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ECOSYSTEMS

Effects of sugarcane cultivation on aquatic macroinvertebrate community structure: a historical comparative case study in São Paulo State

BRUNA NAIARA S. CARDOSO, MARIA HELENA V. CARRASCOSSI, GUILHERME R. GORNI, VANESSA COLOMBO-CORBI, DANIEL P. ABRAHÃO & JULIANO JOSÉ CORBI

Abstract: Over two decades, the area with sugarcane has more than doubled, from 4.8 million hectares in 2000 to 10 million in 2018, in Brazil. São Paulo State is mostly responsible for the sugarcane production in the country, accounting for 51% of the national production. In 2008, a study was conducted analysing the relationship between sugarcane cultivation and the aquatic macroinvertebrate community, showing the impacts of sugarcane on the macroinvertebrate aquatic fauna. The present study aims to gather actual information on the aquatic macroinvertebrate community in the same streams studied in 2008, to make a historical comparison with studies previously carried out. Eight streams were selected; four located in areas of sugarcane cultivation and four located in preserved areas. Three samples were carried out between 2018 and 2020. The aquatic macroinvertebrates were collected using a D-frame aquatic net (250 μm) including riffle and pools areas and identified using specific identification keys. The results of the historical assessment showed better ecological conditions of the streams in 2008 when compared to 2018 in areas of sugarcane cultivation, suggesting that the environmental impact was maintained and increased after ten years.

Key words: agricultural, biomonitoring, land use, community indexes, aquatic insects.

INTRODUCTION

In Brazilian history, the native land cover vegetation was removed and substituted by agriculture, mainly sugarcane and pastures. These processes result in deforestation, especially in the southeast region of Brazil (Martins 2001).

In almost two decades, the area with sugarcane has more than doubled, from 4.8 million hectares in 2000 to 10 million in 2018 (UNICA 2019). São Paulo State is mostly responsible for sugarcane production in the country accounting for 51% of the national production, followed by Goiás State (13%) and Minas Gerais (11%) (CONAB 2016). However, this expansion has raised several questions regarding social and environmental aspects, mainly regarding the use of pesticides and fertilizers.

Currently, Brazil produces about 657 million tons of sugarcane, occupying an area of 9.6 million hectares, producing approximately 32 billion liters of alcohol and about 41 million tons of sugar (UNICA 2019). Alcohol (ethanol) is exported from Brazil to other countries and has also been used as an alternative source of renewable fuel for vehicles (CONAB 2016, Carvalho Filho 2000). São Paulo State is the biggest national producer of sugarcane, reaching 52% of the total in a cultivated area with a production of 360 million tons and an area of 4.8 million hectares (UNICA 2019). The production is intended for sugar and ethanol manufacturing attaining a prominent position in the state's agroindustry. At the same time, in São Paulo State, sugarcane represents around 15% of the total use of rural land, and in 2020, this crop was responsible for around 12% of the sales of pesticides and fertilizers in Brazil (UNICA 2019).

The intensive use of these products has affected not only the target organisms in the plantations, but also the soil, surface and underground water, air, workers, surrounding residents, food (Spadotto 2006) and non-target organisms, such as aquatic macroinvertebrates (Corbi et al. 2010, Egler et al. 2012, Nhiwatiwa et al. 2017, Mello et al. 2019). The removal of riparian vegetation eliminates the protection of the stream, increases the levels of suspended soil particles and chemical contamination, causing changes in the habitat and the loss of aquatic biodiversity (Suriano & Fonseca-Gessner 2013).

Numerous studies (Armas et al. 2005, Bizarro et al. 2008, Corbi & Trivinho-Strixino 2008, Corbi et al. 2010) have been carried out in different research areas aiming to detect possible impacts resulting from the planting of sugarcane in streams and rivers in adjacent areas. These studies have shown that mainly in areas without protective vegetation (riparian forest), fertilizers (containing metals), herbicides and pesticides used during the different stages of sugarcane cultivation (soil preparation, planting, growth) are carried to water bodies through a process of surface runoff from the soil (horizontal process). This can contaminate the water and sediment in these environments and lead to bioaccumulation problems in groups of different trophic levels, such as accumulating in the fat from fish and crustaceans, or even from birds and other land animals, and can even be found in cow's milk that uses water from contaminated streams and rivers (Santos 1999, Martins 2001, Angelotti Netto et al. 2004, Corbi et al. 2010, 2011, 2018).

In this context, a study by Angelotti Netto et al. (2004), indicated that different concentrations of Cd, Pb, Cr and Ni are found in fertilizers widely used in sugarcane cultivation. Previous studies carried out in streams showed higher concentrations of metals, mainly Cu, Al, Zn and Fe in the sediment of environments located in areas adjacent to sugarcane cultivation, when compared to areas that have preserved riparian forests (Corbi et al. 2006, 2018). At the same time, some studies have indicated higher concentrations of Cd, Cu, Pb, Mn, Ni and Zn metals in insect larvae found in streams located in areas impacted by sugarcane activity (Corbi et al. 2008, 2010). It is known that high concentrations of Cd, for example, a non-essential metal for animals, can cause alterations in the life cycle, a decrease in body size and head capsule, as well as deformities in the mouthparts of some species of aquatic insects (Postma et al. 1995, Massabni et al. 2002, Seeland et al. 2013, Colombo-Corbi et al. 2017). It is worth noting that the presence of cadmium in fertilizers is due to an impurity in the production process (Ometto et al. 2000, Angelotti Netto et al. 2004).

Constant environmental monitoring of these areas is essential as the aquatic macroinvertebrate community comprises a group of great ecological importance in the environment, participating in the metabolism of ecosystems, nutrient cycling, energy flow and as part of the food chain as source for other fish and birds (Callisto et al. 2001, Esteves 2011).

The present study aims to gather current information regarding the loss of biodiversity in streams located in areas of sugarcane cultivation, without riparian vegetation, and in preserved areas, to conduct a historical comparison on the status of the macroinvertebrate community compared to the study conducted in 2008

(Corbi et al. 2008). These streams have been monitored over the past 10 years in different environmental assessments (Corbi et al. 2010, 2011, Corbi & Trivinho-Strixino 2017). This work presents the following hypothesis: sugarcane agricultural practices, causing loss in the aquatic macroinvertebrate community.

MATERIALS AND METHODS

Study area

Eight low order streams were selected, located in the hydrographic basin of the Tietê-Jacaré River, in the central region of São Paulo State characterized as cerrado area. The streams are of 1st and 2nd order, they have low water velocity (<1 m s^{-1}), <1.5 m, <2 m and are located at low altitude, 500 m to 700 m. The Água Sumida, Bela Vista, Chibarro and São João streams are located in sugarcane cultivation areas and the Anhumas, São Vicente, Espraiado and Monjolinho streams are in preserved forest areas (Table I). All streams are free from other anthropogenic impacts, such as domestic or industrial activities.

Physical and chemical characterization

In order to help evaluate the integrity of streams, physical and chemical parameters of water and sediment were measured. The physical and chemical variables of the water (pH, temperature, electrical conductivity and dissolved oxygen) were measured *in situ*, in triplicate, from the eight streams, using a multi-parameter meter model Akso AK-88 and were collected in three periods from 2018 to 2019.

The sediment was collected in each stream in the same period using an Ekman-Birge grab (standard area of 255 cm²), placed in plastic pots and then stored in the refrigerator at a temperature below 10° C (ABNT 2015), for later determination of the organic matter. The determination of organic matter was carried out by the loss of mass by ignition (incineration of 5g of the sediment in muffle at 550º C for a period of 4h), according to Carmo & Silva (2012) and the values obtained were converted into percentages.

Macroinvertebrates community

The aquatic macroinvertebrate community was collected, in triplicate, in three periods from 2018 to 2019 (2018 August, 2019 March and August, August dry season and March rainy season), using a D-frame aquatic net (mesh of 0.25 mm opening), for 1 minute (Fontoura 1985), including riffle and pool areas (as used in previous studies). The samples were placed in plastic containers, washed in a 0.25 mm mesh

Table I. Location, coordinates and land use and occupation of streams in the study.

Streams	Location	Coordinates	Land use
Anhumas	Américo Brasiliense	21º43’34” S 48º01’7,6” W	Preserved area
Espraiado	São Carlos	21º58’52” S 47º52’25” W	Preserved area
Monjolinho	São Carlos	23º00’34” S 47º50’10” W	Preserved area
São Vicente	Guarapiranga	21º59’45” S 48º15’31” W	Preserved area*
Água Sumida	Araraquara	21º56’16” S 48º16’39” W	Sugarcane area
Bela Vista	Araraquara	21º54’23” S 48º13’25” W	Sugarcane area
Chibarro	Araraquara and Ibaté	21º52’02” S 48º16’34” W	Sugarcane area
São João	Guarapiranga	21º57’50” S 48º15’52” W	Sugarcane area

***Stream located in sugarcane cultivation area with preserved riparian vegetation .**

sieve, screened in polyethylene trays over a light source (illumination trays) and fixed with 80% alcohol. The insects were identified at the family level, based on the keys available from Hamada et al. (2014) and Mugnai et al. (2010).

Data analysis

The stream macroinvertebrates were analyzed by the participation of each taxonomic group and by the total organisms collected in each point sampled. The following parameters were determined for the macroinvertebrates: number of families, ratio between the Chironomidae number and the total of individuals collected (Chironomidae/total X 100), EPT percentage (Ephemeroptera, Plecoptera and Trichoptera), ratio between the number of EPT (sensitive) and Chironomidae (tolerant) (EPT/Chironomidae X 100), ratio (%) of the number of EPT families by the total number of macroinvertebrate families (EPT/total of families X 100), ratio between the amount of shredders and collectors (shredders/collectors x 100), richness index Margalef, diversity index Shannon and BMWP biotic index (Biological Monitoring Working Party), with regional adaptations (Loyola 2000). The PAST program (Hammer et al. 2001) was used to calculate the richness index (Margalef) and the diversity index (Shannon). Afterward, the results of the present study were compared with the previous results presented in Corbi & Trivinho-Strixino (2008).

RESULTS

Physical and chemical characterization

The pH presented similar values between the forest and sugarcane areas (Table II), with little variation (Oliveira et al. 1999). The temperature did not show different values in relation to the land use and occupation of the soil and the values were similar in both areas (Table II). The electrical conductivity ranged from 10.8 to 73.7 $\mu S\ cm^{-1}$ and differed in both areas, which was higher in the streams in an area cultivated with sugarcane. The concentrations of dissolved oxygen indicated good oxygenation conditions for the forest streams in relation to the sugarcane streams, with values ranging from 5.7 to 8.2 $mg\ L^{-1}$. The organic matter in the streams of forest areas was low, varying from 0.63% for the Monjolinho stream to 5% for the São Vicente stream. Similarly, it was also low in the sugarcane areas, with a maximum of 15% in the Água Sumida stream and a minimum of 6.5% in the Bela Vista stream. Corbi & Trivinho-Strixino

Table II. Environmental characterization of the forest and sugarcane streams: average values of pH, temperature, electrical conductivity, dissolved oxygen and organic matter.

Streams	pH	Temperature (ºC)	Electrical Conductivity ($\mu S\ cm^{-1}$)	Dissolved Oxygen ($mg\ L^{-1}$)	Organic matter (%)
Anhumas	7.5 ± 0.9	22.0 ± 3.7	30.6 ± 8.8	8.2 ± 0.4	2.68 ± 0.42
Espraiado	6.8 ± 0.1	19.0 ± 2.3	10.8 ± 0.7	6.8 ± 0.4	0.72 ± 0.07
Monjolinho	6.6 ± 0.0	21.7 ± 1.3	14.3 ± 1.0	7.6 ± 0.3	0.63 ± 0.04
São Vicente	6.7 ± 0.3	22.7 ± 1.6	73.7 ± 5.1	5.7 ± 0.6	4.95 ± 0.52
Água Sumida	6.0 ± 0.2	22.1 ± 2.7	48.3 ± 15.1	3.7 ± 0.7	15.15 ± 0.98
Bela Vista	6.2 ± 0.5	24.0 ± 6.1	18.3 ± 9.0	3.9 ± 0.2	6.49 ± 0.52
Chibarro	7.1 ± 0.5	22.9 ± 3.8	46.0 ± 7.5	6.2 ± 0.4	13.19 ± 0.42
São João	6.1 ± 0.2	22.7 ± 3.3	39.6 ± 17.8	0.5 ± 0.1	6.67 ± 0.20

(2008) and Costa-Geromel et al. (2022) also found similar values in the areas of sugarcane cultivation, varying between 3% and 15%, for the same streams in the study.

Macroinvertebrate communities

In this study, a total of 3331 organisms were collected, distributed in 9 orders and 40 families (Table III). The Trichoptera and Ephemeroptera organisms had a higher abundance in streams located in forest areas. The families Hydropsychidae, Calamoceratidae, Odontoceridae (Trichoptera) and Leptophlebiidae (Ephemeroptera), exclusive in these areas. Leptoceridae, Hydroptilidae, Polycentropodidae (Trichoptera), Baetidae and Leptohyphidade (Ephemeroptera) were present in both areas (preserved and impacted). Plecoptera larvae were found only in the preserved streams.

The other orders (Odonata, Coleoptera, Diptera, Lepidoptera, Hemiptera and Oligochaeta) were widely distributed in both areas. The orders Odonata and Hemiptera had greater abundance in the streams of the forest and the orders Coleoptera and Oligochaeta, in the streams of sugarcane. Regarding the order Diptera, the family Chironomidae was the most representative, and was found in all streams, corresponding to 51% of the total collected organisms. The family Ceratopogonidae was also found in all streams and the families Empididae, Tabanidae, Dixidae, Simuliidade, Psychodidae and Orthocladiinae (Chironomidae) were exclusive in the forest streams. The families Culicidae, Chaoboridae and Syrphidae occurred only in streams located in sugarcane areas.

Concerning community metrics (Table IV), it is noted that streams in forest areas showed greater fauna richness compared to streams in sugarcane areas, with the number of families ranging from 9 to 22. In all the streams, the Chironomidae (Diptera) dominated the macroinvertebrate fauna, with 52% of the collected macroinvertebrates, from 81% in the São João stream to 33% in the São Vicente stream. The presence of the EPT group was greater in streams in forest areas. The Shannon diversity index and Margalef's index of richness were higher for streams in forest areas, ranging from 1.62 to 2.06 and from 1.88 to 4.08, respectively. In the sugarcane streams, the lowest Shannon diversity was 1.03 for the São João stream and the highest was 2.03 for the Bela Vista stream. The Margalef's richness ranged from 1.92 to 2.91. Regarding water quality, in general, the BMWP index showed excellent quality in the forest streams and regular quality in agricultural areas. São Vicente stream, located in a forest area, present low values of community metrics and poor water quality, probably because of the proximity to the sugarcane culture.

DISCUSSION

Sugarcane cultivation has expanded in Brazil in recent years, mainly in the Southeast region, responsible for the largest production in the country (Ronquim & Fonseca 2018). The replacement of vast areas of native vegetation with this type of monoculture, together with the disposal of pesticides and fertilizers, can cause different losses to the aquatic macroinvertebrate community. Reductions of 42% in aquatic macroinvertebrate taxa have been observed in Europe and Australia due to the contamination of insecticide at concentrations considered environmentally protective by legislation (Beketov et al. 2013). Fierro et al. (2019) compared macroinvertebrate community structures in conserved agricultural areas and also observed faunal reduction in relation to land use changes. Effects on ecological processes that occur in the environment have been observed, for example,

Table III. Aquatic macroinvertebrates community in the forest streams (Anhu = Anhumas; Esp = Espraiado; Mon = Monjolinho; SV = São Vicente) and sugarcane (AS = Água Sumida; BV = Bela Vista; Chi = Chibarro and SJ = São João) represented by the taxonomic group.

Taxonomic group	Anhu	Esp	Mon	SV	AS	BV	Chi	SJ
Coleoptera								
Noteridae	-	-	-	-	-	10	-	-
Scirtidae	-	-	-	-	-	37	-	1
Dytiscidae	3	1	-	1	7	8	1	5
Hydrophilidae	-	-	-	-	1	14	-	3
Gyrinidae	-	-	4	-	-	-	-	-
Dryopidae	-	-	-	1	3	-	-	-
Elmidae	-	4	-	-	-	-	-	-
Diptera								
Ceratopogonidae	13	3	13	13	8	7	6	4
Chaoboridae	-	-	-	-	-	5	-	-
Culicidae	-	-	-	-	-	-	-	3
Empididae	-	-	1	-	-	-	-	-
Dixidae	-	10	54	-	-	-	-	-
Simulidae	1	-	43	-	-	-	-	-
Syrphidae	-	-	-	-	-	-	-	1
Psychodidae	3	-	-	-	-	-	-	-
Tabanidae	-	1	1	-	-	-	-	-
Tanypodinae	340	80	135	36	3	68	47	6
Chironominae	98	94	249	32	200	112	54	145
Orthocladinae	-	1	1	-	-	-	-	-
Ephemeroptera								
Baetidae	5	25	99	-	-	-	23	-
Leptohyphidade	4	-	-	-	-	3	6	-
Leptophlebiidae	-	21	-	-	-	-	-	-
Hemiptera								
Belostomatidae	3	1	1	5	3	5	-	8
Corixidae	-	-	-	-	-	3	-	-
Hebridae	-	3	-	-	-	1	-	1
Naucoridae	-	2	-	-	-	-	-	-
Pleidae	-	127	-	-	-	1	-	-
Veliidae	-	1	-	-	-	-	-	-
Lepidoptera Odonata	1	1	4	-	3	1	1	-
Aeshnidae	-	2	3	-	-	-	-	-

Table III. Continuation.

Calopterygidae	2	-	1	-	-	-	4	-
Coenagrionidae	13	1	24	2	3	8	25	1
Gomphidae	-	-	1	12	-	-	-	-
Libellulidae	11	-	30	24	7	46	-	1
Protoneuridae	-	1	-	-	-	-	-	-
Oligochaeta Plecoptera	47	-	2	77	28	150	90	8
Gripopterydidae	-	14	72	-	-	-	-	-
Perlidae	-	3	-	-	-	-	-	-
Trichoptera								
Calamoceratidae	-	16	-	2	-	-	-	-
Hydroptilidae	99	-	9	-	45	4	-	-
Hydropsychidae	7	2	3	-	-	-	-	-
Leptoceridae	2	42	2	-	-	1	3	-
Polycentropodidae	8	-	-	-	-	-	13	-
Odontoceridae	-	2	-	-	-	-	-	-
Total	660	459	752	205	311	484	273	187

Table IV. Comparison of community metrics for forest and sugarcane streams analyzed by the present study and by Corbi & Trivinho-Strixino (2008).

	Present study								Corbi &Trivinho-Strixino (2008)						
Community metrics	**Anhu***	**Esp**	**Mon**	**SV**	**AS**	**BV**	**Chi**	**SJ**	**Esp**	**Mon**	**SV**	**AS**	**BV**	**Chi**	**SJ**
Number of families	15	22	18	9	9	16	9	11	22	22	17	4	12	10	7
% Chironomidae/total	66	38	51	33	65	37	37	81	54	63	58	90	60	83	74
% EPT	19	27	25	1	14	2	16	0	27	26	25	0	18	25	17
% EPT/Chironomidae	29	72	48	3	22	4	45	0	46	21	9.7	0	15	5	6
% fam. EPT/total fam.	38	39	25	10	9	17	36	0	26	24	24	0	17	26	17
%Shredders/collectors	1.7	46.5	17.3	2.7	2.6	0.7	2.1	0.0	50	40	80	0	0	20	0
Shannon Diversity	1.6	2.2	2.1	1.8	1.3	2.0	1.9	1.0	3.5	3.3	2.2	0.2	3.0	2.7	1.7
Margalef's richness	2.6	4.1	3.2	1.9	1.9	2.9	1.9	2, 3	8.7	7.9	4.8	0.7	5.6	5.1	2.7
BMWP	86	120	102	36	43	71	53	47	130	130	91	6	53	53	23
BMWP*	E	E	E	P	R	G	R	R	E	E	E	B	R	R	B

***E= Excellent; G= Good; R= Regular; P = Poor; B = Bad. Forest streams (Anhu = Anhumas; Esp = Espraiado; Mon = Monjolinho; SV = São Vicente) and sugarcane (AS = Água Sumida; BV = Bela Vista; Chi = Chibarro and SJ = São João)**
***Anhumas was not analyzed in 2008.**

the decline in decomposition litter in streams (Auber et al. 2011).

It can be observed in this study that the fauna richness was influenced by the cultivation of sugarcane, probably by the removal of the riparian forest and the greater supply of pesticides, fertilizers and soil particles in the water as pointed in Corbi et al. (2006). These factors were reflected in the lower Shannon diversity, Margalef's richness, BMWP and the absence of sensitive species in the sugarcane areas. Thus, these analyses confirmed the results obtained in 2008 for the same streams (Corbi & Trivinho-Strixino 2008), in which they also pointed out differences in the composition of the aquatic macroinvertebrate community between the forest and sugarcane streams.

The modification of the landscape with the removal of native vegetation and subsequent replacement by agricultural crops causes a reduction in the number of taxa more sensitive to disturbance to the environment, such as the EPT group and an increase in the number of taxa more tolerant to pollution, such as the Chironomidae (Moya et al. 2007, Corbi & Trivinho-Strixino 2017). Hepp & Santos (2009) observed that the number of EPT families decreased in places with greater impact (agricultural, pasture and urban) due to the higher concentrations of nutrients, conductivity and turbidity and lower concentration of dissolved oxygen when compared to areas conserved. Buss et al. (2002) observed similar responses in their studies in the southeastern region of Brazil. Egler et al. (2012) observed that deforestation and erosion on the banks of streams located in agricultural areas, together with the flow of pesticides, favored the loss of habitats and a lesser complexity of substrates, resulting in a reduction in the richness of taxa. On the other hand, Suriano & Fonseca-Gessner (2013) observed greater participation of Chironomidae in streams located in areas considered impacted by the absence of riparian forest.

However, every year aquatic macroinvertebrates are affected by the planting of sugarcane that goes through different stages, such as sowing, harvesting, constant application of large quantities and variety of pesticides and fertilizers, soil turning, in addition to the removal of ground cover. When analyzing the results of the historical analysis on the contamination status of the sugarcane areas, comparing the community metrics obtained in 2008 (Corbi & Trivinho-Strixino 2008) and the current metrics, it can be observed that in general, the ecological conditions of the forest and sugarcane streams were better in 2008, with greater richness and diversity of species, numbers of taxa and % EPT. On the other hand, in relation to the sugarcane streams, Água Sumida had its current conditions improved compared to 2008, with an increase in all community metrics. In this stream, the quality of the water advanced from terrible to regular and there was the presence of the EPT group, showing that the ecological conditions of this stream are improving, even in the face of environmental stress. The Bela Vista and São João streams also had improved water quality, going from regular to good and from bad to regular, respectively.

The results of this work showed that sugarcane and the absence of a riparian forest continue to negatively influence the aquatic macroinvertebrate community, impacting water quality and altering the richness and diversity of organisms. It also highlights the need for adequate management of the region's water resources, to be able to reconcile agricultural activities, which are important for the country's economic growth, with the maintenance of aquatic communities, without causing major impacts on the functional integrity.

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REFERENCES

ANGELOTTI NETTO A, CRESTANA S, DE OLIVEIRA SC & BARBOSA RVR. 2004. Metais pesados provenientes de atividade agrícola: formas, prevenção e controle. In: Bacia hidrográfica: diversas abordagens de pesquisa. Espíndola ELG & Wendland E (Eds), p. 1-14. Rima Editora, São Carlos, Brasil.

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. 2015. ABNT NBR 15469: Ecotoxicologia – Coleta, preservação e preparo de amostras, ABTN, Rio de Janeiro, 22 p.

ARMAS D, MONTEIRO RTR, AMÂNCIO AV, CORREA RCL & GUERCIO MA. 2005. The use of pesticides in sugar cane at the Corumbataí River Basin and the risk of water pollution. Quim Nova 28: 975-982. http://dx.doi.org/10.1590/S0100-40422005000600008.

AUBER A, ROUCAUTE M, TOGOLA A & CAQUET T. 2011. Structural and functional effects of conventional and low pesticide input crop-protection programs on benthic macroinvertebrate communities in outdoor pond mesocosms. Ecotoxicology 20: 2042.

BEKETOV MA, KEFFORD BJ, SCHÄFER RB & LIESS M. 2013. Pesticides reduce regional biodiversity of stream invertebrates. Proc Natl Acad Sci USA 110: 11039-11043.

BIZARRO VG, MEURER EJ & TATSCH FRP. 2008. Teor de cádmio em fertilizantes fosfatados. Cienc Rural 38: 247-250.

BUSS DF, BAPTISTA DF, SILVEIRA MP, NESSIMIAN JL & DORVILLÉ LF. 2002. Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in south-east Brazil. Hydrobiologia 481: 125-136.

CALLISTO M, MORETTI M & GOULART M. 2001. Macroinvertebrados bentônicos como ferramenta para avaliar a saúde de riachos. Rev Bras de Recur Hidr 6: 71-82.

CARMO DL & SILVA CA. 2012. Métodos de quantificação de carbono e matéria orgânica em resíduos orgânicos. Ver Bras Cienc Solo 36: 1211-1220.

CARVALHO FILHO SM. 2000. Colheita mecanizada: desempenho operacional e econômico em cana sem queima prévia. PhD Thesis, ESALQ (USP), Piracicaba – SP, 108 p. São Paulo. (in Portuguese with English abstract).

COLOMBO-CORBI V, GORNI G R, SANZOVO-FALCOSKI T, COSTA PI & CORBI JJ. 2017. Genetic Diversity Loss in *Chironomus sancticaroli* (Diptera: Chironomidae) Exposed to Pyrimethanil Fungicide: an Analysis Using RAPD Technique. Water Air Soil Pollut 228: 1-3.

CONAB - COMPANHIA NACIONAL DE ABASTECIMENTO. 2016. http://www.conab.gov.br.

CORBI JJ, FROEHLICH CG, STRIXINO ST & SANTOS AD. 2010. Bioaccumulation of metals in aquatic insects of streams located in areas with sugarcane cultivation. Quim Nova: 644-648.

CORBI JJ, FROEHLICH CG, TRIVINHO-STRIXINO S & SANTOS A. 2011. Evaluating the use of predatory insects as bioindicators of metals contamination due to sugarcane cultivation in neotropical streams. Environ Monit Assess 177: 545-554.

CORBI JJ, GEROMEL-COSTA CGA, COLOMBO V, GORNI GR & RIOS L. 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. An Acad Bras Cienc 90: 2711-2719.

CORBI JJ & TRIVINHO-STRIXINO S. 2008. Relationship between sugarcane cultivation and stream macroinvertebrate communities. Braz Arch Biol Technol 51: 569-579.

CORBI JJ & TRIVINHO-STRIXINO S. 2017. Chironomid species are sensitive to sugarcane cultivation. Hydrobiologia 785: 91-99.

CORBI JJ, TRIVINHO-STRIXINO S & DOS SANTOS A. 2008. Environmental Evaluation of Metals in Sediments and Dragonflies Due to Sugar Cane Cultivation in Neotropical Streams. Water Air Soil Pollut 195: 325-333.

CORBI JJ, TRIVINHO-STRIXINO S, DOS SANTOS A & DEL GRANDE M. 2006. Diagnóstico ambiental de metais e organoclorados em córregos adjacentes a áreas de cultivo de cana-de-açúcar (Estado de São Paulo, Brasil). Quim Nova 29: 61-65.

COSTA-GEROMEL C, BERNEGOSSI AC, MOURA L & CORBI JJC. 2022. Adsorption of Metals by Chitosan Beads in Sugarcane Cultivation Streams: Implications for *Chironomus sancticaroli* Insect Larvae (Diptera: Chironomidae). Water Air Soil Pollut 233: 123.

EGLER M, BUSS DF, MOREIRA JC & BAPTISTA D F. 2012. Influence of agricultural land use and pesticides on benthic macroinvertebrate assemblages in an agricultural river basin in southeast Brazil. Braz J Biol 72: 437-443.

ESTEVES FA. 2011. Fundamentos de Limnologia. Rio de Janeiro, Interciência, 828 p.

FIERRO P, VALDOVINOS C, ARISMENDI I, DÍAZ G, JARA-FLORES A, HABIT E & VARGAS-CHACOFF L. 2019. Examining the influence of human stressors on benthic algae, macroinvertebrate, and fish assemblages in Mediterranean streams of Chile. Sci Total Environ 686: 26-37.

FONTOURA AP. 1985. Manual de vigilância da qualidade das águas superficiais. Avaliação biológica da qualidade da água. Instituto de zoologia. Faculdade de Ciências – Universidade do Porto, Porto – Portugal, 38 p.

HAMADA N, NESSIMIAN JL & QUERINO RB. 2014. Insetos Aquáticos na Amazônia brasileira: taxonomia, biologia e ecologia. Editora INPA, 724 p.

HAMMER Ø, HARPER DAT & RYAN PD. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 9. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

HEPP LU & SANTOS S. 2009. Benthic communities of streams related to different land uses in a hydrographic basin in southern Brazil. Environ Monit Assess 157: 305-318.

LOYOLA RGN. 2000. Atual estágio do IAP no uso de índices biológicos de qualidade. V Simpósio de Ecossistemas Brasileiros: Conservação – Anais, Volume I. UFES, Vitória, Espírito Santo, p. 46-52.

MARTINS SJ. 2001. Recuperação de matas ciliares. Editora Conceito. Viçosa. Brazil.

MASSABNI AC, MELNIKOV P, CUIN A, CORBI PP & CORBI JJ. 2002. O Cádmio, seus efeitos no homem e no meio ambiente. Jornal de Bioquímica Médica 11: 5-7.

MELLO JL, CARDOSO BN, COLOMBO-CORBI V & CORBI JJ. 2019. Effects of Agrochemicals on Freshwater Macroinvertebrates: Challenges and Perspectives from Southeastern Brazil. L&O Bulletin 28: 1-4.

MOYA N, TOMANOVA S & OBERDORFF T. 2007. Desenvolvimento inicial de um índice multi-métrico baseado em macroinvertebrados aquáticos para avaliar a condição de riachos na bacia do Alto Isiboro-Sécure, Amazônia Boliviana. Hydrobiologia 589: 107-116.

MUGNAI R, NESSIMIAN JL & BAPTISTA DF. 2010. Manual de Identificação de Macroinvertebrados Aquáticos do Estado do Rio de Janeiro. Rio de Janeiro: Livros Técnicos, 176 p.

NHIWATIWA T, DALU T & BRENDONCK L. 2017. Impact of irrigation based sugarcane cultivation on the Chiredzi and Runde Rivers quality, Zimbabwe. Sci Total Environ 587: 316-325.

OLIVEIRA JB, CAMARGO MN, ROSSI M & CALDERANO FILHO B. 1999. Mapa pedológico do Estado de São Paulo: legenda expandida. Campinas, Instituto Agronômico/Embrapa Solos. Campinas, 64 p.

OMETTO JPHB, MARTINELLI LA, BALLISTER MV, GESSNER A, KRISCHE AV & VICTORIA RL. 2000. The effects of land use on water chemistry and macroinvertebrates rates in two streams of the Piracicaba River basin South-east Brazil. Freshwater Biol 44: 327-337.

POSTMA J, KYED M & ADMIRAAL W. 1995. Site specific differentiation in metal tolerance in the midge *Chironomus riparius* (Diptera, Chironomidae). Hydrobiologia 315(2): 159-155.

RONQUIM CC & FONSECA MF. 2018. Avanço das áreas de cana-de-açúcar e alterações em áreas de agropecuária no interior paulista. Embrapa Territorial-Documentos (INFOTECA-E).

SANTOS A. 1999. Distribuição de metais no reservatório de captação de água superficial Anhumas Américo Brasiliense – SP. USP. Dissertação (Mestrado Química). Universidade de São Paulo, 147 p. (Unpublished).

SEELAND A, ALBRAND J, OEHLMANN J & MÜLLER R. 2013. Life stage-specific effects of the fungicide Pyrimethanil and temperature on the snail *Physella acuta* (Draparnaud, 1805) disclose the pitfalls for the aquatic risk assessment under global climate change. Environ Pollut 174: 1-9.

SPADOTTO CA. 2008. In: QUEIROZ JF et al. Organismos bentônicos: biomonitoramento de qualidade de água. Jaguariúna: Embrapa Meio Ambiente. Disponível em: http://www.cnpma.embrapa.br/download/LivroBentonicos.pdf.

SURIANO MT & FONSECA-GESSNER AA. 2013. Structure of benthic macroinvertebrate assemblages on a gradient of environmental integrity in Neotropical streams. Acta Limnol Bras 25: 418-428.

ÚNICA. 2019. União da Indústria da Cana-de-açúcar. http://www.unicadata.com.br/listagem.php?idMn=90.

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BRUNA NAIARA S. CARDOSO[1]
https://orci.org/0000-0002-7569-1710

MARIA HELENA V. CARRASCOSSI[1]
https://orci.org/0000-0002-9255-2798

GUILHERME R. GORNI[2]
https://orci.org/0000-0002-9156-6864

VANESSA COLOMBO-CORBI[2]
https://orci.org/0000-0003-3388-7990

DANIEL P. ABRAHÃO[1]
https://orci.org/0000-0002-6727-7130

JULIANO JOSÉ CORBI[1]
https://orci.org/0000-0003-0249-9370

[1]Universidade de São Paulo/USP, Escola de Engenharia de São Carlos (EESC), Departamento de Hidráulica e Saneamento (SHS), Laboratório de Ecologia Aquática, Caixa Postal 359, 13566-590 São Carlos, SP, Brazil

[2]Universidade de Araraquara, Centro de Estudos Ambientais, Rua Carlos Gomes, 1338, Centro, 14801-340 Araraquara, SP, Brazil

Correspondence to: **Vanessa Colombo-Corbi**
E-mail: vanessacolombo25@yahoo.com.br

Author contributions

Substantial contribution in the concept and design of the study: Juliano José Corbi. Contribution to data collection: Bruna Naiara Silva Cardoso, Maria Helena Viana Carrascossi and Daniel Peroni Abrahão. Contribution to data analysis and interpretation: Bruna Naiara Silva Cardoso, Guilherme Rossi Gorni, Daniel Peroni Abrahão, Vanessa Colombo-Corbi, Maria Helena Viana Carrascossi and Juliano José Corbi. Contribution to manuscript preparation: Juliano José Corbi and Vanessa Colombo-Corbi. Contribution to critical revision, adding intellectual content: Guilherme Rossi Gorni, Juliano José Corbi, and Vanessa Colombo-Corbi.