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Ecotoxicology and Environmental Safety 69 (2008) 472–479

Ecotoxicology and Environmental Safety

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Effects of discharges from the textile industry on the biotic integrity of benthic assemblages☆

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Received 19 July 2006; received in revised form 26 March 2007; accepted 31 March 2007
Available online 8 May 2007

Abstract

We explored the effects of a textile industry effluent on water quality, habitat quality and structural and functional responses of benthic communities in a lowland stream. Two sampling sites were selected: site 1 was located 300 m upstream of the outflow from the textile factory and site 2 was 500 m downstream from the discharge point. Samples of water, microbenthos, invertebrates and aquatic plants were taken seasonally. The effluent from the textile industry modified the structure of the microbenthic assemblages downstream, increased the density of organisms and the biomass of primary producers, but diminished the species richness. The oxygen consumption of the microbenthic community was 3 × higher downstream of the effluent and abnormal frustules of diatoms were noticed. The richness and abundance of invertebrate taxa were lower at the impacted site. The invertebrate modes of existence and the functional feeding groups were also significantly affected. This study is an important baseline for assessment of lowland streams with high water residence time and a notable development of hydrophytes. It will also provide a baseline for the monitoring and restoration, or remediation, programs using the metrics of biotic integrity, particularly in South American countries where such metrics are rarely employed.

Keywords: Textile industry; Benthic assemblages; Water quality; Habitat quality; Biotic integrity

1. Introduction

Effluents from textile industries are complex mixtures of chemicals, varying in composition over time. These industries can generate both inorganic and organic waste (major ions, metals, detergents, organic solvents, nutrients, phthalates, etc.) mixed with waste waters from the production processes, which change the concentrations of suspended solids, biological oxygen demand (BOD), conductivity, temperature, color and odor of the receiving water bodies (UNESCO/WHOO/UNEP, 1996).

Since biological communities reflect the effects of different stressors, providing an ecological measure of fluctuating environmental conditions (Karr, 1991; Stephens and Farris, 2004), an examination of relationships between environmental variables that affect the aquatic biota, such as habitat structure, flow regime, energy sources, water quality and biotic interactions, is required in the study of river health (Norris and Thoms, 1999).

Bioassays demonstrated that the effluents of a textile industry significantly affected the growth of microalgae (Asselborn and Zalocar de Domitrovic, 2000; Ammann and Terry, 1985) and Rutherford et al. (1992) reported changes in the abundance and diversity of benthic macroinvertebrates in a water body that received the effluent of a knitwear factory. In streams on the Pampean plain that are exposed to textile effluents, changes were detected in the structure of periphyton (Giorgi and Malacalza, 2002) and microbenthic communities (Tolcach and Gómez, 2002). Similarly, Graça et al. (2002), using *in situ* tests, detected changes in the survivorship of two invertebrate species and in the growth of one macrophyte. However, studies that include the structure, function and habitats of aquatic communities exposed to this kind of discharge have been poorly documented (CEPA, 1999).

☆This research was financed by the National Council of Scientific and Technical Researches (CONICET) PIP No. 5305. Our study was conducted without involving humans or experimental animals.
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doi:10.1016/j.ecoenv.2007.03.007

Benthic assemblages are good indicators of local conditions because many benthic organisms have limited migration patterns or a sessile mode of life, which makes them particularly well suited for assessing specific impacts.

The aim of this study was to analyze the impact of a textile industry effluent, originating from the manufacture of synthetic fibres, on a lowland stream. We explored the following topics:

(i) effects of the industrial effluent on water quality,
(ii) changes in the habitat quality,
(iii) structural and functional changes in the microbenthos and invertebrate assemblages.

2. Materials and methods

2.1. Study site

The water body receiving the textile industry effluent is the Don Carlos stream (34°55′-34°50′S–58°00′-58°03′W), which is a small urban stream that runs across the Pampean plain and flows into the Río de la Plata estuary (Argentina) (Fig. 1). Two sampling stations were selected for this study: site 1 was located 300 m upstream of the outflow from the textile factory and site 2 was 500 m downstream from the discharge point.

2.2. Habitat quality

At each sampling site a reach of 50 m was selected and a habitat characterization was carried out. This included a description of the stream, a summary of the aquatic plants, and measurements of instream parameters: width, depth, flow and substrate. The flow velocity was measured with a Cole-Parmer CZ-32922-10 Flow meter and the substrate was categorized as gravel, sand, clay and silt (Folk, 1974). The cover of aquatic plants in each reach was expressed as a percentage and their species were identified according to Cabrera (1964).

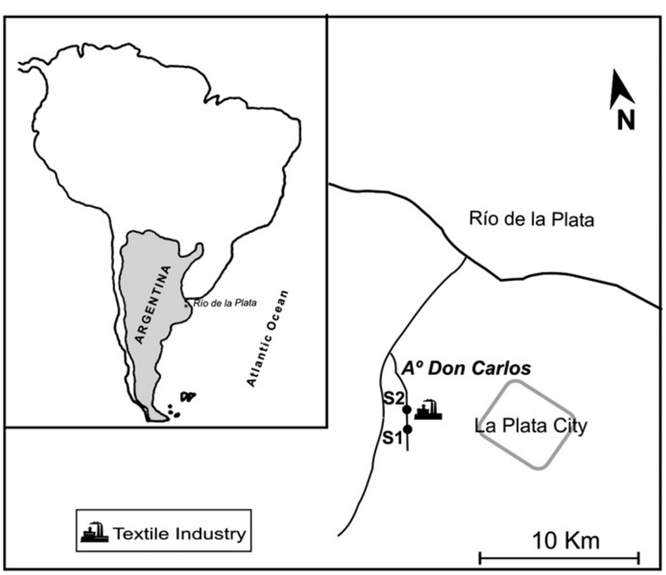

Fig. 1. Map showing the location of the Don Carlos stream and sampling sites.

2.3. Physical and chemical variables

At each site the following physical and chemical variables were measured: dissolved oxygen (Ysi 52 dissolved oxygen meter), temperature and pH (Hanna HI 8633), conductivity (Lutron CD-4303) and turbidity (Turbidity meter 800-ESD). Water samples were taken for analysis of phosphate ($P–PO_4^{3-}$), ammonium ($N–NH_4^+$), nitrate ($N–NO_3^-$), nitrite ($N–NO_2^-$), BOD_5 and chemical oxygen demand (COD) (Mackereth et al., 1978; APHA, 1995). Samples of sediments, at site 1 and at the point of industrial discharge, were collected for analysis of Cu, Cr, Cd, Ni, Pb, phenols and phthalates (APHA, 1992; Beckert and Lopez-Avila, 1989).

2.4. Sample collection and preparation

2.4.1. Microbenthos

The microbenthos was sampled in winter and spring 2004, and summer and autumn 2005. At each sampling site, 15 subsamples of the superficial layer of the bottom sediment (5–10 mm) were collected by pipetting 1 cm^2 (Lowe and Laliberti, 1996; Gómez and Licursi, 2001). The samples obtained were kept cold and in the dark during transport to the laboratory. Two aliquots were used to estimate chlorophyll *a* (APHA, 1995; Lorenzen, 1967). Five subsamples were fixed with formaldehyde (4%) and dedicated to the study of the community composition of the microbenthos, using standard keys, and quantified in a Sedgwick–Rafter chamber, through an optical microscope (Olympus BX 50). Two subsamples were cleaned with H_2O_2 and washing thoroughly with distilled water, after that were mounted on microscope slides with Naprax® for identification of diatoms, which were analyzed with phase contrast and Nomarski DIC optics. A total of 300 valves were counted in each sample, to calculate the Diatom Pampean Index (IDP) for the assessment of organic pollution and eutrophication (Gómez and Licursi, 2001).

The consumption of oxygen was measured in triplicate in the laboratory under artificial darkness and constant temperature (20–22 °C). Two aliquots were carefully placed in glass bottles (100 ml), which were filled with filtered stream water (Whatman GFC filters) and then sealed airtight and wrapped in aluminum foil. The oxygen concentration in each bottle was determined before the bottles were closed and again after 1.5–2 h of incubation, with an oxygen meter (Bott et al., 1978; Rasheed et al., 2004). The DO data were also converted to units of carbon assuming that 1 mole of C is equivalent of 1 mole of O_2 (i.e. 1 mg $O_2 = 0.375$ mg C, Lambert, 1984, Bender et al., 1987).

2.4.2. Invertebrate assemblages

A total of 12 samples of benthic invertebrates were taken, in autumn, winter and spring of 2005, with an Ekman dredge (100 cm^2) and 18 samples of hydrophytes (emergent and floating plants) were collected with a Plexiglas square (1300 cm^2) for examination of phytophilous invertebrates. The material was fixed *in situ* with formaldehyde (5%); after cleaning the sediment and the hydrophytes over a sieve of 250 μm mesh size. The invertebrates were sorted using a stereomicroscope (Olympus SZ40) and identified using standard keys.

Functional feeding groups were identified according to the classification of Merrit and Cummins (1984) modified by Bonetto and Wais (1995). The classifications of Merrit and Cummins (1984) and Heino (2005) were employed to determine the functional habitat traits of the stream invertebrates. The Biotic Index for Pampean Rivers (IBPAMP), for assessment of water quality, was calculated according to Rodrigues Capítulo et al. (2001).

2.5. Statistical analysis

To evaluate if the differences in physical, chemical and biotic variables between the sampling sites were significant, the unpaired *t*-test, of the data normally distributed with equal variances, was used, while the Mann–Whitney Rank Sum Test was employed when the data were not normally distributed and/or had unequal variances. The community similarity percentage (PSc), between sites upstream and downstream of the industrial discharge, was calculated according to Whittaker (1952).

3. Results

3.1. Physical and chemicals characteristics

Physical and chemical variables of the sampling sites, and their significant differences, are shown in Table 1. Phosphate, nitrate and nitrite were higher upstream (site 1) as a consequence of the horticultural activity developed in that area. The temperature, ammonium, BOD_5, COD and conductivity increased downstream while turbidity and dissolved oxygen decreased below the effluent discharge point (site 2). The pH was slightly lower downstream. In the streambed at the industrial discharge the levels of Ni, Cu and Pb were higher than found upstream. A large amount of phthalates was also detected at the discharge point (Table 2).

3.2. Habitat quality

At site 1 the mean depth was 0.5 m, the width 4 m and the velocity $0.02\,m\,s^{-1}$ (± 0.02), while at site 2 the mean depth was 0.35 m, the width 1 m and the velocity $0.15\,m\,s^{-1}$ (± 0.01). The current velocity was significantly different between the two sites ($P<0.05$). The streambed and banks at site 2 were modified by canalization and cleaning activities. This site receives continuous discharges from the textile industry that modify some organoleptic properties of the water such as the transparency, color and odor.

The cover of aquatic plants at site 1 was greater than at site 2 (Table 3). *Ludwigia peploides* was the most abundant species at site 1 while *Typha dominguensis* was most abundant at site 2. At site 1 the proportion of fine sediments, silt and clay, was higher than the proportion of coarse sediments, while at site 2 the streambed consisted of a consolidated bottom ($CaCO_3$ concretions) with a major proportion of sand and gravel (Table 3). The bottom of this site is covered by mats of filamentous bacteria and cyanophytes.

Table 1
Physico-chemical characteristics (means and standard deviations) of the upstream (site 1) and downstream locations (site 2)

	Site 1	Site 2
Temperature (°C)*	15.47±1.25	19.00±1.25
Turbidity (NTU)*	25.23±2.72	6.66±3.41
Disolved Oxygen (mg L^{-1})	3.45±1.68	3.30±1.08
Conductivity (μS cm^{-1})	893±46	987±86
pH	7.67±0.28	7.53±0.07
Nitrate-nitrogen (mg L^{-1})	2.32±1.66	1.14±1.59
Nitrite-nitrogen (mg L^{-1})	0.22±0.11	0.104±0.130
Ammonium-nitrogen (mg L^{-1})*	0.034±0.030	0.923±0.580
Phosphate-phosphorous (mg L^{-1})*	0.92±0.07	0.15±0.09
Biological oxygen demand (mg L^{-1})*	21.50±13.38	71.0±5.3
Chemical oxygen demand (mg L^{-1})*	31.0±11.5	141.0±65.1

*significant differences $P<0.05$.

Table 2
Amounts of Pb, Ni, Cu, Cr, Cd, phthalates and phenols in the streambed sediments upstream (site 1) and at the point of industrial discharge in the stream

	Upstream of the industrial discharge	Point of industrial discharge
Pb, μg g^{-1}	10	20.45
Ni, μg g^{-1}	11.4	155.5
Cu, μg g^{-1}	20	35
Cr, μg g^{-1}	8.6	11.5
Cd, μg g^{-1}	<0.125	<0.125
Phthalates, μg g^{-1}	—	118
Phenols, μg g^{-1}	—	<0.05

Table 3
Granulometric composition of the streambed at the sampling sites and cover of aquatic plants

	Site 1	Site 2
Granulometric composition		
Silt (%)	45	25
Clay (%)	23	11
Sand (%)	29	37
Gravel (%)	3	27
Cover of aquatic plants (%)	56	44

3.3. Microbenthos

At site 1 the microbenthic community mainly consisted of cyanophytes (*Oscillatoria limosa* and *Merismopedia* spp.), diatoms (mainly represented by *Nitzschia frustulum*, *Nitzschia constricta*, *Navicula capitata*, *Surirella tenera*, *Pinnularia subcapitata*, *Craticula cuspidata*, *Craticula ambigua*, *Gomphonema parvulum*) and Chlorophytes only in winter (*Spirogyra* sp. and *Cladophora* sp.). At site 2 an increase of cyanophytes, represented mainly by *Oscillatoria brevis*, *Oscillatoria chalybea*, and *Lyngbya* sp., was observed. Thick mats of filamentous bacteria (*Beggiatoa* spp.) were also noticed, in which ciliate protozoans (*Paremecium caudatum*, *Paramecium* sp., *Glaucoma* sp., etc.) cohabited. This last group was significantly more abundant downstream ($P<0.05$). Furthermore, an increase in the abundance of euglenoids (*Euglena acus*, *Euglena* sp., *Phacus* spp.) and diatoms (*Navicula subminuscula*, *Nitzschia palea*, *Nitzschia umbonata*, *G. parvulum*, among others) was observed but they were represented only by taxa very tolerant to the pollution (Fig. 2). The densities of organisms at site 1 were lower than those at site 2 (Fig. 3a).

The IDP was significantly different ($P<0.01$) between the two sites (Fig. 3b) indicating an acceptable water quality upstream (moderate organic pollution and eutrophication) but very bad quality downstream (very strong

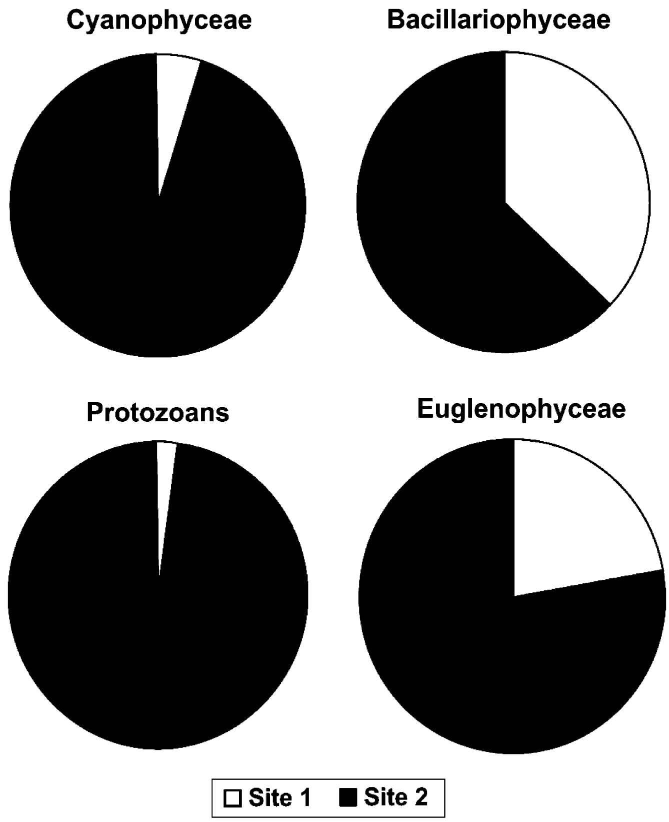

Fig. 2. Relative abundances of the major taxonomic groups in the microbenthic community upstream and downstream of the industrial discharge.

organic pollution and eutrophication). At site 2 deformities in the frustules of some of the diatoms (abnormal patterns of striation, deformed or interrupted raphe and deformities in the outline) were observed, sometimes in up to 3% of the total assemblage, mainly represented by valves of *N. palea*, *N. umbonata, G. parvulum* and *Pinnularia gibba*. The percentage community similarity of the diatoms, between sites 1 and 2, ranged from 8.5% to 13%.

The quantities of Chlorophyll *a* and the oxygen consumption were higher downstream (Fig. 3c and d).

3.4. Invertebrate assemblages

The increased diversity and relative abundance of Diptera downstream were accompanied by a decline in molluscs ($P<0.05$), nematodes, annelids (mainly Tubificidae) and crustaceans (Ostracoda, Ciclopoida, Chidoridae, etc.) (Fig. 4).

The percentage community similarities of the invertebrates at the two sampling sites ranged from 55% to 62%. Some taxa such as the molluscs (*Pomacea canaliculata*., *Omalonix* sp., *Heleobia parchappei*., *Biomphalaria tenagophila*., *Gundlachia concentrica*., *Musculium* sp., *Pisidium vile* and *Pisidium sterkianum*), Hydroidea, Libellulidae, Dugesiidae, Belostomatidae and the Diptera (Muscidae and Sciomyzidae) disappeared at site 2. Meanwhile Collembola, Acari, Isopoda, Diptera (Ephydridae, Psychodidae, Syrphidae, Tipulidae, Tabanidae and Dolichopodidae) and the mollusc *Physa acuta* were only observed at site 2.

The richness and densities of organisms at site 1 were higher than those at site 2 (Fig. 5a).

The IBPAMP index showed significant differences ($P<0.05$) between the sampling sites. Upstream the index ranged from 6 to 8, defining a water quality class with moderate to low pollution; while downstream the index fluctuated between 4 and 5 indicating a heavily polluted water quality class (Fig. 5b).

The filtering collectors and the detritivores decreased downstream where feeding groups of herbivores and gathering collectors were the most abundant (Fig. 6). The main changes in the functional habitat trait groups were mirrored by a decrease downstream of sprawlers, planktonic, clingers ($P<0.05$) and climbers and the increase of the burrowers (Fig. 7).

4. Discussion

The results obtained in this study confirmed that there are changes in habitat, water quality and biotic characteristics downstream of the discharge from the textile industry. The temperature, turbidity, ammonium, COD and BOD_5 showed the most marked changes in the physico-chemical characteristics. The industrial discharge, dredging and cleaning activities increased the water velocity at site 2 diminishing the deposition of silt and leading to exposure of the $CaCO_3$ concretions that underline the streambed. The substrate was mainly composed of fine sediments upstream of the discharge whereas coarse materials were observed downstream. These factors contributed to the decline in the number of species downstream and the abundance of hydrophytes, particularly the floating plants. Nedeau et al. (2003), in studies about the effect of a pharmaceutical industry effluent on a benthic community, remarked on its positive effect on macroinvertebrate assemblages through, on the one hand, increasing the quantity of riffle habitat, and, on the other hand, its negative effect due to the reduced water quality. In our case, both water quality impairment and modifications to the streambed had negative effects on the biota due to changes and reduction of habitats.

The industrial discharge modified the community structure of the microbenthic assemblages downstream by increasing the density of organisms and the biomass of primary producers, but diminished the species richness. Similarly, Biggs (1989) and Giorgi and Malacalza (2002) observed that industrial discharges affect the water quality and periphyton structure by reducing the abundance of diatoms and increasing the presence of cyanophytes and euglenoid species. Although, in our case, the diatoms increased they were represented only by taxa very tolerant to the pollution. In the Don Carlos stream the mats of the sulphur-reducing bacteria, *Beggiatoa* spp., observed at site 2, would imply changes in the aquatic food webs. These

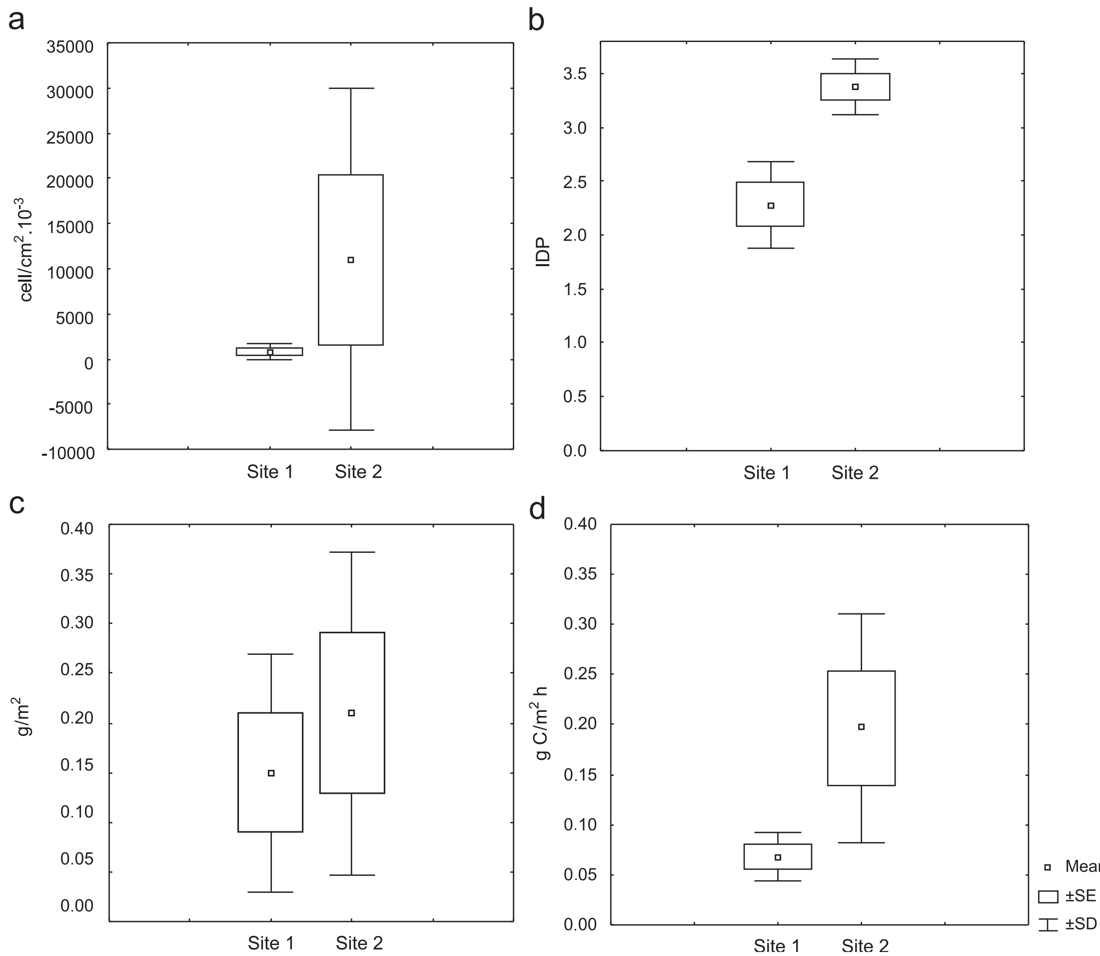

Fig. 3. Comparison of abundance (cells cm^{-2}) (a), Diatom Pampean Index (b), chlorophyll "*a*" (c), and oxygen consumption (d) upstream and downstream of the industrial discharge.

bacteria exclude other heterotrophic bacteria and most macrofauna, and have few elements of the infaunal communities that are found in other muddy biotopes (Williams and Unz, 1989). Bernhard et al. (2000) noted several species of ciliates, nematodes and euglenoids, feeding on organic matter, in relation to the mats of *Beggiatoa* spp. in polluted sites in the Santa Barbara basin (California). Moreover, the combined effects of poor food quality and high temperature (increased metabolism) could have a pronounced effect on sensitive organisms (Nedeau et al., 2003). The tolerance of the species to pollution and eutrophication and the values of IDP support this suggestion. Also in the Don Carlos stream, the oxygen consumption of the microbenthic community was 3 × higher downstream and 5 × higher than in little-disturbed sites on the Pampean plain (Sierra, pers. commun.).

Several authors have related deformities in diatoms to high concentrations of heavy metals (Adsheds-Simonsen et al., 1981, Mc Farland et al., 1997, Ruggiu et al., 1998 and Gómez and Licursi, 2003). In our study, abnormal frustules were observed at the downstream site and higher heavy metal concentrations (Ni, Cu and Pb) were detected on the streambed at the discharge point. Phthalates were also detected in the samples we analyzed. The widespread occurrence of phthalates in the aquatic environment is a major concern because they are known to be toxic and recalcitrant under certain conditions (Oliver et al., 2007). The biological effect and environmental fate of phthalates have been reviewed by Thomas et al. (1978) and Staples et al. (1997a, b), who suggest that maximum residue levels would be found at intermediate trophic levels rather than at the top of the food chain. Zhang and Reardon (1990) point out that some of the phthalates are suspected to be carcinogenic.

The quality and quantity of available habitat affects the structure and composition of resident biological communities (Maddock, 1999). In the Don Carlos stream, the changes in water quality and the modification (bottom composition) or reduction of suitable habitats (macrophyte community structure) downstream of the effluent discharge led to the absence of bivalves and the presence of diverse families of Diptera (Ephydridae, Psychodidae, Syrphidae, Tipulidae, Tabanidae and Dolichopodidae) and the gastropod *P. acuta*. This pulmonate snail is resistant to organic pollution and even to septic conditions (Hart and Fuller, 1974) while the pelecipoda are intolerant of pollution

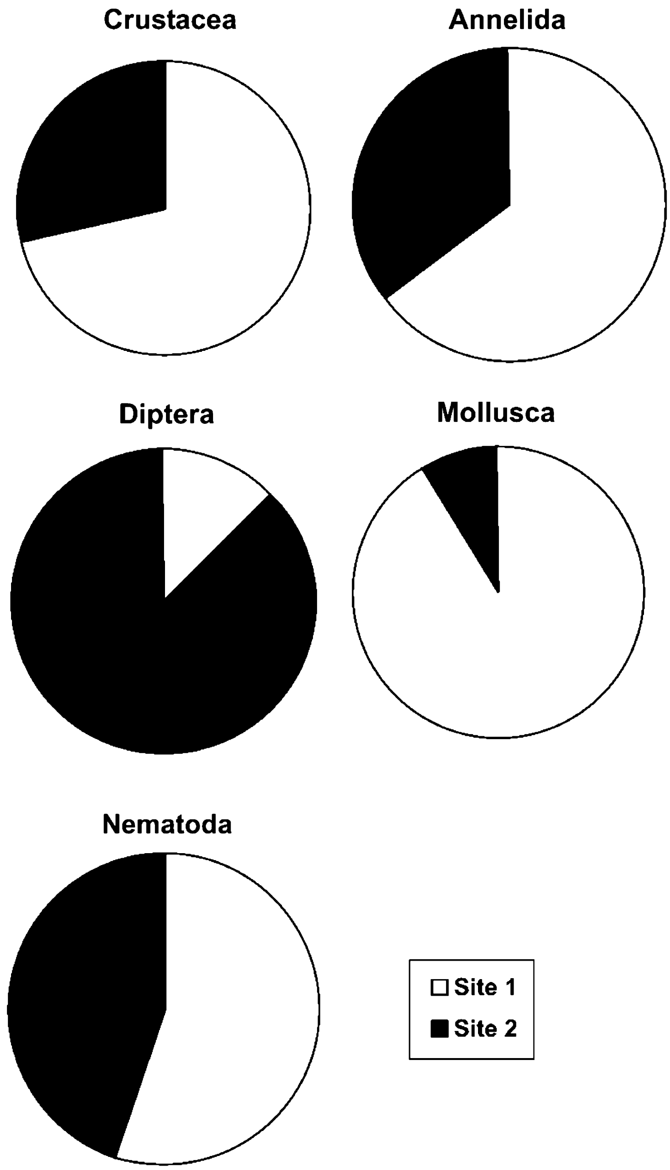

Fig. 4. Relative abundance of the most important taxonomic groups of invertebrates upstream and downstream of the textile discharge.

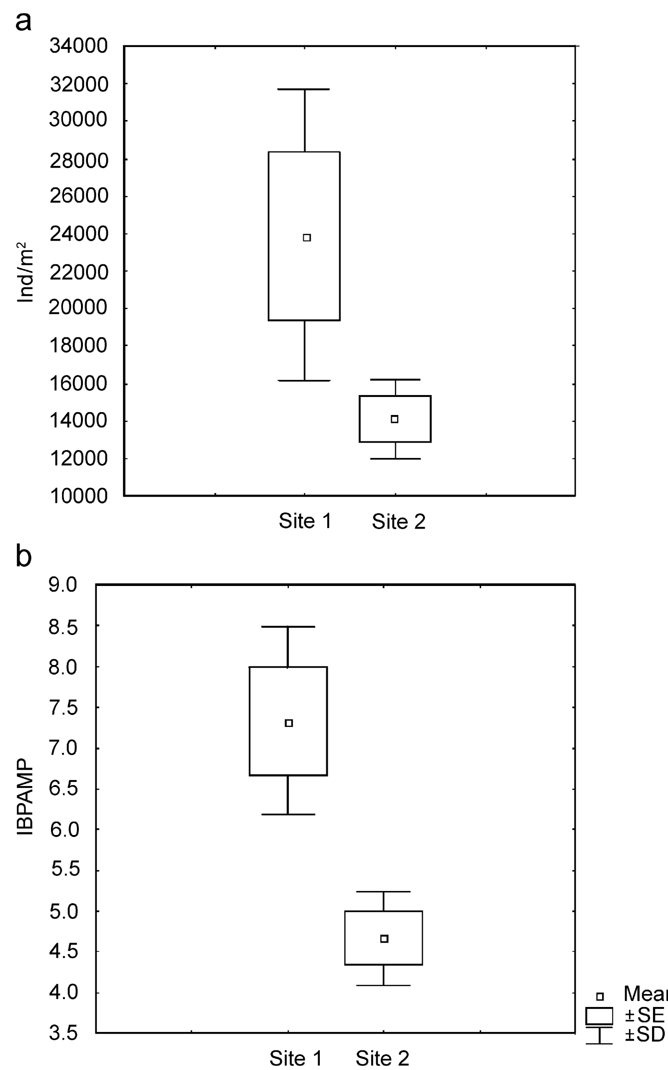

Fig. 5. Comparison of invertebrate abundance (ind/m^2) (a) and IBPAMP index (b) upstream and downstream of the industrial discharge.

(Weber, 1973). Some families of Diptera are frequent in streams with high organic pollution (Hynes, 1971; Sládecek, 1973; Fernández and Schnack, 1977; Varela et al., 1980). We also observed changes downstream of the textile effluent that affected the functional habitat trait groups (decrease of clingers and climbers) and some functional feeding groups (decrease of detritivores and filtering collectors) of the invertebrates.

The modifications observed in the biotic integrity of the benthic community in the Don Carlos stream were consistent with *in situ* tests using *Hyalella curvispina*, *Palaemonetes argentinus* and *Egeria densa*, carried out by Graça et al. (2002) who checked the low survivorship of the crustaceans and a decline in the growth of the hydrophytes downstream of the textile discharge. Tolcach and Gómez (2002) also noticed manifest shifts in the structure of the microbenthic communities when these were tranlocated between sites, upstream to downstream from the textile discharge.

Our results illustrate the points made by Karr (1998) who stressed that human impacts on the biological integrity of water resources are complex and cumulative. These actions jeopardize the biological integrity of a water resource by altering one or more of five principal factors: physical habitat, seasonal flow of water, the food base of the system, interactions within the stream biota, and chemical quality of the water.

5. Conclusion

The results obtained showed how the biological communities in the Don Carlos stream reflected the modifications of the habitat and the effects of a complex mixture of chemicals originating from the textile industries.

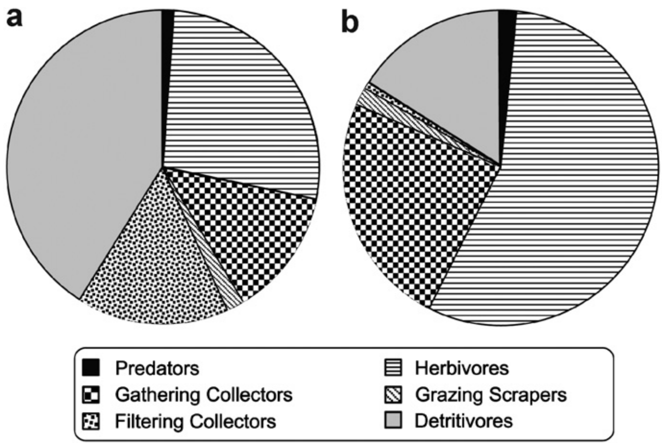

Fig. 6. Relative abundance of functional feeding groups upstream (a) and downstream (b) of the textile discharge.

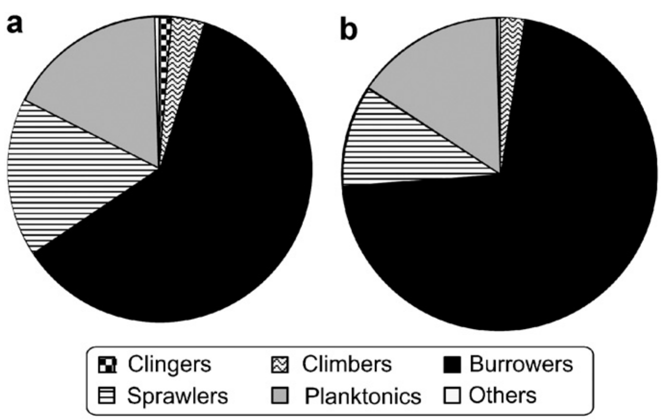

Fig. 7. Relative abundance of the functional habitat trait groups upstream (a) and downstream (b) of the textile discharge.

This study is important in providing a baseline for assessment of lowland streams with high water residence time and a marked development of hydrophytes, and supports the need for monitoring and restoration, or remediation programs using the metrics of biotic integrity, particularly in South American countries where such metrics are rarely employed.

Finally, it is imperative that the regulatory authorities should implement and enforce an appropriate strategy in order to monitor, regulate and protect the streams.

Acknowledgments

The authors are grateful to M.J. Morris for English language revision of the manuscript and to the anonymous referees for the comments and suggestions that have improved the manuscript. We also thank V. Lopez, J. Donadelli and C. Roldán for their assistance during the development of this study.

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