EFFECTS OF BRIDGE CONSTRUCTION ON THE BENTHIC INVERTEBRATES STRUCTURE IN THE PARANÁ RIVER DELTA

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The Physical Connection Rosario-Victoria Project is a 59.3km long highway that links the cities of Rosario (Santa Fe Province) and Victoria (Entre Ríos Province), in the Lower Paraná River and deltaic area, Argentina (Figure 1). Highway construction through the entire lower section of the Paraná River began in 2001 and was completed in 2003. The project includes 12 bridges, whose characteristics are specified in Table I.

The hydraulic characteristics, fluvial morphology and floodplain slope were altered during bridge construction because of dredging and embankments. As a consequence, aquatic habitats have been modified with the subsequent impact on the biota. On the other hand, the lateral channels built would act as faunistic corridors between the main channel of the Lower Paraná River and the Victoria River.

The aquatic habitat impacts associated with pillars and highway construction have been mainly analyzed on vegetation and fish. The environmental impacts were often limited to the pathway analysis for pollutant deposition on roadway and bridges that threaten the water quality (Niemi *et al.,* 1990). Benthic macroinvertebrates are considered by many authors as excellent indicators of environmental conditions of freshwater habitats (see Hellawell, 1986; Rosenberg and Resh, 1993; Traunspurger and Drew, 1996) and have been proposed for biomonitoring studies. The close association of benthic invertebrates to the sediments suggests the possibility of their use as indicators of disturbances originated by the erosion effects under the bridges. The invertebrates distribution and abundance are not only affected by water quality, but also by current velocity and sediments grain size (Minshall and Minshall, 1978; Minshall *et al*., 1985; Cellot *et al*., 1994; Takeda *et al*., 2001).

The hydraulic alterations originated by the bridges and embankments can affect the structure of benthic communities. However, due to the scarce existing information, it is difficult to infer the degree of impact. The present study was carried out in order to assess the impact of highway and bridge construction. The working hypothesis was that the highway and bridges construction cause disturbing effects on benthic community structure.

Materials and Methods

The benthos of four secondary waterways located on the left bank of the deltaic area of the Lower Paraná River (Carbón Chico, Carbón Grande 1, Carbón Grande 2 and Paranacito-Victoria rivers) were sampled on June of 2001, during the low-water level period, at three different stations each (labeled 1, 2 and 3 in Figure 1). The stations were located upstream, under the bridges and downstream from them, at each of the rivers. Three replicates of benthic samples were taken in the center strip of each station. According to the substrate, a Tamura of 322cm^2, an Ekman of 325cm^2 or mud snuppe grabs of 100cm^2 were employed for collection. Additional sediment samples for granulometric analysis (Wentworth scale) and organic matter determination were taken at the same sites. For organic matter measurement, the samples were dried at 60ºC to constant mass, weighed and carbonized for ≥5h at 550ºC. At each sampling station, physical and chemical parameters indicated in Table II were determined.

In the field, benthic samples were filtered through a 200µm sieve and the material was preserved in 5% formaldehyde. In the laboratory, the invertebrates were hand-picked under a 10x dissection microscope and transferred to 70% ethanol for storage. All the organisms were counted and identified up to species level when possible. If the species could not be identified, they were differentiated into morphospecies. The density in ind·m^{-2}, biomass in wet weight (according to Bonomi, 1962), species richness and species diversity using Shannon and Wiener indices were measured.

KEYWORDS / Benthic Invertebrates / Bridge and Highway Impacts / Lower Paraná River / Physical Disturbance /

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TABLE I
CHARACTERISTICS OF THE CONSTRUCTED BRIDGES

Bridge	Length (m)	Number of pillars
Carbón Chico River (navigable)	752	28
Carbón Grande 1 River (navigable)	632	24
Carbón Grande 2 River	512	20
Paranacito Victoria River (navigable)	1112	40

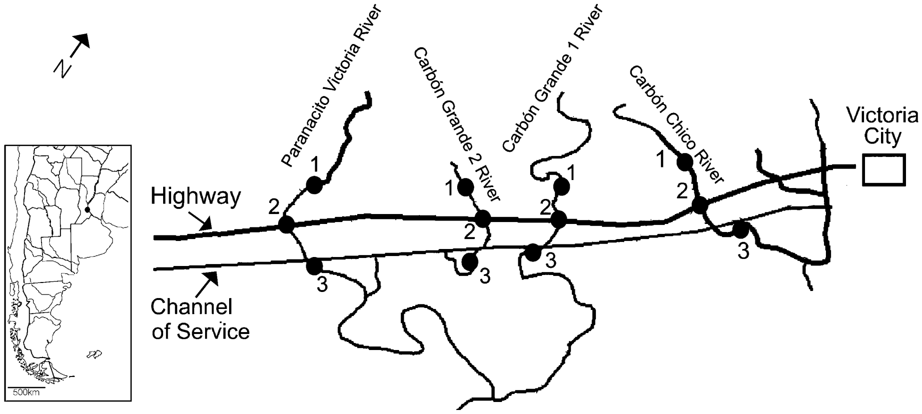

Figure 1. Map of the Lower Paraná River deltaic area showing the sampling stations in the four secondary waterways (Carbón Chico River, Carbón Grande 1 and 2, Paranacito-Victoria rivers) along the built highway. 1, 2, 3: sampling stations.

Community structure was analyzed by multivariate ordination and classification techniques using the Multivariate Statistical Package (MVSP, version 3.1 for windows, Kovach Computing Service) program. Euclidian distance index was applied to abundance data, $\log_{10}(x+1)$ transformed, to obtain the clusters by UPGMA. Principal Components Analysis (PCA) of the physical and chemical standardized variables was used to summarize total data variation and to identify major environmental gradients. Detrended Correspondence Analysis (DCA) was applied to establish species assemblages related to station sampling. Pearson's Coefficient of Correlation was calculated among the significant variables.

Results

The physical and chemical data (Table II) indicate a good water quality, providing suitable habitat conditions for benthic invertebrates.

The bottom sediments showed differences ($p<0.05$) among the sampling stations (Figure 2). The Carbón Chico River was sandy, the Carbón Grande 1 and Paranacito-Victoria rivers were sandy in the sampling sites under the bridge and downstream, while upstream they were silt-clayed. Carbón Grande 2 River showed more similarity amongst the three sampling sites. Very fine and middle sand grain sizes were dominant in sandy bottom. The organic matter in bottom sediments ranged from 0.03 to 2.24% OM, reaching the highest values in Carbón Grande 2, with silt-clayed sediments.

A total of 48 species or morphospecies were collected in the floodplain waterways studied (Table III).

The mean density (Figure 3) varied between 357 ind·m^{-2}, at Carbón Grande 2 under the bridge, and 17930 ind·m^{-2} at Paranacito Victoria under the bridge. High densities were found in all the sampling sites located under a bridge, except in Carbón Grande 2. These high densities are due to species assemblages represented by *Narapa bonettoi*, *Myoretronectes paranaensis* and *Tobrilus* sp., typical species of sandy sediments and mobile riverbed (Figure 4).

The biomass (Figure 3) varied between 0.21 and 5.28g·m^{-2}, with lower values in sandy sediments than in silt-clayed ones, and the highest biomass was obtained in sites with high density of *Limnoperna fortunei*.

Species richness (Figure 5) varied between 5 and 16 and Shannon's index between 2.31 and 3.84, reaching the highest values in silt-clayed sediments.

Organic matter (OM) was negatively related to invertebrate density ($r= -0.58$, $p<0.05$), while biomass was positively related ($r= 0.62$, $p<0.05$) to fine particle size of the substrate (silt and clay), and negatively related ($r= -0.62$, $p<0.05$) to sandy sediments.

TABLE II
PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE WATER AT THE SAMPLING SITES

River	Carbón Chico			Carbón Grande I			Carbón Grande II			Paranacito Victoria		
Sampling site	U	Ub	D	U	Ub	D	U	Ub	D	U	Ub	D
Very fine gravel (%)	0	0	0	0	0	0	4.8	0	0	0	0	0
Very coarse sand (%)	0	0	0	0	0.6	0	16.3	5	0	0	0	0
Middle sand (%)	58.4	42.5	14.8	0.8	8.6	3.5	17.3	15	2.3	5.4	62	23
Very fine sand (%)	37.2	56.8	77.9	6.7	87.7	84.9	21.2	15	33	27.9	35.3	70.3
Silt-clayed (%)	4.4	0.7	7.3	92.5	3.1	11.6	40.4	65	64.7	66.7	2.6	6.6
Organic matter (%)	0.08	0.04	0.41	1.6	0.07	0.38	1.84	2.24	1.34	1.92	0.03	0.45
pH	7.2	7.25	7.3	7.2	7.25	7.3	7.3	7.35	7.4	7.2	7.25	7.3
Temperature (ºC)	15	15	15	16	16	16	17	17.5	18	15	15.5	16
Conductivity (µS·cm^{-1})	110	110	110	100	100	100	100	100	100	90	90	90
Turbidity (NTU)	11	10.5	10	7	7.5	8	9	13	17	9	10	11
Secchi disc (cm)	16.5	16.5	16.5	22	20.3	19	20	20.5	21	16.5	15	13
Depth (m)	4.15	4.65	4	2.85	2.75	3.1	1.26	4.2	0.5	7.3	6.4	5.3
BOD_5 20ºC (mg·l^{-1})	2.1	2.1	2.1	5	5	5	3	3	3	2.8	2.8	2.8
Current velocity (m·s^{-1})	0.19	0.33	0.23	0.22	0.22	0.22	0.1	0.1	0.1	0.4	0.22	0.13
Oxygen (mg·l^{-1})	9.8	9.75	9.7	9.9	10	10.1	10	9.5	9	9.8	9.75	9.7
Benthic Biomass (g·m^{-2})	6.05	5.86	2.06	30.69	6.18	14.65	52.8	24.77	19.73	17.27	12.48	4.32

U: upstream (site 1), Ub: under the bridge (site 2), D: downstream (site 3)

TABLE III
BENTHIC INVERTEBRATE TAXA FOUND AT EACH SAMPLING SITE

River		Carbón Chico			Carbón Grande I			Carbón Grande II			Paranacito-Victoria		
Taxa	Symbol	U	Ub	D	U	Ub	D	U	Ub	D	U	Ub	D
TURBELLARIA													
Turbellaria I	Tu	X	-	-	-	X	-	-	-	-	-	X	-
Turbellaria II	TII	X	-	-	X	-	-	-	-	-	-	X	-
Turbellaria III	TIII	-	-	-	X	-	-	-	-	-	-	-	-
Myoretronectes paranaensis	Mp	X	X	X	-	X	-	-	X	-	-	X	X
NEMATODA													
Tobrilus sp.	To	X	X	X	-	X	-	-	-	-	-	X	X
?*Monhystrella* sp.	Mo	-	-	-	-	-	-	-	-	-	-	-	X
Mermithoidea I	Mt	-	-	-	X	-	X	-	-	X	-	-	-
Tribelos sp.	Tr	-	-	-	-	-	-	X	-	-	-	-	-
OLIGOCHAETA													
Limnodrilus hoffmeisteri	Lh	X	-	-	X	-	X	-	-	X	X	-	-
Limnodrilus udekemianus	Lu	-	-	-	X	-	-	-	-	-	-	-	-
Aulodrilus pigueti	Ap	X	-	-	-	-	-	-	-	X	-	-	-
Paranadrilus descolei	Pd	-	-	-	-	-	X	-	-	-	-	-	-
Bothrioneurum americanum	Ba	X	X	X	-	-	X	-	-	-	-	-	X
Tubificidae I	TuI	X	-	-	-	-	-	-	X	-	-	X	-
Tubificidae immature	Ti	-	-	X	-	-	X	-	-	-	-	-	-
Pristina bilobata	Pb	-	-	-	-	-	-	X	-	-	-	-	-
Pristina biserrata	Ps	-	-	-	-	-	-	X	-	-	-	-	-
Pristina osborni	Po	-	-	-	-	-	X	-	-	X	-	-	-
Narapa bonettoi	Nb	X	X	X	-	X	-	-	-	-	-	X	X
Brinkhurstia americana	Bka	-	-	-	-	-	-	-	-	-	X	-	X
?*Brinkhurstia* sp. 1	Bk	-	-	-	X	-	-	-	-	-	-	-	-
Eiseniella tetraedra	Et	-	-	-	X	-	-	-	-	-	-	-	-
CHIRONOMIDAE													
Coelotanypodini sp. 1	Co	-	-	-	X	-	-	-	-	-	-	-	-
Coelotanypus sp.	Cp	-	-	-	-	-	-	-	-	X	-	-	-
?*Larsia* sp.	La	-	-	-	-	-	-	-	-	X	-	-	-
Chironomini sp. 1	Ch	-	-	-	-	-	-	X	-	-	-	-	-
Fissimentum sp.	Fs	-	-	-	-	-	-	-	-	X	-	-	-
Fissimentum dessicatum	Fd	-	-	-	-	-	X	-	-	-	-	-	-
Polypedilum sp.	Pl	X	-	X	X	-	X	-	X	X	-	-	X
Cryptochironomus sp.	Cr	-	-	-	X	-	-	-	-	-	-	-	-
Parachironomus sp.	Pa	-	-	-	-	X	-	-	-	-	-	X	X
Axarus sp.	Ax	-	-	-	X	X	-	X	X	-	-	-	-
Tanytarsini I	Ta	-	-	-	-	-	-	-	-	-	X	-	-
Tanytarsus sp.	Ty	-	-	-	X	-	X	-	-	X	-	-	-
Rheotanytarsus sp.	Rh	-	-	-	-	-	X	-	-	-	-	-	-
Lopescladius sp.	Lo	X	X	-	-	-	-	-	-	-	-	X	-
Chironomidae n.i.	Cn	X	-	X	-	X	-	-	-	-	X	-	X
CERATOPOGONIDAE	Ce	-	-	-	-	-	-	-	-	-	-	-	X
EPHEMEROPTERA													
Baetis sp.	Bae	-	-	-	X	-	-	-	-	-	-	-	-
Caenis sp.	Ca	-	-	-	X	-	-	-	-	-	-	-	-
TRICHOPTERA													
Trichoptera I	T	-	-	-	-	X	-	-	-	-	X	X	-
Smicridea sp.	Sm	-	-	-	-	-	-	-	-	-	-	X	-
ODONATA													
Zygoptera	Zy	-	-	-	X	-	-	-	-	-	-	-	-
OSTRACODA	Os	-	X	-	-	-	X	-	-	-	-	-	-
COPEPODA													
Potamocaris sp.	Pot	-	-	-	-	X	-	-	-	-	-	X	-
ACARI													
Hydracarina I	Hy	X	X	-	-	-	X	X	-	-	X	X	-
MOLLUSCA BIVALVIA													
Limnoperna fortunei	Lf	X	-	-	X	-	-	X	X	-	X	X	-
Corbicula fluminea	Cf	X	X	X	-	-	-	-	-	-	-	X	-

U: upstream (site 1), Ub: under the bridge (site 2), D: downstream (site 3), x: present, -: absent.
Taxa with symbols were used in DCA and cluster analysis.

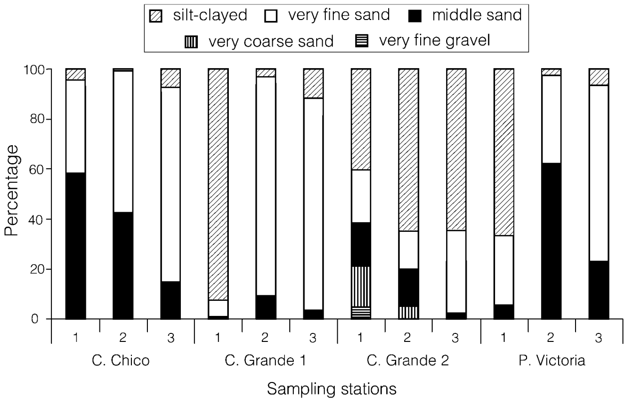

Figure 2. Granulometry of major grain size classes (%) from each sampling station. 1: upstream, 2: under the bridges, 3: downstream.

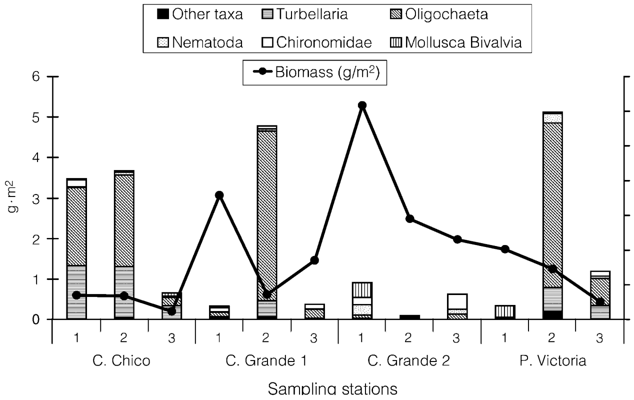

Figure 3. Density ($ind\cdot m^{-2}$), biomass ($g\cdot m^{-2}$ wet weight) and taxonomic groups more representative in the sampling sites.

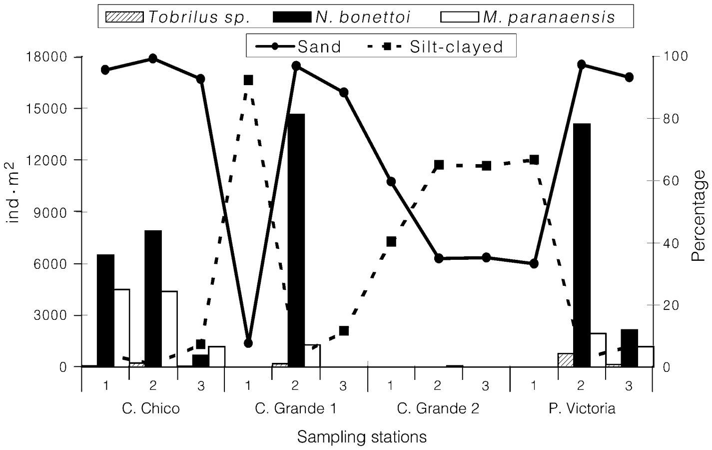

Figure 4. Density ($ind\cdot m^{-2}$) of the dominant species assemblages and their relationships to sediment particle size.

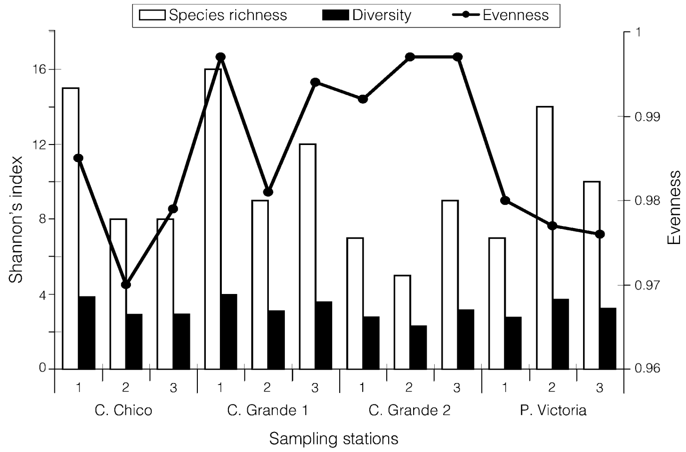

Figure 5. Species richness, diversity (Shannon-Wiener index) and evenness at the sampling sites.

The analysis of the abundance and distribution of the species by UPGMA clustering and application of Euclidian Distance index reveals the existence of two groups (Figure 6). Group A is formed by sites characterized by chironomids and bivalves with higher biomass and silt-clayed sediments with high OM content. Group B is represented mainly by sites with sandy sediments, low OM, high benthic density and dominance of oligochaetes and turbellarians.

The ordination of the physical and chemical variables by PCA explained 84.72% of the variance in the data by the first four component axes. Axis 1 accounted for 37.49% (eigenvalue= 5.99) of the variance and the bottom organic matter (r= 0.32), silt-clay (r= 0.29), temperature (r= 0.36), transparency (r= 0.30) and benthic biomass (r= 0.39) had significantly positive weight on the axis. The variance explained by axis 2 was 19.74% (eigenvalue= 3.15) and pH (r= 0.36) and turbidity (r= 0.50) had positive weight, while O_2 (r= -0.48) and DBO_5 (r= -0.30) negative weight on the axis. Thus, the Carbón Grande 2 and Carbón Grande 1 (only under the bridge) were separated because of the silt-clayed sediments and high OM, and characterized by the highest biomass (Figure 7).

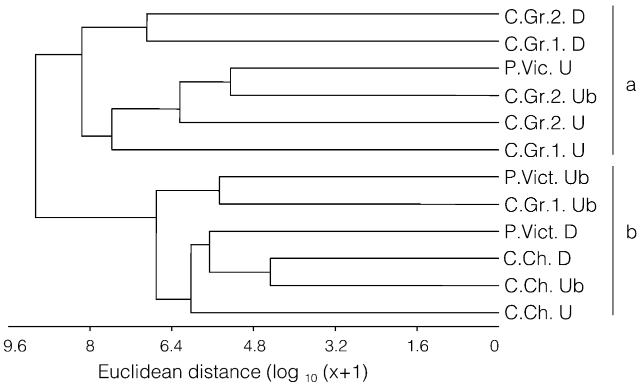

Figure 6. Cluster of dissimilarity (Euclidian distance index) among benthic invertebrate samples obtained by the Unweighted Pair Group Method (UPGMA). Invertebrate abundance data were transformed using $\log_{10}$ (x+1). Abbreviations as in Table II.

Detrended Correspondence Analysis (DCA) using the transformed $\log_{10}$ (x+1) abundance of all taxa indicate that each individual waterway type is represented by a characteristic species assemblage (Figure 8). Group 1 represented by Chironomini sp. 1, *Pristina biserrata, Pristina bilobata* and *Tribelos* sp. explained 19.4% of the variation on axis 2 and characterized Carbón Grande 2 upstream of the bridge (Figure 8b). Group 2 was formed by sites with sandy sediments and was represented by *Narapa bonettoi*, *Myoretronectes paranaensis*, Turbellaria sp. I, *Tobrilus* sp., ?*Monhystrella* sp., *Brinkhurstia americana*, ?*Brinkhurstia* sp., *Smicridea* sp., Trichoptera I, *Parachironomus* sp., *Lopescladius* sp., Ceratopogonidae, *Potamocaris* sp., Hydracarina, *Corbicula fluminea*, *Limnoperna fortunei*, and *Axarus* sp. Group 3, included Turbellaria sp. II, Turbellaria sp. III, *Limnodrilus udekemianus*, *Limnodrilus hoffmeisteri*, *Aulodrilus pigueti*, *Paranadrilus descolei*, *Bothrioneurum americanum*, Tubificidae immature, *Pristina osborni*, *Eiseniella tetraedra*, *Cryptochironomus* sp. Coelotanypodini sp. I, *Coelotanypus* sp., *Fissimentum* sp., *Polypedilum* sp., *Tanytarsus* sp., *Rheotanytarsus* sp., *Larsia sp.*, *Caenis* sp. *Baetis* sp., Zygoptera, Ostracoda and Mermithoidea had positive weight on axis 1 (21% variation) and represented Carbón Grande 1 upstream and Carbón Grande 1 and 2 downstream of the bridge (Figure 8b).

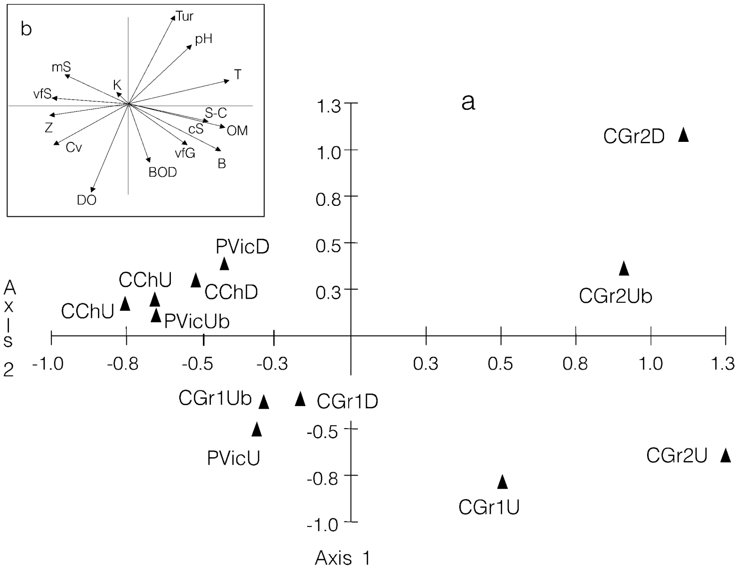

Figure 7. Ordination of the sampling sites with physical and chemical parameters in the plane defined by Principal Components I and II. A: Ordination of the sites (abbreviations as in Table II). B: Ordination of the variables. vfG: very fine gravel, cS: coarse sand, mS: middle sand, vfS: very fine sand, S-C: silt-clayed, OM: organic matter, T: water temperature, K: conductivity, Tur: turbidity, Z: depth, B: biomass, Cv: current velocity, DO: dissolved O_2, BOD: Biological O_2 demand.

Discussion

The main factor determining the structure of benthic assemblages in the four secondary waterways of the Paraná River Delta was bottom grain size. Sampling sites with sandy sediments, under the bridges, showed species assemblages similar to the central sector of the main channel in the Upper and Middle Paraná River and Upper and Lower Paraguay River (Varela *et al.*, 1983; Marchese and Ezcurra de Drago, 1992; Montanholi-Martins and Takeda, 1999; Takeda, 1999; Takeda *et al.*, 2000; Marchese *et al.*, 2002; Ezcurra de Drago *et al.*, 2004). Species were represented by *M. paranaensis*, *Tobrilus* sp., *Parachironomus* sp., *Lopescladius* sp., *Potamocaris* sp. and *B. americana*, while *N. bonettoi* was the dominant species. *C. fluminea*, turbellarians and nematodes were found in low densities.

Different benthic assemblages were recorded in silt-clayed bottom sediments, mainly upstream from the bridges. The species present were *L. hoffmeisteri*, *L. udekemianus*, *P. descolei*, *A. pigueti*, *B. americanum*, *E. tetraedra*, *Cryptochironomus* sp., *Coelotanypus* sp., *Larsia* sp., *Fissimentum* spp., *Rheotanytarsus* sp., *Tanytarsus* sp., *Caenis* sp. *Baetis* sp. and *Limnoperna fortunei*. Similar benthic assemblages were found in the Lower Paraguay River by Ezcurra de Drago *et al*. (2004) and in the banks of the main channel and floodplain channels of the Middle Paraná River by Marchese and Ezcurra de Drago (1992) and Marchese *et al*. (2002).

The high diversity index (>2.30) found in the studied secondary channels suggests good conditions for benthic invertebrates colonization and development. In the Carbón Grande River a high index (3.98) was attained in comparison with the value obtained (3.0) in low hierarchy secondary channels of the Middle Paraná River (Marchese and Ezcurra de Drago, 1983; Bertoldi de Pomar *et al*., 1986). The Shannon's diversity index is in general <1.0 in the central sector of the main channel and high hierarchy secondary channels of the Paraná River because of their hydrosedimentological dynamics that are very rigorous for species colonization (Marchese and Ezcurra de Drago, 1992, 1999; Montanholi and Takeda, 1999; Takeda, 1999; Marchese *et al.*, 2002). Although sampling sites with sandy sediments (mainly under and downstream from the bridges) showed high species richness and diversity, the highest values were attained in sites with silt-clayed

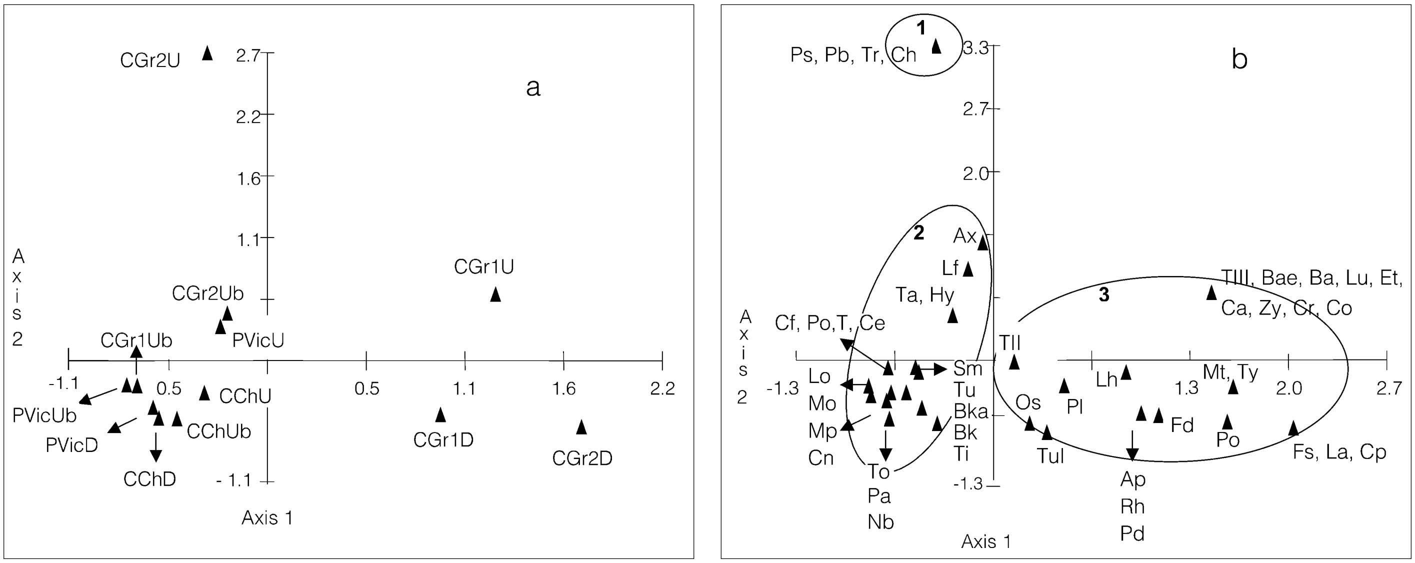

Figure 8. Ordination of the benthic invertebrate samples from the secondary channels of the Lower Paraná River in the plane defined by Detrended Analysis Correspondence (DCA). a: Ordination of the sites. b: Ordination of the benthic species. Abbreviations as in Table III.

sediments (upstream), in coincidence with the results reported by Di Persia (1980, 1986), Di Persia *et al.* (1982), Marchese and Ezcurra de Drago (1983, 1992, 1999), Varela *et al.* (1983), Takeda (1999), Montanholi and Takeda (1999), and Marchese *et al*. (2002) in the Upper and Middle Paraná River.

Species density was higher under the bridges than upstream and downstream, in contrast to the species richness pattern. The highest density was explained by the presence of *M. paranaensis* and *N. bonettoi* that are typical *r*-strategists with a high reproduction rate and its small body size allows fast colonization of the mobile sand bed if they meet their ecological requirements (Marchese *et al*., 2002; Ezcurra de Drago *et al*., 2004). The increased density observed in disturbed sites, in the present study, is in sharp contrast to the results of most stream experiments (Resh *et al*., 1988; Doeg *et al*., 1989; Death, 1996; McCabe and Gotelli, 2000). However, as in other studies (Sparks *et al*., 1990; Englund, 1991; Wootton *et al*., 1996; Bradt *et al*., 1999) the abundance of some species like *N. bonettoi* can increase in unstable bottom sediments. Death (1996) stated that if physical conditions are highly unstable, a particular suite of species well adapted to survive in such conditions will be established. This pattern is predicted by the dynamic-equilibrium model (Huston, 1979, 1994) that integrates the intermediate disturbance (Connell, 1978) and intermediate productivity (Grime, 1973) hypotheses. At high levels of disturbance, biodiversity is maximized in habitats with high rate of population growth, whereas at low levels of disturbance, maximum diversity is attained in habitats with sparse resources (Ward *et al*., 1999). The species richness found in these secondary channels is greater than that found in similar channels of the Middle Paraná River. This could suggest that the benthic structure is in an intermediate stage of self-organization after the impacts of highway and bridge construction on the Lower Paraná River.

Gore (1982) reported that stable density and diversity of benthic invertebrates was achieved in 250-315 days depending on the distance from the colonization source in a new channel of the Tongue River, Wyoming, USA. Cline *et al.* (1982) also reported that macroinvertebrate abundance had apparently recovered in one year following bridge construction and channel realignment. The primary impact was the change of the physical structure of the system by reworking channel morphology, substrates and flow regime. Yount and Niemi (1990) judged that the streams normally appear to be able to recover in less than two years after being crossed by roads and pipelines.

The species assemblage found under the bridges (except at Carbón Grande 2) suggests a similar degree of impact associated with the interference of the bridges and embankments in all the studied rivers. In spite that the results only refer to data obtained in low water levels, the degree of disturbances caused by the bridges can be thought to be different between different water levels. The alterations are the consequence of erosion under the bridges due to the turbulent flow, mainly at the pillars, that affects the surrounding bottom. Although the construction of the bridges have affected the benthic structure due to the erosion process of bottom sediments, the typical species assemblage related to sandy unstable sediments colonized the habitat successfully in less than one year.

The Carbón Grande 2 River showed different bottom sediments as compared to the other rivers, with predominance of fine grain size and high organic matter, due to the low flow and high deposition of fine particles. Larger changes are expected in the bottom sediments in this river than in the others during high water levels, when a flow increase may scour away a large part of the organic material deposited during the previous periods.

The main effect on the benthic structure of Carbón Grande 1, Carbón Chico and Paranacito-Victoria rivers was biomass reduction, diminishing the resources supply for higher trophic levels. In spite of the high abundances attained in mobile sand bed, the dominant species *N. bonettoi* contributes little to benthic biomass, due to their low individual biomass of 3µg dry weight (Marchese, 1994).

The lateral channel construction may act as a corridor connecting different habitats. Ward *et al*. (1999) and Amoros and Bornette (2002) indicated that excessive connectivity reduces habitat heterogeneity, with a concomitant decline of biodiversity.

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