

IMPACTS OF A RESERVOIR ON FISH ASSEMBLAGES OF SMALL TRIBUTARIES OF THE CORUMBÁ RIVER, BRAZIL

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ABSTRACT

Fish community surveys were conducted in five tributaries of the Corumbá River before and after damming. Electrofishing samples were collected monthly in the pre-impoundment period (March 1996 to August 1996) and 15 in the post-impoundment period (September 1996 to February 1999). A self-organizing map (SOM, an Artificial Neural Network algorithm) was used to represent the patterns of fish assemblages. Samples collected in both the pre- and post-impoundment periods were randomly dispersed on the SOM, and, therefore, a clear and significant pattern of separation between samples collected during these two time periods was not found. Mean and maximum water depth, which is correlated with ground water level, did not significantly separate the pre- and post-impoundment samples. However, we found significant differences between the two periods for water temperature, pH, conductivity, DO and current velocity, but abundances of fish species (summarized in the clusters identified by the SOM) did not differ significantly. Instead, the validity of the clusters distinguished by the SOM was confirmed by significant differences in some biotic variables: species richness, equitability and log transformed total abundance. Indicator species values identified the most preferred cluster (and respective complex of environmental factors) for a given species. Only one cluster did not contain any significant species indicator values, but it was dominated by samples from the Furnas Stream, which was the only effluent that could be entered by fish from the main river channel after the damming owing to its location below the dam, which has no fish ladder. Copyright © 2008 John Wiley & Sons, Ltd.

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INTRODUCTION

Tens of thousands of dams along rivers have been constructed worldwide (Petts, 1984; Nilsson and Berggren, 2000). This number will probably significantly increase in the future (Allan, 1995), and the number of studies will increase accordingly (e.g. Kinsolving and Bain, 1993; Orth and White, 1993; Koryak and Hoskin, 1994; Travnicek *et al.*, 1995; Matthews, 1998; Penczak *et al.*, 1998; Jackson *et al.*, 2001; Matthews and Marsh-Matthews, 2007). Of these studies, the number of papers is highest for evaluation of changes to assemblages in main-channel tailwaters (downstream of dams), and therefore more and greater changes for these fish populations have been recorded (Poff *et al.*, 1997; Poff and Hart, 2002). Less attention was paid to a river section located upstream from the reservoirs in main channels (Kruk and Penczak, 2003; Cumming, 2004; Matthews and Marsh-Matthews, 2007), which retained some naturalness after damming (Petts, 1984; Penczak *et al.*, 1998, Penczak and Kruk, 2005). This is manifested in the fact that they have water temperature, discharge and velocity, which are not much altered but dependent on climate only (Petts, 1984; Penczak *et al.*, 1998; Penczak and Kruk, 2005). Thus, the effect of the dam is limited to that of precluding riverine species migration (Petts, 1984; Kruk and Penczak, 2003). Very little is known about fish in dammed first order streams above low dams (Cumming, 2004) or in streams that are tributaries of rivers that were later dammed (Liensch *et al.*, 2000; Matthews and Marsh-Matthews, 2007).

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Herbert and Gelwick (2003) and Guenther and Spacie (2006) undertook such a study, in parallel, to sample sites in impounded tributaries (i.e. emptying to a reservoir) and in free-flowing rivers. They showed significant differences in the populations of 'fluvial specialists', piscivore abundance and composition, and a total richness, but they could not be sure that such effects would be obtained in a given stream after its damming. This is because, despite the morphological similarity between the investigated streams, we know that there are no two identical streams/rivers (just as there are no two identical individuals of a species). Their results are statistically well documented, but they constitute an assumption, because qualitative and quantitative changes in the stability of the fish population are dependent on the scale of time and space (Matthews, 1998). Liensch *et al.* (2000), in their research, have used fish samples collected in pre- and post-impoundment periods in the Buncombe Creek Oklahoma, but the pre-impoundment samples were collected by other researchers applying different sampling tools without the specification of length or area sampled. Likewise the sites' locations were not exactly in the same places in both terms. But despite these limitations Liensch *et al.* (2000) found some changes in assemblage composition but more clear differences only in the species numbers between spring and summer seasons. A time scale analysis can be very attractive for investigations because changes of environment and the fish reaction to them occur 'from minute to minute, from day to day, from year to year, [or] over centuries' (Matthews, 1998).

A pre- and post-impoundment study by Matthews and Marsh-Matthews (2007) was conducted on the same streams (which were subsequently impacted by dams); the studies concerned one species (*Cyprinella lutrensis*, red shiner), and the authors drew the very important conclusion that reservoir effects on red shiner (in the tributaries that they investigated) did not appear until decades after impoundment. The changes in the populations of red shiner were visible after 'combinations of extreme drought and flood events'. Hence, we aimed to determine whether and/or how all fish species forming assemblages changed over a given time in the same, small tributaries before and after damming of the main channel. Because some of the catchments around the reservoir were very dry before the impoundment, we expected that the streamlets that we investigated would benefit somewhat from the water supply after the damming, that is increased level of subsoil water.

We aimed to determine the following: (1) whether fish assemblages differed between the pre- and post-impoundment periods in the investigated streams; (2) whether sites in the pre- and post-impoundment periods differed according to selected abiotic (environmental) and biotic (assemblage attributes) variables and (3) whether there are some characteristic species in assemblages before and after impoundment.

MATERIALS AND METHODS

Study area

The five sampled streams (Taquaral, Rochedo, Taquarí, Gameleiras and Furnas) are tributaries of the Corumbá River, an affluent of the western bank of the Paranaíba River, located in the central part of Brazil at the upper Paraná River basin (Figure 1). The Corumbá is a plateau river that runs, for most of its length, along a narrow valley and on a rocky bed. The area drained by this river covers 34 000 km² and is mainly overgrown by savannah vegetation (Paiva, 1982). The lower part of the Corumbá Reservoir was constructed in September 1996 with the purpose of generating hydropower. It is 65 km² in area, with a volume of 1.5 billion m³, an average depth of 23 m, and a hydraulic retention time of 30 days. Sampling was carried out in lotic parts of the streams before and after the reservoir was filled (September 1996).

The maximum and minimum average temperatures in this region are 29°C, which occurs during September, and 13.7°C, occurring during July, respectively. The amount of rainfall is small and extremely seasonal, with 88% of the total precipitation registered between October and March. Hence the seasons are distinguished there on the basis of temperatures rather than precipitation. All samples of the pre-impoundment period were collected in the dry season; eight of those from the post-impoundment period were obtained in the dry season, and seven were obtained in the rainy one. Three of the sampled streamlets now empty into the newly formed reservoir; one is located above the section situated upstream from the reservoirs, and the last is located downstream of the dam (Figure 1).

The distances from the dam of the five sampled stretches are presented in Figure 1, and some information on the stretch morphology is given in Table I. The Furnas Stream mouth is located 1250 m below the Corumbá Dam.

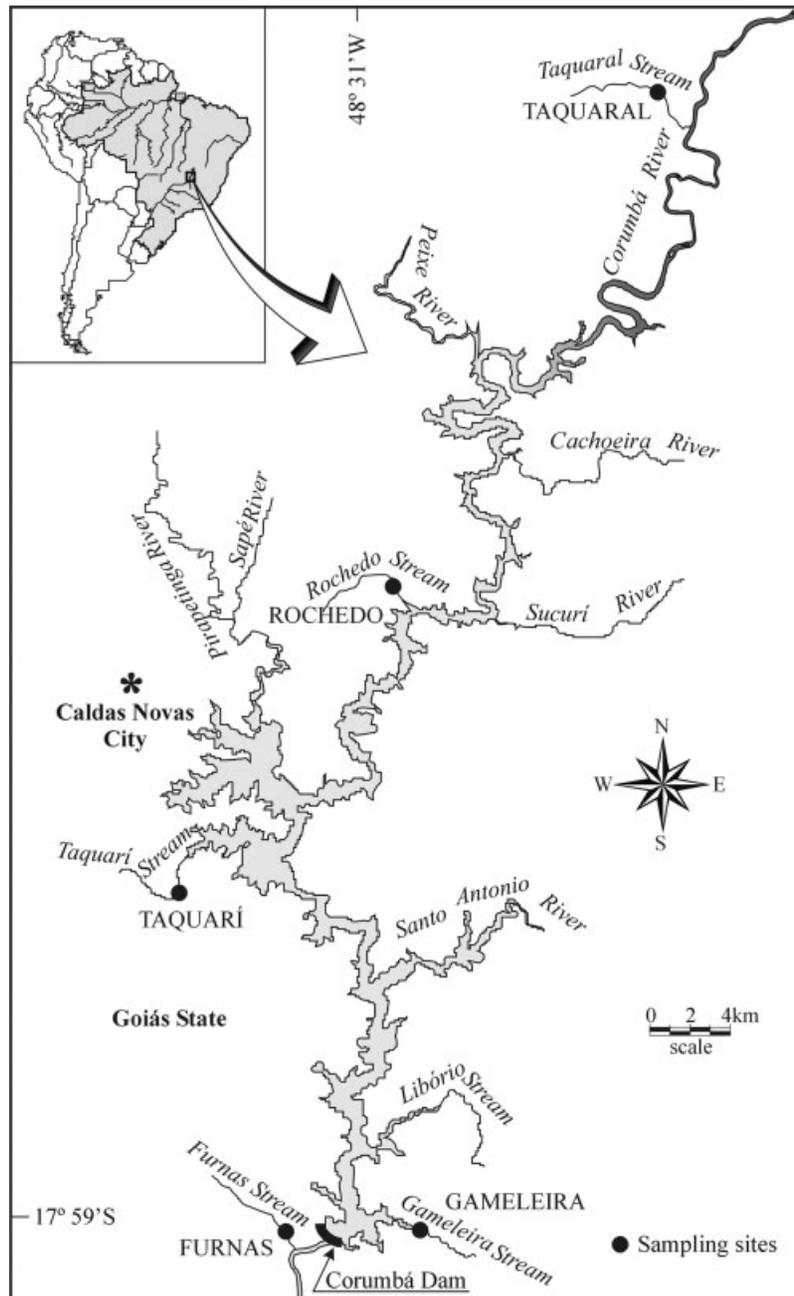


Figure 1. Extent of the Corumbá River showing investigated streamlets and the distribution of sampling sites

Fish surveys

A total of 23 319 fish belonging to 73 taxa were caught and identified during 21 sampling events at each site; 20 sampling occasions in the Taquaral Stream only. The matrix with numbers of individuals collected at each site is available on request because of its large dimensions. Fish assemblage attributes used in analyses were species richness, diversity (as measured using the Shannon index, $H' = -\sum p_i \times \ln(p_i)$, where p_i is the proportion of

Table I. Morphometry of sampled stretches of five studied streams

Streams and their symbols Parameters	Taquaral, AR	Rochedo, RO	Taquarí, TQ	Gameleiras, GA	Furnas, FU
Mean width (m)	3.0	4.0	3.0	6.5	3.5
Maximum depth (m)	0.4	0.6	0.5	0.9	0.5
Bottom type	Gravel	Rocks	Rocks, large rolled stones, abundant gravel	Rocks, large rolled stones, small sandy deposits	Rocks, gravel, coarse sand, litter deposits

Sites' position and their distance from the dam are marked on Figure 1.

individuals being members of the i th species), equitability of species diversity ($E = H'/\ln S$, where S is the number of species having the indicated p_i value).

Fish samples were collected in two periods: from March 1996 to August 1996 (pre-impoundment; 6 monthly samples) and from September 1996 to February 1999 (post-impoundment; 15 samples collected quarterly), by electrofishing. The electrofishing apparatus was composed of a 220 V (DC) generator. During sampling a stop net (5 mm bar mesh) was always placed at the upstream and downstream limit of each site, the length of which was 50 m. Two people parallel waded downstream along these narrow streams and electrofished with 40 cm diameter anode-dipnets for a constant effort and the whole width of the river was sampled by this method. At each sampling event, measurements of the following abiotic parameters were also obtained: water temperature, pH, conductivity, dissolved oxygen and both mean and maximum depth and velocity. All of this data are available on request, as it cannot be published here due to its length.

Statistical analysis

A self-organizing map (SOM) with a Kohonen unsupervised learning algorithm was used in the study for ordering samples (Kohonen, 1982; Lek and Guegan, 1999, 2000; Lek *et al.*, 2005). The SOM was simulated and the cluster analysis was performed in the Matlab (Ver. 6.1.0.450) environment. The data (73 taxa \times 104 samples, log transformed numbers of individuals and normalized 0–1) were presented onto the neurons in the input layer. The map (SOM, output layer) obtained after the learning process contains all the fish samples assigned to neurons (the latter displayed as hexagons). We tried to employ output layers of different sizes but classifications were not as clear as with the size chosen by us for the study that is 5×4 neurons. Generally, samples that were assigned to the same neurons or to nearby neurons were similar and samples assigned to distant neurons differed. Additionally, samples assigned to nearby neurons differed considerably if those neurons belonged to different clusters, which were identified with use of a hierarchical cluster analysis (Ward linkage, Euclidean distance). The SOM software also allows for visualization of species importance in the output neurons (named component planes) in the form of a greyness gradient (Kruk, 2007a). Summing up, the Kohonen algorithm recognized the structure of the data set, distinguished clusters, neurons and assigned fish samples to them (Lek *et al.* 2005; Kruk, 2007a).

More details regarding the Kohonen algorithm are available in papers which applied the algorithm for community studies (Chon *et al.*, 1996; Giraudel *et al.*, 2000; Park *et al.*, 2003; Penczak *et al.*, 2004; Kruk, 2006, 2007a,b). We would like to stress that the SOM description is more detailed in our former papers which are cited here. We have to note also that about 5000 papers were published with applying the method but mainly in engineering sciences. In biology about 200, but in freshwater fish ecology only a few. This smaller number is not a result of the fact that the SOM is not perfect, but rather difficult for study. Despite this problem we would like to underline that the SOM has two important advantages: it is based on nonlinear mathematics and its both input and output layers are not limited even by huge data sets (Kruk *et al.*, 2007).

An attempt at ordination with the detrended correspondence analysis (DCA, version of DECORANA; Hill, 1979) was undertaken using the same dataset as for the SOM. DCA is free of lax criteria for stability and a bug in the rescaling algorithm. The bug caused sensitivity of ordination results to sample order, mainly on the third axis and

higher. These problems have been corrected in the multivariate analysis using PC-ORD statistical software (McCune and Mefford, 1992).

We used conventional statistical methods (DCA and obtained from this analyse sample scores) to identify differences between the four clusters distinguished by the SOM according to Hoesinghaus *et al.* (2003). We categorized samples according to their clusters and classified the month and year of the samples into pre- and post-impoundment periods (in neurons, these are represented by two numbers followed by two letters that refer to the name of the streamlet). Therefore, the three factors considered were the clusters (I1, I2, II1 and II2), the periods (pre- and post-impoundment), and their interactions (ANOVA terminology). These factors were used to determine differences in abiotic (water temperature, pH, conductivity, dissolved oxygen, mean and maximum depth and velocity) and biotic (species richness, equitability and abundance) parameters. As several tests were performed (a two-way ANOVA for each parameter), we opted for the protected ANOVA protocol (Scheiner, 1993) to minimize Type I Error. In this protocol, a MANOVA is first applied and ANOVAs were conducted for each parameter separately only if the MANOVA was significant. When the interaction was not significant and another factor was significant, a *post-hoc* comparison (Duncan test) was performed to identify which levels of a factor differed significantly.

The SOM does not offer any statistical indication of which neurons or clusters (and respective complex of environmental factors) are most important for given species. This fact was perceived by Park *et al.* (2005) who developed an index of the relative importance to quantify the meaning of each variable distinguished in the SOM map in order to obtain a better interpretation of ecological data. To partially resolve this problem, we used however the indicator value (IndVal) proposed by Dufrene and Legendre (1997). The indicator values were obtained from the original data matrix (number of individuals) and were attributed to the clusters distinguished by the SOM. The species that presented significant indicator values (identified by the Monte Carlo statistics) were considered. IndVal assumes its maximum (100%) when all individuals of a species are found in a single group of sites and when the species occur in all sites of that group. According to Dufrene and Legendre (1997) a threshold level of 25% for the index was accepted, which supposes that a species important for an assemblage is present in at least 50% of one site cluster and that its relative abundance (there expressed in biomass) in that cluster reaches at least 50%.

We then compared the graphs produced by the SOM for species importance (named component planes) with the indicator values. Surprisingly, the results matched perfectly, which then allowed us to identify the most important cluster for a given species. This same result was obtained by Gosselain *et al.* (2005) for diatom taxa.

RESULTS

The output layer of the SOM was partitioned into four main clusters: I1 consisting of neurons A1–A2, B1–B2, C1–C2; I2 made up of neurons A3–A4, B3–B4; II1 comprised of neurons D1, E1–E2; and II2 containing neurons C3–C4, D2–D4, E3–E4 (Figure 2). The samples from both pre- and post-impoundment periods were located randomly on the SOM (Figure 2). There were no significant differences between the pre- and post-impoundment samples in terms of species richness, equitability, Shannon diversity index and log-transformed abundance (two-way ANOVA, $p > 0.05$). The impoundment impact may have caused a separation of the Furnas Streamlet sites only (neurons A2 and A1 with exception FU9608, cluster I1).

The pre- and post-impoundment samples were not significantly different in terms of mean and maximum water depth, which might be correlated with underground water level, and also no significant difference was found between the four clusters (ANOVA; $p = 0.41$ and 0.64). Hence our hypothesis, that differences in local hydrology between the pre- and post-impoundment periods (severe drought conditions before the impoundment was established and flooded conditions afterwards) might have affected the structure of fish assemblages, was refuted. In addition, clusters did not differ significantly in terms of other abiotic variables analysed. However, we found significant differences between the pre- and post-impoundment periods for water temperature (Figure 3a), pH (Figure 3b), conductivity (Figure 3c), DO (Figure 3d) and velocity (Figure 3e) for samples collected during the same season of the year.

We tested the validity of the clusters on the SOM using some biotic variables and found significant differences among clusters when comparing species richness (Figure 4a), equitability (Figure 4b) and log transformed total

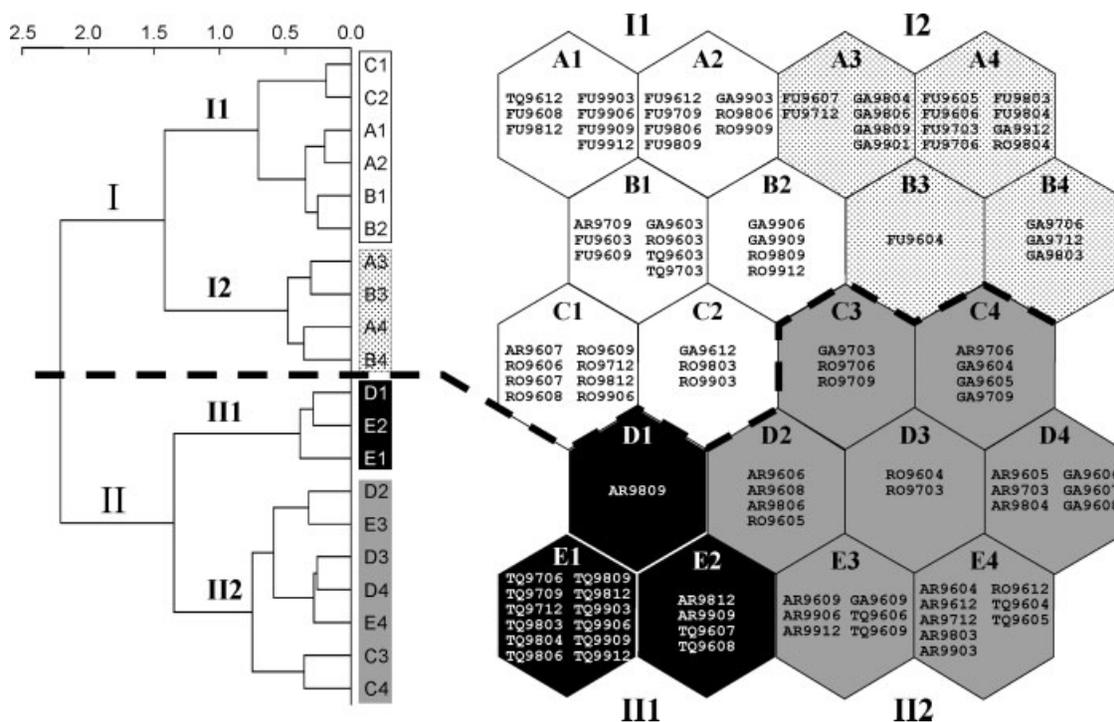


Figure 2. The structure of the self-organizing map (5×4) applied in order to classify the 104 collected samples (considered here as sites) from the tributaries (streamlets) of the Corumbá River. The clusters were identified with the use of a Ward dendrogram. In neurons, following abbreviations were used for streams investigated: Taquaral, AR; Rochedo, RO; Taquarai, TQ; Gameleira, GA; Furnas, FU. After these symbols abbreviation for year and a month numbers are included. The broken line separates the main clusters

abundance (Figure 4c). However, the Shannon diversity index did not differ significantly among clusters, which means that fish diversity during the pre- and post-impoundment periods was similar. The abundance data matrix was also summarized using DCA. Sample scores of this analysis were generated and the clusters identified by SOM were used to identify differences in DCA sample scores. An ANOVA analysis showed that the clusters differed significantly, demonstrating that they occupied distinct spaces in the DCA ordination.

At cluster I2, significant IndVal values were found for the following species: *Apareiodon affinis*, *Astyanax altiparanae*, *Bryconamericus stramineus*, *Characidium zebra*, *Imparfinnis schubarti*, *Leporinus friderici*, *Pimelodus absconditus*, *Pimelodus maculatus* and *Pimelodella* sp. Significant IndVal values were observed for *Cetopsorhamdia iheringi*, *Hypostomus regani*, *Lebistes reticulatus* and *Neoplecostomus paranensis* at cluster III1 and for *Astyanax eigenmanniorum*, *Apareiodon ibitiensis*, *Apareiodon piracicabae*, *Brycon nattereri*, *Bryconamericus* sp., *Corydoras* sp. and *Gymnotus carapo* at cluster II2 (Figure 5a–c). Only cluster I1 did not contain any species with significant IndVal values (i.e. was not significantly most preferred by any species). This was likely because its ichthyofauna display weak fidelity, which was established especially after the impoundment, due to intense fish movement between the main river channel and the stream (located downstream of the dam).

The component planes (Figure 5a–c) contained a great deal of information about the specificity and fidelity of the species presented here. We can easily determine from these three figures which species exhibit significant IndVal values at given SOM clusters. We can also identify which species are eurytopic (present in all clusters) and which are stenotopic (present in just one cluster or neuron). We can also establish the species that are sympatric (occurring together, such as *L. microphthalmus*, *O. niloticus*, *P. pulcher* and *S. insculpta*) and asympatric (always separated, such as *A. fasciatus* and *A. scabripinnis paranae* or *C. monoculus* and *N. paranensis*). It is also possible to determine which species present similar or opposite values of abundance on the SOM.

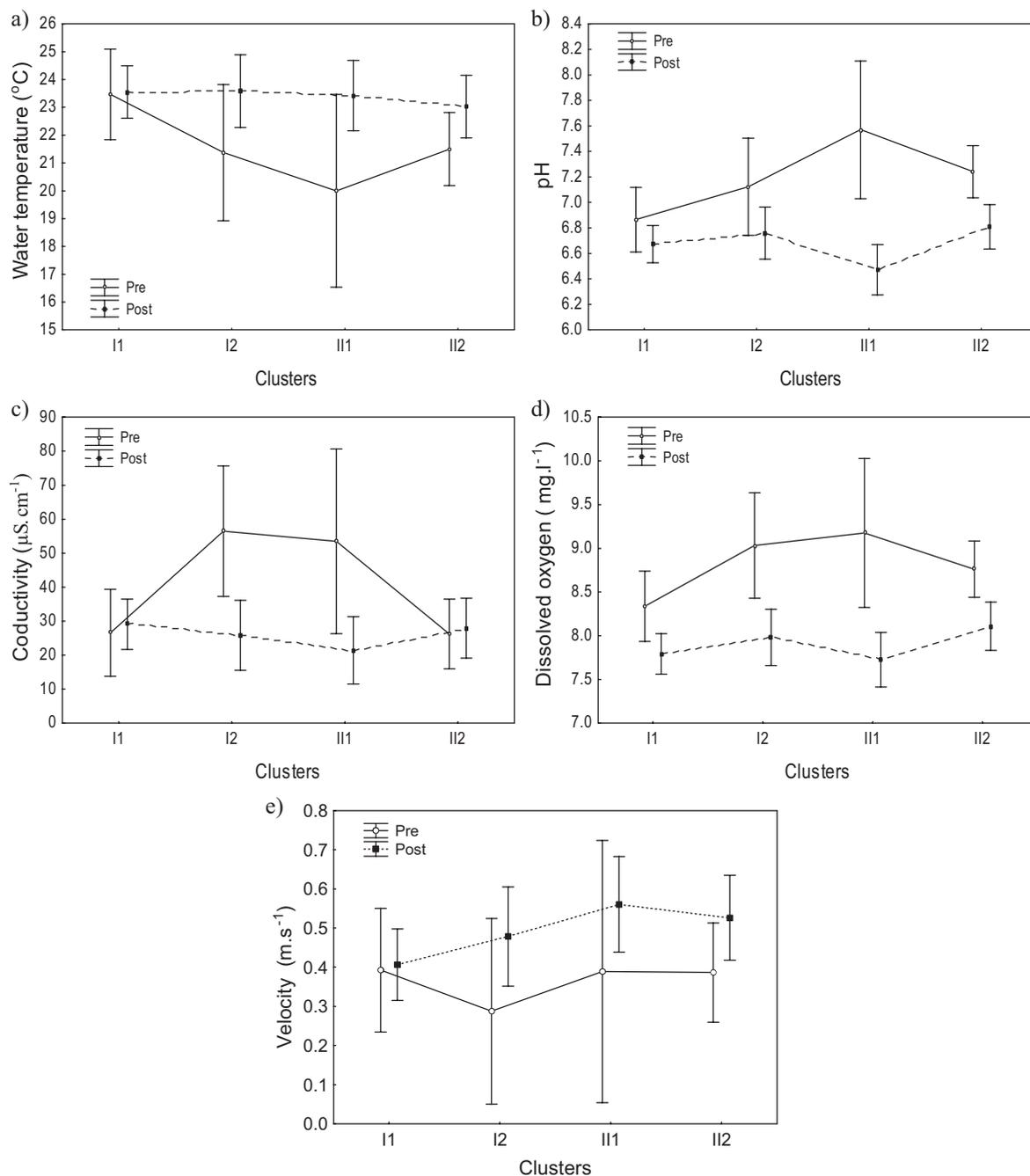


Figure 3. Differences between the pre- and post-impoundment periods in: water temperature (a), pH (b), conductivity (c), DO (d) and velocity (e) at the four clusters distinguished by the SOM

DISCUSSION

The impacts of dams have been evaluated in many studies and have been demonstrated to be catastrophic to the persistence and stability of fish assemblages in main river corridors (Orth and White, 1993; Koryak and Hoskin, 1994; Travnicek *et al.*, 1995; Matthews, 1998; Penczak *et al.*, 1998; Głowacki and Penczak, 2000; Penczak and Kruk, 2005). However, their effects on small streamlet communities can be different, as shown in the present and

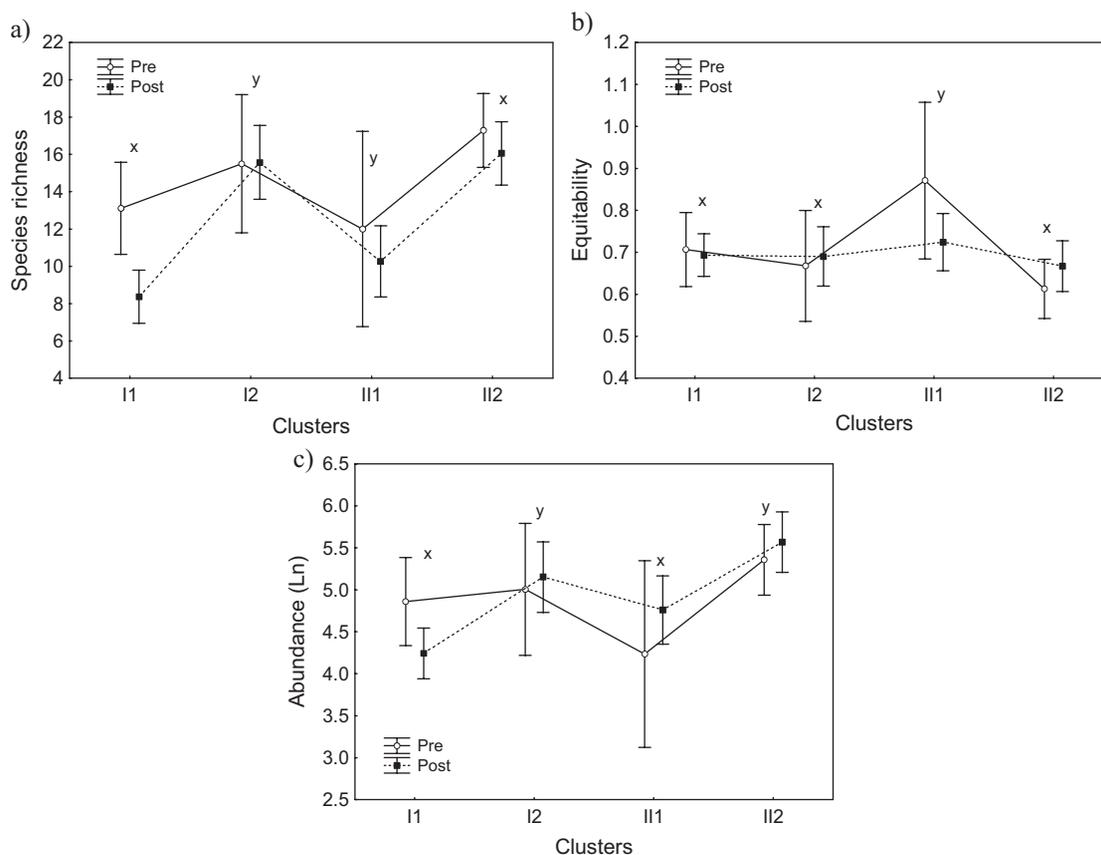


Figure 4. Differences between the four clusters in species richness (a), equitability (b) and log transformed total abundance (c) between pre- and post-impoundment periods. Letters above the bars (x and y) show differences identified by the *post-hoc* test

other similar research (Herbert and Gelwick, 2003; Cumming, 2004; Guenther and Spacie, 2006). Matthews and Marsh-Matthews (2007), nevertheless, stated that the effect of a dam on the populations of some species can be delayed for decades. We did not find also any significant differences between the pre- (03.1996–08.1996) and post-impoundment periods (09.1996–12.1999) for water temperature, pH, conductivity, DO and velocity for samples, but some perceived changes in fish assemblage composition in the four streams flowing into the Corumbá River, upstream of the dam, were not always significant.

Only one streamlet, which enters the Corumbá River below the dam, acquired a new species set after the impoundment was established; this new assemblage consisted of obligatory riverine species (*A. altiparanae*, *Pimelodella* sp.) that were searching for a new migration route since the former route was obstructed by the dam which did not include a fish pass. Dams and stream impoundments have interfered with the required movements of obligatory riverine species (Smith, 1991; Albanese *et al.*, 2004; Penczak, 2006).

Liensch *et al.* (2000) conducted their own research in 1995, measuring species composition and relative abundance and they recorded little changes in fish assemblages and besides in the lower course of the impounded creek only, but most change occurred between spring and summer samples which indicates an interesting seasonal impact that was observed in the number of species caught. In our study, all samples of the pre-impoundment period were collected in the dry season and these from the post-impoundment period were obtained both in the dry and the rainy seasons only, hence seasonality problem was not formulated in the aim of the study. However, the samples from the post-impoundment period collected in dry and rainy seasons (Figure 2) occurred in the same or similar numbers in four investigated streams because the amount of rainfall is small in this part of the country, and it is of no

consequence for discharge increase in the investigated streams. Some differences in this matter we recorded in the Gameleiras Stream. In subcluster I2 two samples were obtained in rainy, and five in dry seasons, however essential variability in fish collected caused that we could not prove any significant difference (Duncan test, $p > 0.05$).

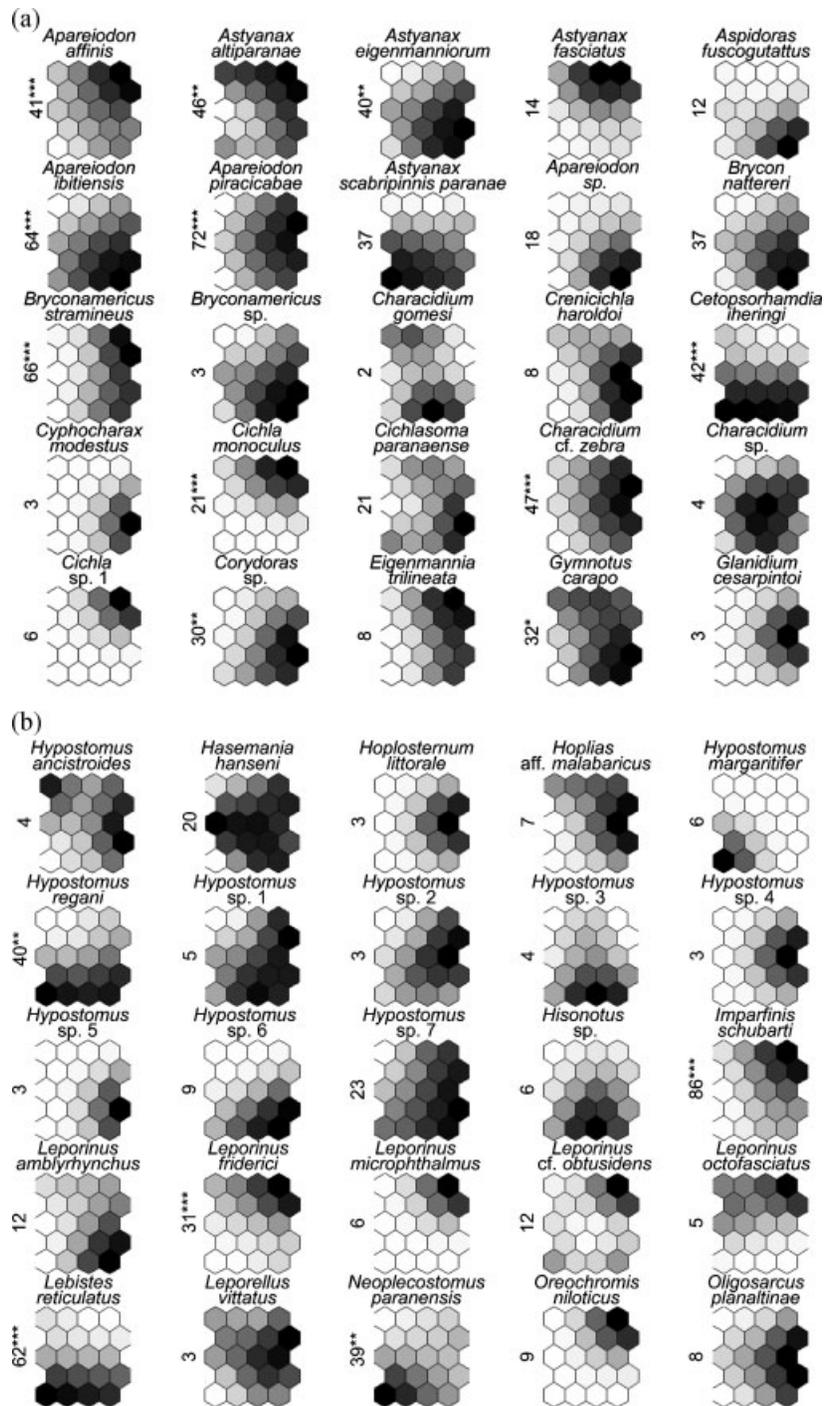


Figure 5. The species planes (a–c). The intensity of the grey colour indicates relative species abundance. On the left margin of each figure, an indicator value (IndVal) is presented and its significance level for given cluster is marked: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

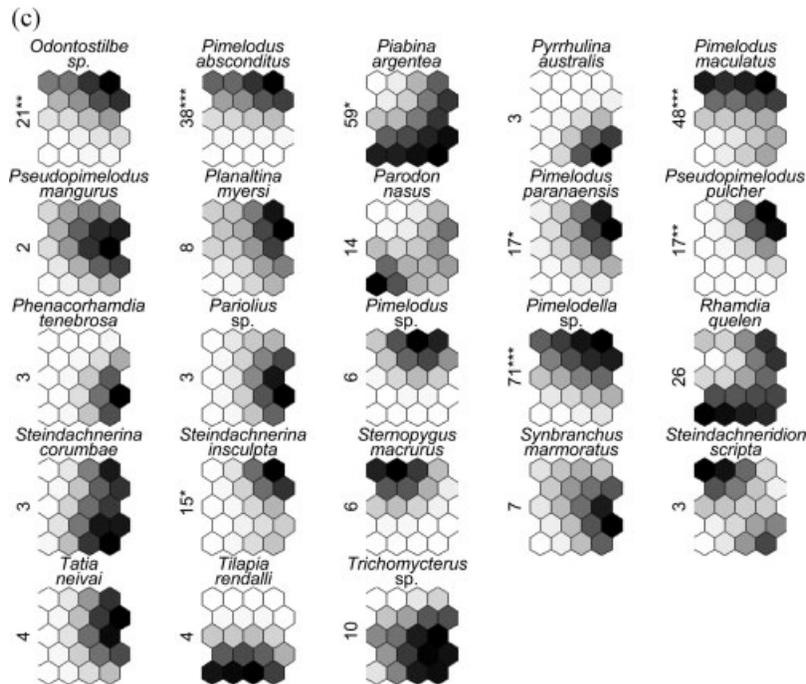


Figure 5. (Continued)

We attribute special importance to the use of SOMs in such studies because the algorithm of this method is useful for analysing nonlinear relationships between variables and those with strongly skewed distributions. The SOM is especially important in the population/inventory study, in which the absence of a species in certain samples is expressed by zeros, which make the distributions of rare species counts strongly skewed and thus difficult to be normalized by any transformation (Quinn and Keough, 2002). The method can allow for drawing conclusions about the validity of each species ordered on the self-organizing map (Park *et al.*, 2005). Only a few environmental variables displayed significant relationships with fish assemblages in the streamlets studied, perhaps because of their cumulative effect, which could mask their separate roles (Northcote *et al.*, 1985). Rose (2000), while analysing this problem in detail, stated that quantitative relationships between environmental quality and fish populations are elusive, controversial and difficult to determine. Mahon and Smith (1989) observed that fish species on the Scotian Shelf are distributed independently of environmental gradients if assemblages consist of highly coevolved, interdependent species, but this finding likely does not apply directly to small streamlet habitats.

The assemblage definition based on the dominance of species (Echelle *et al.*, 1972; Johnson *et al.*, 1977; Ryder and Kerr, 1978; Matthews, 1998) was supported by the data from this study as well as others conducted in the European temperate zone (Kruk, 2007a; Kruk *et al.*, 2007). We could not find any significant impact of impoundment on differentiation and numbers of assemblages except for the clearly separated assemblage distinguished on the basis of samples collected in the Furnas Stream, but only from samples collected in the post-impoundment period. The native populations of this streamlet were enriched by a few obligatory, riverine species searching for a migration route after the impoundment was established, as discussed above.

Since there were few significant differences between the pre- and post-impoundment periods (the Furnas Stream being the only exception), we then looked for differences in species composition among the four clusters distinguished by the SOM. In the Furnas Stream (cluster II) mobile components of obligatory riverine species occasionally appeared (sometimes even in large numbers).

The Kohonen algorithm (SOM) is a very useful ordination method; previously it had successfully ordered data collected in two small tropical streamlets of the Paraná River (Penczak *et al.*, 2004) as well as in temperate European rivers (Penczak and Kruk, 2005; Penczak *et al.*, 2005; Kruk, 2006; Kruk *et al.*, 2007) and a Chinese river

(Park *et al.*, 2003). However, it seems that, in some part of tropical Brazil, every small water body has its own fish assemblage. This finding is corroborated by Penczak *et al.* (2004) studying the streams of Agua do Rancho and Caracu (located 10 km apart but possessing completely different fish assemblages) and by Abes and Agostinho (2001) who studied the Agua Nanci Stream nearby and found similar results. In conclusion, regional factors are important in determining fish assemblages in the streams studied.

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