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ARTICLE

Ecological attributes of aquatic invertebrates in two water turbidity scenarios in a lake of the Pantanal, Brazil

Cristina Márcia de Menezes Butakka[1,3] & Simoni Maria Loverde-Oliveira[2,4]

[1] Universidade de Cuiabá (UNIC), Programa de Mestrado Acadêmico em Ambiente e Saúde. Cuiabá, MT, Brasil.
[2] Universidade Federal de Rondonópolis (UFR), Programa de Pós-Graduação em Geografia. Rondonópolis, MT, Brasil.
[3] ORCID: https://orcid.org/0000-0003-0618-8078. E-mail: cristinabutakka@yahoo.com.br
[4] ORCID: https://orcid.org/0000-0003-1202-220X. E-mail: si.loverde@hotmail.com

Abstract. The objective of this work was to determine the taxonomic structure and Functional Feeding Groups (FFGs) of benthic invertebrates and their roles in two different water turbidity scenarios in a floodplain lake in the Pantanal wetland (Sinhá Mariana Lake, Barão de Melgaço, state of Mato Grosso). We studied the benthic invertebrate fauna at 18 sampling sites in periods of high turbidity (HT) and low turbidity (LT) during high water (HW) and low water (LW). We hypothesize that the structure of Chironomidae assemblages (species and functional feeding groups) varies between sites in Sinhá Mariana Lake, and the density and diversity attributes of species in this family and their functional feeding groups are reduced under increased turbidity. Depth, water temperature, turbidity, pH, pCO_2, water color, and organic matter content of the sediment were analyzed in each sampling site. Chironomidae presented higher density and diversity in periods of high water (HW) in sites with low turbidity water (LT). The dominance increased in periods of low water (LW). The main FFGs were represented by collector-gatherers, while the smallest groups corresponded to shredder-herbivores (50% and 9% of the total abundance, respectively). Collector-gatherers (*Aedokritus* sp., *Chironomus strenzkei, Goeldichironomus petiolicola, G. maculatus, Beardius phytophilus*), predators (*Ablabesmyia* gr. *annulata, Labrundinia* sp. and *Cryptochironomus brasiliensis*) and shredder-herbivores (*Asheum* sp., *Polypedilum* sp., *Polypedilum* gr. *fallax*) predominated in high water (HW) periods. A change in the community structure from the HW to LW was evidenced, characterized by the substitution of collector-gatherers for collector-filterers. *Notodiaptomus deitersi* (Crustacea) was dominant in LW (dominance index = 10.9) and *Aedokritus* sp. (Insecta) in HW (dominance index = 5.4). Water turbidity and the hydrological cycle are important factors determining spatial and temporal patterns in communities, particularly changes in FFGs. Changes in turbidity in different sites and periods alter the structure of trophic communities and lead to questions about the main drivers of communities in Pantanal wetlands as areas of high ecological relevance for maintaining biodiversity.

Keywords. Benthic invertebrates; Functional Feeding Groups; Chironomidae; Wetland; Sinhá Mariana Lake.

Resumo. Atributos ecológicos de invertebrados aquáticos em dois cenários de turbidez da água em um lago do Pantanal, Brasil. O objetivo deste trabalho foi determinar a estrutura taxonômica e os Grupos Alimentares Funcionais (GAFs) dos invertebrados bentônicos e seu papel em dois cenários contrastantes de turbidez da água em uma lagoa do Pantanal (Lagoa de Sinhá Mariana, Barão de Melgaço, Mato Grosso). Estudamos a fauna de invertebrados bentônicos em 18 locais de amostragem em períodos de alta turbidez (HT) e baixa turbidez (LT), durante as águas altas (HW) e águas baixas (LW). Nossa hipótese é que a estrutura das assembleias de Chironomidae (espécies e grupos funcionais de alimentação) varia entre locais na Lagoa de Sinhá Mariana e os atributos de densidade e diversidade das espécies desta família e seus grupos funcionais de alimentação serão reduzidos sob condições de aumento da turbidez da água. Profundidade, temperatura da água, pH, turbidez, oxigênio dissolvido, pCO_2, cor da água, clorofila, composição granulométrica e teor de matéria orgânica do sedimento foram analisados em cada local de amostragem. Nossos dados mostraram que os Chironomidae apresentaram maiores densidades, diversidade, riqueza e índices de dominância em períodos de águas altas (HW) em locais com águas de baixa turbidez (LT). Os principais GAFs foram representadas por coletores-coletores, enquanto os menores corresponderam a trituradores-herbívoros (50% e 9% da abundância total, respectivamente). Coletores-catadores (*Aedokritus* sp., *Chironomus strenzkei, Goeldichironomus petiolicola, G. maculatus, Beardius phytophilus*), predadores (*Ablabesmyia* gr. *annulata, Labrundinia* sp. e *Cryptochironomus brasiliensis*) e trituradores-herbívoros (*Asheum* sp., *Polypedilum* sp., *Polypedilum* gr. *fallax*) predominaram nos períodos de águas altas (HW). Evidenciou-se uma mudança na estrutura da comunidade de HW para LW, caracterizada pela substituição de coletores-catadores por coletores-filtradores. *Notodiaptomus deitersi* (Crustacea) foi dominante em LW (índice de dominância = 10,9) e *Aedokritus* sp. (Insecta) em HW (índice de dominância = 5,4). A turbidez da água e o ciclo hidrológico são factores importantes

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que determinaram os padrões espaciais e temporais nas comunidades, particularmente as mudanças nos GFAs. As mudanças da turbidez em diferentes locais e períodos alteram a estruturação das comunidades tróficas e podem levar às questões sobre os principais direcionadores das comunidades nas áreas úmidas pantaneiras, como áreas de alta relevância ecológica para manutenção da biodiversidade.

Palavras-chave. Invertebrados bentônicos; Grupos Funcionais Alimentares; Chironomidae; Áreas úmidas; Lagoa de Sinhá Mariana.

INTRODUCTION

Many species of aquatic invertebrates are considered resistant to water turbidity, which favors communities dominated by sediment colonizers. Studies on water quality conducted by Ferreira *et al.* (2014, 2017) and Martins *et al.* (2015) found insects associated with higher turbidity in small streams and reservoirs, respectively. They identified associations of the most sensitive and other species more tolerant to the amount of suspended solids and water turbidity. Aquatic communities respond to the spatial and temporal variations in this variable as confirmed by Lima *et al.* (2013) and Firmiano *et al.* (2017) for aquatic insects in their habitats.

In large wetlands, such as the Pantanal of Mato Grosso, aquatic ecosystems support an extraordinary diversity and abundance of wildlife, making this "great swamp" a globally significant biome of biological diversity (Junk *et al.,* 2006). Large parts of the Pantanal seasonally dry out; therefore, many aquatic species have short life cycles and re-establish quickly after drought, migrate, or they can estivate in muddy sediments (Wantzen *et al.,* 2011). Changes in the aquatic system of Pantanal during the rain and drought regime increase the discharge of sediments in rivers, streams, and lakes, resulting in silting processes and decreased water transparency, with increased turbidity (Wantzen *et al.,* 2008). Lakes have also been shown to change from low turbidity to high turbidity as a result of heavy rains (Loverde-Oliveira & Huszar, 2007) in periods of instability. Some lakes show recurrent shifts between a clear and a turbid state in a periodic multi-year pattern that appears to be driven by a combination of internal processes and forcing by weather-related cycles in nutrient load (Loverde-Oliveira *et al.,* 2009).

The increase in water level creates new habitats and waterbodies previously disconnected such as rivers and lakes, which can cause dispersion, movement, and reproduction of organisms (Zerlin & Henry, 2014), providing new resources for aquatic invertebrates. Zoobenthos is a group of invertebrates that spend at least part of their life cycle at the bottom substrate of water bodies (Rezende, 2007; Henriques-Oliveira & Nessimian, 2010; Gonçalves & Menezes, 2011). Studies on the attributes of these groups, especially the family Chironomidae (Aburaya & Callil, 2007; Santos & Callil, 2010) in the Pantanal, are indispensable to complement the understanding of community structure, as well as the functioning of aquatic ecosystems. This family is a useful group to explore temporal relations between species richness and abundance, due to their ecological importance as well as operational aspects (Siqueira *et al.,* 2008).

The family Chironomidae was selected us to investigate its attributes, such as diversity and trophic groups present according to the literature (Coffman & Ferrington-Jr., 2006), to determine their densities and dominance of morphospecies. The Functional Feeding Groups of aquatic insects are widely adopted in studies to characterize the environment (Hamada *et al.,* 2014) and were created by Cummis (1973). This classification was based on morphological characteristics, explored resources, and capture methods. Trophic groups, guilds, or Functional Feeding Groups are defined as groups of species that exploit the same class of resource in a similar way. In places with an increase in the number of collectors, this may indicate a greater amount of organic matter, which is related to an increase in nutrients (Mandaville, 2002). However, in lentic environments, with the riparian forest preserved, detritivore and shredder-herbivores groups are more abundant, followed by collectors, due to the fragmentation of organic matter (Hershey *et al.,* 2010).

The objectives of this work were to investigate the benthic invertebrate fauna, with emphasis on the family Chironomidae in Sinha Mariana Lake, and to identify conditions of environmental turbidity associated with species of this family and their trophic groups along an environmental gradient in periods of high and low water.

So, we hypothesized that: (1) Turbidity values increase in an environmental gradient from sampling sites in the Mutum River to near Chacororé Lake and Cuiabá River (Corixo Tarumã) sites; (2) the structure of Chironomidae assemblages (species and Functional Feeding Groups) varies between sites in Sinhá Mariana Lake; (3) the density and diversity of Chironomidae species and their functional feeding groups are increased under conditions of reduced water turbidity in high water.

MATERIAL AND METHODS

In the Sinhá Mariana Lake, research has been conducted to understand the temporal distribution patterns of phytoplankton (Loverde-Oliveira & Huszar, 2007), the morphological characteristics and their implications on the limnology of lakes (Fantin-Cruz *et al.,* 2008), and the composition and structure of fish communities (Galina & Hahn, 2009; Pacheco & Da-Silva, 2009). Other studies evaluated the presence of macrophytes (Nunes & Da-Silva, 2009) and the species richness of aquatic invertebrates in different habitats (Wantzen *et al.,* 2011). In this lake, Teixeira-de-Melo *et al.* (2015) experimentally evaluated the role of free-floating plants in formation fish communities in two different water transparency scenarios.

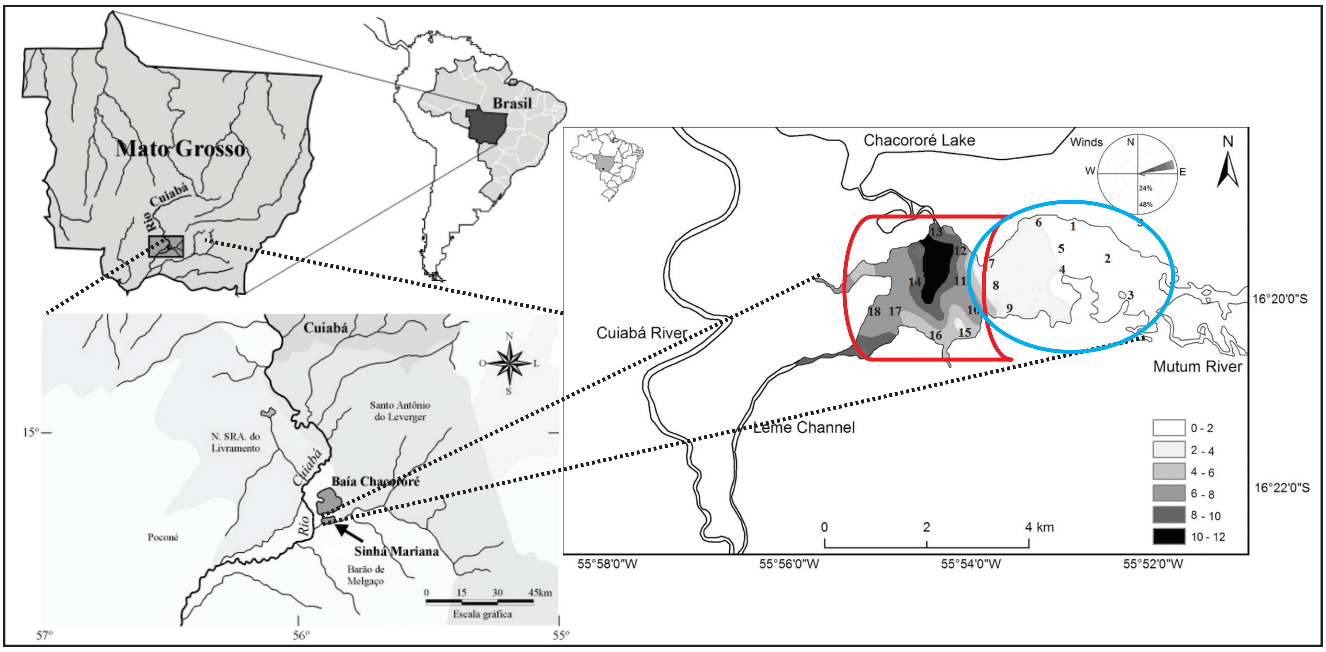

Figure 1. Sinhá Mariana Lake, state of Mato Grosso, Brazil, with 18 sampling sites, showing the Cuiabá River to the west during the dry period (September 2013). In blue, sites under conditions of low turbidity (LT – S1 to S9), and in red, high turbidity (HT – S10 to S18). Map on the right with a drawing of the Sinhá Mariana Lake adapted from Teixeira-de-Melo *et al.* (2015).

The Sinhá Mariana Lake (Fig. 1) is an extension of the Mutum River in the Pantanal (16°14′S, 55°58′W, state of Mato Grosso, Central Brazil) and situated on the left bank of the Cuiabá River, a tributary of the Paraguay River (Loverde-Oliveira & Huszar, 2007).

The Mutum River basin has areas of lowland swampland with an altitude from 100 to 200 meters, areas on the plateau with an altitude from 600 to 900 meters, and a steep transition area between lowlands and plateaus with altitudes from 200 to 600 meters. This region has a predominance of Grassy-Woody Savanna, Savanna Park, Seasonal Semideciduous Alluvial Forest, and Forested Savanna (Correa *et al.,* 2022). The geological substrate of the region is the River alluvium, mainly associated with the dynamics of water courses and floodplains, and are recent deposits resulting from sedimentation along the surface drainages (rivers and streams) and the overflows of Chacororé and Sinhá Mariana lakes (Del'Arco *et al.,* 1982).

The Sinhá Mariana Lake is a permanent, elongated waterbody, with an area of 10.40 km^2, a maximum depth of 4.8 m, and an average of 3.5 m in the high-water period (Teixeira-de-Melo *et al.,* 2015), formed by the widening of the Mutum River with black waters and rich in dissolved organic matter. It remains connected in its western portion to two more turbid water systems, the Chacororé Lake and the Cuiabá River. This morphometric and connectivity arrangement determines the constant exchange of allochthonous material and the occurrence of two regions with distinct water turbidity. Consequently, the waters of Sinhá Mariana Lake have a decreasing gradient of turbidity from the east (inlet of the Mutum River) to the west (flow into the Cuiabá River). This complex hydraulic pattern is mainly shaped by the main river activity under the influence of flooding of the connected areas, which can define the turbidity of the water (Nunes & Da-Silva, 2009).

Sampling was conducted during periods of high water (HW, March 2012) and low water (LW, September 2012) at 18 sampling sites in the Sinhá Mariana Lake. Nine sites were located in the clear water compartment influenced by humic compounds originating from the Mutum River (S01 to S09), and nine sites in the turbid water compartment originating from the Chacororé Lake (S10 to S18), also influenced by the Cuiabá River and Corixo Tarumã (Fig. 1, Table 1).

Duplicates were collected using a Petersen Grab sampler in each sampling site. The biological material was washed through 1,000; 500 and 200 μm mesh sieves, and fixed in 70% alcohol, whose samples were analyzed under a stereomicroscope. All invertebrates were screened, counted, and assigned to FFG, and classified according to morphological identification and information from the relevant literature (Coffman & Ferrington-Jr., 2006). The individuals from the Chironomidae family were separated and mounted on slides with a permanent medium (Euparal) for identification to the lowest possible taxonomic level, according to identification keys (Coffman & Ferrington-Jr., 2006; Trivinho-Strixino, 2011).

The measure of the difficulty of a beam of light crossing a certain amount of water is called turbidity, caused by solid material in suspension (silt, clay, colloids, organic matter). Turbidity was measured using a turbidimeter directly on the water surface, comparing the scattering of a light beam passing through the sample with the scattering of a beam of equal intensity when going through a standard suspension. Limnological data were obtained concomitantly with benthic sampling using portable probes, with direct reading on the device. The depth was taken with a Sechhi disc until reaching the lake bed

Table 1. Sites, aquatic environments and their geographic coordinates during the high and low water periods in the Sinhá Mariana Lake.

Sites	Environmental	Geographical coordinates	
		High Water	Low Waters
S1	Littoral – Riparian vegetation	16°19′20.5″S, 55°52′51.3″W	16°19′19.5″S, 55°52′51.3″W
S2	Pelagic region	16°19′29.9″S, 55°52′48.6″W	16°19′31.7″S, 55°52′48.7″W
S3	Littoral – Mouth of a blackwater river (Mutum R.)	16°20′09.1″S, 55°52′36.8″W	16°20′09.6″S, 55°52′37.0″W
S4	Littoral – Riparian vegetation	16°20′10.8″S, 55°53′14.0″W	16°20′10.4″S, 55°53′19.1″W
S5	Pelagic region	16°19′44.5″S, 55°53′19.1″W	16°19′43.4″S, 55°53′20.7″W
S6	Littoral – Riparian vegetation	16°19′10.6″S, 55°53′28.2″W	16°19′12.4″S, 55°53′26.4″W
S7	Littoral – Riparian vegetation	16°19′29.1″S, 55°53′42.9″W	16°19′30.0″S, 55°53′43.3″W
S8	Pelagic region	16°19′57.9″S, 55°53′51.9″W	16°19′58.0″S, 55°53′51.9″W
S9	Littoral – Riparian vegetation	16°20′16.3″S, 55°53′45.5″W	16°20′11.9″S, 55°53′47.7″W
S10	Littoral – Riparian vegetation	16°19′19.4″S, 55°54′15.2″W	16°19′16.5″S, 55°54′19.4″W
S11	Pelagic region	16°19′57.6″S, 55°54′01.3″W	16°19′57.2″S, 55°54′01.9″W
S12	Littoral – Exchange with the Chacororé Lake	16°19′27.3″S, 55°54′11.7″W	16°19′26.9″S, 55°54′11.7″W
S13	Littoral – Exchange with Chacororé Lake	16°19′23.1″S, 55°54′32.6″W	16°19′23.4″S, 55°54′32.2″W
S14	Pelagic region	16°19′48.9″S, 55°54′21.9″W	16°19′51.1″S, 55°54′35.9″W
S15	Littoral – Riparian vegetation	16°20′29.2″S, 55°54′05.2″W	16°20′28.1″S, 55°54′06.1″W
S16	Littoral – Riparian vegetation	16°20′32.3″S, 55°54′23.4″W	16°20′32.1″S, 55°54′18.0″W
S17	Pelagic region	16°20′08.9″S, 55°54′39.5″W	16°20′11.0″S, 55°54′37.7″W
S18	Littoral – Exchange with the Corixo Tarumã	16°20′15.0″S, 55°55′11.8″W	16°20′17.0″S, 55°55′12.4″W

and then measured with a ruler. Water temperature, pH (pHmeter), and dissolved oxygen (DO, oximeter) were determined using specific devices for direct reading. Chlorophyll-a was estimated using the method of Nusch & Palme (1975); pCO_2 based on Carmouze (1994), and direct color reading (Nessler Quanti 200). The sediment was sampled for particle size analysis (Graham, 1985) using the classical method and organic matter content according to Allen (1989).

Data analysis

In addition, we calculated the diversity indices for the family Chironomidae and analyzed the assemblage through their FFGs. The community structure was characterized using the Shannon-Wiener (H′) diversity index (Pielou, 1975) and the taxonomic composition and morphospecies density dominance index (Chironomidae). The results of these indices were presented for each site and period. The dominance index was calculated using the Kownacki formula (1971), and its values were classified as dominant ($10 < d < 100$) and subdominant ($1 < d < 9.99$).

The densities of FFGs were calculated and their classification was carried out according to morphology together with classical literature. The Chironomidae analyzed were assigned to the appropriate FFG based on the classification proposed by Cummins (1973), Coffman & Ferrington-Jr. (2006) and adapted by Hamada *et al.* (2014): collector-gatherers (removing fine particles from the lower substrate); predators (eating other animals); shredder-herbivores (feeding coarse particulate organic matter > 1 mm) and collector-filterers (capturing fine particles between 0.45 µm and 1 mm from the water column).

The assemblage structure was analyzed using Kownacki's (1971) dominance index for all communities including the taxa identified at the lowest taxonomic level. A one-way ANOVA was applied using Statistics 7.0 to determine differences ($\alpha = 0.05$) in density, diversity, and dominance of the family Chironomidae and limnological variables (dependent variables) according to sites and periods (high and low water). Spearman's correlation coefficient (r) was used using density and diversity data to estimate associations between species and FFGs in the sites.

RESULTS

Environmental characteristics

The mean values and the standard deviation of depth (m), water temperature (°C), pH, turbidity (NTU), pCO_2, and color measured in the 18 sites and different water periods are shown in Fig. 2. The water depth decreased from 2.34 ± 0.68 (HW) to 0.88 ± 0.39 meters (LW). Depth significantly changed between periods (Fig. 2A; $F_{1,34} = 61.47$; $p = 0.00$), and among sampling sites (Fig. 2B; $F_{17,36} = 2.75$; $p = 0.00$). Regarding the thermal structure, temperatures were above 27°C in Sinhá Mariana Lake (Fig. 2C, D), especially between 28.96°C ± 2.60 (S5) and 33.79°C ± 0.01 (S11), and varied significantly among sites ($F_{17,18} = 2.65$; $p = 0.02$).

There was a tendency to increase turbidity across sampling sites (Fig. 2F; site S2 – 8.15 ± 10.59 NTU to S13 – 51.40 ± 57.41 NTU), with significantly higher values in the low water period (Fig. 2E; ANOVA $F_{17,36} = 4.56$; $p = 0.00$). The mean pH values (Fig. 2H) varied slightly from S10 (6.14 ± 0.00) to S18 (7.20 ± 1.04), sites with higher turbidity, but with pH neutrality between the sites ($F_{17,36} = 6.37$; $p = 0.00$), and a slight reduction in the high water period (Fig. 2G; $F_{17,34} = 13.78$; $p = 0.00$). The highest values of pCO_2 (Fig. 2I; $F_{17,34} = 24.69$; $p = 0.00$) were identified in the period of high waters (1,649 ± 654), and Color ($F_{1,34} = 15.82$; $p = 0.00$) in the period of low water (Fig. 2K; 260 mg Pt / L ± 152), with an increment of this variable in sites S10-S12 (Fig. 2L).

Organic matter values (%) were higher than 60% in sites S2, S3, S5, S8, and S10 (Fig. 3A; $F_{2,69} = 3.39$; $p = 0.03$), and significantly increased (Fig. 3B; $F_{1,34} = 7.77$; $p = 0.00$) in the high water period (HW; 67.03% ± 27.17).

Faunal composition and spatial distribution in water turbidity

In total, 1,368 specimens of thirty-three invertebrates' morphotypes were sampled, mostly aquatic insects (77.85%) and crustaceans (14.25%). *Aedokritus* sp. (12%), *Notodiaptomus deitersi* (10%), *Ablabesmyia* gr. *annulata* (7%) and *Chironomus strenzkei* (7%) were the most abundant (Table 2), proving to be determinants for differences in assemblage attributes, as well as in numerical densities. For all invertebrate groups, One-way ANOVA did not reveal significant differences between periods and sites for the density of organisms ($F_{1,34} = 1.90$; $F_{17,18} = 0.58$, respectively $p < 0.05$). However, using the dominance index of Kownacki (Table 2), *Notodiaptomus deitersi* (Crustacea) was dominant in the low water period (LW), and *Aedokritus* sp. (Insecta, Chironomidae) was subdominant in the high water period (HW).

Only within the family Chironomidae, *Corynoneura* sp., *Beardius phytophilus,* and *Parachironomus* sp.4 were found exclusively in the HW period, while *Pelomus* sp., *Polypedilum* gr. *fallax, Dicrotendipes* sp., and *Fissimentum* sp.2 only in the low water period (LW). Considering other aquatic insects, *Campsurus notatus* (Table 2), were subdominant, with differences in density ($F_{2,69} = 9.67$; $p = 0.00$), which resulted in higher values in LW.

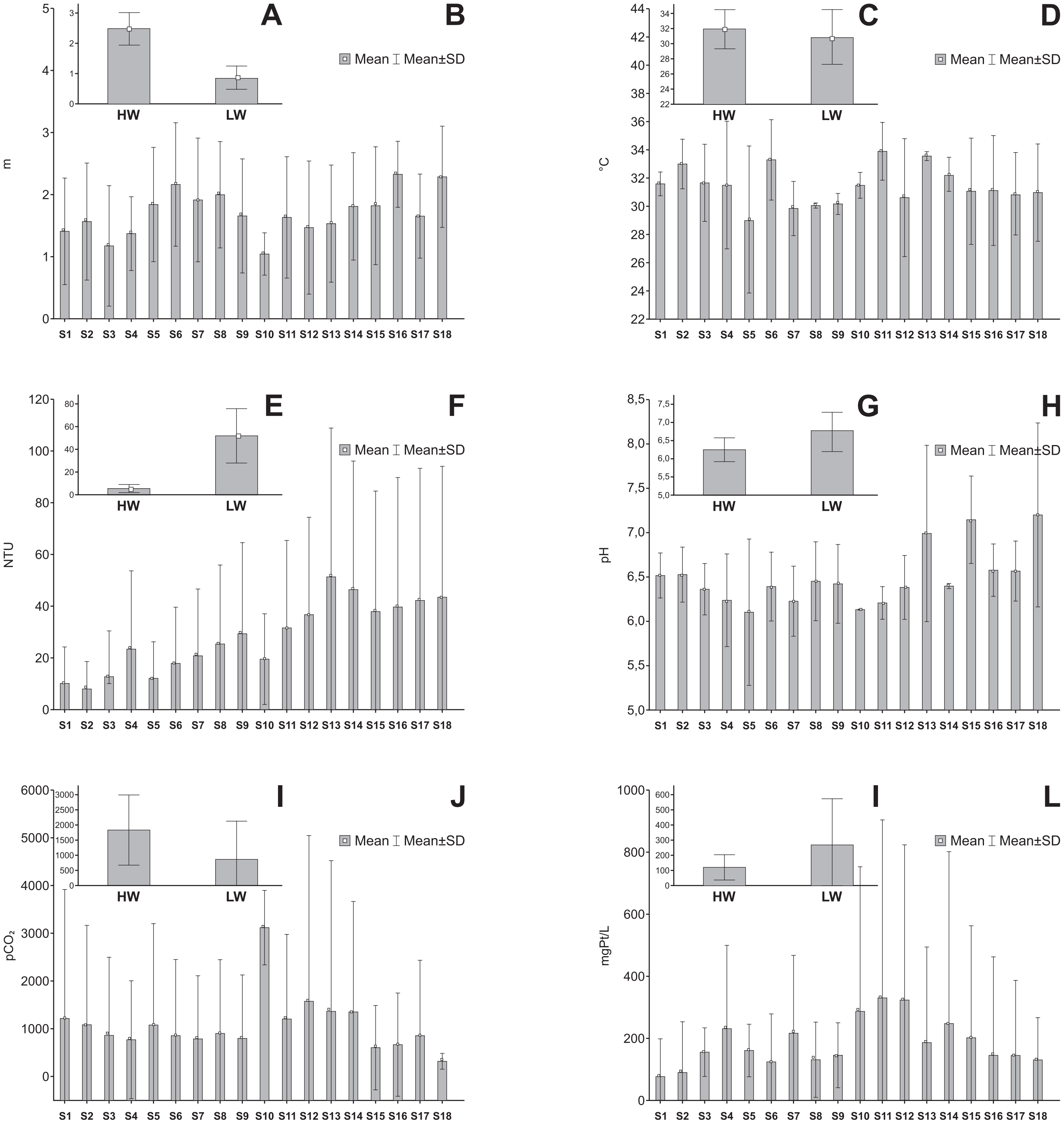

Figure 2. Mean and standard deviation of water depth (m) (A, B), water temperature (°C) (C, D), turbidity (NTU) (E, F), pH (G, H), pCO_2 (I, J), and color (K, L) at 18 sampling sites in the Sinhá Mariana Lake in periods of high (HW) and low water (LW).

Table 2. Mean density (± standard deviation) and Kownacki dominance index in the sampled periods at the Sinhá Mariana Lake. Dominants (10 ≤ d ≤ 100); Subdominants (1 ≤ d ≤ 9.99). MD = Mean density.

COMPOSITION	HW		LW	
	MD (SD)	Kownacki	MD (SD)	Kownacki
Annelida				
Oligochaeta	31.35 ± 69.38	0.99	10.78 ± 29.72	0.52
Hirudinea	—		0.98 ± 4.16	0.01
Crustacea				
Cladocera	3.92 ± 16.63	0.02	18.62 ± 48.58	0.68
Copepoda	27.43 ± 87.71	0.35	—	
Cyclopoida	0.98 ± 4.16	0.01	4.9 ± 13.26	0.18
Calanoida	—	—		
Notodiaptomus deitersi			128.36 ± 248.89	**10.86**
Ostracoda	3.92 ± 12.91	0.05	2.94 ± 9.07	0.07
Nematoda	26.46 ± 82.78	0.83	27.43 ± 92.38	0.99
Hydracarina	—		8.82 ± 33.27	0.21
INSECTA				
Trichoptera (larva)	12.74 ± 35.17	0.24	—	
Trichoptera (adulto)	22.54 ± 79.06	0.43	—	
Ephemeroptera				
Polymitarcyidae				
Campsurus notatus	—		21.56 ± 34.52	**1.82**
Coleoptera	5.88 ± 14.82	0.11	—	
Elmidae (ad)	17.64 ± 62.28	0.33	18.62 ± 47.81	0.90
Elmidae (lv)	—		3.92 ± 12.91	0.09
Hemiptera (ninfa)	33.31 ± 132.79	0.42	4.9 ± 20.79	0.06
Diptera				
Ceratopogonidae	—		0.98 ± 4.16	0.01
Chaoboridae				
Chaoborus sp.	—		5.88 ± 17.11	0.21
Chironomidae				
Chironomidae (Pupa)	48.99 ± 203.49	0.61	—	—
Tanypodinae	0.97 ± 4,16	0.01	—	—
Pentaneurini (larva)	7.83 ± 18,37	0.20	—	—
Ablabesmyia gr. *annulata* Joahnsen, 1905	63.68 ± 125,32	**2.81**	34.29 ± 42.55	**4.56**
Labrundinia sp.	47.03 ± 162,55	**1.19**	6.86 ± 29,09	0.08
Chironominae				
Chironomini	19.59 ± 63,41	0.37	—	
Asheum sp.	14.69 ± 29.17	0.46	9.8 ± 37.4	0.24
Beardius phytophilus Trivinho-Strixino & Strixino, 2000	26.45 ± 48.49	**1.33**	—	
Chironomus strenzkei Fittkau, 1968	50.95 ± 186.25	**1.29**	37.23 ± 79.31	**3.60**
Cryptochironomus brasiliensis Silva *et al.,* 2010	18.61 ± 56.58	0.35	0.98 ± 4.16	0.01
Dicrotendipes sp.	—		0.98 ± 4.16	0.01
Fissimentum desiccatum Cranston & Nolte, 1996	21.55 ± 53.62	0.82	8.82 ± 29.17	0.32
Fissimentum sp.2	—		0.98 ± 4.16	0.01
Goeldichironomus petiolicola Trivinho-Strixino & Strixino, 2005	41.15 ± 68.44	**2.08**	16.65 ± 29.93	**1.01**
G. maculatus Trivinho-Strixino & Strixino, 1991	23.51 ± 58.96	0.89	2.94 ± 12,47	0.04
Parachironomus sp.4	23.51 ± 42.35	0.89	—	
Pelomus sp.	73.48 ± 186.28	**3.71**	9.8 ± 24.36	**2.19**
Polypedilum sp.	—		36.25 ± 83.71	0.36
Polypedilum gr. *fallax*	—		1.96 ± 8.31	0.02
Tanytarsini	17.63 ± 53.77	0.56	—	
Tanytarsus sp.	18.61 ± 44.24	0.47	19.6 ± 78.85	0.47
Pseudochironomini				
Aedokritus sp.	143.05 ± 330.39	**5.41**	13.72 ± 39.92	0.50
Orthocladiinae				
Corynoneura sp.	33.31 ± 85.09	0.84	—	

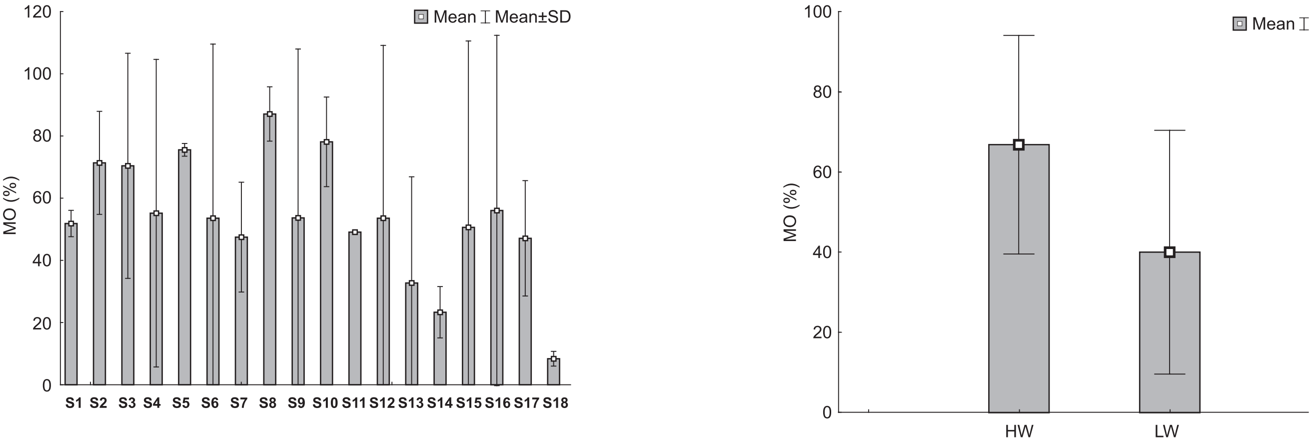

Figure 3. Mean and standard deviation of the organic matter (%). (A) at 18 sampling sites in the Sinhá Mariana Lake, (B) in periods of high (HW) and low water (LW).

Differences in the Chironomidae assemblage attributes are illustrated in Fig. 4. Considering only this family of insects, density reached the highest values (Fig. 4A) in site S2 (2,275 ± 3,218 ind/m^2) and S9 (1,508 ind / m^2 ± 711; Fig. 4A; $F_{17,36}$ = 2.68; p = 0.00). The increase was significant for the HW period (Fig. 4B; 881 ± 1,116 ind / m^2; $F_{1,32}$ = 5.80; $p < 0.05$).

In sites with low turbidity (LT – S1-S9), there was an upward trend in diversity indices of Chironomidae species (Fig. 4C; $F_{1,16}$ = 1.72; p = 0.04) with significant differences. The Dominance Index achieved variability across sites (Fig. 4E; $F_{1,16}$ = 3.31; p = 0.04). *Ablabesmyia* gr. *annulata, Chironomus strenzkei, Cryptochironomus brasiliensis, Fissimentum desiccatum, Goeldichironomus petiolicola, G. maculatus, Polypedilum* sp., and *Aedokritus* sp. were recorded in sites with higher diversity. Diversity had a characteristic variation (Fig. 4C), with the highest mean values in sites S05 (H′ = 0.68 ± 0.05) and S09 (H′ = 0.83 ± 0.15). The attributes of diversity and dominance were opposite in relation to the periods (Figs. 4D and 4F). Water turbidity values showed a negative correlation with the attributes of density and diversity indices (r_s = –0.56; r_s = –0.60, $p < 0.05$, respectively) and a positive correlation with dominance (r_s = 0.48; $p < 0.05$).

The mean density of Functional Feeding Groups (FFGs) of Chironomidae are shown in Fig. 5A (morphospecies) and Fig. 5B. Collector-gatherers, predators, shredder-herbivores, and collector-filterers were identified in the Sinhá Mariana Lake, and all were present in the HW and LW periods. All showed differences (Fig. 5B; $F_{4,67}$ = 3.24; $p < 0.05$) and predominated in the HW. Collector-gatherers (*Aedokritus* sp., *Chironomus strenzkei, Goeldichironomus petiolicola, Beardius phytophilus, G. maculatus, Parachironomus* sp.4 and *Fissimentum desiccatum*) were present in most sites, reaching 50% of the total, whereas the highest density of predators (*Ablabesmyia* gr. *annulata, Labrundinia* sp., *Cryptochironomus brasiliensis*) reached 23%.

Collector-filterers represented 18% of the fauna, despite the tendency to increase the mean numerical density to increase from the high (20 ± 49 ind/m^2) to low water (94 ± 197 ind/m^2) periods. The least representative was shredder-herbivores (9%). Using the Spearman Correlation Index, the functional feeding groups showing a positive correlation with turbidity were predators, especially represented by *Cryptochironomus brasiliensis* and *Ablabesmyia* gr. *annulata* (r_s = –0.45; $p < 0.05$). Under conditions of higher water turbidity during the low water period (Fig. 2E), this last species was subdominant (Table 2).

Collector-gatherers were negatively correlated (r_s = –0.44; $p < 0.05$) with turbidity, with the record of *Asheum* sp., *Beardius* sp., *Goeldichironomus petiolicola, G. maculatus,* and *Pelomus* sp. *Chironomus strenzkei,* a species from this trophic group, was positively associated with turbidity (r_s = 0.65; $p < 0.05$), as it was subdominant in periods of low water with high turbidity. *Notodiaptomus deitersi,* a dominant microcrustacean in periods of low water, was positively correlated with turbidity (r_s = 0.63; $p < 0.05$).

DISCUSSION

Physical changes in the bottom substrate caused by the suspension of organic matter, with a consequent increase in turbidity (Davies-Colley & Smith, 2007), are translated into different effects on the structure of the biota (Teixeira-de-Melo *et al.,* 2015), on its density and diversity values. The highest turbidity, pH, and color in the low-water period (Figs. 2E, G, and K) coincided with the period of strong winds that caused turbulence and mixing of the water column. This result was decisive for biological processes, as reported by Wantzen *et al.* (2011) for this same lake.

The Sinhá Mariana Lake shows peculiar floodplain characteristics due to the permanent hydrological connectivity with the river throughout the year, which is subjected to changes in the water level. Spatially, there was variation between sites and periods, mainly for depth, turbidity, and pCO_2. The Mutum River transports large amounts of humic compounds into the Sinhá Mariana Lake, which contributes to the formation of black water in its lake system (Nunes & Da-Silva, 2009), as recorded in the first sites (S1-S9).

The increased organic matter in site S8 (85%) may be relevant to the demand from the riparian vegetation that carries material to the limnetic region. Site S10 (Riparian

Vegetation), with a shallower depth, presented the highest pCO_2 values (3,122.00 uatm ± 400.93), which coincided with the accumulation of organic matter (67% ± 27). In larger particles, organic matter is intercepted mainly by shredder-herbivores and collector-gatherers. These functional feeding groups break down large organic particles into smaller sizes, releasing pCO_2.

The organic matter in the beds of rivers and lakes is a structurally important variable, in quantity and quality (Mariani *et al.,* 2006), to the availability of habitats and food resources for benthic organisms (Ptatscheck *et al.,* 2020). In places with the highest organic matter content, there was an increase in species diversity. The lateral influx of water from the Mutum River into the lake was relevant to the increase in Chironomidae diversity up to site S9, related to the drift of water into the Sinhá Mariana Lake.

In tributaries of the Pantanal of Mato Grosso, Aburaya & Callil (2007) documented that communities are influenced by factors that determine trophic distribution in microhabitats. The Sinhá Mariana Lake corresponds to the area formed by intersecting gradients, and aquatic habitats are directly influenced by the Cuiabá River and the Chacororé Lake. The increase in water turbidity was verified along the gradient from site S13, located close to the confluence with the Chacororé Lake, with the

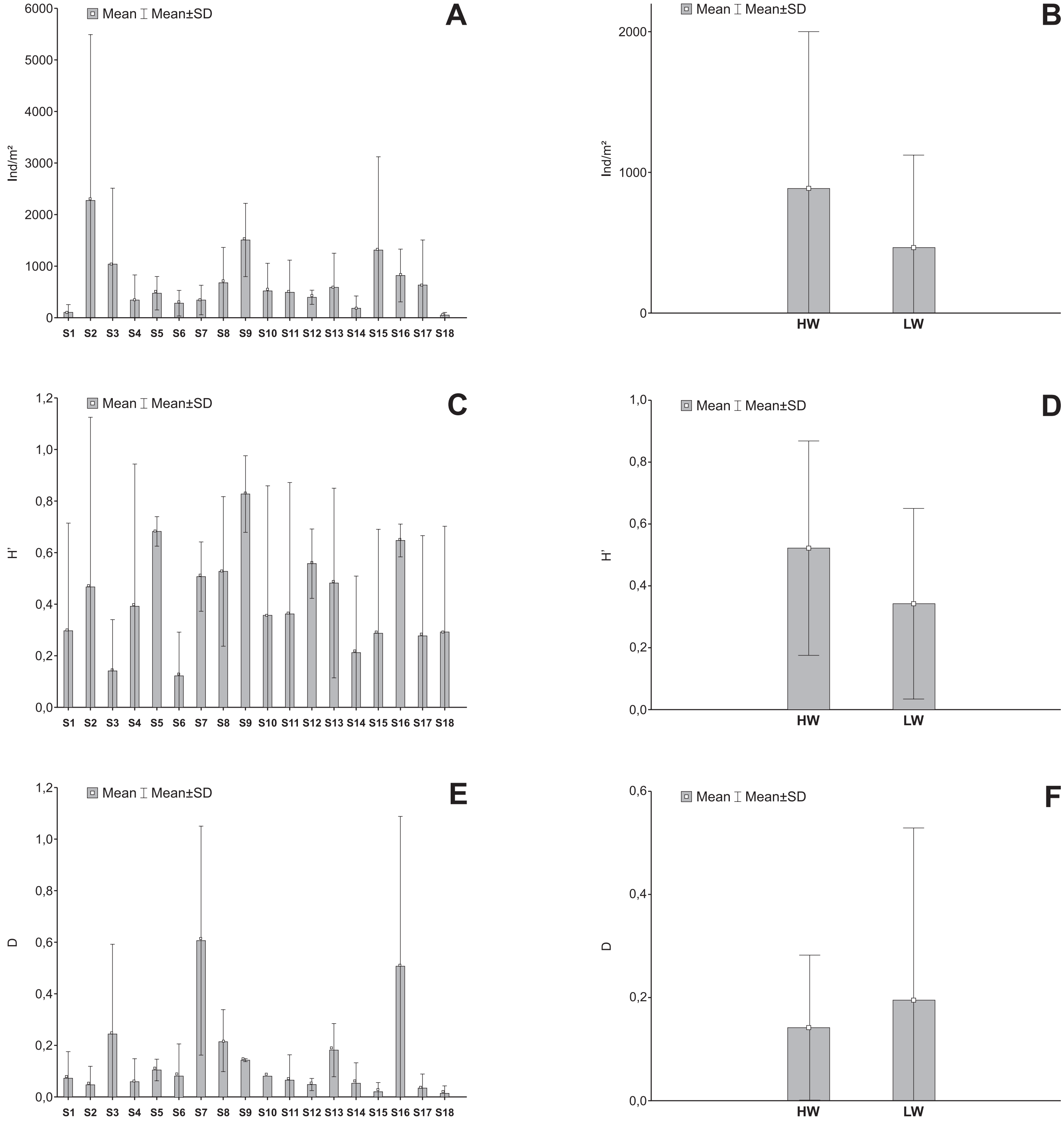

Figure 4. Mean and standard deviation of Chironomidae attributes (Density, Diversity, and Dominance) at 18 sampling sites in the Sinhá Mariana Lake, in periods of high and low water.

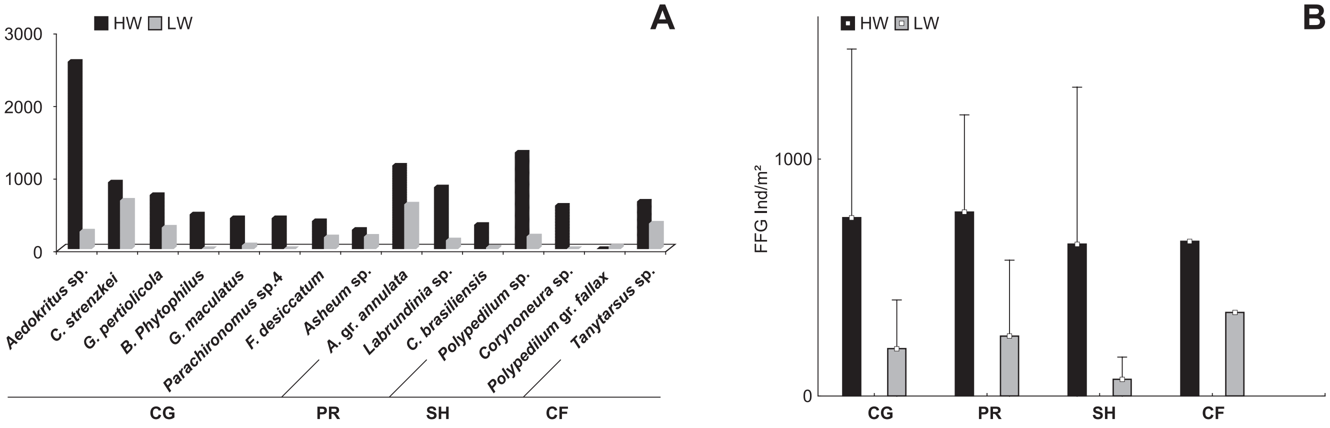

Figure 5. Chironomidae morphospecies (A) and FFGs (B) found in the Sinhá Mariana Lake. CG = Collector-gatherers; PR = Predators; SH = Shredder-herbivores; CF = Collector-filterers. Mean density and standard deviation of FFGs, in periods of high and low water.

greatest variability in water turbidity values (57 NTU ± 40) and stability until site S18. Water flow from the Cuiabá River to the Corixo Tarumã can change its direction or disrupt contact when water levels are too low, and macrophyte stands can block the channels, as Wantzen *et al.* (2011) observed. Except for S3 and S6, diversity (Fig. 4C) reached the highest values in sites with clearer waters and reduced water turbidity (Fig. 2F). During the flood period, the values of this variable were reduced, probably due to the dilution of the suspended material.

No significant changes were identified for the groups, considering the density of the organisms. However, flow fluctuations increased the density of the family Chironomidae in the HW period, probably related to food resources, which resulted in a well-structured community. Functional Feeding Groups change depending on the availability of food resources (Henriques-Oliveira & Nessimian, 2010).

In sites with low turbidity, 14 species were recorded throughout the sampling period, and 11 species in sites with high turbidity. *Cryptochironomus brasiliensis, Fissimentum desicatum, Goeldichironomus petiolicola, Polypedilum* sp., and *Tanytarsus* sp. were recorded in sites with greater diversity, notably sites S2 (near the Mutum River) and S9 (riparian vegetation), due to the contribution of collector-gatherers (*Aedokritus* sp. and *C. strenzkei*), subdominants and predators (*Ablasbemyia* gr. *annulata* and *Labrundinia* sp.).

Sites S7 and S16 showed greater dominance due to the contribution of *Ablabesmyia* gr. *annulata, C. strenzkei, Dicrotendipes* sp., and *Fissimentum* sp.2. The low water period was favorable to the development of collector-filterers related to low levels of organic matter and pCO_2. The subdominance of some organisms in the collector-scavenger group refers to detritivores organisms that feed on organic particles, such as the chironomids *Chironomus strenzkei, Beardius phytophilus, G. petiolicola,* and *Pelomus* sp., as they convert organic matter into food and decompose organic matter. Other groups of invertebrates that also make up foragers, such as *Notodiaptomus deitersi* and *Campsurus notatus,* include detritivores (Table 2). When sediment movement increases during floods, collector-filterer larvae make lateral movements toward the lake shore to avoid the current. These larvae are subjected to predation by fish and are found in crevices that serve as refuges. *Campsurus notatus* dig burrows that are secondarily colonized by caddisflies and chironomids in the same density range.

An investigation by Wantzen *et al.* (2011) in the Sinhá Mariana Lake found that *Campsurus* sp. increased in density during decreasing water levels, which indicated that the nymphs take advantage of suspended food sources in floodplain areas and burrow in sediments. Fonseca *et al.* (2007) investigated its significant role in the carbon cycle through the impact of bioturbation of this species in the Batata Lake.

Among all invertebrates, the dominance of *Notodiaptomus deitersi,* a collector-filterer, in the low-water period suggests that it has environmental plasticity regarding variations in water turbidity. Other species, such as *Goeldichironomus petiolicola, Ablabesmyia* gr. *annulata* and Elmidae increased with the reduction in pCO_2. Some predators (*Cryptochironomus brasiliensis* and *Labrundinia* sp.) were present in environments with low pH. Physical disturbances are important in controlling the density and distribution of other FFGs such as predators (*Ablabesmyia* gr. *annulata, Chaoborus* sp., and Ceratopogonidae), collector-gatherers, and herbivore-shredders (*Polypedilum* gr. *fallax* and *Corynoneura* sp.). Predatory caddisflies (Trichoptera) and hemipterans (Hemiptera) were rarer at the sites.

FFGs have a structure determined by the available food supply, such as algae and detritus (Butakka *et al.,* 2014). The important role of these groups in food chains was investigated by Henriques-Oliveira & Nessimian (2010) on the interaction between producers and secondary consumers, opportunistic omnivores, which feed on a wide variety of foods. In their aquatic phase, some species can survive under unfavorable oxygen conditions and adjust to environmental changes (Butakka *et al.,* 2016).

In the present study, *Chironomus strenzkei,* a forager and detritivore species more adapted to environmental variability, predominated in sites with low diversity or zero diversity (S15 – high water; S10 – low water). Species of this genus may be the only insects present in the sediment (Butakka *et al.,* 2014), and in the Sinhá Mariana Lake, it contributed the highest values during the flood and subdominant periods. In the Upper Paraná River floodplain, Butakka *et al.* (2016) recorded this species in biotopes rich in organic matter and classified it as a generalist species.

The flood pulse determines the availability of habitat resources (Castro *et al.,* 2013), which depends on connectivity, with an important role in sites that sustain high species richness (Siqueira *et al.,* 2008), facilitating trophic interactions, migration, and dispersal of organisms (Wantzen *et al.,* 2008). *Corynoneura* sp., characteristic of lotic systems (Trivinho-Strixino, 2014), was transported from the channels to the Sinhá Mariana Lake during the flood period (Table 2).

Ecological processes in the hyporheic zone may naturally load groundwater with bioavailable solutes in waters, which appear to exert proximal control over the structure of FFGs and biodiversity. Sites S2, S9, and S15 had the highest density values, which included more adapted species, such as *Aedokritus* sp., *Polypedilim* sp., *Ablabesmyia* gr. *annulata* and *Chironomus strenzkei.* The transition conditions in turbid waters are structural and functional elements that contribute to the spatio-temporal dynamics of wetlands, exclusively as in the Sinhá Mariana Lake (Loverde-Oliveira & Huszar, 2007).

CONCLUSION

The natural hydrological dynamics, the flood pulse in the Sinhá Mariana Lake, and its interactions with the river and streams must be considered important objects in the landscape planning of the Pantanal. The flood period contributed to increased density and diversity in sites with reduced water turbidity. The functional structure of the invertebrate community determines the scale at which protection efforts should better be directed to maintain local ecological conditions.

Sites with low turbidity favored groups of detritivores, shredder-herbivores, and predators. Collector-filterers were provided during the low-water period. The results demonstrated that environmental gradient processes and the hydrological cycle are important factors determining the spatial and temporal patterns of the benthic community. Changes in turbidity in different sites and periods can raise questions about the main drivers of communities in the Pantanal wetlands, areas of high ecological relevance for maintaining biodiversity.

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