Limnetica, 38(2): 575-586 (2019). DOI: 10.23818/limn.38.33

Aquatic insects as bioindicators of heavy metals in sediments in Cerrado streams

Renata de Moura Guimarães Souto[1,*], Juliano J. Corbi[2] and Giuliano Buzá Jacobucci[3]

[1] Programa de Pós-Graduação em Ecologia e Conservação de Recursos Naturais, Universidade Federal de Uberlândia – UFU. Rua Ceará, s/n, Bloco 2D, Bairro Umuarama, CEP 38408-100, Uberlândia, MG, Brazil.
[2] Departamento de Hidráulica e Saneamento (SHS), Escola de Engenharia de São Carlos, Universidade de São Paulo – USP. Av. Trabalhador Sãocarlense, 400, CP 359, CEP 13566-590, São Carlos, SP, Brazil.
[3] Instituto de Biologia, Universidade Federal de Uberlândia – UFU. Rua Ceará, s/n, Bloco 2D, Bairro Umuarama, CEP 38408-100, Uberlândia, MG, Brazil.

[*] Corresponding author: guimaraesrm@gmail.com

Received: 10/06/17 Accepted: 11/06/18

ABSTRACT

Aquatic insects as bioindicators of heavy metals in sediments in Cerrado streams

Aquatic insects are the most widely used organisms in freshwater biomonitoring of human impacts and can provide reliable information on habitat and water quality. The Brazilian Cerrado has received strong anthropogenic impacts over the last decades, including the massive use of fertilizers in agriculture containing different concentrations of metals, with high potential of aquatic ecosystem contamination. In this context, this paper compared bioaccumulation of heavy metals among four trophic groups of aquatic insects from Cerrado streams. Sampling of sediments and aquatic insects for metal analysis (Cu, Mn, Cd and Zn) and for the bioaccumulation factor (BAF) calculation was performed from April to July, 2012. All metals were found in the stream sediments. Analysis of variance (ANOVA) showed no differences in metal concentrations among feeding guilds for Zn and Cu ($F_{3,8} = 0.045$; $p > 0.005$; $H = 4.641$; $p > 0.005$ respectively). With respect to manganese, the predators accumulated significantly lower concentrations than collector gatherers ($F_{3,8} = 20.416$; $p < 0.05$, Tukey < 0.05). Cadmium was not detected in the fauna. The results of the present study suggested that the use of aquatic insects as bioindicators might be an important strategy to detect metal pollution in aquatic environments.

Key words: benthic macroinvertebrates, bioaccumulation, metal pollution, functional trophic groups, sediments

RESUMO

Insetos aquáticos como bioindicadores de metais pesados em sedimentos em córregos de Cerrado

Os insetos aquáticos são os organismos mais utilizados no biomonitoramento de ecossistemas aquáticos e podem fornecer informações confiáveis sobre o habitat e a qualidade da água. O Cerrado brasileiro recebeu fortes impactos antrópicos nas últimas décadas, incluindo o uso intenso de fertilizantes na agricultura contendo diferentes concentrações de metais pesados, com alto potencial de contaminação aquática. Neste contexto, este trabalho comparou a bioacumulação de metais entre quatro grupos tróficos de insetos aquáticos de córregos de Cerrado. A coleta de sedimentos e insetos aquáticos para análise de metais pesados (Cu, Mn, Cd and Zn) e para cálculo do fator de bioacumulação (BAF) foi realizada de abril a maio de 2012. Todos os metais foram encontrados nos sedimentos dos riachos estudados. A análise de variância (ANOVA) não mostrou diferenças de concentração de metal entre os grupos tróficos para zinco e cobre ($F_{3,8} = 0.045$; $p > 0.005$; $H = 4.641$; $p > 0.005$, respectivamente). Em relação ao manganês, os predadores acumularam concentrações significativamente mais baixas do que os coletores ($F_{3,8} = 20.416$; $p < 0.05$, Tukey < 0.0500). O cádmio não foi detectado na fauna. Os resultados do presente estudo sugerem que o uso de insetos aquáticos como bioindicadores pode ser uma estratégia importante para detectar a contaminação de metais em ambientes aquáticos.

Palavras chave: *macroinvertebrados bentônicos, bioacumulação, poluição por metais, grupos tróficos funcionais, sedimentos*

INTRODUCTION

The Cerrado is the second largest Biome in South America, occupying 22 % of the Brazilian territory, where the sources of the three major river basins of South America (Amazon/Tocantins, San Francisco and Prata) are found (MMA, 2013). The Brazilian Cerrado is considered a hotspot of biodiversity, which is a priority area to be conserved, since it presents high biodiversity and strong environmental impacts (Myers *et al.*, 2000).

The conversion of natural areas of Cerrado into agricultural fields, as well as the pollution and/or impoundment of waters, have reduced the occurrence of many species in the biome (Alho & Martins, 1995; Corbi & Trivinho-Strixino, 2017). The use of fertilizers, containing different concentrations of metals such as lead, nickel, chromium, cadmium, aluminum and zinc (Angelotti-Netto *et al.*, 2004) in different kinds of agriculture cultivation, in addition to the deforestation of riparian vegetation, have caused impacts on the water resources of the adjacent areas, leading to the contamination of the aquatic sediments as pointed out by Corbi *et al.* (2008; 2010; 2013; 2018).

Several studies conducted in contaminated aquatic systems have reported a correlation between the concentration of metals in sediment and in the resident fauna (Pourang, 1996; Solà *et al.*, 2004; Murphy & Davy-Bouker, 2005; Solà & Pratt, 2006; Dural *et al.*, 2006; Corbi *et al.*, 2011) as a result of bioaccumulation and biomagnification processes (Corbi *et al.*, 2010). Toxic effects of metals can occur at the individual level, for example, increasing mortality of sensitive species and also changing other vital processes such as growth and reproduction (Casper, 1994; Amisah & Cowx, 2000; Chanu, *et al.*, 2017).

Aquatic insects represent 90 % of aquatic invertebrate fauna, and they are essential elements in lentic and lotic trophic webs, influencing energy flow and nutrient cycling (Ferrington, 2008; Strayer, 2013; Nicacio & Juen, 2015).

Patterns of diversity and distribution of aquatic insects can be related to several factors in the aquatic environment, such as type of substrate, water flow, organic matter availability, oxygen concentration as well as environmental conditions surrounding the watercourse (Ward *et al.*, 1995; Buss *et al.*, 2004). Other factors besides those related to the local aquatic environment might also interfere in the distribution of the macroinvertebrates, such as dispersion processes, watercourse size (scale) and latitudinal gradients (Heino *et al.*, 2003; Johnson *et al.*, 2004; Soininen *et al.*, 2004; Mykrä *et al.*, 2007; Molozzi *et al.*, 2012).

Because aquatic insects reflect environmental changes, these organisms and other benthic invertebrates are the most widely used organisms in freshwater biomonitoring of human impact and can provide reliable information on habitat and water quality in different approaches from the suborganismal to the ecosystem level (Bonada *et al.*, 2006; Woodcock & Huryn, 2007; Corbi *et al.*, 2013; Strayer, 2013; Ceneniva-Bastos *et al.*, 2017).

Aquatic insects can be considered sentinels in aquatic environments and are highly suitable to be used in biomonitoring programs of organic pollution (Zelinka & Marvan, 1961; Zamora-Muñoz & Alba-Tercedor, 1996) and heavy metals (Winner *et al.*, 1980; Poulton *et al.*, 1995; Smolders *et al.*, 2003). In watercourses polluted by metals, species richness and diversity of benthic macroinvertebrate communities can be reduced by direct and indirect impacts of contaminants (Gray, 1989; Winner *et al.*, 1975; Smolders *et al.*, 2003; Carter *et al.*, 2017). Oligochaetes, chironomids, and Hydropsychid caddisflies are relatively tolerant to metal, whereas some genera of Ephemeroptera, mainly within the family Heptageniidae, are considered highly sensitive to metals (Winner *et al.*, 1980; Clements *et al.*, 2000).

For a given metal, the uptake proportions of water and food by insects will depend both on the bioavailable concentration of the metal associated with each source and the mechanism and rate by which the metal enters the insect bodies. Besides this, the quantities of metals accumulated by an individual reflect the net balance between the rate of metal influx from both dissolved and particulate sources and the rate of metal efflux from the organism (Hare, 1992).

In this sense, metal bioaccumulation can also be related to the trophic level of the aquatic insects considered. Studies conducted by Santoro *et al.*, (2009) and Corbi *et al.*, (2010) showed high bioaccumulation in collector organisms, suggesting that biological absorption through immediate contact with the sediment is the most effective form of metal contamination. On the other hand, bioaccumulation of metals could occur in a cascading process with higher concentrations in organisms at higher trophic levels, such as fishes and other vertebrates (Hamilton & Buhl, 2004).

Considering the ecological and biomonitoring relevance of aquatic insects, it is important to identify more specific aspects in relation to the bioaccumulation process, which can occur in diverse ways for different trophic groups. However, a comparative study of metal bioaccumulation considering all trophic functional feeding groups (filter feeders, collector-gatherers, predators and shredders) of aquatic insect fauna occurring in the Cerrado is not yet available in the literature. Thus, the aim of this paper is to compare the bioaccumulation among four feeding guilds of aquatic insects that occur in tropical Cerrado streams contaminated by metals, under the hypothesis that there is higher bioaccumulation of heavy metals in the collectors, as obtained by Santoro *et al.* (2009) when evaluating this theme in the functional trophic groups of temperate regions.

MATERIALS AND METHODS

Study area

The study was performed in low order streams (Marimbondo, Sucupira Cassu and Capim Branco; among these, the first two are first order streams) in the Triângulo Mineiro region, Minas Gerais state, Brazil (Fig. 1). The local climate is tropical and, according to the Köppen climate classification, is of Aw type, megathermic, with summer rains between October and March and winter drought from April to September.

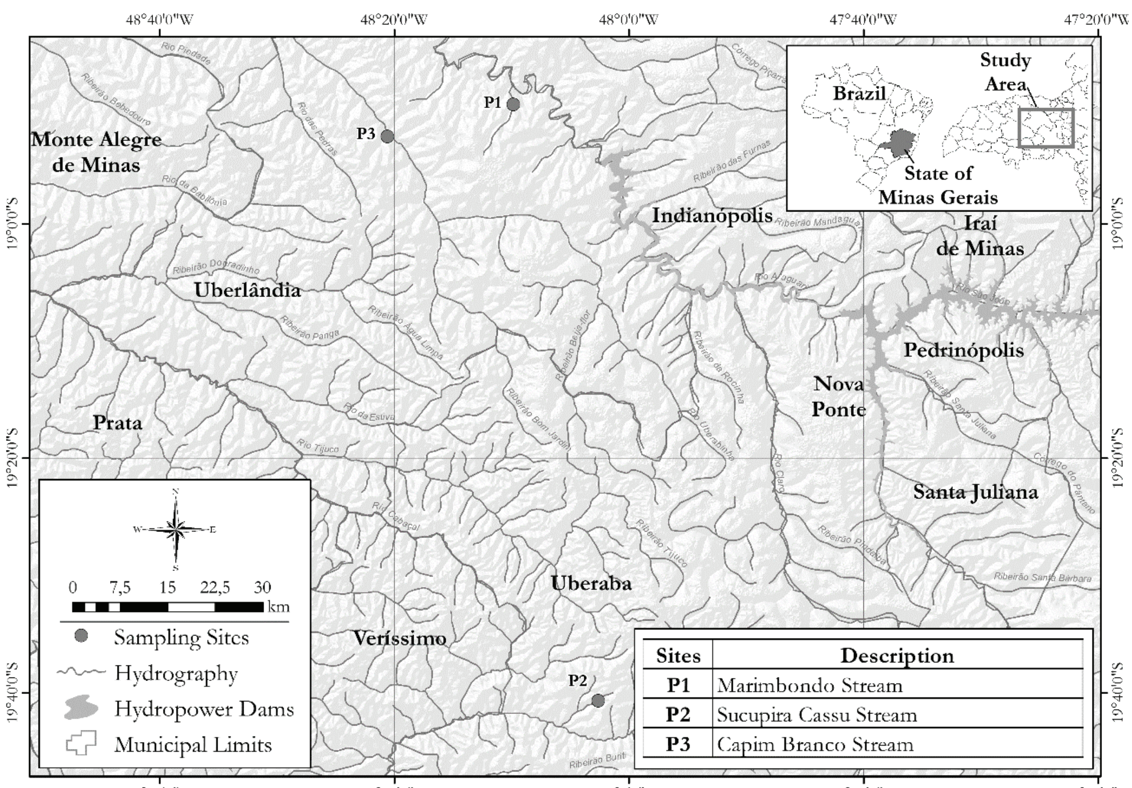

Figure 1. Location of sampling sites. *Localização dos pontos amostrais.*

The Triângulo Mineiro region was marked by extensive cattle ranching until the end of the 60s. In the late 70s, soybean cultivation was introduced. The flat topography and the ease of access to limestone deposits in the area were factors that favored agricultural expansion and with it, the intense use of pesticides. Tax incentives also stimulated pine and eucalyptus plantation (Schneider, 1996). More recently, large areas of the region have been dedicated to sugarcane cultivation (Brito & Dos Reis, 2012).

All streams are very similar in physical structure and local land use. They present low water velocity (< 1 m/s), shallow depth (< 1 m), small width (< 1.5 m) and have predominantly sand and fine gravel substrates. They are located in agriculture and pasture areas and are free from other anthropogenic impacts such as industrial, domestic or mining activities.

Sampling and storage

Sediments for metal analysis (Cu, Mn, Cd, Zn) were sampled, in triplicate, from the three sites and were collected from April to July 2012. Sediments were frozen until testing. Aquatic insects were collected in the same period using a D-frame aquatic net (mesh sieve 250 µm) and sampled exhaustively until there was enough biomass for metal analysis. Each sample, from each food guild, consisted of 0.1 g (dry weight), and three samples from each guild were collected in each of the three sampled streams. Three streams were considered for fauna collection in order to obtain a sample size sufficient for statistical analysis.

Insects captured in the net were transferred to polypropylene bags and stored in ice during transportation to the laboratory. Then, they were identified and frozen until analysis. Three sediment sub-samples were collected from the streams for organic matter analyses.

Analytical procedures

Sediment samples for metal determination were lyophilized and homogenized with a pestle and mortar. Each of the weighed samples, of approximately 3.0 g, were placed in 100 mL beakers, to which 5.0 mL of HNO3 and 5.0 mL of distilled water was added and digested to near dryness at 90 ºC on a hotplate. The digested samples were filtered - after cooling - through filter papers and collected in 100 mL beakers. The filter papers (filters Whatman 42) were washed with 20 mL of distilled water and the contents of the beakers were transferred to 100 mL volumetric flasks. The solutions were analyzed for metals in a PyeUnicam flame atomic absorption spectrophotometer. Digestion and detection were undertaken in triplicate (Corbi *et al.*, 2010).

Frozen insects were lyophilized and homogenized with a pestle and mortar. Aquatic insects were pooled to obtain at least 0.10 g of dry weight, and then placed in a 100 mL beaker, in which 5.0 mL of HNO_3, 5.0 mL of distilled water and 1.0 mL of H_2O_2 was added and digested to near dryness at 90 ºC on a hotplate. Digested samples were cooled at room temperature, filtered using filter papers (and collected in 25 mL beakers). Pooled samples were analyzed by

Table 1. Concentration of metals in sediments: mean concentration values ± standard deviation (n = 3) (mg/Kg). *Concentração de metais em sedimentos: médias das concentrações ± desvio padrão (n-3) (mg/Kg).*

Metal/Streams	Marimbondo	Capim Branco	Sucupira Cassu
Zn	22.407±1.675	26.169±12.396	8.789±3.281
Cu	28.059±3.753	37.216±26.666	3.009±2.162
Mn	221.843±72.024	283.381±36.286	54.200±1.612
Cd	1.218±0.041	1.543±0.257	0.509 ± 0.88

Table 2. Stream macroinvertebrate community and the respective feeding guilds. *Comunidade de macroinvertebrados bentônicos e respectivas guildas alimentares.*

Collector gatherers (CG)	Filter feeders (F)	Shredders (SH)	Predator (P)
Ephemeroptera	**Trichoptera**	**Coleoptera**	**Megaloptera**
Baetidae	Hydropsychidae	Ptylodactilidae	**Odonata**
Caenidae		Pyralidae	Gomphidae
Leptophlebiidae			Libellulidae
			Protoneuridae

inductively coupled plasma-atomic emission spectrometry (ICP-AES). Digestion and detection were undertaken in triplicate. The detection limits were: Cd – 0.0002 mg/L; Cu – 0.001 mg/L; Mn – 0.0005 mg/L; Zn – 0.0004 mg/L (Corbi *et al.*, 2010).

Organic matter was determined by mass loss after ignition (550 ºC, 4 h) in dry fractions of sediments - dried in a stove at 60 ºC for 12 h – (Maitland, 1979).

Data analysis

We calculated the bioaccumulation factor (BAF), in order to test metal bioaccumulation in aquatic fauna (Klavins *et al.*, 1998). The bioaccumulation factor (BAF) is the ratio of the substance concentration in the body and the substance in the environment. It is considered bioaccumulation when metal concentrations in organisms are larger than the concentrations of the aquatic sediment. Thus, for values ≥ 1, bioaccumulation is accepted. The BAF is described by the following formula:

$$BAF = \frac{Organism\ metal\ concentration}{Sediment\ metal\ concentration}$$

To test differences in bioaccumulation of metals among different feeding guilds, Univariate Analysis of Variance and Tukey's t test were performed (in the condition of the data presenting variance homogeneity), using the Systat Software. In the absence of variance homogeneity, the Kruskal-Wallis test statistic was used. All differences were considered significant if $p < 0.05$.

RESULTS AND DISCUSSION

Metals in sediments

All metals were detected in the sediments but without significant concentration differences among streams (Zn: $F_{3,8} = 4.498$, $p > 0.0639$; Cu: $F_{3,8} = 3.8666$; $p = 0.0832$; Mn: $F_{3,8} = 1.1537$, $p = 0.3779$; Cd: $F_{3,8} = 2.9632$, $p = 0.1271$) (Table 1). The concentrations found can be considered relatively low when compared to the concentrations found by Corbi *et al.* (2010) in tropical streams located in areas under the influence of

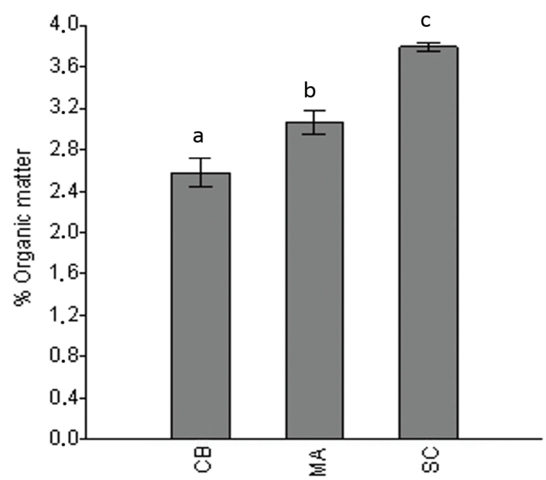

Figure 2. Mean values and standard deviation of organic matter in sediments – CB: Capim Branco Stream; MA: Marimbondo Stream and SC: Sucupira Cassu Stream. *Valores médios e desvio padrão da matéria orgânica nos sedimentos – CB: córrego Capim Branco; MA: córrego Marimbondo e SC: córrego Sucupira Cassu.*

agricultural crops - streams with absence of riparian vegetation. In our study, the three studied streams present relatively well conserved riparian vegetation (Gonçalves, 2012), which gives them some protection against the input of metals from the agricultural and livestock activities that occur in their surroundings, since, according to Lowrance *et al.* (1997), riparian forest provides effective control (buffer systems) in some types of agricultural watersheds.

The organic matter content was significantly different among streams ($F_{2,9} = 99.37$; $p < 0.001$) with levels ranging from 2.36 % (Capim Branco stream) to 3.85 (Sucupira Cassu stream) and the highest concentration was detected in Sucupira Cassu stream (Fig. 2). This is an important parameter because the amount of organic matter of the sediment influences metal absorption in the aquatic system (Rocha & Rosa, 2003).

Metals in aquatic insects

The aquatic insect communities were composed of four feeding guilds - filter feeders, collector buffer systems-gatherers, predators and shredders - in all streams (Table 2). Of the four metals analyzed, three (Cu, Mn and Zn) were detected in the aquatic fauna (Table 3).

The analysis of variance (ANOVA) showed no differences of metal concentrations among feeding guilds for Zn ($F_{3,8} = 0.045$; $p > 0.005$) and the Kruskal-Wallis One-way Analysis of Variance also showed no differences in metal concentrations among feeding guilds for Cu ($H = 4.641$; $p > 0.005$). For manganese, the predator species accumulated significantly lower concentrations than collector gatherers ($F_{3,8} = 20.416$; $p < 0.05$, Tukey < 0.0500) (Fig. 3).

In Sucupira Cassu stream, all metals bioaccumulated in the biota. Zinc was also bioaccumulated in the other streams and the bioaccumulation of manganese for Marimbondo stream was only observed in shredders (Table 4).

Similarly, Santoro *et al.*, (2009) and Besser *et al.* (2001), found metal bioaccumulation in benthic macroinvertebrates from several trophic groups. However, in our study bioaccumulation was mainly detected in the Sucupira Cassu stream, which had the highest values of organic matter. This show the importance of organic compounds in metal bioaccumulation process, as pointed by Rocha & Rosa (2003). It is known that

Table 3. Mean values ± standard deviation concentrations (n = 3) (mg/Kg) of metals in stream macroinvertebrate community. *Média ± desvio padrão das concentrações de metais em macroinvertebrados bentônicos.*

Trophic Functional Groups/ Site	Cd	Cu	Mn	Zn
Collector gatherers				
CB	nd	20.99 ±4.17	181.77 ± 33.14	85.25 ± 9.84
M	nd	17.66 ± 4.45	216.10 ± 50.21	84.09± 12.71
SC	nd	11.89±8.17	166.13 ± 50.33	79.45 ± 5.73
Filter feeders				
CB	nd	25.67 ± 2.50	150.02 ± 51.79	63.16 ± 12.53
M	nd	21.40 ± 1.37	179.90 ± 52.84	92.29 ± 4.93
SC	nd	8.10 ± 4.02	157.18 ± 20.88	92.31 ± 7.43
Shredders				
CB	nd	11.63 ±2.53	126.02 ± 43.97	73.83 ± 6.81
M	nd	11.37 ± 6.38	224.59 ± 11.29	74.53 ± 6.73
SC	nd	6.70 ± 3.95	160.67 ± 35.65	106.24 ± 1.39
Predator				
CB	nd	20.39 ± 4.26	113.47 ± 17.88	91.11 ± 10.39
M	nd	18.39 ± 4.59	101.16 ± 18.19	73.08 ± 4.35
SC	nd	16.77 ± 7.66	70.62 ± 1.92	94.37 ± 11.27

*CB: Capim Branco Stream; MA: Marimbondo Stream and SC: Sucupira Cassu Stream.

metal availability is related to the kind of chemical compound in which it is present, and the bioavailable fraction could varies depending on the environmental characteristics (Rocha & Rosa, 2003; Corbi *et al.*, 2006).

Unlike Santoro *et al.* (2009) and Corbi *et al.* (2010), who found significantly high metal concentrations in collectors, our study, considering other functional trophic groups, pointed to different patterns of bioaccumulation depending on the metal analyzed. We could consider that the distinctive level of bioaccumulation may not only be related to the feeding guilds, but also to the specific characteristics of each family, genus or even species of aquatic insects.

Metal accumulation could be related, for example, to specific metabolism, since the processes that affect the toxicity and the bioaccumulation can differ between species and some can regulate the bioaccumulation of some metals by absorption and loss, maintaining low concentrations of intracellular metals, thus preventing the toxicity of the metal (Cain, 2004).

Another issue to consider is that metal accumulation could be related to specific diet differences. Goodyear & Macnell (1999) indicated consistent variation in the diet of species of a feeding guild. Hare (1992) addresses an important example: the broad "predator" category includes insects that (1) consume their prey whole (including gut contents and exoskeleton, e.g. some Trichoptera) or (2) pierce their prey and suck only internal parts, for example, Hemiptera. Both the metal content of the food consumed and the efficiency of metal assimilation by the two types of predators are likely to differ, potentially affecting metal accumulation. Supporting this line of thought, the research of Cain *et al.*, 2004 showed high concentrations of metals in two herbivore and detritivore species of Ephemeroptera, while in a third herbivore species (*Baetis* spp.) relatively low concentrations of Cu were found, thus depicting the difficulty in assigning metal bioaccumulation standards based on functional food category, since differences in bioaccumulation of rate metals at the same trophic level may be a consequence of differences in eating habits.

Another hypothesis for explaining patterns of accumulation was proposed by Smock (1983), who predicts that accumulation of metals in aquatic invertebrates decreases with the increase of body size. Corroborating these results, Kiffney & Clements (1994) observed variation in effects of metals among species and life stages of Ephemeroptera, with younger stages showing high sensitivity. According to Powlesland & George (1986), the highest initial lipid content or a high specific metabolic rate facilitates the absorption of toxic substances. Considering this

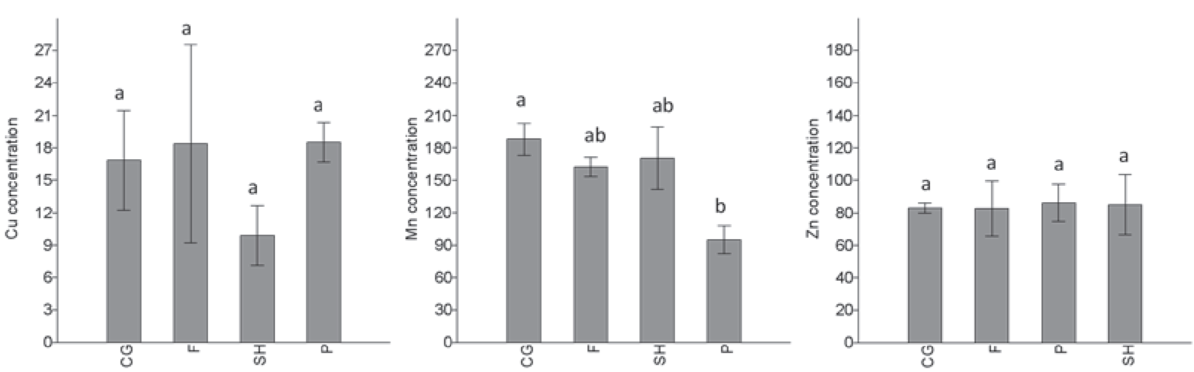

Figure 3. Values of metal concentrations (mg/Kg) in functional trophic groups of benthic macroinvertebrates (n = 3). CG- Collector Gatherers; F – Filter feeders; SH- Shredders and P- predator. a – Copper; b –Manganese; c – Zinc (data pooled up from all the streams) * Means followed by the same letter do not differ significantly. *Valores da concentração de metais (mg/Kg) em grupos tróficos funcionais de macroinvertebrados bentônicos (n = 3). CG- Coletores catadores; F – Filtradores; SH- Fragmentadores e P- predadores. a – Cobre; b –Manganês c – Zinco (dados agrupados de todos os riachos). * Médias indicadas pela mesma letra não diferem significativamente.*

reasoning, in a study like ours in which the main objective is to compare the bioaccumulation of metals in different feeding guilds, it would be necessary to standardize the larval instar of the organisms considered for the analysis.

Also, regarding bioaccumulation (BAF > 1), it was observed that accumulation of zinc by fauna was quite distinct. Besser *et al.* (2001), who studied the bioavailability of metals in the food chain, also found high concentrations of zinc in benthic fauna compared to other metals. Zinc is an essential element in small quantities for plants and animals, according to Wood's (1974) classification.

In the present study, manganese was less efficiently transferred to upper trophic levels, so predators had significantly lower concentrations of this metal than the other trophic groups, whereas zinc and copper showed high transfer efficiency among trophic levels. In the same way, Besser *et al.* (2001) found wide variation in the bioaccumulation of different metals in aquatic invertebrates, suggesting that the routes of exposure for the biota differ among different metals.

The high bioaccumulation of zinc, copper and manganese by aquatic insects reflects the sensitivity of these organisms and also points to possible sub-lethal effects in the aquatic fauna – when in high concentrations in the environment - such as the occurrence of morphological, physiological, biochemical, behavioral and reproductive changes in the organisms (Connell & Miller, 1984). As an example, a study conducted by Wentsel *et al.* (1977) pointed to the reduction and delay in adult emergence of *Chironomus* larvae exposed to sediments containing high concentrations of Cd, Zn and Cr. Sildanchandra & Crane (2000) also showed a reduction in the weight of *C. riparius* larvae as well in the survival, growth, development and emergence when exposed to high concentrations of Cd. In the study conducted by Ducrot *et al.* (2004), when *Chironomus riparius* larvae were exposed to different concentrations of copper, disturbances in reproduction were observed, with reduction in the number of eggs. These effects may have consequences not only for the community of aquatic insects, but also for higher trophic levels such as fish, amphibians and birds that feed on these organisms. Another issue to be considered is the possibility that the metals accumulated by insects in the aquatic phase migrate to the terrestrial phase (Rossaro *et al.*, 1986). Thus, there might be also implications in the adult ecology and the metal transfer to upper trophic levels in terrestrial food chains. These are issues that require attention from the scientific community since the expectation is that by 2025, demand for fertilizers in Brazil will grow more than twice the world aver-

Table 4. Bioaccumulation Factor (BAF) for benthic macroinvertebrate samples from streams. Values correspond to the ratio of metals concentration in the fauna and metals concentration in the sediment (mg/Kg). *Fator de Bioacumulação (BAF) nos macroinvertebrados bentônicos. Valores correspondem à razao da concentração de metais na fauna e nos sedimentos (mg/Kg).*

	Cu	Mn	Zn
Capim Branco			
CG	0.564051	0.641441	3.257667
F	0.68965	0.529404	2.413856
SH	0.312402	0.444722	2.821188
P	0.548125	0.400423	3.481881
Marimbondo			
CG	0.629587	0.974149	3.753028
F	0.762777	0.810973	4.11905
SH	0.405248	1.012398	3.326197
P	0.655616	0.455989	3.261484
Sucupira Cassu			
CG	3.953104	3.065146	9.040051
F	2.691618	2.900045	10.50249
SH	2.227759	2.964336	12.0869
P	5.574032	1.302893	10.73628

*CG: collector gatherers; F: filter feeders;
SH: shredders and P: predator.

age (Vale, 2014) placing the watercourses of the Cerrado (sites of remarkable biodiversity) at the center of a disturbing environmental scenario.

Considering the results of the present study and many others concerning metal accumulation in streams, the use of aquatic insects as bioindicators could be an important complementary strategy to detect metal pollution in aquatic environments in a more realistic way. However, this study brings to light that the process of bioaccumulation of metals in aquatic insects in tropical streams is complex to understand and involves many aspects, like physiological, morphological and ecological aspects, and demands more investments in research with a toxicological focus (in the field and in the laboratory), so that the responses of different species to the exposure of different metals can be known.

It will help to create a database to generate a model that allows the prediction of bioaccumulation of metals in communities of invertebrates under certain concentrations of metals in water and sediments. This predictive model could help us to develop a national freshwater metal monitoring program, especially in waters under the influence of agriculture, and would be a valuable tool for preventive and remediation actions.

ACKNOWLEDGEMENTS

We thank CAPES for granting a PhD scholarship to R. M. G. S.

REFERENCES

ALHO, C. J. R. & E. S. MARTINS. 1995. Cerrado – impactos do processo de ocupação. In: *De grão em grão o cerrado perde espaço*, Alho, C. J. R. & E. S. Martins (eds.): 369-382. World Wildlife Fund (WWF) e Sociedade de Pesquisas Ecológicas do Cerrado, Brasília, Brasil.

AMISAH, S. & I. G. COWX. 2000. Impacts of abandoned mine and industrial discharges on fish abundance and macroinvertebrate diversity of the upper River Don in South Yorkshire, UK. *Journal of Freshwater Ecology*, 15: 237-250. DOI: 10.1080/02705060.2000.9663741

ANGELOTTI-NETTO, A., S. CRESTANA, S. C. DE OLIVEIRA & R. V. R. BARBOSA. 2004. Metais pesados provenientes de atividade agrícola: formas, prevenção e controle. In: *Bacia hidrográfica*. Espíndola, E. L.G. & E. Wendland (eds.): 1-14. Rima Editora, São Carlos, Brasil.

BESSER, J. M., W. G. BRUMBAUGH, T. W. MAY, S. E. CHURCH & B. A. KIMBALL. 2001. Bioavailability of metals in stream food webs and hazards to brook trout (*Salvelinus fontinalis*) in the upper Animas River watershed, Colorado. *Archives of Environmental Containation and Toxicology*, 40: 48-59. DOI: 10.1007/s002440010147

BONADA, N., N. PRAT., V. H. RESH. & B. STATZNER. 2006. Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annual Review of Entomology*, 51: 495-523. DOI: 10.1146/annurev.ento.51.110104.151124

BRITO, J. L. S. & L. N. G. DOS REIS. 2012. Mapeamento das áreas de conversão do uso da terra para cana-de-açúcar na mesorregião do Triângulo Mineiro/Alto Paranaíba-MG por meio de imagens TM/Landsat. *Revista Caminhos da Geografia*, 13(41): 170-186.

CAIN, D. J., S. N. LUOMA & W. G. WALLACE. 2004. Linking metal bioaccumulation of aquatic insects to their distribution patterns in a mining-impacted river. *Environmental Toxicology and Chemistry*, 23: 1463-1473. DOI: 10.1897/03-291

CARTER, J. L., V. H. RESH & M. J. HANNAFORD. 2017. Macroinvertebrates as Biotic indicators of Environmental Quality. In: Hauer, F. R., Lamberti, G. A. (Eds.), Methods in stream ecology: Volume 2: Ecosystem Function. Third Edition. Academic Press, San Diego, California, pp. 293-318.

CASPER, A. F. 1994. Population and community effects of sediment contamination from residential urban runoff on benthic macroinvertebrate biomass and abundance. *Bulletin of Environmental Contamination and Toxicology*, 53: 796-799. DOI: 10.1007/BF00196206

CENEVIVA-BASTOS, M., D. B. PRATES, R. M. ROMERO, P. C. BISPO & L. CASATTI. 2017. Trophic guilds of EPT (Ephemeroptera, Plecoptera, and Trichoptera) in three basins of the Brazilian Savanna. *Limnologica - Ecology and Management of Inland Waters*, 63: 11-17. DOI: 10.1016/j.limno.2016.12.004

CHANU, C. M., S. GUPTA & A. GUPTA. 2017. Acute toxicity of cadmium in *Anisops sardeus* (Heteroptera: Notonectidae): Effects on adult and nymphal survival and swimming behavior. *Ecotoxicology and Environmental Safety*, 145: 169–175. DOI: 10.1016/j.ecoenv.2017.07.026

CLEMENTS, W. H., D. M. CARLISLE, J. M. LAZORCHAK & P. C. JOHNSON. 2000. Heavy metals structure benthic communities in Colorado mountain streams. *Ecological Application*, 10: 626-638. DOI: 10.1890/1051-0761(2000)010[0626:HMSBCI]2.0.CO;2

CONNELL, D. W. & G. J. MILLER. 1984. *Chemistry and Ecotoxicology of Pollution*. John Wiley & Sons. New York. USA.

CORBI, J. J., S. TRIVINHO-STRIXINO, A. DOS SANTOS & M. DEL GRANDE. 2006. Diagnóstico ambiental de metais e organoclorados em córregos adjacentes a áreas de cultivo de cana-de-açúcar (estado de São Paulo, Brasil). *Química Nova*, 29(1): 61-65. DOI: 10.1590/S0100-40422006000100013

CORBI, J. J., S. TRIVINHO-STRIXINO & A. DOS SANTOS. 2008. Environmental evaluation of metals in sediments and dragonflies due to sugar cane cultivation in Neotropical streams. *Water, Air & Soil Pollution*, 195: 325-333. DOI: 10.1007/s11270-008-9749-1

CORBI, J. J., C. G. FROEHLICH, S. TRIVINHO-STRIXINO & A. DOS SANTOS. 2010. Bioaccumulation of metals in aquatic insects of streams located in areas with sugar cane cultivation. *Química Nova*, 3: 644-648. DOI: 10.1590/S0100-40422010000300030

CORBI, J. J., P. KLEINE & S. TRIVINHO-STRIXINO. 2013. Are aquatic insect species sensitive to banana plant cultivation? *Ecological Indicators*, 25: 156-161. DOI: 10.1016/j.ecolind.2012.09.020

CORBI, J. J. & S. TRIVINHO-STRIXINO. 2017. Chironomid species are sensitive to sugarcane cultivation. *Hydrobiologia*, 785: 91-99. DOI: 10.1007/s10750-016-2908-2

CORBI, J. J., C. G. A. GEROMEL-COSTA, V. COLOMBO, G. R. GORNI & L. RIOS. 2018. Environmental diagnosis of metals in streams near sugarcane cultivation areas: current and historical analysis in the central region of the State of São Paulo. *Anais da Academia Brasileira de Ciências*, 90(3).

DUCROT, V., A. R. R. PÉRY, R. MONS & J. GARRIC. 2004. Energy-based modeling as a basis for the analysis of reproductive data with the midge (*Chironomus riparius*). *Environmental Toxicology and Chemistry*, 23: 225-231. DOI: 10.1897/03-52

DURAL, M., M. Z. L. GÖKSU, A. A. ÖZAK & B. DERICI. 2006. Bioaccumulation of some heavy metals in different tissues of *Dicentrarchus Labrax* L, 1758, *Sparus aurata* L, 1758 and *Mugil Cephalus* L, 1758 from the Camlik Lagoon of the eastern cost of Mediterranean (Turkey). *Environmental Monitoring and Assessment*, 118: 65-74. DOI: 10.1007/s10661-006-0987-7

FERRINGTON, L. C. 2008. Global diversity of non-biting midges (Chironomidae; Insecta-Diptera) in freshwater. *Hydrobiologia*, 595: 447-455. DOI: 10.1007/s10750-007-9130-1

GONÇALVES, R. C. 2012. *Larvas de Odonata como bioindicadores de qualidade ambiental de cursos d`água no Cerrado*. Master's Thesis, Universidade Federal de Uberlândia, Brasil.

GOODYEAR, K. L., S. MCNEILL. 1999. Bioaccumulation of heavy metals by aquatic macro-invertebrates of different feeding guilds: a review. *Science of the Total Environment*, 229: 1-19. DOI: 10.1016/S0048-9697(99)00051-0

HAMILTON, S. J., K. J. BUHL. 2004. Selenium in water, sediment, plants, invertebrates, and fish in the Blackfoot river drainage. *Water, Air, and Soil Pollution*, 159: 3–34. DOI: 10.1023/B:WATE.0000049143.55199.76

HARE, L. 1992. Aquatic insects and trace metals: bioavailability, bioaccumulation, and toxicity. *Critical Reviews in Toxicology*, 22(5/6): 327-369. DOI: 10.3109/10408449209146312

HEINO, J., T. MUOTKA, R. PAAVOLA & L. PAASIVIRTA. 2003. Among taxon congruence in biodiversity patterns: can stream insect diversity be predicted using single taxonomic groups? *Canadian Journal of Fisheries* *and Aquatic Sciences*, 60: 1039-1049. DOI: 10.1139/f03-081

JOHNSON, R. D, W. GOEDKOOP & L. SANDIN. 2004. Spatial scale and ecological relationships between the macroinvertebrate communities of stony habitats of streams and lakes. *Freshwater Biology*, 49: 1179-1194. DOI: 10.1111/j.1365-2427.2004.01262.x

KIFFNEY, P. M. & W. H. CLEMENTS. 1994. Effects of heavy metals on a macroinvertebrate assemblage from a rocky mountain stream in experimental microcosms. *Journal of the North American Benthological Society*, 13: 511-523. DOI: 10.2307/1467847

KLAVINS, M., A. BRIEDE, E. PARBLE, V. RODINOV & I. KLAVINA.1998. Metal accumulation in sediments and benthic invertebrates in lakes of Latvia. *Chemospheree*, 36: 3043-3053. DOI: 10.1016/S0045-6535(98) 00010-1

LOWRANCE, R., L. S. ALTIER., J. D., NEWBOLD, R. R. SCHNABEL, P. M., GROFFMAN, J. M. DENVER, D. L. CORRELL, J. W. GILLIAN, J. L. ROBINSON, R. B. BRINSFIELD, K. W. STAVER, W.; LUCAS, A. H. TODD. 1997. Water quality functions of riparian forest buffers in Chesapeak Bay watersheds. *Environmental Management*, 21: 687-712.

MAITLAND, P. S. 1979. The distribution of zoobenthos and sediments in Loch Leven, Kinross, Scotland. *Archiv fur Hydrobiologie*, 85: 98-125.

MMA-BRASIL. MINISTÉRIO DO MEIO AMBIENTE. 2013. O Bioma Cerrado. http://www.mma.gov.br/biomas/cerrado.

MOLOZZI, J., M. J. FEIO, F. SALAS, J. C. MARQUES & M. CALLISTO. 2012. Development and test of a statistical model for the ecological assessment of tropical reservoirs based on benthic macroinvertebrates. *Ecological Indicators*, 23: 155-165. DOI: 10.1016/j.ecolind.2012.03.023

MURPHY, J. F. & J. DAVY-BOWKER. 2005. Spatial structure in lotic macroinvertebrate communities in England and Wales: Relationship with physical, chemical and anthropogenic stress variables. *Hydrobiologia*, 534: 151-164. DOI: 10.1007/s10750-004-1451-8

MYERS, N., R. A. MITTERMEIER, C. G. MITTERMEIER, G. A. B. FONSECA & J. KENT. 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403: 853-858. DOI: 10.1038/35002501

MYKRÄ, H., J. HEINO & T. MUOTKA. 2007. Scale-related patterns in the spatial and environmental components of stream macroinvertebrate assemblage variation. *Global Ecology and Biogeography*, 16: 149–159. DOI: 10.1111/j.1466-8238.2006.00272.x

NICACIO, G. & L. JUEN. 2015. Chironomids as indicators in freshwater ecosystems: an assessment of the literature. *Insect Conservation and Diversity*, 8: 393-403. DOI: 10.1111/icad.12123

POURANG, N. 1996. Heavy metal concentration in surficial sediments and benthic macroinvertebrates from Anzali wetland, Iran. *Hydrobiologia*, 331: 53-61. DOI: 10.1007/BF00025407

POWLESLAND, C. & J. GEORGE. 1986. Acute and chronic toxicity of nickel to larvae of *Chironomus riparius* (Meigen). *Environmental Pollution (Series A) Ecological and Biological*, 42: 47-64. DOI: 10.1016/0143-1471(86)90044-9

ROCHA, J. C. & A. H. ROSA. 2003. *Substâncias Húmicas Aquáticas: Interação com Espécies Metálicas*. UNESP. São Paulo. Brasil.

ROSSARO, B., G. F. GAGGINO & R. MARCHETTI. 1986. Accumulation of Mercury in larvae and adults, *Chironomus riparius* (Meigen). *Bulletin of Environmental Contamination and Toxicology*, 37: 402-406. DOI: 10.1007/BF01607780

SANTORO, A., G. BLO, S. MASTROLITTI & F. FAGIOLI. 2009. Bioaccumulation of heavy metals by aquatic macroinvertebrates along the Basento River in the South of Italy. *Water, Air & Soil Pollution*, 201: 19-31. DOI: 10.1007/s11270-008-9923-5

SCHNEIDER, M. O. 1996. *Bacia do rio Uberabinha: uso agrícola do Solo e Meio Ambiente*. Ph.D. Thesis. Universidade de São Paulo, Brasil.

SILDANCHANDRA, W. & M. CRANE. 2000. Influence of sexual dimorphism in *Chironomus riparius* Meigen on toxic effects of cadmium. *Environmental Toxicology and Chemistry*, 19:

2309-2313. DOI: 10.1002/etc.5620190921

SMOCK, L. A. 1983. The influence of feeding habits on whole-body metal concentrations of aquatic insects. *Freshwater Biology*, 13: 301-311. DOI: 10.1111/j.1365-2427.1983.tb00682.x

SOININEN, J., R. PAAVOLA & T. MUOTKA. 2004. Benthic diatom communities in boreal streams: community structure in relation to environmental and spatial gradients. *Ecography*, 27: 330-342. DOI: 10.1111/j.0906-7590.2004.03749.x

SOLÀ, C., M. BURGO, A. PLAZUELO, J. TOJA, M. PLANS & N. PRAT. 2004. Heavy metal bioaccumulation and macroinvertebrate community changes in a Mediterranean stream affected by acid mine drainage and an accidental spill (Guardiamar River, SW Spain). *Science of the Total Environment*, 333: 109-127. DOI: 10.1016/j.scitotenv.2004.05.011

SOLÀ, C. & N. PRAT. 2006. Monitoring metal and metalloid bioaccumulation in *Hydropsyche* (Trichoptera, Hydropsychidae) to evaluate metal pollution in a mining river. Whole body versus tissue content. *Science of the Total Environment*, 359: 221-231. DOI: 10.1016/j.scitotenv.2005.04.007

STRAYER, D. 2013. Endangered freshwater invertebrates. In: *Encyclopedia of Biodiversity* (2nd ed). Levin, S. A. (ed.): 176-187. Academic Press, Amsterdam, The Netherlands.

VALE. 2014. *Fertilizantes*. http://www.vale.com/brasil/pt/business/mining/fertilizers/paginas/default.aspx

WENTSEL, R., A. MCINTOSH, W. MCCAFFERTY, G. ATCHISON & V. ANDERSON. 1977. Avoidance response of midge larvae (*Chironomus tentans*) to sediments containing heavy metals. *Hydrobiologia*, 55: 171-175. DOI: 10.1007/BF00021058

WINNER, R. W., M. W. BOESEL & M. P. FARRELL. 1980. Insect community structure as an index of heavy-metal pollution in loctic ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences*, 37:647-655. DOI: 10.1139/f80-081

WOOD, J. M. 1974. Biological cycles for toxic elements in the environment. *Science*, 183: 1049-1052. DOI: 10.1126/science.183.4129.1049

Con el apoyo de:

GOBIERNO DE ESPAÑA | MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA | Fundación Biodiversidad