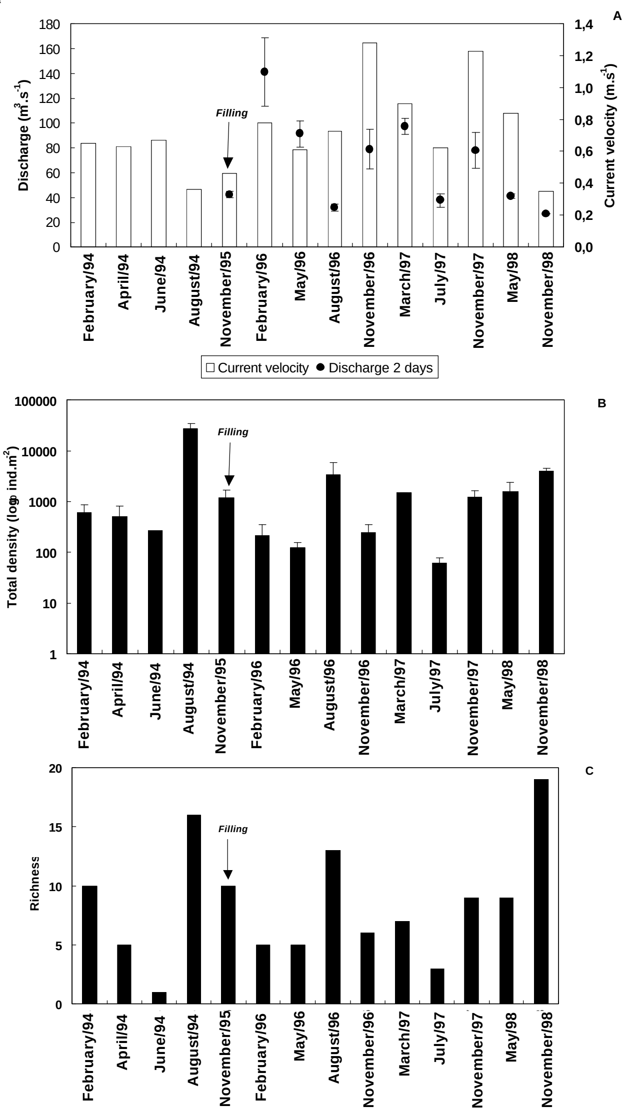

Figure 2: Mean daily effluent discharges of the seven days prior to the sample date ($m^3.s^{-1}$) with standard deviation, surface current velocity ($m.s^{-1}$) (A), total density of individuals ($ind.m^{-2}$) (log scale) (B), and taxa richness (C) of the invertebrate community downstream the Mogi-Guaçu Reservoir (São Paulo State, Brazil), in the pre-filling, filling and post-filling phases.

Total density and richness showed similar temporal variation pattern and had high correlation coefficient (Tab. I). In general, higher values of total density of organisms and taxa richness matched with the driest and/or lowest surface current velocity months in the pre- and post-filling phases (Fig. 2B and C). However, either the total density as the richness showed a tendency to negative correlation (not significant) with the surface current velocity measured during the sampling (Tab. I). Surface current velocity was correlated with the mean effluent discharge of the sampling day (Tab. I). It was observed negative correlation between total density and the mean of daily effluent discharges of the two days prior to the sample date (Tab. I). High negative correlation between richness and the mean of daily effluent discharges of the two days prior to the sample date was observed (Tab. I).

Table I: Spearman rank correlation coefficients (r_s) between biotic and hidrologic factors of a site downstream the Mogi-Guaçu Reservoir (São Paulo State, Brazil)

Parameters	**n**	r_s	**p**
Effluent discharge(1) x surface current velocity	10	0.697	< 0.050(3)
Total density x surface current velocity	14	-0.125	> 0.500
Taxa richness x surface current velocity	14	-0.277	> 0.200
Total density x taxa richness	14	0.903	< 0.001(3)
Total density x effluent discharge(2)	9	-0.783	$= 0.020$(3)
Taxa richness x effluent discharge(2)	9	-0.892	< 0.005(3)

(1) mean daily discharge
(2) mean of daily effluent discharges of the two days prior to the sample date
(3) significative correlation ($\alpha = 0.05$)

After filling values of total density and richness were in the same range of the pre-impact period (Fig. 2B and C).

The temporal continuum of similarity can be divided in three phases according to Jaccard index (Fig. 3). The first one comprising samplings from February/94 to August/94 (Group 1), the second from November/95 to November/97 (Group 2), and the third from May/98 to November/98 (Group 3). With regards to relative abundance (Fig 4),

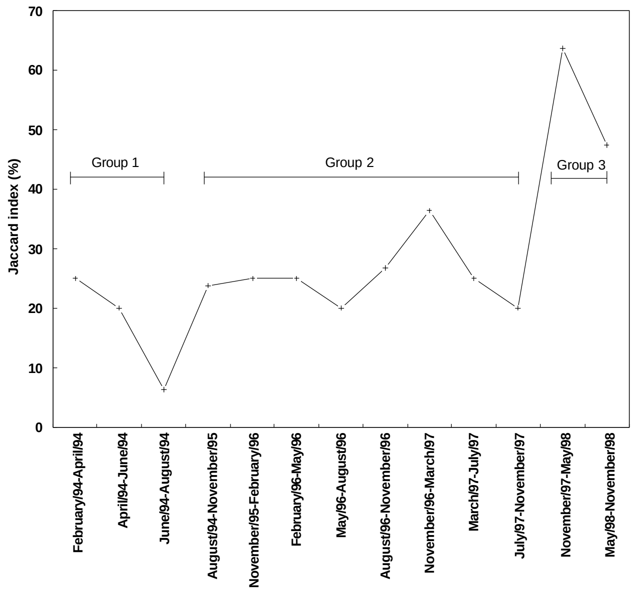

Figure 3: Temporal variation of Jaccard index (%) downstream Mogi-Guaçu Reservoir (São Paulo State, Brazil), in the pre-filling, filling and post-filling phases.

Group 1 was dominated by Plumatellidae (74.5%). In the Group 2, dominance was shared by Chironomidae (33.9%), Plumatellidae (27.9%), and Naidinae (9.5%). In the Group 3, dominance was shared by Chironomidae (45.5%), Trichoptera (13.8%), and Ephemeroptera (10.6%). Since Chironomidae was important in the Groups 2 and 3, the differentiation between them was due to the other two taxa more abundant in each group.

According to Renkonen index, the similarity between pre- and post-filling phases was higher to 40% for 58.4% of the pair wise sample analyses.

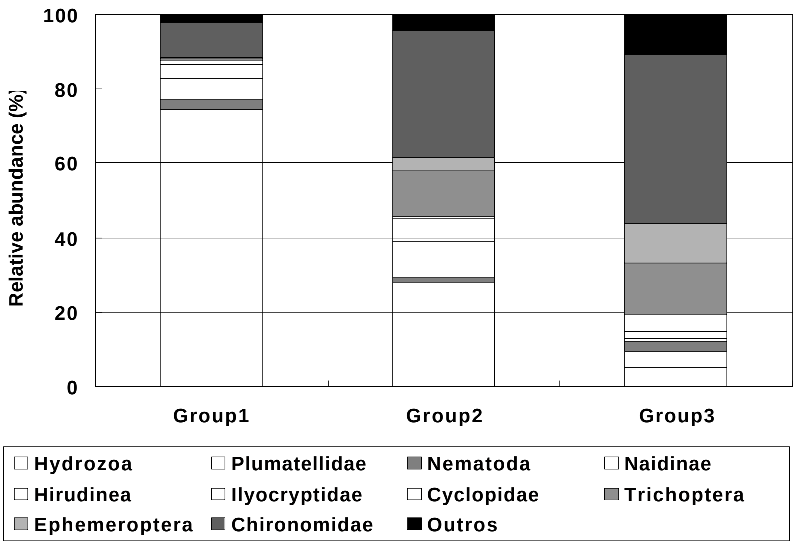

Figure 4: Total relative abundance of taxa of the invertebrate community downstream Mogi-Guaçu Reservoir (São Paulo State, Brazil). Groups are the same established by the Jaccard index analysis.

Discussion

The surface current velocity was correlated with the mean effluent discharge of the sampling day, revealing indirectly the influence of discharge on surface current velocity. As the surface current velocity do not necessarily reflect the bottom current velocity and is an instantaneous measurement, its influence on benthic community parameters, as density and richness, may be uncertain. In this case the use of the mean of effluent discharges of the days prior to the sample date can be more interesting, improving the analyses. In fact, richness showed weak correlation with current velocity, but significant negative correlation with effluent discharge. Water discharge is a key factor to the benthos due to its influence on the availability of food, substrate composition, current velocity and temperature (Henricson & Sjöberg, 1984).

Although total density and richness were highly correlated, density did not show significant correlation with current velocity and discharge as the richness. Thus, richness was more sensible than density to discharge variations. Moreover, as the number of organisms in populations is variable through the time, a potential anthropic impact is not always the cause of change in abundance (Underwood, 1992).

On the analyzed site of Mogi-Guaçu River probably periods of low current velocity increase organic matter accumulation on substrate and reduce the loss of organisms by the scouring of the bottom. In this case, the occurrence of higher richness could reflect higher food availability and a stable current. On those conditions taxa like Plumatellidae and Naidinae increased in proportion. In the case of Chironomidae, generalist genera like Parachironomus, Polypedilum, and Rheotanytarsus increased quickly on such periods

(Anaya et al., 1996; Brandimarte et al., 1997). The increase of filtering organisms like Plumatellidae and Rheotanytarsus could corroborate the hypotheses related to the increase of organic matter resulting of reduced current.

Changes in the community downstream dam should be expected in response to the changed water flow and its consequences. At first, substrate and flow alterations in the regulated river represent a physical stress to the community (Loeb, 1994). Moreover, dam promotes the deposition of particles into the reservoir, modifying quali- and quantitatively the organic matter transported downstream (Baxter, 1977; Cummins, 1979; Davies, 1979; Donnelly, 1993). Inasmuch as major parameters like water temperature, dissolved oxygen, pH and substrate composition did not change after filling (Brandimarte, 1997; Brandimarte et al., 1999), observed changes in the taxa composition of the post-filling phase could be associated to changes in water flow and food availability.

The decline of richness and density is an expected change and it is a common tendency below impoundments (Voelz & Ward, 1991; García de Jalón et al., 1994). Initially, at least, it is related to material deposition into the reservoir and to the decreased transport of organic matter downstream (Marchant, 1989; Armitage & Blackburn, 1990; Munn & Brusven, 1991; García de Jalón et al., 1994).

The increase of current velocity in the regulated river may also be responsible by richness and density decline. Increased flow to over 2 $m.s^{-1}$ would result in scouring of the bottom, causing decrease in the aquatic vegetation and the loss of fine particulate organic food material from substrate. Such conditions would reduce faunal abundance and loss of certain species (Armitage, 1984). In other hand, if the increase of flow is less severe, it may only wash away the accumulated fine sediments, leaving a coarse substrate, improving the habitat and faunal diversity (Stanford & Ward, 1979). In the sampling site of Mogi-Guaçu River, the surface current velocity increased after filling but did not attain values so high as 2 $m.s^{-1}$ and did no result in great changes of total density and richness.

An important feature to be discussed was the decrease of relative abundance of Plumatellidae. Flow increase after river damming could be partially responsible because Bryozoa are favored by conditions of gentle flow (Baxter, 1977).

Increase of density occurs if the conditions in the regulated river become more stable, resulting in a more homogeneous habitat, with environmental conditions suitable to few taxa, which would reach high densities (Armitage, 1978; Armitage & Blackburn, 1990). However, the increase or decline of environmental stability depends on the operational features of the reservoir and the success or even the disappearance of taxa downstream the dam is variable in the different cases (Valentin et al., 1995). In general, great impacts occur in reservoirs with higher residence time. Operation based in wide fluctuation on daily flows and current velocities will result in lowered diversity and density of invertebrates (Henricson & Sjöberg, 1984). Decrease of density, for example, was observed downstream the Cow Green (USA) and Valparaiso reservoirs (Spain) (Armitage, 1978; García de Jalón et al., 1994). The absence of high oscillation in the current could be used as an indicative of the increase of stability in the regulated river. As the Mogi-Guaçu is a run-of-the-river reservoir, current oscillations continue to exist as in the pre-filling phase and, consequently, values of total density were maintained in the same range of the pre-impact period.

During the first year after filling, in the sampling site downstream the Mogi-Guaçu Dam seemed that structural features like total density and richness would tend to decrease (Brandimarte et al., 1999). However, considering a three-year period after filling it was observed that in fact both continued to vary in the range observed before damming.

The Jaccard index can be considered a measure of the community persistence (Townsend et al., 1987). According to this index, damming affected the structure of the community downstream already during the filling as indicated by the breakdown of the temporal continuum in November/95. By the analysis of the relative abundance of taxa it is clear that this change was gradual, the second group depicting a transitional phase between the first and third groups. The structural change occurred in the downstream site before than in the reservoir area (Brandimarte et al., 1999), but the replacement of taxa was partial as demonstrated by the relatively high percentage of similarity, or Renkonen index, between communities of some months of pre- and post-filling phases.

The irregularity of the sampling frequency in the post-filling phase did not limit our conclusions. In Mogi-Guaçu Reservoir, due to reservoir operation, the effluent discharge presented a strong seasonality, presenting three value ranges with three sampling dates in each one.

Several factors are indicative that the river channel benthic invertebrate community of the studied site downstream the Mogi-Guaçu Dam in general was not severely impacted. A run-of-the-river reservoir does not drown a large area because the purpose of the dam is essentially to direct and control the flow of the stream, impounding a small water volume (Baxter, 1977). Consequently the lake environment did not become truly lentic, keeping a short residence time. So it would be expected that changes in the flow of energy and material downstream were not so drastic. In fact, as stated before, did not occur relevant changes in water chemistry and substrate composition that could severely influence and change the community in the regulated reach. Moreover the tendency of increase of richness with the current velocity reduction remained after filling. Finally, considering the taxonomic level used in this paper, the alteration of taxa composition did not cause great dissimilarity between the communities of pre- and post-filling periods.

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