Effects of environmental factors on community structure of Leptophlebiidae (Insecta, Ephemeroptera) in Cerrado streams, Brazil

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ABSTRACT. We analyzed the effects of environmental factors on abundance, species richness, and functional group richness of Leptophlebiidae in 16 sampling points along four Cerrado streams. Across three periods of 2005, we collected 5,492 larvae from 14 species in stream bed substrate. These species belong to three functional feeding groups: scrapers, filtering collectors and shredders. The abundance and species richness were not affected by water quality, but habitat quality related to presence of riparian vegetation had positive effects on the abundance of shredders. Our results add important information on the natural history of the species and functional groups of aquatic insects and also provide relevant data for the monitoring and conservation of streams in the Brazilian Cerrado.

KEYWORDS. Aquatic insects; functional feeding groups; environmental changes.

RESUMO. **Efeito de fatores ambientais sobre Leptophlebiidae (Insecta: Ephemeroptera) em córregos de Cerrado, Brasil.** O efeito de fatores ambientais sobre a abundância, riqueza de espécies e grupos funcionais alimentares de Leptophlebiidae foi analisado em 16 locais pertencentes a quatro córregos de Cerrado, a partir de coletas de substrato em três períodos de 2005. Foram amostradas 5.492 larvas distribuídas em 14 espécies, classificadas em três grupos funcionais alimentares: raspadores, coletores-filtradores e fragmentadores. A abundância e riqueza de espécies não foram afetadas por nenhum dos fatores ambientais investigados, mas a integridade dos hábitats exerceu efeito positivo sobre a abundância dos fragmentadores, consequência da intrínseca interação desses organismos com a mata ciliar. Dessa forma, acreditamos que este trabalho agrega informações bioecológicas sobre as espécies e grupos funcionais de insetos aquáticos e poderá contribuir no monitoramento e conservação de riachos do Cerrado.

PALAVRAS-CHAVE. Insetos aquáticos; grupos funcionais alimentares; alterações ambientais.

Aquatic ecosystems are complex biological systems in which physic-chemical processes influence and are influenced by interspecific interactions (Bae *et al.*, 2011). Anthropogenic disturbances and land use in the drainage basin may impact the aquatic environment during and after the runoff (Cabette *et al.*, 2010; Dias-Silva *et al.*, 2010). The removal of riparian vegetation has a negative effect on the input of organic matter, which is the source of energy in small stream ecosystems (Delong & Brusven, 1994).

Habitat quality is a major factor determining the colonization and establishment of ecological communities in lentic and lotic systems (Tate & Heiny, 1995). Pollution, eutrophication, siltation, dams, flood control, fisheries and introduction of exotic species contribute directly to the loss of aquatic biodiversity (Agostinho *et al.*, 2005).

Aquatic insects are among the most commonly used bioindicators of aquatic habitat quality, owing to the key role in organic material cycling in aquatic ecosystems (Bello & Cabrera, 2001) and cross-ecosystem linkages between aquatic and the adjacent riparian environment (Da-Silva *et al.*, 2010).

Mayflies are abundant and diverse aquatic insects in both lentic and lotic environments, especially in streams (Brittain, 1982). They are good bioindicators due to their low tolerance to environmental change (Da-Silva & Domingues, 2009). In most cases, environmental disturbs changes species abundance and composition (e.g. Shimano *et al.*, 2010; Souza *et al.*, 2011). Mayflies also play key roles in transference of materials between aquatic and terrestrial environments through respiration and adult biomass (Da-Silva *et al.*, 2010).

Currently, 10 families and 290 species of mayflies are known to occur in Brazil, from which Leptophlebiidae (mayflies) ranks the second most speciose, with 77 species (Salles *et al.*, 2013). Much attention has been given to taxonomic studies (e.g. Da-Silva *et al.*, 2002; Salles *et al.*, 2004; Domínguez *et al.*, 2006; Polegatto & Batista, 2007; Boldrini *et al.*, 2009). However, ecological data about these organisms are reduced (e.g. Shimano *et al.*, 2010, 2013; Souza *et al.*, 2011).

Therefore, our goal was to analyze how environmental factors and habitat integrity influence species richness, abundance, and functional group abundance of Leptophlebiidae in Cerrado streams. We tested the hypothesis that environmental integrity is more important than changes in water chemistry for mayflies.

MATERIAL AND METHODS

The Pindaíba River Basin (14°16’46”S and 15º57’17”S; 51°26’37”W and 52°37’03”W; 930 m a.s.l) has 10,029 km^2 and is located in the eastern region of state of Mato Grosso, central Brazil. It is the major tributary of the right bank of the Rio das Mortes. Its headwaters are in the Acantilados plateau (Brasil, 1981) in the city of Barra do Garças.

The climate in the region is Köppen's *Cwa*, with two well-defined seasons: dry season between May and September and a rainy season between December and March. Annual average rainfall ranges from 1.200 to 1.600 mm and average temperatures from 20 to 25°C, with September and October being the warmest months (Brasil, 1981).

We sampled mayfly larvae in 16 sampling points of four 1st to 4th order streams (Strahler, 1957) (Fig. 1) on the left bank of the Pindaíba River: Cachoeirinha (CS), da Mata (MS), Papagaio (PS) and Taquaral (TS). Samplings were conducted in three periods of the year of 2005: January (peak of the rainy season), July (peak of the dry season) and October and November (early rainy season). We established 100-m linear transects on the right bank in each sampling point. These transects were further divided into 20 5-m segments (Cabette *et al*., 2010; Dias-Silva *et al*., 2010; Shimano *et al*., 2012, 2013). Samples of the substrate were obtained through a sieve of 18 cm diameter and 250 µm mesh, and were collected three times per segment.

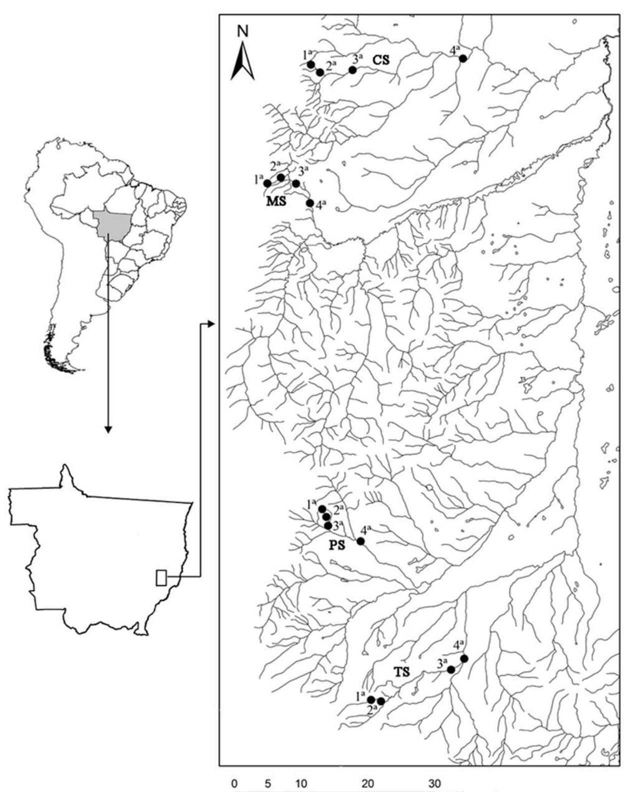
Larvae were identified to the species or morphospecies level using taxonomic keys (Domínguez *et al*., 2006). Specimens were conserved in 85% ethanol and are housed at the zoobotanical collection James A. Ratter (CZNX, Universidade do Estado de Mato Grosso). We classified each species/morphospecies into functional trophic group according to the literature (Bello & Cabrera, 2001; Polegatto & Froehlich, 2003; Baptista *et al.*, 2006; Shimano *et al.*, 2012).

The environment integrity of each sampling point was measured by the protocol proposed by Nessimian *et al.* (2008). The protocol generates 12 variables about the local environment, including land use, the conservation status of the riparian zone, characteristics and morphology of streams. Each variable has four to six ordered levels according to integrity. The final index varies from zero (more impacted locals) to one (more conserved ones; Nessimiam *et al*., 2008).

Ten environmental variables were recorded: stream width (measured using Leica DISTOM®); depth (measured using sonar Echotest® mod II); water temperature, pH, turbidity, dissolved oxygen, conductivity (measured using Horiba® multiparameter probe); water hardness (measured using EDTA 0.002M); nitrate and phosphorus (measured using spectrophotometer).

To test the influence of environmental variables on species abundance, richness, and abundance of Functional Feeding Groups (FFG) of Leptophlebiidae genera [Filtering Collectors (FC), shredder (S), and scrapers (SC)], simple linear regressions were used (Zar, 1999).

To avoid multicollinearity among predictor variables, we calculated a pair-wise Pearson's correlation matrix between environmental variables. We removed variables with $r \geq 0.7$ (Graham, 2003).



Abbreviations	Geographic coordinates
CS1	14°50'30"S, 52°24'54"W
CS2	14°50'50"S, 52°24'22"W
CS3	14°50'33"S, 52°21'34"W
CS4	14°49'45"S, 52°12'55"W
MS1	14°59'53"S, 52°28'42"W
MS2	14°59'18"S, 52°27'30"W
MS3	14°59'59"S, 52°26'29"W
MS4	15°01'32"S, 52°26'29"W
PS1	15°27'01"S, 52°24'30"W
PS2	15°27'32"S, 52°24'42"W
PS3	15°28'11"S, 52°24'32"W
PS4	15°28'59"S, 52°21'47"W
TS1	15°41'54"S, 52°20'03"W
TS2	15°41'57"S, 52°19'56"W
TS3	15°39'35"S, 52°13'52"W
TS4	15°38'53"S, 52°12'53"W

Fig. 1. Sampling sites of leptophlebiid larvae with geographic coordinates in four streams of Bioma Cerrado, Brazil: CS, Cachoeirinha stream; MS, da Mata stream; PS, Papagaio stream; TS, Taquaral stream. Roman numbers represent the stream order.

RESULTS

We recorded 5,492 leptophlebiid larvae from 13 genera and 14 species (Tab. I). The most abundant species were *Miroculis* sp. (n=2,031) and *Farrodes* sp. (n=1,353), comprising 61% of the total species abundance, followed by *Terpides sooretamae* Boldrini &Salles, 2009 (n=1,177) representing 21% of the total species abundance. The least abundant species were *Tikuna bilineata* (Needham & Murphy, 1924) (n=2), *Traverella* sp. (n=17), and *Simothraulopsis* sp. (n=25).

We found species belonging to three functional feeding groups: scrapers, filtering collectors, and shredders (Tab. I). Scrapers comprised seven genera and also had the highest abundance, with 3,760 species, representing 68.5% of the total abundance, and occurred in all sampling points (frequency 100%). Shredders comprised four genera with 30.7% of the total abundance (n=1,684) and occurred in 14 sampling points (87.5%). Filtering collectors included two genera, comprising 0.9% (n=48) of the total abundance and occurred in only seven sampling points (46.8%).

The Habitat Integrity Index (HII) ranged from 0.61 to 0.96. The less disturbed sites were Mata Stream 1 (MS1) with HII 0.96 and Taquaral Stream 1 (TS1) with 0.94. The most disturbed sites were Taquaral Stream 3 (TS3) and Taquaral Stream 4 (TS4), both with 0.64, and Cachoeirinha Stream 1 (CS1) with 0.61. We found that environmental variables did not explain species abundance and richness (Tab. II). Thus, it seems that the variance of these variables along sampling points could not predict mayfly community structure. However, the HII significantly influenced shredders' abundance ($R^2 = 0.286$; $p = 0.033$; Fig. 2), but not other functional groups (Tab. II).

DISCUSSION

Leptophlebiidae is a speciose taxa, with several generalist genera widespread in aquatic ecosystems (Domínguez *et al.*, 2006). Here, we presented relevant data about the distribution and ecology of 14 mayfly species. Most information about the ecology of leptophlebiids in Brazil are sparse and anecdotal (Da-

Tab. I. Abundance and frequency of leptophlebiid larvae in four streams of Bioma Cerrado, Brazil (CS, Cachoeirinha stream; MS, da Mata stream; PS, Papagaio stream; TS, Taquaral stream).

	CS				MS				PS				TS				Frequency
	1ªO	2ªO	3ªO	4ªO	1ªO	2ªO	3ªO	4ªO	1ªO	2ªO	3ªO	4ªO	1ªO	2ªO	3ªO	4ªO	%
Askola sp.	0	2	18	0	0	5	0	2	7	3	3	0	1	6	0	0	56.2
Farrodes sp.	3	218	70	5	35	172	196	161	124	122	126	15	58	9	31	11	100.0
Fittkaulus cururuensis Savage, 1986	1	38	19	0	0	1	20	19	1	6	4	23	32	7	0	3	81.3
Gênero 4 sp.	0	8	0	0	4	0	6	0	12	3	20	0	29	1	0	0	50.0
Hagenulopsis sp.	0	4	90	0	6	5	9	2	45	12	6	0	3	9	0	0	68.8
Miroculis sp.	61	506	391	0	2	18	174	62	0	25	115	54	31	266	111	215	87.5
Paramaka convexa (Spieth, 1943)	0	0	9	0	0	0	2	0	0	1	2	0	1	0	9	7	43.85
Simothraulopsis sp.	0	0	0	0	1	1	8	3	2	1	1	1	0	0	2	7	62.5
Terpides sooretame Boldrini & Salles, 2009	1	8	4	0	0	122	325	100	94	16	73	4	388	42	0	0	75.0
Thraulodes sp.	0	0	0	0	0	0	0	0	20	4	0	0	1	0	0	0	87.5
Tikuna bilineata (Needham & Murphy, 1924)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	12.5
Traverella sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	2	12.5
Ulmeritoides sp. 2	8	8	5	0	0	3	32	9	0	1	2	17	6	19	15	13	81.3
Ulmeritoides sp. 3	52	22	7	0	0	1	19	21	0	0	1	1	20	47	1	1	75.0
Abundance by sites	126	814	613	5	48	328	791	379	305	194	353	115	570	406	185	260	100%

Tab. II. Functional Trophic Groups (FTG) of leptophlebiid genera of four streams of Bioma Cerrado, Brazil (FC, filtering collectors; S, shredder; SC, scrapers) and references consulted.

Genera	FTG	References consulted
Askola Peters, 1969	SC	Polegatto & Froehlich, 2003; Baptista *et al.*, 2006
Farrodes Peters, 1971	SC	Polegatto & Froehlich, 2003; Siegloch, 2006; Baptista *et al.*, 2006
Fittkaulus Savage & Peters, 1978	S	Inference to *Terpides*
Gênero 1	SC	Inference to *Farrodes*
Hagenulopsis Ulmer, 1920	SC	Baptista *et al.*, 2006
Miroculis Edmunds, 1963	SC	Polegatto & Froehlich, 2003
Paramaka Savage & Domínguez, 1992	FC	Salles, 2006
Simothraulopsis Demoulin, 1966	SC	Polegatto & Froehlich, 2003
Terpides Demoulin, 1966	S	Bello & Cabrera, 2001
Thraulodes Ulmer, 1920	SC	Polegatto & Froehlich, 2003
Tikuna Savage, Flowers & Porras, 2005	S	Inference to *Terpides*
Traverella Ednunds, 1948	FC	Polegatto & Froelich, 2003
Ulmeritoides Traver, 1959	S	Shimano *et al.*, 2011

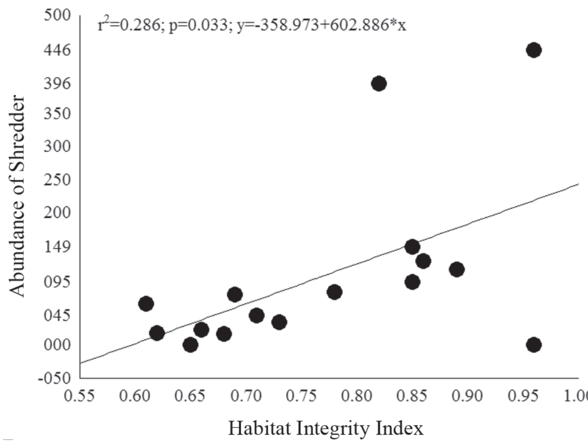


Fig. 2. Relationship between abundance of shredders and Habiat Integrity Index (IIH) in four streams of Bioma Cerrado, Brazil (CS, Cachoeirinha stream; MS, da Mata stream; PS, Papagaio stream; TS, Taquaral stream).

Silva *et al.*, 2010). A recent study (Shimano *et al.*, 2012) provided information about the distribution of functional groups of mayflies. However, the same study did not investigate the influence of environmental and anthropogenic factors on the community.

The dominance of scrapers is related to the high abundance of *Miroculis* and *Farrodes*. Both genera are known for their wide geographic ranges and generalist habits, inhabiting most aquatic environments (Domínguez *et al.*, 2002; Baptista *et al.*, 2006), including the semi-lotic ones (Da-Silva *et al.*, 2002). Likely, these morphospecies may constitute more than one species, since it is difficult to identify their larvae to the specific level (Shimano *et al.*, 2010).

Although *Farrodes* is commonly classified as a scraper (Bello & Cabrera, 2001; Polegatto & Froehlich, 2003; Baptista *et al.*, 2006; Shimano *et al.*, 2011), they are opportunist feeders and likely use a wider range of food sources (Anderson & Sedell, 1979; Bello & Cabrera, 2001). For example, a species of *Farrodes* was classified as filtering collectors (Polegatto & Froehlich, 2003). Filtering-collectors had the lowest abundance in our study. There is no natural history information about the two species recorded, but they only occurred in medium-sized streams (3rd and 4th orders). The same result was found by Shimano *et al.* (2010), in the Suiá-Miçú river basin regarding *Paramaka convexa* (Spieth, 1943).

Shredders were highly abundant, mainly due to the poorly-known species *Terpides sooretame*, which represented 87 % of the shredder abundance. It is only known that it has a wide geographic range within the drainage basin in Mato Grosso (Shimano *et al.*, 2011). With the records of *Fittkaulus* and the rare *Tikuna*, the Pindaíba River basin now holds three genera of the *Terpides* lineage (Bondrini *et al.*, 2009). Shredders feed on allochthonous plant material (Cummins & Klug, 1979; Vannote *et al.*, 1980), contributing to the primary production though. Shredders were also the organisms that were affected by environmental disturbances. Despite the relatively low correlation, the relationship between HII and shedder abundance is an important result, since the fragmentation is an important function of ecosystem of small streams. This result corroborates in part our hypothesis that environmental integrity affects mayflies more than physico-chemical parameters.

The HII index takes into account land use patterns, the conservation status of both riparian vegetation and stream channel (Nessimian *et al.*, 2008). Most sampling sites stood as medium highly conserved. However, the small changes affected significantly the abundance of shredders. These organisms play key roles in energy cycling in headwaters (Allan & Castillo, 2007).

The riparian vegetation plays a key functional and ecological role, silizing stream banks and providing structural heterogeneity (Ruppenthal *et al.*, 2007). Therefore, the loss of riparian vegetation in springs and headwaters has profound consequences for the aquatic

Tab. III. Mean values of environmental variables in four streams of Bioma Cerrado, Brazil (CS, Cachoeirinha stream; MS, da Mata stream; PS, Papagaio stream; TS, Taquaral stream).

Local	pH	Conductivity	Turbidity	Temperature	Dissolved oxygen	Phosphorus	Width	HII
CS1	6.65	100.75	31.95	21.75	3.10	0.16	1.93	0.61
CS2	6.33	54.57	26.56	23.83	3.10	0.15	2.33	0.69
CS3	6.17	13.57	21.58	24.03	5.92	0.19	3.28	0.73
CS4	6.66	7.50	19.63	23.58	6.76	0.12	7.91	0.65
MS1	6.38	0.30	1.60	25.03	7.33	0.06	1.08	0.96
MS2	5.93	0.57	2.27	24.17	6.68	0.04	1.07	0.86
MS3	6.51	3.03	35.67	23.27	8.32	0.14	4.82	0.82
MS4	6.64	7.00	21.41	23.55	6.93	0.12	10.87	0.85
PS1	7.03	14.30	2.95	24.27	6.20	0.16	2.96	0.85
PS2	6.80	18.97	6.89	23.80	6.10	0.16	2.53	0.66
PS3	6.80	11.97	3.60	23.90	5.20	0.10	6.13	0.78
PS4	6.61	6.01	24.98	23.48	7.28	0.13	4.74	0.71
TS1	6.71	7.30	2.28	24.65	6.77	0.11	1.36	0.94
TS2	6.37	9.77	4.58	23.98	6.39	0.10	6.00	0.83
TS3	6.66	7.50	19.63	23.58	6.76	0.12	5.42	0.64
TS4	6.64	6.84	22.01	23.54	6.99	0.12	8.09	0.64

Tab. IV. Results of linear regression between species abundance, richness, and abundances of functional trophic groups of leptophlebiid genera in four streams of Bioma Cerrado, Brazil (FC, filtering collectors; S, shredder; SC, scrapers) and environmental variables. * $P<0.05$.

	Values of r^2					Values of p				
	Abundance	Richness	SC	S	FF	Abundance	Richness	SC	S	FF
pH	0.08	0.01	0.15	0.00	0.00	0.28	0.71	0.14	0.92	0.94
Conductivity	0.00	0.01	0.02	0.02	0.03	0.93	0.68	0.61	0.58	0.55
Turbidity	0.05	0.07	0.08	0.00	0.03	0.39	0.31	0.30	0.95	0.49
Temperature	0.01	0.01	0.01	0.01	0.00	0.68	0.78	0.79	0.69	0.81
Dissolved oxygen	0.02	0.00	0.13	0.08	0.02	0.63	1.00	0.17	0.30	0.60
Phosphorus	0.08	0.00	0.14	0.00	0.02	0.29	0.99	0.15	0.90	0.63
Width	0.06	0.06	0.03	0.04	0.04	0.36	0.36	0.51	0.46	0.47
HII	0.05	0.00	0.00	0.29	0.11	0.39	0.92	0.83	***0.03**	0.21

food web and the maintenance of ecosystem processes (Allan, 2004; Allan & Castillo, 2007).

Our results about the influence of environmental variables on the species richness and abundance support the findings of other studies with different aquatic insects (Nessimian *et al.*, 2008; Dias-Silva *et al.*, 2010; Nogueira *et al.*, 2011). This result could be due to: (i) each water chemistry variable may have not significant relationships with community structure (Cabette *et al.*, 2010), and (ii) the larvae of aquatic insects can tolerate the wide variation in water chemistry (Dias-Silva *et al.*, 2010), since Cerrado streams face prolonged dry and rainy seasons, with multiple flood pulses in the latter. The lack of relationship between HII and abundance and species richness of other functional feeding groups may be related to the characteristics of sampled streams. Even the altered streams kept remnants of riparian forest in one of the margins.

Water chemistry variables did not influence species richness, abundance, and richness of functional feeding groups of Leptophlebiidae. However, shredders were significantly affected by changes in habitat quality. The decrease in shredder abundance can probably disturb nutrient cycling. The effects of these changes will better understood when we analyze the relationships between functional groups and the HII than only species richness. This study added relevant information about the species and functional groups of Ephemeroptera that could be useful for the monitoring and conservation of streams in the Cerrado.

Acknowledgements. This study was funded by the Fundação de Amparo à Pesquisa do Estado de Mato Grosso (#098/04) and CAPES/PROCAD (#109/2007). LSB and JDB received fellowships from CNPq (PELD #558069/2009-6). Lorivaldo A. Castro provided logistics during field work. Frederico F. Salles helped in species identification. Diogo B. Provete reviewed the English language. Several undergrad students from UNEMAT helped in fieldwork.

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Received 3 April 2013. Accepted 25 September 2013. ISSN 0073-4721
Article available at: www.scielo.br/isz