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PRIMARY RESEARCH PAPER

Deforestation and sewage effects on aquatic macroinvertebrates in urban streams in Manaus, Amazonas, Brazil

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Abstract In the last few years, awareness in developed countries has increased regarding the importance of urban watercourses as essential natural resources for human well being. Macroinvertebrates have been used as bioindicators to complement physico-chemical evaluation of water quality after environmental perturbations. The city of Manaus is closely associated with the Amazonian rain forest and with its dense hydrographic network. Any perturbation, such as deforestation and/or water pollution in the city's streams, therefore causes changes in the local ecosystem as the population increases. In this study, 65 streams were sampled in October and November 2003. Samples were taken from streambed sediment in the center of the channel and litter/sediment at the edge of the stream. Deforestation, total Nitrogen (TN), total Phosphorus (TP), depth, width, electrical conductivity, temperature and dissolved Oxygen (DO) were measured. A total of 115,549 specimens were collected, distributed among 152 taxa. Oligochaeta, *Chironomus*, Psychodidae and Ceratopogonidae were the taxa with the greatest frequencies of occurrence and the highest total abundances. Higher deforestation, TN and TP were correlated with lower DO and greater electrical conductivity, pH and water temperature. Deforestation, TN and TP were not associated with water velocity and stream width. Depth was the only variable

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correlated (negatively) with deforestation and not correlated with TN and TP. Greater deforestation, TN and TP were correlated with lower richness of taxa; but these variables did not affect abundance. Canonical Correspondence Analysis ordenated the streams into two groups; the majority of the streams were in the group with high levels of deforestation and with high values of TP, TN, pH, electrical conductivity and temperature, where the macroinvertebrates were reduced to a few taxa. The other group was composed of streams that were well oxygenated and deep, where richness of taxa was higher. These results indicate changes in community composition in response to changes in environmental conditions. The highest taxa correlation was with streams that were well oxygenated and had the greatest depth and water velocity. Species Indicator Analysis identified 29 taxa as indicators of nonimpacted streams, 16 as indicators of deforested streams and three as indicators of streams impacted by deforestation and domestic sewage. Of the total sampled streams, 80% were impacted by deforestation and water pollution and had fauna tolerant of these perturbations. Water pollution, represented by TN and TP, affected the macroinvertebrate fauna in a way similar to deforestation, i.e., causing reduction in taxa richness, simplifying the insect community composition without changing abundance. Use of the taxa suggested in this study as environmental indicators could improve the evaluation of water quality in the streams in Central Amazonia.

Keywords Urban streams · Aquatic macroinvertebrates · Environmental indicators · Deforestation · Domestic sewage · Neotropical streams

Introduction

Population growth associated with the urbanization processes is changing many hydrological systems (Thorne and Williams, 1997). Several studies have suggested the need for understanding water degradation processes in urban environments as a basis for designing projects to recover, maintain and/or sustainably use this natural resource (e.g. Wash, 2000; Chu and Karr 2001).

Over the last few years, awareness in developed countries has increased regarding the importance of urban water as an essential natural resource for human well being (Powell et al., 1996). Water scarcity in some parts of the world and the high human mortality associated with waterborne diseases are some of the reasons that lead to this new way of thinking (Chamizo-Garcia and Orias-Arguedas, 1999; Karr and Morishita-Rossano, 2001). In Latin America conservation proposals need to include urban areas, since 70% of the population lives in cities (Primack et al., 2001).

Deforestation and water pollution are the two main perturbations that affect watercourses. Organic pollution caused by domestic sewage results, especially, in water eutrophication (Wash, 2000; Sonneman et al., 2001; Wash et al., 2001; Taylor et al., 2004). While deforestation along the edges of watercourses often results in land-use mosaics that degrade the environment without producing any benefits, resulting in such problems as channel siltation and temperature increase (Allan, 1995; Martins, 2001; England and Rosemond, 2004).

Bioindicators, including macroinvertebrates, have been used frequently for monitoring and evaluation of perturbation in aquatic environments (Alba-Tercedor and Sánchez-Ortega, 1988; Alba-Tercedor, 1996; Callisto et al., 2000; Galdean et al., 2000; Takeda et al., 2000). Rosenberg and Resh (1993) suggested that the high density, diversity, small body size and short life cycle of aquatic macroinvertebrates when compared to other organisms favor their use in aquatic-ecosystem monitoring, complementing the physical, chemical and physico-chemical evaluation of the environment. Aquatic macroinvertebrates respond quickly to perturbation, provoking change in the local community structure and reducing richness to a few tolerant and generalist groups (Clements, 1994; Dickman and Rygiel, 1996; Kulmann et al., 2000). Macroinvertebrates represent the second largest group of organisms in aquatic ecosystems (Allan, 1995). They also are responsible for the maintenance of aquatic ecosystems because they are important components of the nutrient cycle (Rosenberg and Resh, 1993) and serve as food for other aquatic (Perrow et al., 1996; Callisto et al., 2002) and terrestrial (Roque et al., 2003) organisms.

Despite knowledge of the importance of the macroinvertebrates as a tool for evaluation and monitoring of aquatic ecosystems, and despite the importance of macroinvertebrates in the maintenance of these ecosystems, few studies have been done on this group in the Amazonian region (e.g. Callisto et al., 1998a, b, c; Nessimian et al., 1998; Cleto-Filho and Walker, 2001).

Morley and Karr (2002) surveyed the world literature published between 1991 and 2001 and found only 30 papers concerning the direct estimation of human effects on the biota in watercourses in urban areas. According to these authors, without knowledge about the fauna that inhabit urban watercourses it is difficult to plan conservation strategies for these areas.

The city of Manaus is closely associated with the Amazonian rain forest and with its dense hydrographic network. Because of this, a complex system of relationships exists between the flora, fauna and the water systems in this region. Any perturbation, such as deforestation and/or water pollution in the streams of the city, therefore results in changes in the local ecosystem as the city grows. According to Agostinho et al. (2005), this disturbance type is among the reasons for declines in biodiversity in Brazil's inland waters.

The aim of the present study was to evaluate the effect of urbanization on the macroinvertebrate fauna of streams in Manaus, as macroinvertebrates are considered to be a fundamental group in the aquatic community. This knowledge will be important for understanding the effect of human impact on the stream biota and will help in developing plans to follow the results of a habitat-improvement project that is now beginning as an iniciative of the Manaus municipal government (e.g. Projeto social e ambiental dos igarapés de Manaus - PROSAMIM).

Materials and methods

Study area

The sampled streams are located in urban areas in the city of Manaus, Amazonas state, Brazil (Fig. 1, see Electronic Supplementary Material). They are "ïgarapés de terra firme" (upland streams) that are not affected by the flood pulse that characterizes the major rivers of the region (Junk et al., 1989). They have different levels of perturbation, caused mainly by complete or partial removal of riparian vegetation and by pollution from domestic sewage that is dumped into these streams without any treatment. In general, only streams with headwaters in forested fragments in protected areas such as the Universidade Federal do Amazonas campus have intact vegetation and are free from domestic sewage.

Macroinvertebrate sampling and identification

Sampling was done in 65 streams (Fig. 1, see Electronic Supplementary Material), during the dry season in October and November 2003. In each stream, an area 60 m in length was delimited and five samples of bed sediments from the center

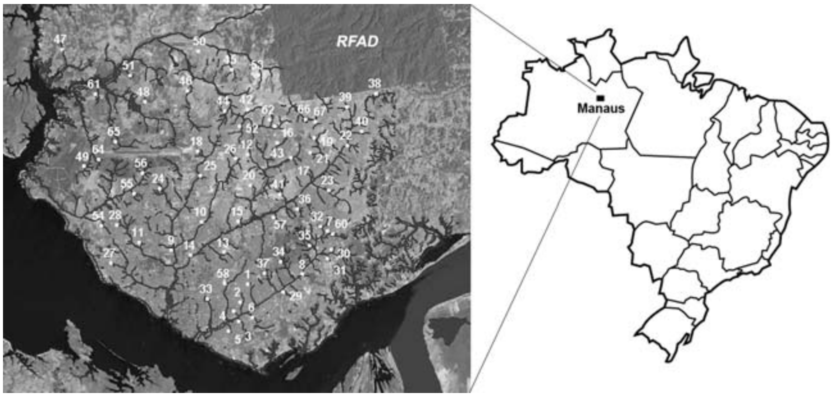

Fig. 1 Landsat satellite image of the Manaus urban area (year 2003) with aquatic macroinvertebrate sampling sites

of channel and five samples from litter/sediments from the edge of the stream were collected with a modified Petersen dredge (345 cm^2) and with an entomological aquatic net (570 cm^2, 1 mm^2 mesh), respectively.

Samples were placed in plastic bags and transported to the laboratory where they were washed under running water, using a metal sieve (125 μm mesh); then they were kept in plastic bags containing 90% ethanol until they were processed under a dissecting microscope.

Taxa identification was done to the lowest level possible using bibliographic sources (e.g. Barnes et al., 1995; Epler, 1995; Trivinho-Strixino and Strixino, 1995; Merritt and Cummins, 1996; Hamada and Couceiro, 2003; Pes et al., 2005) and the help of specialists (see Acknowledgments).

Environmental variables

Deforestation

The rates of deforestation in each stream sampled were obtained from a 2003 Landsat satellite image classified into forested and deforested areas. The classification process consisted of image manipulation, identification of the classified areas, signature extraction, and accuracy assessment by comparison with the unclassified image that was used as a base. Deforestation rates for each stream were obtained for 100–m buffers around the geographical coordinates obtained for each stream sampled. Coordinates were obtained using a Garmin GPS.

Total nitrogen (TN) and total phosphorus (TP)

Water Samples were taken in the water column with polypropylene bottles (60 ml). The TN and TP concentrations were obtained using the methodology of Valderrama (1981).

Other environmental variables (physical and chemical)

The measurement of depth and width were done with a ruler calibrated in millimeters. Water velocity was estimated by the time a plastic float takes to move one meter. Electrical conductivity was measured with a portable conductivimeter WTW, model LF90, pH was measured with a portable potentiometer WTW, model pH90. Temperature and dissolved Oxygen were measured, near the bottom, with a portable Oxymeter YSI, model 55.

Statistical analysis

Pearson's correlation was used between deforestation, TN and TP and the other abiotic variables. Spearman's correlation was used between deforestation, TN and TP and the biotic variables: macroinvertebrate richness and abundance. Richness was estimated using Jackknife 1 (Cowell and Coodington, 1994).

Canonical Correspondence Analysis (CCA) was used to verify the relationship between the abiotic variables and macroinvertebrates and the sampled streams. The Monte Carlo test was applied to verify if there was any correlation between taxa and the environmental variables represented by the CCA axis. A Species Indicator Analysis (Dufrene and Legendre, 1997) based on the results of the CCA was done for streams that were unimpacted, impacted by deforestation and impacted by deforestation and domestic sewage.

Linear regression analyses were used to verify the relationship between frequency of occurrence and taxa abundance and between abundance and taxa richness in the studied streams. Prior to these tests the abundance values were log $(x + 1)$ transformed (Zar, 1996).

Frequency of occurrence (%) was obtained by dividing the number of streams in which the taxon occurred by the total number of sampled streams.

In all statistical tests the probability level used was 0.05.

Results

A total of 115,549 specimens distributed among 152 taxa were collected (Table 1). Macroinvertebrate abundance in the sampled streams was not related to taxa richness (linear regression, $r^2 = -0.02$, df = 63, $p = 0.83$; Fig. 2). There was a significant relationship between the frequency of

Table 1 Values of biotics and environmental variables in 65 streams in the urban area of Manaus, AM, in October and November 2003

	Total	Minimum	Maximum	Mean	Std. Dev.
Biotic variables					
Richness	152	0	84	24.78	18.42
Abundance	115,549	0	27,994.00	1,777.68	3,999.34
Environmental variables					
Depth (cm)		3.33	83.33	14.58	11.67
Velocity (m/s)		1.32	10.44	3.84	1.84
Width (cm)		0.50	10.00	2.36	1.91
Electrical Conductivity (μS/cm)		2.62	662.33	197.22	150.70
Dissolved oxygen (Hg/l)		0.80	8.87	3.24	1.94
Temperature (°C)		25.00	33.00	29.12	1.93
Deforestation (%)		0.00	100.00	79.27	32.52
Total Nitrogen (μmoles/l)		0.21	170.56	31.65	32.25
Total Phosporous (μmoles/l)		0.40	13.27	4.76	3.89
pH		4.83	7.83	6.52	0.66

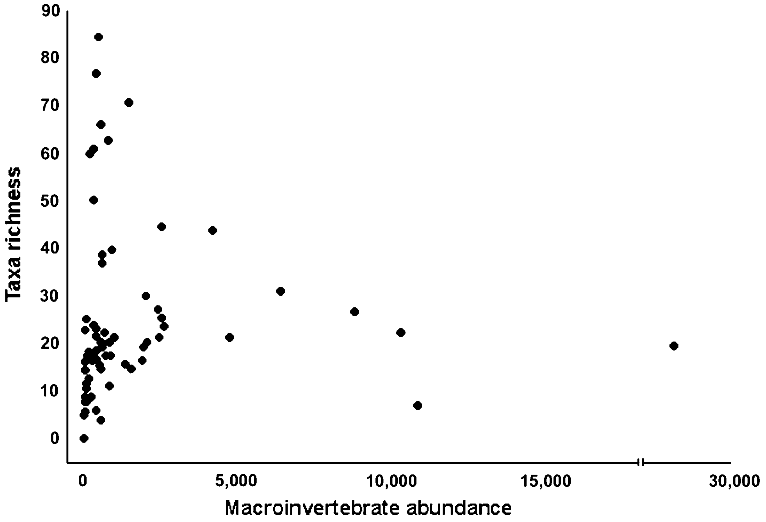

Fig. 2 Relationship between aquatic macroinvertebrate richness and abundance in urban streams in Manaus, AM, in October–November 2003

occurrence of taxa and their abundance (linear regression, $r^2 = 0.34$, df = 63, $p < 0.01$; Fig. 3). The taxa with the highest frequencies of occurrence also had the highest abundances. Oligochaeta, *Chironomus*, Psychodidae and Ceratopogonidae were the most frequent and abundant taxa (Fig. 3). Table 2

Environmental variables are presented in Table 1. Deforestation varied from zero to 100%. The mean ratio between TN and TP (TN:TP) in the studied streams in Manaus was 6:1. The concentrations of TN varied from 0 to 171 μmoles/liter, with a mean concentration of 32 μmoles/liter. The concentrations of TP varied from 0 to 13 μmoles/liter, with a mean concentration of 5 μmoles/liter.

High levels of deforestation and high TN and TP concentrations affected the other environmental variables in a similar way. This influence is reflected in lower DO concentration and in greater electrical conductivity, pH and water temperature. Deforestation levels, TN and TP concentrations did not affect water velocity and stream width. The only difference observed in the relationship of deforestation, NT and PT with the other abiotic variables investigated was the negative correlation between deforestation and depth. These variables were not correlated with TN or TP.

The increases in deforestation, and in TN and TP concentrations were correlated with reduction of macroinvertebrate taxa richness ($r = -0.40$,

Fig. 3 Taxa with frequency of occurrence above 50% and their abundances in urban streams in Manaus, AM, in October–November 2003

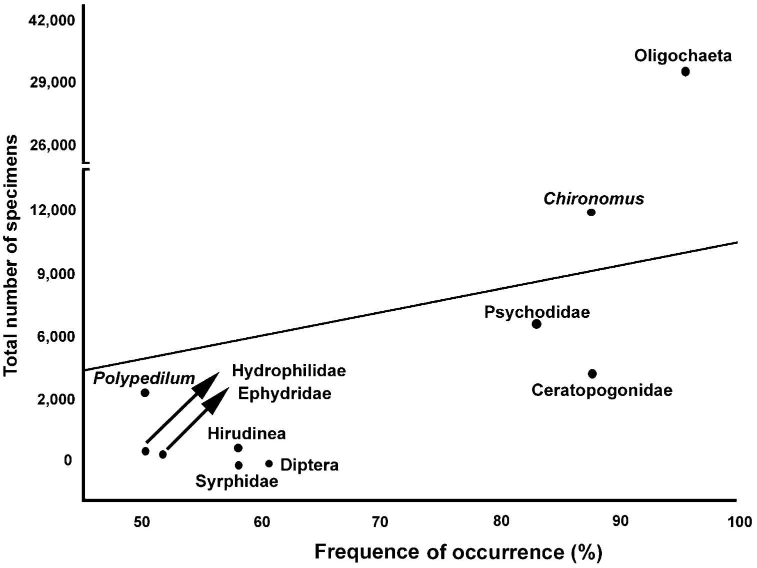

Table 2 Pearson correlation (r) between deforestation rates, total Nitrogen (TN) and total Phosphorus (TP) with the other environmental variables measured in urban streams in Manaus, AM, in October–November 2003

Environmental variables	Deforestation		TN		TP	
	r	*p*	*r*	*p*	*r*	*p*
Depth	–0.29	0.02	–0.15	0.23	–0.22	0.08
Velocity	–0.10	0.42	–0.23	0.06	0.03	0.80
Width	0.20	0.11	0.12	0.35	0.06	0.62
Electrical Conductivity	0.52	>0.001	0.61	>0.001	0.68	>0.001
Dissolved Oxygen	–0.42	>0.001	–0.56	>0.001	–0.59	>0.001
Temperature	0.64	>0.001	0.25	0.04	0.30	0.02
pH	0.62	>0.001	0.43	>0.001	0.49	>0.001

$r = -0.44$, $r = 0.46$, respectively), without affecting their abundance ($r = 0.10$, $r = 0.05$, $r = -0.02$, respectively).

All of the studied environmental variables were highly correlated with axis I of the CCA (Table 3). The Monte Carlo test indicated that this axis was the only one that showed significant correlation between variables and taxa ($p < 0.01$).

The CCA ordenated the streams into two groups. One, where the majority of the streams are found, included the streams with higher levels of deforestation and eutrophication, i.e., with high values of TP, TN, pH, electrical conductivity and temperature (Fig. 4a). In this group macroinvertebrates were reduced to a few taxa. The other group included streams with well oxygenated water and greater depth; this is the group with higher taxa richness. These results indicate that there was a change in the community composition

Table 3 Intraset correlation between environmental variables and the first two axes of the Canonical Correspondence Analysis

Environmental variable	Axis I	Axis II
Depth	0.44	0.16
Velocity	0.35	–0.10
Width	–0.30	0.20
Electrical Conductivity	–0.69	0.25
Dissolved Oxygen	0.76	0.17
Temperature	–0.40	–0.20
Deforestation	–0.61	–0.02
Total Nitrogen	–0.56	0.23
Total Phosphorus	–0.66	0.31
pH	–0.73	0.12

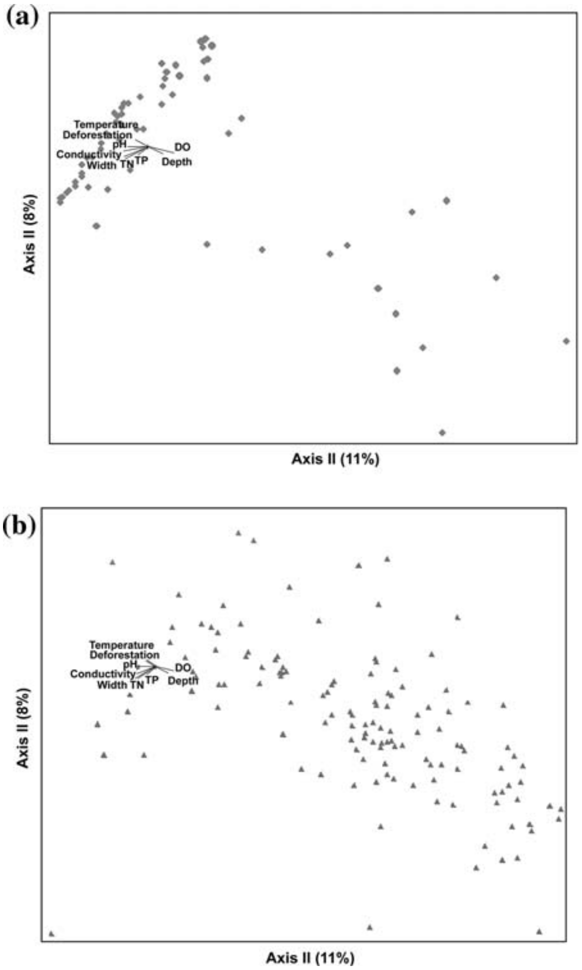

Fig. 4 Canonical Correspondence Analysis (CCA) between: (**a**) abiotic variables and streams and (**b**) abiotic variables and taxa

in response to changes in the environmental variables (Fig. 4b).

The highest taxa correlation was observed in streams that were well oxygenated and had greater depth and higher water velocity. These taxa were *Tanytarsus*, *Macronema*, *Phylloicus*, *Stenochironomus*, Elmidae, *Progomphus*, Leptophlebiidae, *Endotribelos*, Tanytarsini, *Cernotina*, Leptohyphidae, *Labrundinia*, *Macrobrachium, Ablabesmyia*, *Beardius*, *Euryrhyncus* and Pseudochironomini (Table 4). Streams with higher electrical conductivity, pH, TP, TN and deforestation were correlated with Diptera, Psychodidae, Ephydridae, Oligochaeta, Syrphidae, Ceratopogonidae, *Microvelia*, Aeshnidae, Chilopoda, Isopoda, *Culex* and *Lucilia* (Table 4).

When the environmental variables were plotted against the CCA results, one group, formed by the streams correlated with high DO and depth (13 streams), can be divided into two subgroups, one with and the other without deforestation (Fig. 5). The studied streams can therefore be placed in three categories: (1) nonimpacted, (2) impacted by deforestation but not by pollution and (3) impacted by both deforestation and pollution by domestic sewage. Applying Species Indicator Analysis to this arrangement we found that 29 taxa can be used as indicators of nonimpacted streams, 16 of streams impacted by deforestation but not by pollution and three of streams impacted by both deforestation and domestic sewage pollution (Table 5).

Discussion

According to Resh et al. (1988), human perturbation changes community structure in watercourses because species are adapted to certain environmental conditions. In general, environmental perturbation reduces taxa richness to a few tolerant and generalist groups. Modifying species distribution and abundance can change ecological processes in the ecosystems (Covich et al., 1999). Considering all of the studied streams, 80% (n = 52) were dominated in frequency of occurrence and abundance by Oligochaeta, *Chironomus*, Psychodidae and Ceratopogonidae. These organisms are considered tolerant and typical of impacted environments (Clements, 1994; Dickman and Rygiel, 1996; Callisto et al., 2000; Kulmann et al., 2000; Karr and Morishita-Rossano, 2001). Only 20% (n = 13) of the streams possessed fauna similar to that found in preserved areas in Central Amazonia, such as the Reserva Florestal Adolpho Ducke (e.g. Penny, 1981; Bobot and Hamada, 2002; Delgado, 2002; Froehlich, 2003; Holzenthal and Pes, 2004; Pes, 2005). Despite the low abundance observed in these preserved streams we can observe, through the ACC, that they have high richness and that each stream has a distinctive fauna.

Increased urbanization and loss of vegetation cover reduce the biological integrity of watercourses (Roy et al., 2003) and compromise the

Table 4 Correlation between taxa and first Axis of the Canonical Correspondence Analysis. Positive values are related to well-oxygenate streams with greater depth and water velocity, while negative values are correlated with higher deforestation rates, pH and electrical conductivity

Taxa		Axis I	Taxa		Axis I
Tanytarsus	Diptera	0.65	Coenagrionidae	Odonata	0.40
Macronema	Trichoptera	0.65	*Larsia*	Diptera	0.39
Phylloicus	Trichoptera	0.61	*Polypedilum*	Diptera	0.37
Stenochironomus	Diptera	0.59	*Gynothemis*	Odonata	0.37
Elmidae	Coleoptera	0.58	*Cricotopus*	Diptera	0.36
Progomphus	Odonata	0.56	Pyralidae	Lepidoptera	0.36
Leptophlebiidae1	Ephemeroptera	0.56	*Coelotanypus*	Diptera	0.34
Endotribelos	Diptera	0.54	*Microphlebia*	Ephemeroptera	0.34
Tanytarsini	Diptera	0.53	*Helicopsyche*	Trichoptera	0.34
Cernotina	Trichoptera	0.53	*Aeschnosoma*	Odonata	0.33
Leptohyphidae1	Ephemeroptera	0.53	*Leptonema*	Trichoptera	0.33
Labrundinia	Diptera	0.53	*Callibaetis*	Ephemeroptera	0.32
Macrobachium	Decapoda	0.53	*Fissimentum*	Diptera	0.32
Ablabesmyia	Diptera	0.53	*Cryptochironomus*	Diptera	0.29
Beardius	Diptera	0.52	*Caenis*	Ephemeroptera	0.28
Euryrhyncus	Decapoda	0.51	*Clinotanypus*	Diptera	0.28
Pseudochironomini	Diptera	0.50	Megapodagrionidae	Odonata	0.28
Cyrnellus	Trichoptera	0.49	*Zelusia*	Ephemeroptera	0.28
Campylocia	Ephemeroptera	0.49	Plathelmintes	Plathelmintes	0.27
Nilothauma	Diptera	0.46	*Enderleina*	Plecoptera	0.27
Miroculis	Ephemeroptera	0.46	Perlidae	Plecoptera	0.27
Marilia	Trichoptera	0.46	*Nanocladius*	Diptera	0.27
Nectopsyche	Trichoptera	0.45	Empididae	Diptera	0.27
Caladomyia	Diptera	0.44	*Simothraulopsis*	Ephemeroptera	0.27
Cladopelma	Diptera	0.44	*Austrotinoides*	Trichoptera	0.25
Triplectides	Trichoptera	0.43	Notonectidae	Heteroptera	0.25
Coleoptera	Coleoptera	0.43	*Zenithoptera*	Odonata	0.25
Protosialis	Megaloptera	0.42	*Neotrichia*	Trichoptera	0.25
Brasilocaenis	Ephemeroptera	0.41	*Parachironomus*	Diptera	0.24
Harnischia	Diptera	0.41	*Paratendipes*	Diptera	0.24
Veliidae	Heteroptera	0.41	*Farrodes*	Ephemeroptera	0.24
Pentaneura	Diptera	0.41	Naucoridae	Heteroptera	0.24
Rheotanytarsus	Diptera	0.40	*Macrogynoplax*	Plecoptera	0.24
Corynoneura	Diptera	0.40	*Protoptila*	Trichoptera	0.24
Chironomini	Diptera	0.40	*Hetaerina*	Odonata	0.23
Coryphorus	Ephemeroptera	0.40	Gyrinidae	Coleoptera	0.22
Stridulivelia	Heteroptera	0.40	*Paratanytarsus*	Diptera	0.22
Scirtidae	Coleoptera	0.40	*Saetheria*	Diptera	0.22
Aturbina	Ephemeroptera	0.22	*Tanypus*	Diptera	0.04
Paracloedes	Ephemeroptera	0.22	Noctuidae	Lepidoptera	0.04
Ulmeritoides	Ephemeroptera	0.22	*Micrathyria*	Odonata	0.04
Epigomphus	Odonata	0.22	*Orthemis*	Odonata	0.04
Chiromini2	Diptera	0.21	*Lopescladius*	Diptera	0.04
Rhagovelia	Heteroptera	0.21	*Erythodiplax*	Odonata	0.03
Thienemanniella	Diptera	0.21	*Phyllocycla*	Odonata	0.03
Oxyethira	Trichoptera	0.20	Curculionidae	Coleoptera	0.02
Cecidomyidae	Diptera	0.19	*Chironomus*	Diptera	0.02
Tipulidae	Diptera	0.18	*Djalmabatista*	Diptera	0.02
Smicridea	Trichoptera	0.18	*Paraphenocladius*	Diptera	0.02
Dryopidae	Coleoptera	0.17	Gerridae	Heteroptera	0.02
Apedilum	Diptera	0.17	Belostomatidae	Heteroptera	0.02
Lauterborniella	Diptera	0.17	Noteridae	Coleoptera	–0.03
Manoa	Diptera	0.17	*Monopelopia*	Diptera	–0.05

Table 4 continued

Taxa		Axis I	Taxa		Axis I
Macrostemum	Trichoptera	0.17	Gastropoda	Mollusca	–0.05
Parametriocnemus	Diptera	0.15	Ochteridae	Heteroptera	–0.06
Leptohyphidae	Ephemeroptera	0.15	*Erythemis*	Odonata	–0.06
Ambrysus	Heteroptera	0.15	Stratiomyidae	Diptera	–0.06
Ranatra	Heteroptera	0.15	Orthocladiinae	Diptera	–0.07
Nematoda	Nematoda	0.15	Sarcophagidae	Diptera	–0.07
Libellulidae	Odonata	0.14	*Mesovelia*	Heteroptera	–0.07
Tenagobia	Heteroptera	0.13	Drosophilidae	Diptera	–0.07
Stempellina	Diptera	0.12	Hydrophilidae	Coleoptera	–0.07
Perithemis	Odonata	0.11	Dolichopodidae	Diptera	–0.08
Onconeura	Diptera	0.11	*Pantala*	Odonata	–0.08
Denopelopia	Diptera	0.11	*Lucilia*	Diptera	–0.10
Dytiscidae	Coleoptera	0.10	*Culex*	Diptera	–0.10
Oecetis	Trichoptera	0.10	Isopoda	Crustacea	–0.11
Macrothemis	Odonata	0.08	Chilopoda	Miriapoda	–0.12
Dicrotendipes	Diptera	0.08	Aeshnidae	Odonata	–0.12
Hirudinea	Annelida	0.08	*Microvelia*	Heteroptera	–0.13
Zavreliella	Diptera	0.07	Ceratopogonidae	Diptera	–0.14
Goeldichironomus	Diptera	0.06	Syrphidae	Diptera	–0.17
Belostoma	Heteroptera	0.06	Oligochaeta	Annelida	–0.21
Bivalva	Mollusca	0.06	Ephydridae	Diptera	–0.23
Tabanidae	Diptera	0.06	Psychodidae	Diptera	–0.25
Paracladopelma	Diptera	0.05	Diptera	Diptera	–0.31

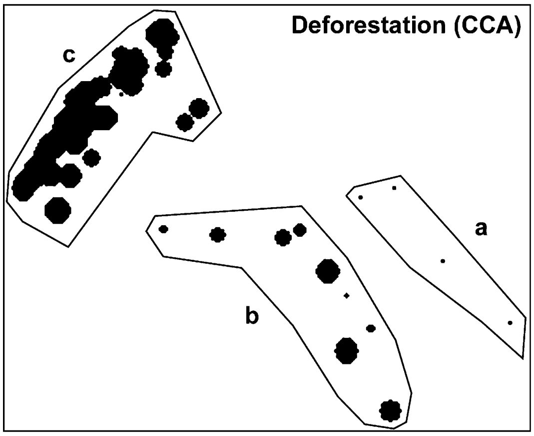

Fig. 5 Ordination using deforestation rates of streams sampled in the October–November 2003 period in Manaus, AM, using Canonical Correspondence Analysis (CCA): (**a**) nonimpacted streams, (**b**) impacted with deforestation and (**c**) impacted with deforestation and domestic sewage. Circle size represents the percentage of deforestation; larger circles represent 100% deforestation and smaller ones, no deforestation

quality of the surface waters (Silva et al., 2001). According to Benstead et al. (2003), 22,360 km^2 of stream banks in tropical forest are affected annually by deforestation and very little is known about the ecological effects of this impact on the aquatic community.

Riparian vegetation helps to maintain stream integrity, especially by avoiding siltation of the watercourse due to the sediments transported from the stream banks (Waters, 1995; Lima and Zakia, 2001). Riparian vegetation also avoids temperature increase due to the higher light incidence (Allan, 1995). Regardless of the importance of the vegetation for maintaining the biota of aquatic ecosystems the majority of the streams in Manaus do not have the minimum amount of riparian vegetation required under Brazilian law. Rather, many streams have their banks occupied by houses that dump domestic sewage directly into the stream, changing the physico-chemical characteristics of the water and even greater effects on the aquatic organisms.

We did not observe any relationship between deforestation and macroinvertebrate abundance ($p > 0.05$); however, reduction of taxa richness was observed ($p < 0.05$). Some studies on the effect of deforestation on macroinvertebrate fauna, such as those by Trayler and Davis (1998) in Australia and Benstead et al. (2003) in

Table 5 Taxa suggested as environmental indicators in urban streams located in Manaus, AM, after a Species Indicator Analysis: (a) nonimpacted streams (b) impacted with deforestation and (c) impacted with deforestation and domestic sewage

Taxa	Group	Taxa	Group
Ablabesmyia	a	*Stridulivelia*	a
Beardius	a	Tanytarsini	a
Caladomyia	a	*Tanytarsus*	a
Campylocia	a	Tipulidae	a
Cernotina	a	*Triplectides*	a
Corynoneura	a	Cecidomyidae	b
Cyrnellus	a	*Cladopelma*	b
Elmidae	a	*Coelotanypus*	b
Endotribelos	a	*Cricotopus*	b
Euryrhyncus	a	*Cryptochironomus*	b
Harnischia	a	Empididae	b
Helicopsyche	a	*Fissimentum*	b
Labrundinia	a	*Gynothemis*	b
Macrobachium	a	*Larsia*	b
Macronema	a	*Nanocladius*	b
Marilia	a	*Onconeura*	b
Miroculis	a	*Parachironomus*	b
Nilothauma	a	*Paratendipes*	b
Pentaneura	a	*Polypedilum*	b
Phylloicus	a	*Rheotanytarsus*	b
Progomphus	a	*Thienemaniella*	b
Pseudochironomini	a	*Chironomus*	c
Scirtidae	a	Ephydridae	c
Stenochironomus	a	Psychodidae	c

Madagascar, indicate that macroinvertebrate richness and abundance is lower in deforested areas. One explanation for this fact is that deforestation results in the reduction of allochthonous material (Henry et al., 1994; Uieda and Kikuchi, 1995). Benstead and Pringle (2004), stated that differences in the communities between preserved and deforested streams in Madagascar are mainly the result of the ability of taxa to tolerate changes in available food resources. According to Walker (1986) the determinant factor for macroinvertebrate abundance in Amazonian streams is the availability of substrates (leaves, tree trunks and fruits) provided by the adjacent forest.

Camargo et al. (1995) and Thorne and Williams (1997) stated that the factor that most compromises water quality in urban streams is organic pollution resulting from domestic sewage; this causes eutrophication, especially increasing Phosphorus (P) and Nitrogen (N) concentrations. These are considered to be the most critical nutrients for autotrophic production and are associated with domestic sewage impacts in streams. Increase in P concentration in urban streams is the result of detergent use, while N concentration increase is the result of human excrement (Esteves, 1998). In Japan, studies have shown that P and N concentrations in the urban environment are sometimes as high as the concentration found in agricultural areas, where nutrient enrichment occurs due to runoff of fertilizers (Nagumo and Hatano, 2000). Although P concentration is elevated in urban streams, the concentration of this nutrient is not as high as that observed for N (Paul and Meyer, 2001). The observed mean N:P ratio in urban streams in Manaus was 6:1. In streams with low nutrient concentrations, P is the main factor that limits primary production. Nitrogen concentration tends to be limiting only when P is abundant or when the N concentration is less than 16 times higher than the P concentration (Allan, 1995).

In the Amazonian region there are few studies that can be used to compare with our results. Delgado (2002) reported *Progomphus* as one of the most representative Odonata genera in the Reserva Florestal Adolpho Ducke (a preserved area in Manaus). In our study, this genus was correlated with streams that were well oxygenated and with greater depth and water velocity. *Progomphus* presence has been associated with sand substrate (Assis et al., 2004). Absence of this genus in the deforested and polluted streams can be explained by the surface compaction of the sand due to the formation of a layer of algae and fine sediments such as silt and organic material; this barrier does not allowing *Progomphus* species, which burrow in the sand, to obtain Oxygen. The most representative Trichoptera genera collected in the urban streams were *Phylloicus*, *Macronema*, *Cernotina* and *Cyrnellus.* The presence of these genera in the studied area is associated with preserved streams. Human activities and vegetation cover percentage have been associated with Trichoptera distribution in *Cerrado* (savanna) systems (Oliveira, 1996). *Phylloicus* and *Triplectides* use plant material to construct cases (Wiggins, 1998), and these taxa are restricted to forested streams. In the Chironomidae, *Stenochironomus*, Tanytarsini, *Tanytarsus*, *Caladomyia* and *Endotribelos* are found in streams with litter banks (Sanseverino and Nessimian, 1998; Nessimian et al., 2003). *Macrobrachium*, *Euryrhyncus* and *Campylocia* were predominant in forested environments. Walker (1990) compared several substrates such as free water, sand bottom, roots, clay banks and litter in the Amazonian region and found that aquatic fauna was concentrated mainly in the litter. Also, this author stated that Decapoda and Ephemeroptera are the dominant faunal groups in Amazonian black waters (Walker, 1994). Few individuals of these two groups were collected in the sampled urban streams. Aquatic insect distribution is determined by adaptations or tolerance to environmental physical–chemical factors, while density is controlled by interactions between habitat and food availability (Merritt and Cummins, 1996). In spite of the large number of collected taxa in the urban streams, the great majority were collected in low abundance and were present in only a few streams.

High values of electrical conductivity, temperature and pH were correlated with high levels of deforestation and high concentrations of TN and TP. Nutrient enrichment of aquatic ecosystems has been associated with increases in macroinvertebrate abundance (Scrimgeour et al., 2000). This fact was partially observed in our study where a correlation between abundance of tolerant groups, such as Oligochaeta, and nutrient enrichment was observed (CCA, Table 4). However, this effect was not found for macroinvertebrates as a whole (Table 4). In forested streams in Central Amazonia Oligochaeta are found in small numbers and the Hirudinea species are small and rare (Fittkau, 1964). Oligochaeta were collected in high abundance in the urban streams of Manaus and Hirudinea were neither rare nor small, probably due to the organic enrichment undergone by these streams.

Environmental variables (physical, chemical and physical–chemical) have great influence over the biotic communities. Hamada et al. (2002) related black fly species (Simuliidae) in Central Amazonia to physical–chemical characteristics of the habitat. Abiotic variables were altered in the majority of the sampled streams due to the action of deforestation and water pollution. Organic enrichment was reflected in high values of pH and electrical conductivity, which were correlated with increases in the populations of Syrphidae, Ephydridae and Psychodidae, all of which are macroinvertebrate groups usually associated with eutrophication.

Elevated water temperature has been associated with deforestation (Dodds, 2002), and this accelerates insect life cycles. High temperatures also result in lower DO concentrations, thereby affecting biotic community production (Allan, 1995). Many burrowing animals do not survive under anoxic conditions and do not tolerate for a long period of time the sulfides and ammonia present in this type of environment (Wang et al., 2001). Very low concentrations of DO result in greater effort of the animals to obtain Oxygen, thereby increasing their absorption of contaminants. DO and depth were negatively correlated with the amount of deforestation near the streams. According to Covich et al. (1999), if there is DO available and adequate substrate, invertebrates are diverse and abundant.

Changes in macroinvertebrate community structure have also been related to factors that indicate physical variation of the habitat (Roy et al., 2003). It is known that substrate availability is related to the maintenance of riparian vegetation (Boujsen and Barriga, 2002). Preservation of this vegetation results in more protection against predators, shelter against water current, food (secondary production), case construction (e.g. Trichoptera), oviposition sites and emergence for aquatic insects and other macroinvertebrates. The absence of substrates can affect the movement pattern, facilitating drift due to absence of interstitial substrates that serve as shelter for invertebrates.

Our study demonstrated that the majority (80%) of streams in the urban area of Manaus are impacted, having their abiotic characteristics modified by deforestation and water pollution. These impacted streams had macroinvertebrate fauna that is tolerant to these perturbations and, based on the available literature, is distinct from the fauna of nonimpacted streams in the region Deforestation and water pollution, represented by high concentrations of TN and TP, cause reduction in the richness of aquatic macroinvertebrates and simplify the community structure; however, these perturbations did not affect the abundance of macroinverbrates as a whole. Our results suggest that some of the observed taxa can be used as indicators of streams that are nonimpacted, impacted by deforestation and impacted by deforestation and water pollution. These indicator taxa can be used in water-quality evaluation and in monitoring the recovery of streams in the study area.

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