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Impact of Bauxite Tailings on the Distribution of Benthic Macrofauna in a Small River ('Igarapé') in Central Amazonia, Brazil

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ABSTRACT: Environmental deterioration resulting from the impact of bauxite tailings on the distribution of benthic macrofauna was studied in the Igarapé Água Fria, a side channel semi-isolated from the Rio Trombetas, near Porto Trombetas, Oriximiná, Pará, Brazil. The objective of this study was to relate the occurrence and seasonal distribution of the benthic macrofauna, especially larvae of Chironomidae (Insecta: Diptera) to the activities of a bauxite mine during the rainy season (May–June) and the dry season (October–November) in 1994 and 1995, at three sampling stations (comparing a reference site to polluted sites). Over the four collecting periods, we found low generic richness and low densities of Chironomidae. The chironomids *Chironomus, Goeldichironomus*, and *Polypedilum* predominated in the study area. The fine-grained bauxite tailings, dispersed by local currents, have covered much of the river bottom with drastic consequences for the benthic macrofauna.

Environmental gradients are important in determining the distribution and composition of benthic macroinvertebrate communities. Dermott (1985) found that the community structure of aquatic organisms was strongly limited by low pH. Other investigators have established that benthic macroinvertebrate communities are more depauperate in species richness and have lower density and biomass in waters of low pH (Margalef, 1983; Ward, 1992; Rosenberg and Resh, 1993). Most Amazonian igarapés (semi-isolated side channels of rivers) are situated in drainage basins of clear, acidic (pH < 4.5) rivers, thus naturally supporting low densities and biomass of benthic invertebrates (Callisto, 1996). In spite of these characteristics, the Amazon region possesses very high species richness of Chironomidae, many of which are endemic (Fittkau, 1971).

In the region of Porto Trombetas, numerous bodies of water have been directly or indirectly affected by bauxite mining. The Mineração Rio do Norte S/A mining company began its bauxite extraction operations in the Serra do Saracá in 1979. The ore is processed by washing with water jets, which generates a liquid effluent (tailings) containing 7% to 9% finely granulated solid particles (ca. 96% smaller than 50 μm), mainly represented by aluminum oxide (21%), silicates (4%) and iron oxides, at an annual volume of 18 million m^3 (Lapa and Cardoso, 1988; Bozelli, 1992). The presence of these bauxite tailings in the beds of some waterbodies has been demonstrated

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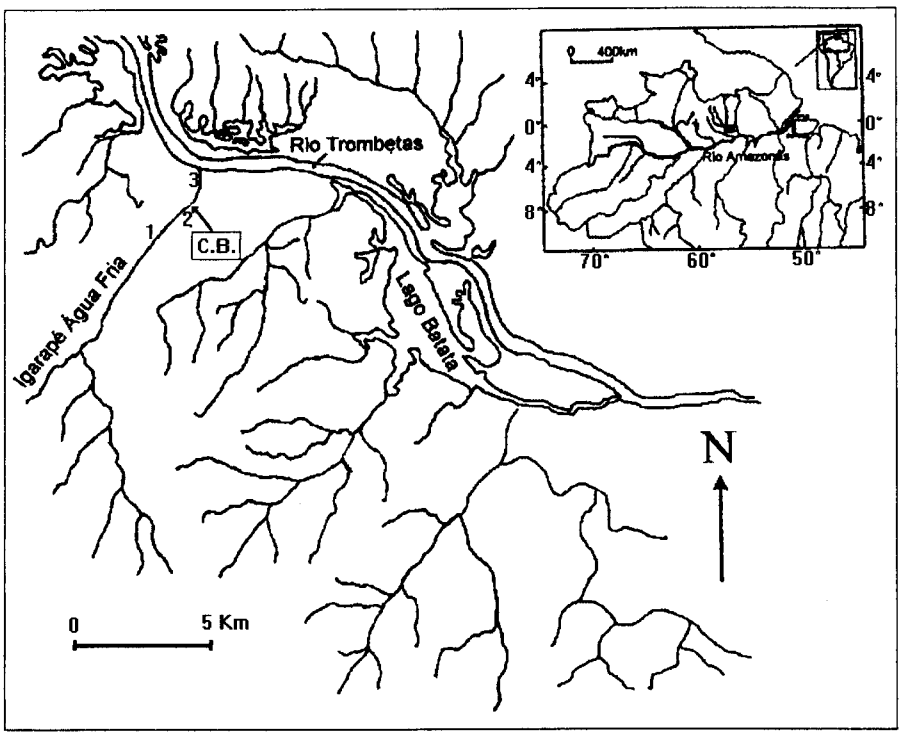

Fig. 1. Location of igarapé Água Fria and the respective sampling stations (C.B. = catchment basin for bauxite tailings).

to be an important factor altering the characteristics of these ecosystems (Callisto, 1996, 1997; Callisto et al., 1998). In many aquatic ecosystems of the Rio Trombetas drainage basin, changes in sediment particle size has been responsible for drastic ecological changes in the benthic macroinvertebrate communities (Callisto and Esteves, 1995, 1996a, b). Large variations in water level in these systems are also strongly related to the flood pulse of the Rio Trombetas.

The Amazonian igarapés are ecologically highly fragile (Callisto et al., 1998) because of their characteristic acid pH and low concentrations of C, N, and P in the sediments. Inputs of energy (e.g., allochthonous organic matter) or material of human origin can cause changes in their structure and function, resulting in unpredictable ecological changes, and in extreme situations, may entirely eliminate benthic macroinvertebrates (Callisto, 1996).

The objective of this study was to investigate the impact of bauxite tailings on the occurrence and seasonal distribution of the benthic macroinvertebrates, with emphasis on the larvae of Chironomidae (Insecta: Diptera).

Study Area

The Igarapé Água Fria is situated at 1°28′S and 56°19′W, near Porto Trombetas in the municipality of Oriximiná, State of Pará, central Amazonia, Brazil (Fig. 1). The Igarapé Água Fria is characterized by acid waters, low specific conductance, un-

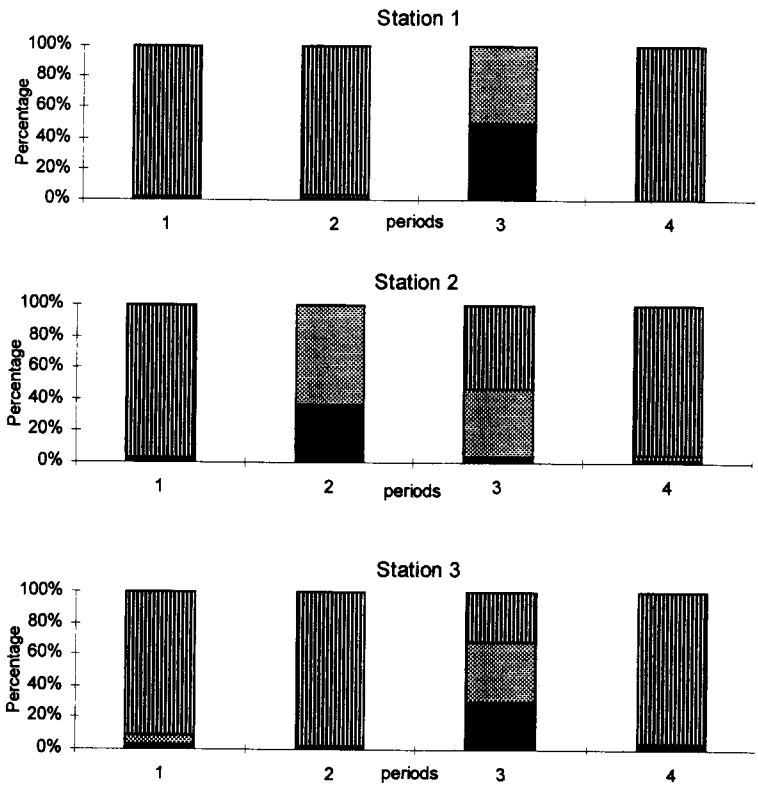

Fig. 2. Distribution of sand ( ), silt ( ) and clay ( ) in the sediments of Igarapé Água Fria. (1: rainy 1994; 2: dry 1994; 3: rainy 1995; 4: dry 1995).

detectable total alkalinity, and extreme variations in water level between the rainy and dry seasons (Callisto et al., 1998). Sediments are poor in C, N, and P compared to other lotic systems in the region, and composed of silts and clays during the rainy season, and sand during other times of the year (Fonseca et al., 1998a) (Fig. 2).

Adjacent to the Igarapé Água Fria is a catchment basin for bauxite tailings. This catchment basin is used as storage for runoff from the industrial area. The tailings, because of their fine particle size, have been gradually transported along the igarapé as water levels fluctuate during the rainy and dry seasons.

This study was conducted during the rainy season (May–June) and the dry season (October–November) in 1994 and 1995. Station 1 was located in the main bed of the igarapé, about 500 m upstream from its point of confluence with the Rio Trombetas. Station 2 was located 50 m from the main body of the igarapé, at the intersection between the igarapé and the spillway of a containment basin for residues from bauxite washing. Station 3 was located at the mouth of the igarapé at the Rio Trombetas.

The water column became thermally stratified during the rainy seasons of both years. At those times, the water of the Rio Trombetas effectively dammed the water of the igarapé. As a result, the depth of the river increased, thereby extensively flooding areas of the adjacent igapó (cyclically inundated forest).

Table 1. Abiotic variables of the water column and sediment at Stations 1, 2, and 3 in the Igarapé Água Fria during the rainy seasons and the dry seasons of 1994 and 1995. (n.d. = not detected).

	1994						1995					
	Station 1		Station 2		Station 3		Station 1		Station 2		Station 3	
Variable	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Depth (m)	7.7	0.8	6.4	1.6	8.8	2.3	5.8	0.2	4.6	0.1	3.0	0.4
Secchi disk (m)	1.7	0.8	1.2	1.2	2.0	1.7	1.4	0.2	0.8	0.1	1.3	0.3
Water temperature (°C)	25.5	31.0	25.4	26.5	25.3	28.0	24.9	30.0	25.5	33.4	26.8	27.6
pH	4.6	3.9	4.7	4.4	4.7	4.5	4.4	4.5	5.2	3.6	6.0	4.4
Specific conductivity (µS/cm)	13.0	55.5	12.3	17.2	10.4	17.8	60.0	13.5	13.0	92.0	10.0	11.5
Total alkalinity (mEq/lCO_2)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	10.4	n.d.
Dissolved oxygen (% sat.)	15.1	79.2	11.9	61.3	7.7	69.1	97.2	88.7	98.9	102.3	102.9	86.3
Total organic carbon (mmol/g)	11.7	0.4	27.5	19.8	0.9	0.5	17.5	0.3	0.1	0.2	1.8	1.8
Total nitrogen (mmol/g)	4.4	0.6	2.8	6.4	0.6	0.6	0.7	0.04	0.05	0.04	0.09	0.06
Total available phosphorus (µmol/g)	2.0	0.4	0.4	3.1	1.9	0.3	1238.2	23.5	15.9	8.2	49.5	22.0

The tailings from the containment basin adjacent to the Igarapé Água Fria contain more than 98% clays smaller than 1 mm (Callisto and Esteves, 1996b). These clay particles are responsible for increasing water turbidity. The tailings also cause an increase in water temperature because they absorb solar radiation. Sediment laden water often reaches temperatures about 5°C higher than the igarapé water. The temperature difference between the igarapé and water currents present in the containment basin favor transport of bauxite tailings along the water surface. During the period of declining water levels in the Rio Trombetas, a drastic reduction of more than 7 m in the water level of the igarapé occurs, followed by the flow of large amounts of tailings into the main igarapé. Sedimentation of some tailings at Station 3 occurs before the remaining tailings reach the Rio Trombetas.

Materials and Methods

Sediments and benthic macroinvertebrates were collected twice; each time 60 sample units with a 0.025 m^2 core sampler, at the three sample stations in the rainy and dry seasons of 1994 and 1995. Analyses were restricted to the upper 10 cm of the core. In the laboratory, the samples were washed through 1.00 and 0.50 mm mesh sieves, sorted using a stereomicroscope, and the organisms preserved in 70% ethanol. For taxonomic identification, the chironomid larvae were prepared as previously reported (Callisto et al., 1996), and the remaining organisms according to Merritt and Cummins (1988). Granulometric composition of unsieved samples was determined according to Suguio (1973).

Water samples were collected about 10 cm above the bottom with a Van Dorn bottle sampler. Temperature was measured with an electronic thermometer to a precision of 0.1°C. Water transparency was measured with a Secchi disc. Specific conductivity and pH of the water column were measured with portable DIGIMED conductivity and pH meters, respectively. Total alkalinity was determined by the Gran method as modified by Carmouze (1994). Dissolved oxygen was determined by the Winkler method as modified by Golterman et al. (1978). All data were gathered prior to 11 A.M.

Results and Discussion

General observations

Igarapé Água Fria is characterized by having acid water, warm temperatures (24.9–33.4°C), low specific conductivities (10.4–92.0 µS/cm) and zero total alkalinity. However, dissolved oxygen concentrations, total organic carbon, total nitrogen and total available phosphorus varied widely between 1994 and 1995 (Table 1). The benthic macroinvertebrate community, because of frequent overflows of silt and clay materials from the catchment basin, was strongly affected in the adjacent igarapé (Stations 2 and 3). In this area of the igarapé, the presence of bauxite tailings altered the sediment characteristics. As a result, the sediment at Station 2 was similar to other areas of the Rio Trombetas drainage basin affected by bauxite tailings, having a high content of silts and clays and low concentrations of available P, total N, and organic C. These changes were reflected in the chironomid fauna which disappeared from that part of the lake during the 1995 rainy season. The oscillations of the C, N, and P contents in the sediment can be attributed to large variations in water levels in this ecosystem that parallel the oscillations of the flood pulse of the Trombetas River, to which the igarapé is permanently connected. Flooding of the adjacent

Table 2. Densities (individuals/m²) of benthic macrofauna in the Igarapé Água Fria during the rainy seasons and the dry seasons (in parentheses) of 1994 and 1995.

Taxa	1994						1995					
	Station 1		Station 2		Station 3		Station 1		Station 2		Station 3	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Nematoda							16					
Oligochaeta	16	24				8	48	32			48	8
Ostracoda				8								
Cladocera				8								
Hydracarina				8								
Order Ephemeroptera												
Family Polymitarcyidae												
Campsurus sp.				16		24			8		80	
Family Caenidae				16								
Order Odonata												
Family Libellulidae										8		
Order Diptera												
Family Chaoboridae												
Genera 1	136	8	176				36		64		24	
Genera 2	104		144				36					
Family Ceratopogonidae		8										
Family Chironomidae												
Alotanypus						24						
Ablabesmyia				8							8	
Labrundinia		8										
Monopelopia (?)				8								
Djalmabatista				32		8						
Tanypus				16							32	
Chironomus		168		16			8					
Cladopelma		24		24								
Endochironomus								8				
Goeldichironomus	8	32		16		24						
Parachironomus		272		16								
Polypedilum (*Polypedilum*)	8	56	8			16						56
Polypedilum (*Tripodura*)						32						
Polypedilum		32		64								
Tanytarsini several genera		112	16	64		8	8				16	16
Total density (ind./m²)	272	744	344	320	0	144	152	40	72	8	208	80

"igapó", periodically inundated forest, contributes to increases in the input of allochthonous organic matter as observed in other floodplain systems (Junk et al., 1989; Bonetto et al., 1994).

During the rainy seasons of 1994 and 1995, the highest densities of chaoborid larvae belonging to two genera were recorded at Stations 1 and 2 (Table 2). This increase in density may be related to the low dissolved oxygen concentrations at the bottom of the water column which most likely resulted from thermal stratification. The water column varied 5°C from top to bottom. Chaoborid larvae migrate daily into the water column, alternating between a planktonic and a benthic habitat (Callisto and Esteves, 1996a). Chaoborids are also negatively phototactic and remain at the bottom during the day seeking out areas of low light penetration (Green, 1972; Strixino, 1973). Preliminary taxonomic sampling of chaoborid imagoes identified the occurrence of *Sayomyia, Lutzomiops*, and *Corethrella* in the Igarapé Água Fria (S. J. Oliveira, pers. comm.).

Larvae of the ephemeropteran *Campsurus* sp. (Polymitarcyidae) also were recorded at Stations 2 and 3. The larvae of the benthic *Campsurus* are preferentially distributed in soft silt-clay substrates (Callisto and Esteves, 1996a). The occurrence of *Campsurus* at these sites indirectly suggests the existence of changes in sediment granulometry (Callisto, 1996; Callisto et al., 1998). In earlier investigations, this taxon was found in high densities and biomass in the area impacted by bauxite tailings in Lake Batata (in the Rio Trombetas drainage basin), but was absent from the natural (unimpacted) areas of that lake (Callisto, 1994; Callisto and Esteves, 1995, 1996a; Fonseca et al., 1998b). The occurrence of this organism is an indication of environmental deterioration resulting from activities associated with bauxite mining in the Porto Trombetas area.

Chironomid diversity

It has been recognized since the 1960's that the Amazon region possesses an extremely rich chironomid fauna composed of approximately 1000 species belonging principly to the subfamily Chironominae (Fittkau, 1971). One of the most dominant group of chironomids in Igarapé Água Fria, the genus *Polypedilum*, is particularly species rich in the Amazon (Bidawid and Fittkau, 1995); however, the larvae of most species remain unknown. Members of the tribe Tanytarsini that were collected in the Igarapé Água Fria, could not even be identified to the generic level suggesting that they belong to the many yet undescribed, endemic species of the region (Fittkau and Reiss, 1973).

By contrast, the subfamily Orthocladiinae was absent from the benthic fauna collected in Igarapé Água Fria. This subfamily is relatively abundant in polar and high-altitude regions with their numbers gradually decreasing toward the equator, with few species found in Amazonia (Fittkau and Reiss, 1973).

Nessimian and Sanseverino (1995) found a negative correlation between the occurrence of *Goeldichironomus* spp. larvae and dissolved oxygen content in a marsh located between sand dunes in northern Rio de Janeiro State. In the present investigation, hemoglobin-containing *Goeldichironomus* larvae were found together with larvae of Chaoboridae. Our data suggest a positive relationship between the occurrence of these organisms and the low dissolved oxygen concentration at the sediment-water interface at the sampling stations. Low dissolved oxygen levels could also explain the odor of hydrogen sulfide (H_2S) detected during collection of sedi-

ment samples. H_2S is extremely toxic to benthic macroinvertebrates, and red chironomid and chaoborid larvae are most resistant to low oxygen levels and the presence of toxic gases (Ward, 1992). The presence of hemoglobin in larvae of *Goeldichironomus* and the vertical migratory capability of chaoborids are probably adaptive strategies for such conditions.

The data obtained in this investigation corroborate the information previously reported regarding aquatic ecosystems near the bauxite mining operations in the Rio Trombetas drainage basin (Callisto and Esteves, 1995, 1996a). Investigations focusing on benthic macroinvertebrate communities in lotic (e.g., igarapés and the Rio Trombetas) and lentic ecosystems (e.g., Lake Batata) have shown that drastic alterations in the granulometric composition are the principal factor causing ecological changes (Callisto and Esteves, 1996b; Callisto et al., 1998). The siltation of this aquatic ecosystem is directly reflected in changes in the benthic macroinvertebrate assemblages of the igarapé. The results from this study emphasize the role of benthic macroinvertebrates as indicators of the degree of ecological degradation in these aquatic ecosystems, especially in the Igarapé Água Fria.

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