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Effects of the proximity from an industrial plant on fish assemblages in the rio Paraíba do Sul, southeastern Brazil

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This work aims to analyze changes in the fish assemblages along a longitudinal reaches of the rio Paraíba do Sul, one of the most used Brazilian aquatic systems, to assess the river "health" and to identify eventual recovery trends. Standardized monthly samplings were carried out at six sites, from October 1997 to September 1999, using casting, sieves, seine and gill nets. Three zones were searched: upstream (Z I), downstream (Z III) and nearby the source of pollution (Z II). Three univariate distribution methods were used: ABC (abundance-biomass curves), *K*-dominance curves, and geometric class's distribution. Additionally, cluster analysis was applied to detect eventual patterns. The ABC and *K*-dominance curves showed Z II with evident indication of stress in both yearly cycles, followed by Z III and Z I. Few rare species and absence of common species in Z I, presence of common and abundant species, mainly opportunist, in Z II, and the highest number of rare species in Z III, was the overall pattern showed by geometric class. Number of fish was higher at Z II, while number of species did no change significantly among zones. Cluster analysis separate Z II samples from Z I and III. All the three univariate methods showed evident signals of stress at Z II, which showed indication of organic enrichment as expressed in the high abundance of common species, although physicochemical variables (ammonia, nitrogen, total phosphorous and DBO) have increased slightly from Z1 to Z III. A lesser stress condition was shown at the downstream zone (Z III), indicating the river recovery capacity. The use of biological indicators in this study proved to be a better tool to assess non-point sources pollution when compared to traditional physicochemical measurements.

Objetiva-se no presente trabalho, analisar mudanças nas assembléias de peixes ao longo de um trecho longitudinal do rio Paraíba do Sul, um dos sistemas aquáticos mais usados do Brasil, para avaliar a "saúde" do rio e identificar eventuais tendências de recuperação. Amostragens mensais foram realizadas em seis locais, de outubro de 1997 a setembro de 1999, utilizando redes de espera, tarrafas, peneiras e picaré. Foram atribuídas três zonas para avaliar as assembléias de peixes: Z II (complexo industrial da cidade de Volta Redonda - fonte da poluição), Z I (montante do complexo industrial) e Z III (jusante do complexo industrial). Três métodos univariados foram usados: ABC (curvas de abundância-biomassa), curvas de *K*-dominância, e distribuição por classes geométricas. Adicionalmente, foram aplicadas análises de agrupamento para verificar padrões de distribuição das espécies. A curva ABC e a curva de *K*-dominância indicaram maior estresse para a Z II, em ambos os ciclos anuais seguido pelas Z III e I. A classe geométrica apresentou um padrão de poucas espécies raras e ausência de espécies comuns para a Z I, presença de espécies comuns e abundância de espécies oportunistas para a Z II, e maior número de espécies raras na Z III. O número de indivíduos foi maior na Zona II, enquanto o número de espécies não teve variação significativa entre as zonas. A análise de agrupamento separou as amostras da Z II das Z I e III. Todos os três métodos utilizados no presente trabalho apresentaram maior número de espécies comuns para a Z II, indicando maior estresse para Z II, zona que recebe maior carga de efluentes de origem orgânica e industrial. Uma melhor condição foi apresentada para o trecho mais a jusante (Z III), indicando a capacidade de recuperação do rio. O uso de indicadores biológicos neste estudo provou ser uma melhor ferramenta para avaliar poluição difusa quando comparada com métodos físico-químicos tradicionais.

Key words: Fish community, Neotropical fauna, Pollution, Water quality, ABC curves, Cluster analysis.

Introduction

Large rivers in southeastern Brazil are under increasing degradation process from misuse, being strongly influenced by human activity yielding detrimental ecological effects. The rio Paraíba do Sul is one of the most used lotic systems in the country because its proximity to the major industrial and urban Brazilian centers, and its water is widely used for both

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domestic and industrial purposes. The most used reaches of the Paraíba do Sul river is located in its middle-lower segment, due to a major industrial plant (Pfeiffer *et al*., 1986), which carries into the river a large amount of non-point source pollution from both organic and inorganic pollutants; some 20 Km downstream this point there is the intake pump water to hydropower uses and, afterward, to the Rio de Janeiro city water supplier. Concerns of populations and environmental managers have being raised as result of the decreased water quality and poor habitat condition, which has decreased water flow in the last years (Hydroscience, 1977).

The use of biota to assess the anthropogenic impacts on the integrity of rivers is attaining greater importance (Miller *et al*., 1988; Rosenberg & Rech, 1993; Scott & Hall, 1997; Gafny *et al.,* 2000; Hughes, 2000; Karr *et al*., 2000). Assessing fish community structure is one efficient way to evaluate biotic integrity in rivers in different parts of the world (Karr, 1981; Karr, 1986; Edds, 1993; Paller *et al*., 1996; Ganasan & Hughes, 1998; Waite & Carpenter, 2000; Meador & Goldstein, 2003) since complex biotic and abiotic processes can reflect a variety of activities developed by the man, which can change fish structure and composition. Many studies linking fish community structure and environmental degradation as result of anthropogenic influences, such as agriculture and urbanization are available (Klein, 1979; Goldstein, 1981; Karr *et al*., 1985; Steedman, 1988; Roth *et al*., 1996; Lammers & Allan, 1999; Schlieger, 2000; Waite & Carpenter, 2000; Meador & Goldstein, 2003). Fish community composition changes are important tool to characterize environmental quality. For instance, the number of individuals can be used to reflect the biomass and energy in the system, while the species number to reflect habitat diversity and fish behavior.

Some researches have been carried out attempting to detect fish changes as result of environmental deterioration in the rio Paraíba do Sul. Araújo (1983) and Pfeiffer *et al*. (1986) found heavy metal traces in several fish species in the area near to the Volta Redonda municipality in the middle-lower segment; Araújo (1996) and Araújo *et al*. (2001) described the fish community composition and reported that there is a decreased abundance although richness were not very depressed yet; Araújo (1998) and Araújo *et al*. (2003) applying the Index of Biotic Integrity – IBI in a narrow reaches of the Paraíba do Sul river (c.a. 80 km), and found that the lowest quality in fish assemblages occurred near to cities that receives large amount of organic and industrial pollutants.

Three univariate methods (abundance-biomass curves, K-dominance curves and number of species per geometric classes) were developed to evaluate the ecological "health" (*sensu* Norris & Thoms, 1999) with emphasis to benthic macrofauna (Gray *et al*., 1988; Gray, 1989; Warwick & Clarke, 1991; Pagola-Carte, 2004); these methods seek to assess the degree of stress caused by pollutants. Adaptations of these methods for fish community have been performed by Andrews & Rickard (1980), García *et al*. (1998), Araújo *et al*. (2000) and Bervoets *et al*. (2005), among others.

The aim of this paper is to assess the ecological "health" in the most polluted reaches of the rio Paraíba do Sul and to identify eventual recovery trends. For that purpose we used fish assemblage structure as an indicator of environmental condition. We compare the structure of the fish assemblages in three sections (zones) of the river where we expected to evaluate the extent of the pollution impact. Ecosystem perturbation such as enrichment with organic matter is expected to reduce species richness and enhance abundance of opportunist's species. The underlying hypothesis is that environmental condition influence fish assemblages.

Materials and Methods

Study area and sampling. The rio Paraíba do Sul is 1080 km long, with its drainage basin covering an area of approximately 57,000 km^2, draining into the Atlantic Ocean at Southeast Brazil. The study area (Fig. 1) is an 80 km long reaches (Latitude: 22º24'-22º25'S; Longitude: 44º16'W-43º43'W), in the Middle-Lower reaches. The middle reach of the rio Paraíba do Sul flows 400 to 600 m above sea level and drains ancient, predominantly sedimentary, soil covered by tropical forest. This ecoregion is characterized by both un- and semi-consolidated sand, gravel, silt and clay, with basalt outcroppings, low mountains, low nutrient soils, fragmented semi-deciduous seasonal rain forest, and poor croplands. The climate is mesothermic with high relative humidity, hot and wet summers and dry winters. Annual rainfall ranges from 100–300 cm, with the average generally over 200 cm (DNAEE, 1983). Most precipitation occurs between November and January, and heavy rains occasionally cause large floods of the rio Paraíba do Sul. June through August is the driest period of the year (Carvalho & Torres, 2002). Temperature ranges from the minimum of 20-22°C in June through August and maximum of 32-34°C in December through February, with an annual average of 26-28°.

River flow in this reach averages 318 m^{3}s^{-1}, ranging from 109 m^{3}s^{-1} in the dry period to 950 m^{3}s^{-1} in the wet period (Hydroscience, 1977). The rio Paraíba do Sul waters are widely used for human consumption, industrial use, irrigation, hydroelectric power plants and recreation. The total water volume removed for domestic uses is estimated at 160 m^3 s^{-1}; other uses like industry and agriculture lack official volume estimates (Carvalho & Torres, 2002). Human actions at the landscape scale disrupt the geomorphic processes that maintain the riverscape and its associated biota and frequently result in habitat that is both degraded and less heterogeneous. Aloctone material carrying into the river is favored, mainly in rainy period, due the rare vegetal cover.

The study reaches was chosen because it drains one of the most important industrial regions in Brazil, and includes the most polluted reaches of the river (Pfeiffer *et al*., 1986), with several textile, chemical and food industries, and a large industrial plant (steel) at Volta Redonda municipality. Agriculture and sand mining are also common in the area. We divided the longitudinal river reaches in three sections, according to the proximity of the major industrial plant in Volta

Redonda municipality: Zone I (Z I) – a relatively less perturbed section in the upper reaches near to Porto Real (site 1) and Barra Mansa (site 2) municipalities; Zone II (Z II) - near to the highest impacted area, in the vicinity of Volta Redonda (sites 3 and 4) industrial plant; and Zone III (Z III) - the lowest section, about 20 km below Volta Redonda, located in Barra do Piraí (sites 5 and 6) municipality.

Monthly sampling was carried out at the 6 sites in the three river zones (Fig. 1), from October 1997 to September 1999. River morphometry (width ca. 200 m) was similar at all sites. Several standardized fishing methods were used to collect the maximum number of species and individuals in different sizes and microhabitats. Fishing equipment included gill nets, cast nets, seines and sieves. Sampling unit was the sum of the total number of fish catched by 15 casting nets, 20 sieves and 2 seines tries, with fishing being conducted at daytime. Seine net were 10 m long, 2 m height, and 5 mm mesh size; sieves were 80 cm diameter and 3 mm mesh size; casting net were 4 m diameter and 2 cm mesh size.

All fishes were identified, counted and weighted (in g), being fixed in 10% formalin for two days, and then preserved in 70% alcohol. Voucher specimens were deposited in the fish collection of the Laboratory of Fish Ecology, Universidade Federal Rural do Rio de Janeiro.

Physicochemical variables. Temperature (degrees Celsius), transparency (cm), turbidity (UNT), pH, dissolved oxygen (mg/l) and conductivity (µS/cm)) were taken at each sampling occasion using a multiprobe water quality checker HORIBA U-10. Additionally a water quality database comprising information on ammonia, nitrogen, total phosphorous, BOD and benzo-alpha-phyrene from each sampling site during 1997-99 was supplied by the Laboratory of Hydrology from COPPE-UFRJ.

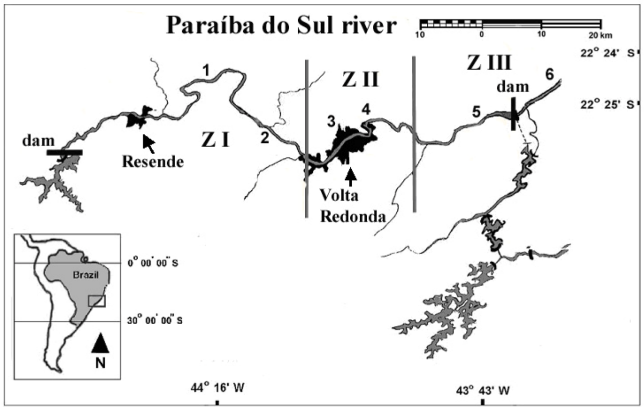

Fig. 1. Study area, rio Paraíba do Sul reaches. Indication of the six sampling sites and three zones - Z I (sites 1 and 2); Z II (sites: 3 and 4); and Z III (sites 5 and 6). Buffers marked in black indicate main sources of urban and industrial pollution. Dams indicated by black line marks.

Fish community assessment. Three distributional univariate methods were used: ABC curves (abundance-biomass curves), K-dominance curves and distribution per geometric classes. The ABC curves followed Warwick (1986) while the k-dominance curves followed Lambshead *et al*. (1983). We use these two curves because according to Warwick (1986) the condition of an animal community can be illustrated with the use of combined *k*-dominance plots of the abundance and biomass, where species are ranked in order of importance on the x-axis (logarithmic scale) with percentage dominance on the y-scale (cumulative scale). To compare data sets from the three zones the ABC-index was calculated according to Meire & Dereu (1990):

$$\text{ABC index} = \frac{\sum_{i=1}^{N} \boldsymbol{B_i - A_i}}{\boldsymbol{N}}$$

where *Bi* is the percentage dominance of species *i* (ranked from the highest to the lowest biomass) and *Ai* is the percentage dominance of species *i* (ranked from the most to the least abundant species), and *N* is the total number of species. The index is negative for situations characterized by a strong stress, close to zero for moderate stress, and positive for lack of stress (Meire & Dereu, 1990; Coeck *et al*., 1993). Species abundance patterns, presented as the number of species in x 2 geometric classes (1, 2-3, 4-7, 8-15, etc.) were plotted following Gray & Pearson (1982).

An additional cluster analysis in mode Q was applied to sampling sites in order to seek patterns, where Bray-Curtis distance and Ward method of clustering were applied using the FITOPAC software computer program developed by Shepherd (2001).

Results

Environmental variables. General water quality characteristics of the different sampling zones are summarized in Table 1. These results clearly show that all sites had good water quality characteristics, when compared with national and international water quality standards (Brazilin Environmental Council - CONAMA resolution nº 20 of 06/18/1986; Environmental Protection Agency, 1999). Ammonia, nitrogen, total phosphorous and DBO showed a trend for increased values from Z I to Z III. The pH was higher at Z II, while transparency decreased from Z I to Z III, showing an opposite pattern compared with turbidity. Conductivity was higher in Z1 and lower in Z II.

Species composition. A total of 7286 individuals comprised in 15 families and 51 species were catched (Table 2). The Ostariophysi superorder amounted to 76%, while Acanthopterygii, 24% of the total number of species, being the former comprised mainly by Characiformes (41.18%) and Siluriformes (29.41%). Characidae family showed the most richness amounting to 29.41% of total number of species, followed by Cichlidae (13.73%).

Introduced species comprised 15.7% of the total number of species, being 5 exotic in Cichlidae (genera *Oreochromis* and *Tilapia*) and Poeciliidae (*Poecilia reticulata*) families, and the other 3 allochthonous (*Cichla monoculus*, *Hyphessobrycon eques*, and *Metynnis maculatus*) (Table 2).

Total number of fish was the highest in Z II and the lowest at Z I in both periods (1997/98 and 1998/99) (Table 3). Number of species did not vary much among the zones but tended to be the highest at Z III and the lowest at Z I. The most abundant species were *Poecilia reticulata* and *Geophagus brasiliensis* amounted to 39.7% and 27.4% of the total number fish, respectively. These two opportunist species plus *Tilapia* sp. predominated in Z II. Nineteen species were distributed in the three zones, while twenty-nine species contributed less than 1% to the total number of fish, with 10 being recorded only once during the two yearly period (Table 3).

Effects of environmental stress on the three zones. The ABC curves showed that Z II was the most stressed section in both yearly periods, with the abundance curve lying near to the

Table 1. Means ± standard error for water quality characteristics in the three sampled zones of the rio Paraíba do Sul, 1997/99. Dates indicated by a slash correspond to the two yearly periods: 1997-98/1998-99. n = number of samples. ND = not available. *Data supplied by the Laboratory of Hydrology from COPPE-UFRJ.

Physicochemical variables	Z I	Z II	Z III
Transparency (cm)	44±0.03/39±0.03 n=24	44±0.02/44±0.38 n=24	41±0.03/40±0.03 n=24
Turbidity (UNT)	48±5.10/58±10.46 n=21	59±15.10/38±4.44 n=22	69±13.13/35±5.46 n=22
Temperature (°C)	22.94±0.70 / 22.23±0.52 n=24	25.25±1.33/23.04±0.51 n=24	23.82±0.75/23.38±0.55 N=24
pH	6.89±0.24 / 6.53±0.21 n=24	7.67±0.43/7.20±0.20 n=24	7.59±0.16/7.15±0.16 n=24
Conductivity (µS/cm)	85±0.04/84±0.01 n=24	57±0.01/69±0.01 n=24	66±0.02/68±0.01 n=24
Dissolved oxygen (mg/L)	6.69±0.40 n=9	6.90±0.17 n=9	7.06±0.11 n=9
Ammonia * (mg/l)	0.06±0.01 n=5	0.06±0.01 n=11	0.14±0.02 n=5
Nitrogen * (mg/l)	0.47±0.09 n=5	0.54±0.01 n=11	0.63±0.21 n=4
Total Phosphorus * (mg/l)	0.08±0.02 n=5	0.11±0.02 n=10	0.12±0.02 n=5
DBO * (mg/l)	2.18±0.13 n=9	2.13±0.05 n=15	2.40±0.23 n=9
Benzo-alpha-phyrene * (µg/l)	ND	0.12±0.08 n=2	0.04±0.01 n=9

Table 2. Fish species collected in the rio Paraíba do Sul, from 1997/99. Species are listed following Reis *et. al.* (2003).

- Superorder Ostariophysi
  - Order Characiformes
    - Family Characidae
      - *Astyanax bimaculatus* (Linnaeus, 1758)
      - *Astyanax parahybae* (Eigenmann, 1908)
      - *Astyanax giton* Eigenmann, 1908
      - *Astyanax scabripinnis* (Jenyns,1842)
      - *Astyanax* sp. 1 Baird e Girard, 1854
      - *Astyanax* sp. 2 Baird e Girard, 1854
      - *Astyanax taeniatus* (Jenyns,1842)
      - *Deuterodon* sp. 1 Eigenmann, 1907
      - *Deuterodon* sp. 2 Eigenmann, 1907
      - *Hyphessobrycon bifasciatus* Ellis, 1911
      - *Hyphessobrycon reticulatus* Ellis, 1911
      - *Hyphessobrycon eques* (Steindachner 1882)
      - *Metynnis maculatus* (Kner, 1858)
      - *Oligosarcus hepsetus* (Cuvier, 1829)
      - *Probolodus heterostomus* Eigenmann, 1911
    - Family Erythrinidae
      - *Hoplias malabaricus* (Bloch, 1794)
      - *Hoplerythrinus unitaeniatus* (Agassiz, 1829)
    - Family Curimatidae
      - *Cyphocharax gilbert* (Quoy e Gaimard, 1824)
    - Family Anostominae
      - *Leporinus copelandii* Steindachner, 1875
      - *Leporinus mormyrops* Steindachner, 1875
      - *Leporinus* sp. Spix & Agassiz, 1829
  - Order Siluriformes
    - Family Auchenipteridae
      - *Glanidium albescens* Lütken, 1874
      - *Trachelyopterus striatulus* (Steindachner, 1877)
    - Family Pimelodidae
      - *Pimelodus maculatus* La Cepède, 1803
      - *Pimelodus fur* (Lütken, 1874)
    - Family Heptapteridae
      - *Pimelodella* sp. Eigenmann & Eigenmann, 1888
      - *Rhamdia quelen* (Quoy & Gaimard, 1824)
      - *Rhamdella* sp. Eigenmann & Eigenmann, 1888
  - Order Siluriformes (cont.)
    - Family Callichthyidae
      - *Callichthys callichthys* (Linnaeus, 1758)
      - *Corydoras nattereri* Steindachner, 1877
    - Family Loricariidae
      - *Hypostomus affinis* (Steindachner, 1877)
      - *Hypostomus auroguttatus* Kner, 1854
      - *Hypostomus* sp. Lacépede, 1803
      - *Loricariichthys castaneus* (Castelnau, 1855)
      - *Harttia loricariformis* Steindachner, 1877
      - *Rineloricaria* sp. Bleeker, 1862
  - Order Gymnotiformes
    - Family Gymnotidae
      - *Gymnotus cf. carapo* Linnaeus, 1758
      - *Gymnotus* sp. Linnaeus, 1758
    - Family Sternopygidae
      - *Eigenmannia virescens* (Valenciennes, 1842)
- Superorder Acanthopterygii
  - Order Synbranchiformes
    - Family Synbranchidae
      - *Synbranchus marmoratus* Bloch, 1795
  - Order Cyprinodontiformes
    - Family Poecilidae
      - *Phalloceros caudimaculatus* (Hensel, 1868)
      - *Poecilia reticulata* (Peters, 1859)
  - Order Perciformes
    - Family Sciaenidae
      - *Pachyurus adspersus* Steindachner, 1879
    - Family Cichlidae
      - *Australoheros facetum* (Jenyns, 1842)
      - *Cichla monoculus* Spix & Agassiz, 1831
      - *Crenicichla lacustris* (Castelnau, 1855)
      - *Geophagus brasiliensis* (Quoy & Gaimard, 1824)
      - *Tilapia rendalli* (Boulenger, 1897)
      - *Oreochromis niloticus niloticus* (Linnaeus, 1758)
      - *Oreochromis* sp. Gunther, 1862
      - *Tilapia* - hybrid *O. Mossambicus* (Peters, 1844 - male) vs. *O. niloticus niloticus* (Linnaeus, 1758 - female)

biomass curve consistently; the ABC-index was close to zero in 1997/98 and negative in 1998/99 (Fig. 2). The biomass curve showed higher cumulative values when compared with abundance curve in 1997/98, and lied more closely in 1998/99 for Z I. The opposition situation was shown for Z III, with abundance and biomass curves lying near each other in 1997/98 and lying father apart in 1998/99. The ABC-index values were positive for Z I and III in both periods with higher values for Z I. Therefore Z II was the worse situation followed by Z III, while Z I showed the best situation (Fig. 2), according to ABC curves.

The *K*-dominance curves (Fig. 3) showed a similar pattern when compared with the ABC curves, with Z II showing a few highly dominant species in both periods. In 1997/98 the k-dominance curves for Z II and III were closely coincident, while in 1998/98, Z I and III curves coincided closely and differed from Z II.

In relation the geometric class (Fig. 4), Z I showed few rare species and absence of high abundant common species; Z II showed higher number of rare species than Z I, but was dominated by a few number of extremely abundant species (opportunist species); Z III showed the highest number of rare species, but was dominated by common species.

Cluster analysis showed for both yearly periods a clear separation among the zones. In 1997/98 (Fig. 5), cluster 2 and 3 showed samples mainly from Z II, while cluster 1 showed samples from Z I and III. In 1998/99 (Fig. 6) this separation was more consistent, with cluster analysis showing three groups; cluster 3 was formed mainly by Z II samples (most stressed zone) while clusters 1 and 2 were formed by Z I and III samples. Cofenetic correlation was 0.46 for 1997/98 and 0.57 for 1998/99 indicating a better separation in the latter period but a still high number of species distributed all over the three zones.

Table 3. Total number of individuals by species per zones during the two sampling cycles (1997/1999) in the rio Paraíba do Sul.

Species	Z I		Z II		Z III		Total	%
	1997/98	1998/99	1997/98	1998/99	1997/98	1998/99		
Poecilia reticulata	19	16	607	551	43	97	1333	39.7
Geophagus brasiliensis	24	43	404	117	112	220	920	27.4
Tilapia sp.	0	1	6	178	0	8	193	5.7
Phalloceros caudimaculatus	4	3	5	2	61	3	118	3.5
Rineloricaria sp.	5	2	24	19	24	16	90	2.7
Astyanax giton	7	2	8	36	12	21	86	2.5
Tilapia rendalli	0	0	48	16	5	5	74	2.2
Astyanax sp. 1	10	5	28	6	12	12	73	2.2
Astyanax bimaculatus	4	31	0	5	10	15	65	1.9
Astyanax parahybae	4	34	0	19	0	6	63	1.9
Astyanax sp. 2	1	8	19	4	1	10	43	1.3
Oligosarcus hepsetus	2	7	1	4	9	13	36	1.1
Pimelodus maculatus	6	12	4	12	0	1	35	1.0
Deuterodon sp. 1	0	2	0	1	10	19	32	0.9
Hyphessobrycon reticulatus	0	0	0	0	0	24	24	0.7
Oreochromis niloticus niloticus	0	0	20	1	2	0	23	0.7
Hypostomus sp.	4	2	6	4	1	3	20	0.6
Corydoras nattereri	0	0	0	0	8	11	19	0.6
Hyphessobrycon egues	0	4	0	1	2	12	19	0.6
Astyanax scabripinnis	2	1	1	0	0	7	11	0.3
Hoplias malabaricus	1	5	2	1	1	1	11	0.3
Leporinus copelandii	9	0	1	0	1	0	11	0.3
Callichthys callichthys	0	0	0	5	1	3	9	0.3
Hypostomus auroguttatus	0	0	9	0	0	0	9	0.3
Hypostomus affinis	1	0	7	1	0	0	9	0.3
Probolodus heterostomus	4	4	0	0	0	1	9	0.3
Gymnotus cf. carapo	0	2	1	0	0	1	4	0.1
Rhamdia sp.	0	0	0	0	2	2	4	0.1
Hyphessobrycon bifasciatus	0	0	1	0	1	1	3	0.1
Tilápia vermelha	0	0	2	1	0	0	3	0.1
Leporinus sp.	0	0	2	0	0	0	2	<0.1
Crenicichla lacustris	1	0	1	0	0	0	2	<0.1
Cichla monoculus	0	1	0	0	0	0	1	<0.1
Australoheros facetum	0	0	0	1	0	0	1	<0.1
Cyphocharax gilbert	0	0	0	0	0	1	1	<0.1
Gymnotus sp.	0	0	0	0	0	1	1	<0.1
Hoplerythrinus unitaeniatus	0	0	0	0	1	0	1	<0.1
Leporinus mormyrops	0	1	0	0	0	0	1	<0.1
Loricariichthys castaneus	0	0	1	0	0	0	1	<0.1
Pimelodella sp.	0	0	0	0	1	0	1	<0.1
Total number of fishes	108	186	1208	985	320	554	3361	100.0
Total number of species	18	21	24	22	22	27		

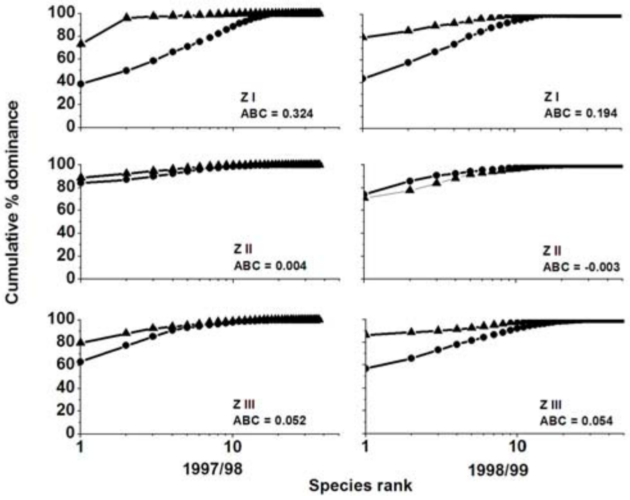

Fig. 2. ABC curves for fish species in the three zones of the rio Paraíba do Sul, in 1997/99. Round marks - abundance; triangle marks - biomass. ABC-indexes indicated for each zone.

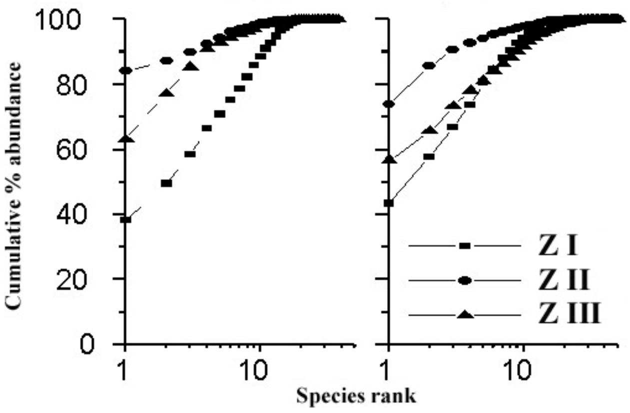

Fig. 3. K-dominance curves for the fish species in the three zones of the rio Paraíba do Sul, in 1997/99.

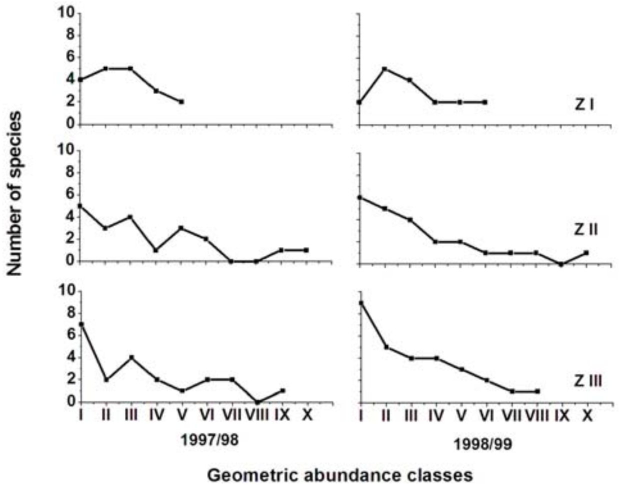

Fig. 4. Number of species per geometric classes (x 2) in the three zones of the rio Paraíba do Sul, in 1997/99.

Discussion

Overall water quality characteristics were acceptable for all zones and no indication of acute pollution was detected. Levels of measured environmental variables are well within the expected values for rivers of Class 2 according to CONAMA resolution, which states that such water should be suitable for domestic supply, after conventional treatment, being good for aquatic communities, aquaculture and other similar uses. Although the study area encompass a major urbanized and industrialized river reaches, which is considered the most impacted segment of the rio Paraíba do Sul watershed (Pfeiffer *et al.*, 1986; FEEMA, 1987), the physico-chemical water quality measurements did not confirm this statement. According to the records there is a trend for slightly worse condition at Z III and a comparatively better condition at Z I. This relatively good water quality can be explained by high dilution capacity of this river reaches; additionally water samples were collected from the main channel, not near to effluent entrance. According to Pratt & Coler (1976) no trend can be detected when water samples are taken far from pollutants sources and sites of discharges near to the river margins.

The fish assemblages in the rio Paraíba do Sul is comprised mainly by species adapted to altered environments such as *Poecilia reticulata, Geophagus brasiliensis* and *Tilapia* sp., which are opportunists ones, commonly associated to organic enrichment; these species take advantage of large organics loads from Municipal discharges and other industrial pollutants sources. High abundances of opportunist species in impacted environments have been reported in the current literature (Fausch *et al.*, 1990; Ganasan & Hughes, 1998; Soto-Galera *et al.*, 1998). Ganasan & Hughes (1998) reported that sites in a major degraded area in the Khan river near to Indore City in India, were comprised mainly by three tolerant species: *Poecilia reticulata, Channa punctatus* and *Diaphus dumerili.* Odum (1969) reported that specialist species are quickly replaced by opportunists ones when there is environmental alteration. Rougharden (1974) stated that generalist species show advantage over the specialists in case of deterioration. Krebs (1985; 1994) associated low species abundance to limited food availability and reported that balanced communities show stable species abundance. Winemiller (1995) reported that other parameters associated with life history such as taxonomic diversity local, biogeographic events and biotic interactions should be considered in order to have a more complete picture of the fish assemblage composition.

The three univariate methods used to assess environmental influences on ichthyofauna (ABC curves, k-dominance curves and geometric class species distribution) are in close agreement with each other. They showed a clear gradient in the level of disturbance across the zones, with a more stressed situation near to the industrial plant at Z II. The industrial plant at Volta Redonda municipality is undoubtedly a major source of alteration on the rio Paraíba do Sul, being comprised by several industries such as steel, pesticides and

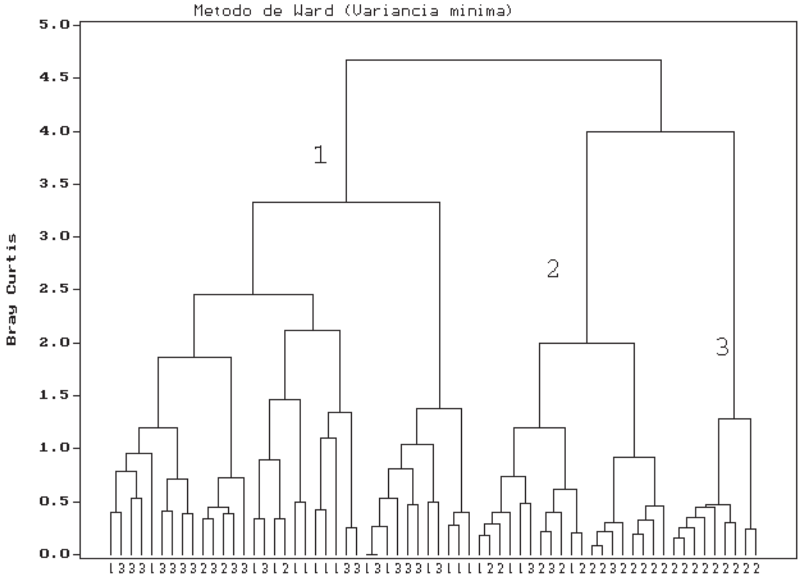

Fig. 5. Cluster analysis of fish abundance on mode Q, showing the three zones in the Paraíba do Sul river, in 1997/98. In x-axis = 1: Z I; 2: Z II; 3: Z III.

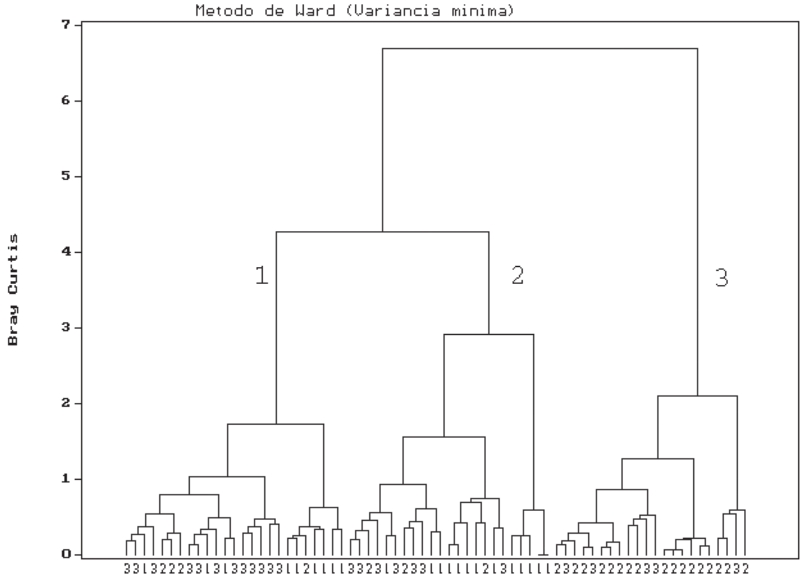

Fig. 6. Cluster analysis of fish abundance on mode Q, showing the three zones in the Paraíba do Sul river, in 1998/99. In x-axis = 1: Z I; 2: Z II; 3: Z III.

several organic synthetic materials. Warwick (1986) has suggested that relationship between abundance and biomass species curves can indicate pollution-induced stress. Where biomass curves lies above the abundance curve the assemblage is not affected by pollution; where the two curves cross one another, the first stages of pollution-induced occur; on the other hand, where the abundance curve lies above the biomass curve the assemblage is from a grossly polluted habitat. Such patterns were confirmed in this study by the ABC index confirming Z II as the most stressed zone.

The *K*-dominance and geometric class have also been used as indicator of pollution stress. The unstressed sites show steep curves with many rare species and few common species in geometric classes, whereas stressed sites show few rare species and dominance by a few highly common species (Gray, 1989). In this study, geometric classes showed a recovery capacity for Z III when compared to Z I and II. In Z III there was higher number of rare species and lower number of common species.

Deteriorating water quality is among the major factors contributing to the disappearance of some species in many rivers and streams. Karr *et al*. (1985), Ganasan & Hughes (1998), Soto-Galera *et al*. (1998), Allen *et al*. (1999) and Waite & Carpenter (2000) found that pollution effect reflected decreasing richness at community and population level. At the community level, pollution reduces both species diversity and abundance. Only certain species and only few individuals can survive in pollution and, thus, polluted habitats are poorer in species richness.

Indications of organic enrichment were showed in Z II, as indicated by high abundance of common species, and a lesser stressed situation in both upstream and downstream zones. Thus, water quality conditions seem to be a major barrier for the distribution of sensitive fish species in the rio Paraíba do Sul. Similar pattern was found by Gafny *et al*. (2000); Gregory *et al*. (1991); Bryce *et al*. (1999) and Araújo *et al*. (2003) who related habitat condition to fish assemblage structure in rivers receiving domestic effluent. The shape of the relationship between rivers response variable and a measure of stress likely depends mutually on the sensitivity of the response variable and mode of action of the environmental stressor. Nonlinear responses are expected whenever the species in question, or the majority of species, exhibit a sensitivity threshold to a particular stress, such as frequency or magnitude of pollution (Norris & Thoms, 1999; Allan, 2004). Such study reported hypothetical relationship depicting possible responses of streams or rivers biological condition (taxon richness, assemblage similarity) to a gradient of increasing environmental stress. In the study case, it is difficult to assess the relationship between anthropogenic gradient and biological condition since no direct parameter of this first gradient was measured.

Another feature that causes decreasing ichthyofauna diversity is habitat degradation (Angermeier & Karr, 1984; Karr *et al*., 1985; Li *et al*., 1987; Rutherford *et al*., 1987; Allan *et al*., 1997; Allan, 2004) such as margins erosion and destruction of habitats that are used as shelter and reproduction sites for large number of species. This situation is very common in the rioParaíba do Sul, as result of the increasing urban pressure. More studies of this kind are needed to determine whether physical improvements in the rio Paraíba do Sul condition are associated to fish assemblages composition and structure. Furthermore, dam construction obstructing the natural river course also contributes to decreasing fish abundance and diversity. Further analyses of the species present at the longitudinal the dams plus better knowledge of life histories are required to substantiate this hypothesis. However, given our knowledge of how dams and reservoirs alter lotic fish assemblages (Agostinho *et al*., 2000; Bowen *et al*., 1996; Dieterman *et al*., 2004; Pringle *et al*., 2000; Quist *et al*., 2004; Schiemer, 2000; Schmutz *et al*. 2000) we believe that habitat fragmentation is also contribution to river alterations. The low species richness at zone I is probably linked to this kind of alteration.

According to Gray (1989) three changes occur in the fish community structure as result of stressors: decreasing diversity, dominance of opportunists and reduction in size of dominant species. He also mentioned that there are changes in community structure as the stressor effect: common species are dominant in the first stages of impact; changes in the mean size are the second stage; the third stage is characterized by reduction of diversity. In this work it was found a still high diversity in the study area where 51 species were recorded although this community has been dominated by few common species, specially at the most impacted Z II, corroborating the rio Paraíba do Sul fish community could be in the first stage of alteration. However, this interpretation of this information remains highly subjective and more studies are needed.

Some of the founds in this work seems to corroborate those founds by Araújo (1998) and Araújo *et al*., (2003) which adapted and developed the Index of Biotic Integrity (IBI) for this area, and reported that Barra Mansa and Volta Redonda reaches were the most impacted zones being classified as Very Poor, while Barra do Piraí reaches, located some 40 km downstream Volta Redonda, as Poor, indicating the river recovering capacity downstream the impacted area.

There is a great concern on the ecosystems integrity based on species as taxonomic functional unit, since biological diversity is decreasing and resources conservation often are inadequate. Winemiller (1995) reported that components and structure resilient mean that all organism and decedents should obtain some success by nutrition, growth, survive and reproduction process. In the studied reaches of the rio Paraíba do Sul, the use of biological indicator in response to environmental degradation was better succeed when compared to traditional physicochemical measurements. According to Metcalfe (1989), physicochemical measurements give a picture of the moment when they are collected; therefore it is necessary larger number of analyses to obtain robust and suitable tendencies. On the other hand, biological measurements are efficient to assess non-point source pollution (diffuse pollution), which must be considered in regional scales (Pratt & Coler, 1976; De Pauw & Vanhooren, 1983; karr *et. al.*, 1986). Our results depict signals of alteration in fish assemblages at Z I, followed by a most evident polluted section at Z II, followed by a recovery capacity of the river at Z III. Further analyses to detect the underline causes of this pattern are required to obtain a more detailed relationship between the environmental constraints and species occurrence.

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