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The influence of habitat integrity and physical-chemical water variables on the structure of aquatic and semi-aquatic Heteroptera

Karina Dias-Silva[1]; Helena S. R. Cabette[1]; Leandro Juen[2] & Paulo De Marco Jr[2]

[1] *Programa de Pós-Graduação em Ciências Ambientais, Departamento de Ciências Biológicas, Universidade do Estado de Mato Grosso. Rua Abaeté 139, 78690.000 Nova Xavantina, MT, Brazil. E-mail: karinabionx@gmail.com*
[2] *Programa de Pós-Graduação em Ecologia e Evolução, Departamento de Biologia Geral, Universidade Federal de Goiás. 74001-970 Goiânia, GO, Brazil.*

ABSTRACT. This work aimed to assess the effect of certain physical-chemical variables and the Habitat Integrity Index (HII) have on an aquatic and semi-aquatic heteropteran community. We collected in five streams (from 1^{st} to 4^{th} order) that differed in habitat integrity, in order to test 1) whether heteropteran richness decreases with the Habitat Integrity Index; and 2) whether richness responds to alterations in water physical-chemical variables, since these influence community structure. In each stream, linear transects of 100 m were demarcated. A total of 1425 specimens from 10 families, 30 genera and 67 morphospecies were collected. Species richness was correlated with the Habitat Integrity Index (HII), showing a positive relationship only for Gerromorpha. This may be due to the fact that streams with greater integrity offer nearby marginal vegetation where prey and shelter can be easily found, representing optimal places for oviposition and hunting. Species adapted to such conditions are more sensitive to alterations in the physical structure of rivers. Significant differences in the composition of Heteroptera and studied infra-orders were also observed, which suggests that the anthropic disturbances over these sites have changed these insect communities. Our results indicate that the alteration in riparian areas can lead to significant changes in Heteroptera composition, even though species richness was not affected. The physical-chemical variables showed no influence on the distribution of species. This result suggests that the environment presented insufficient variation that could cause changes in the investigated community, which implies that factors other than those analyzed here may explain such variation. Three species *Rhagovelia trailli* (White, 1879), *Rhagovelia* sp. 4 and *Tenagobia incerta* (Lundblad, 1928) were considered to be indicators of pristine sites. The results indicate that aquatic and semi-aquatic Heteroptera and more specifically the sub-order Gerromorpha can be an important tool to assess environmental habitat integrity and enhance conservation actions of riparian forests.

KEY WORDS. Aquatic insect; Biomonitoring; Cerrado; Gerromorpha; Nepomorpha.

Abiotic and environmental variables are very important to the ecology of aquatic insects. They directly affect the tolerance limits of organisms and consequently the distributional range of species (Death & Winterbourn 1995). Along with environmental variables, biotic interactions (such as predator-prey interactions, competition for food resources and habitats, and parasitism) are also important in shaping a species' ecological niche (Palmer 1999, Collier 2008, Schmidt *et al.* 2009).

Geological characteristics and the presence of riparian vegetation, among other factors, determine the physical-chemical variables and water flow in aquatic environments. They may also determine the physical structure of the river channel, its substrate type, frequency and intensity of disturbance (e.g. flood pulse), habitat heterogeneity, biotic interactions and the sources of energy input that become available as food. Therefore, they are important determinants of macroinvertebrate diversity and community structure in lotic aquatic environments (Reice 1980, Vannote *et al.* 1980, Townsend *et al.* 1997, Fincke 1999, Chesson 2000, McCabe & Gotelli 2000).

Human activities can also affect some physical-chemical features of aquatic environments (e.g. hydrological characteristics, water quality). Among the most common anthropogenic impacts on these environments are: soil erosion and removal of the river channel's substrate, changes in the water drainage and river margin structure, construction of dams and reservoirs, input of wastes from agriculture and cattle rearing, and release of sewage (Watson *et al.* 1982, Tundisi *et al.* 1988, Delacerda *et al.* 1991, Bhardwaj & Tyagi 1993, Pinto-Coelho 1998, McClain & Elsenbeer 2001, Galindo-Leal & Câmara 2003, Davidson *et al.* 2004). Additionally, the removal of riparian vegetation may also have a negative effect on the input of organic matter, a primary energy source in aquatic systems (Delong & Brusven 1994, Pozo *et al.* 1997). These activities are causing rapid and significant declines in habitats and freshwater species (Dudgeon *et al.* 2006).

Environmental alterations may affect community structure, particularly of sensitive species which can become more or less abundant or disappear in the presence of disturbances. Such species are known as bioindicators (Niemi & McDonald 2004, Bonada *et al.* 2006, McGeoch & Chown 1998).

Monitoring aquatic ecosystems is a very difficult task because they are highly complex and are the result of interactions between physical, chemical and biological variables (Smith *et al.* 2007). However, organisms living in affected areas may be good indicators of river quality and the overall ecological integrity of the environments where they occur (Wright & Center 1984, Rosenberg & Resh 1993, Metcalf-Smith 1994, Karr 1999, Smith *et al.* 1999). Monitoring such organisms may help in making management decisions in impacted areas.

Macroinvertebrates (especially aquatic insects) are widely used as bioindicators because they have limited ability to migrate and are highly susceptible to environmental impacts (Hilty & Merenlender 2000, Oertli *et al.* 2008). One group of aquatic macroinvertebrates are the Heteroptera (Hemiptera). Species in this diverse insect suborder occupy a broad spectrum of aquatic habitats, have a multitude of shapes, and are adapted to a broad variety of niches (Spencer & Andersen 1994). Aquatic Heteroptera are classified under the infra-order Nepomorpha (benthic or nektonic), whereas semi-aquatic species represent the infra-order Gerromorpha (pleustonic) (Nieser & Melo 1997, Karaouzas & Gritzalis 2006).

Aquatic Heteroptera require specific habitats, being vulnerable to the loss of physical integrity of aquatic systems. Consequently, heteropteran diversity often correlates with the physical integrity of the environment. In addition to their vulnerability, some features of these insects allow them to be used as bioindicators. One example is Water striders, relatively long-lived, predatory invertebrates that feed on aquatic and terrestrial insects (Pennak 1978). They meet much of the criteria outlined by (Beeby 2001) for an appropriate sentinel (accumulator) species. Each generation can survive up to one year (Merritt & Cummins 1996), and their wingless forms have low mobility (Wilcox & Distefano 1991).

In this study we test the following hypotheses: Heteroptera species richness 1) decreases in direct proportion to the integrity index of the environment; 2) responds to alterations in physical-chemical variables of the water, since these influence community structure.

MATERIAL AND METHODS

Aquatic and semi-aquatic Heteroptera were sampled during the rainy season, in the Pindaíba river basin, a tributary of the Rio das Mortes river. The Pindaíba river basin is located in eastern Mato Grosso state and extends for about 10,323 km^2, comprising part of the Araguaiana, Barra do Garças, Cocalinho and Nova Xavantina regions.

The local weather is classified as Cwa, in accordance with the Köppen's classification, with two well-defined seasons: a dry season (May through September) and a rainy season (December through March). The annual precipitation averages from 1200-1600 mm, and temperatures range from 20-25°C. September and October as the warmest months (Brasil 1981).

Within the Pindaíba river basin, five streams were selected for sampling. Stream selection was carried out using satellite images of six streams, and taking the condition of the riparian vegetation into consideration. Sampling sites were as follows: Da Mata (MS, preserved value HII above 0.70), Caveira (CVS, value degraded HII down 0.70), Taquaral (TS, preserved), Cachoeirinha (CS, degraded) and Papagaio (PS, preserved), all tributaries along the left margin of the Pindaíba river (Fig. 1). Their characteristics and stream orders – 1st and 4th classification proposed by Strahler (1957) – are very similar to those found in the headwaters and in the Roncador ridge. The riparian vegetation from MS, TS and PS are more preserved than that found in CS and CVS, offering contrasting environments for analysis. A general description of sample sites characteristics, including estimated habitat integrity (explained bellow), is presented in Appendix 1.

In each sample site, linear transects of 100 m were demarcated and defined as the basic sampling unit for all statistical analyses. Samples were collected on every five meters comprising 20 points in each one of the orders of the streams. This general design was adapted from previous studies (Ferreira-Peruquetti & De Marco 2002, Ferreira-Peruquetti & Fonseca-Gessner 2003). Each sample was made of three sub-samples collected from the center to the margin of the body of water, using a 18 cm strainer with 0.50 mm mesh, followed by a surface sampling using capture active of the same sampling method above, but supported by *in loco* observation.

We evaluated anthropic alterations around each site using a Habitat Integrity Index (HII), a protocol composed of 12 questions that attempt to evaluate the structure of the bodies of water in terms of conservation of the riverine vegetation, pattern of land-use beyond that site, retention devices, substrate type, aquatic vegetation and debris. The HII varies from 0 (highly altered systems) to 1 (pristine not altered habitats). A detailed description of the protocol can be found in Nessimian *et al.* (2008)

Stream width was obtained with the aid of a laser measuring tape, depth was assessed through an echobatimeter, water temperature was measured with a digital thermometer with precision of 0.05°C, and the remaining abiotic data (pH, turbidity, dissolved oxygen, conductivity, total solids) were assessed with a Horiba® Multiparameter Water Quality Meter; flow was measured with a MJP Geopacks Infiltrometer in accordance with the Pinto & Holtz (1976) method. Laboratory analyses focused on total hardness, calcium and magnesium assessment through the EDTA titulometry method (disodium salt 0.002 mol L^{-1}), as well as ortho-phosphate and nitrate concentrations by means of a spectrophotometer.

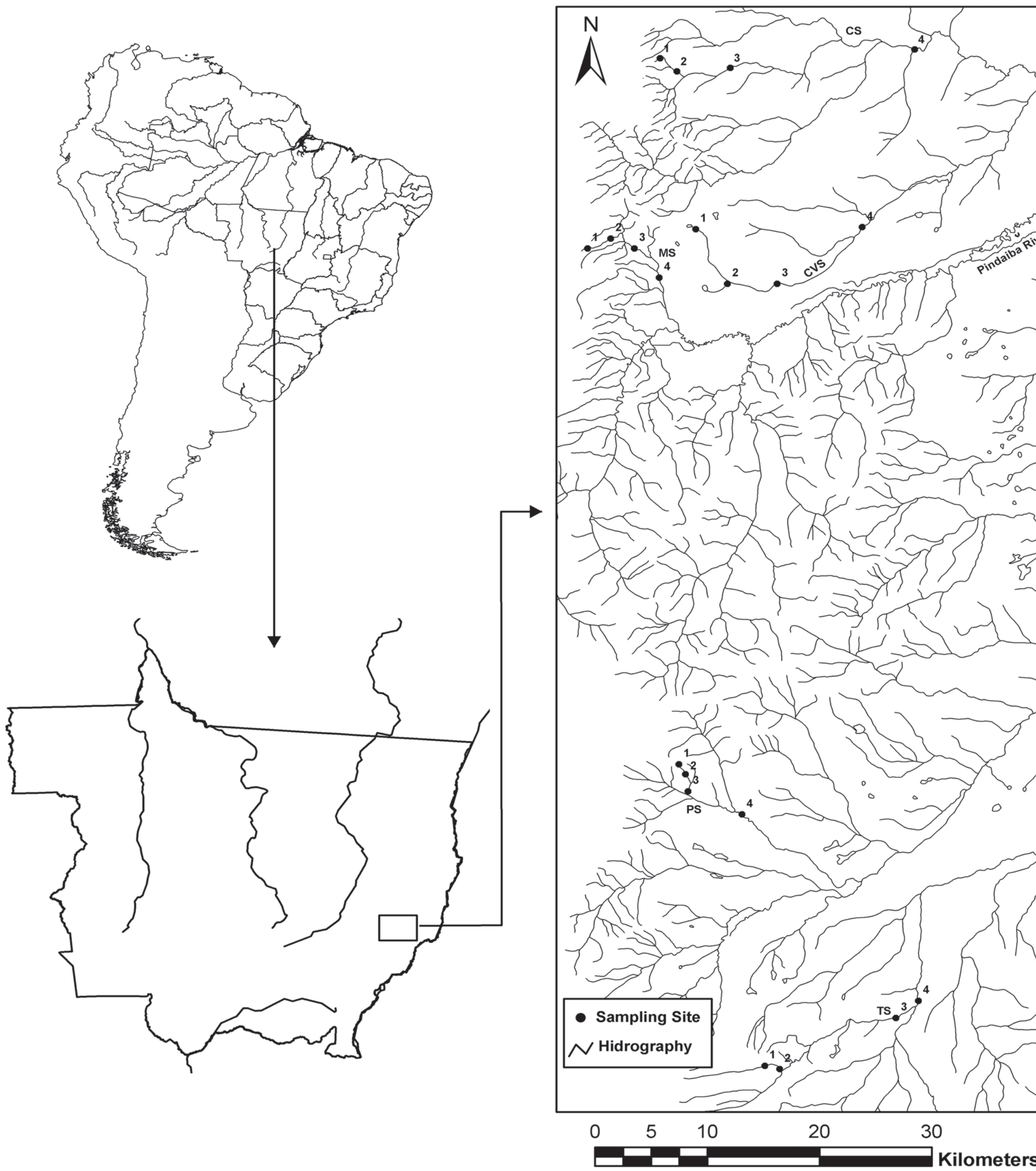

Figure 1. Study sites location in the Basin Pindaíba River, Mato Grosso, Brazil.

Heteroptera samples were kept in 85% alcohol solution and were identified with the help of available taxonomic keys (Hungerford 1933, Lauck 1962, De Carlo 1964, Nieser & Melo 1997, Nieser *et al.* 1999, Estévez & Polhemus 2001, Goodwyn 2001, Ribeiro 2005, 2007). The samples were deposited at the James Alexander Ratter Zoobotanical Collection at UNEMAT, at the Nova Xavantina campus (CZNX).

Considering that observed species richness is almost always a biased estimation of the total number of species present in a community, the richness measure used here was based on a non-parametric estimator, the first-order jackknife (Heltshe & Forrester 1983). The 20 segments in each stream should not be considered statistically independent, but may be used as appropriate units to estimate species richness in each stream (Silva *et al.* 2010) using the jackknife procedure with the help of the software EstimateS Win 7 5.0 (Colwell 2000).

Relationships between richness of species and HII were tested using simple linear regression. The t Student test was used to compare the estimated abundance of each species and species richness with stream preservation, according to ZAR (1999). Streams were ranked as preserved or degraded according to the presence or absence of riparian vegetation in the satellite images of the basin. The state of stream conservation was,validated during sampling. Due to substantial differences in the habits of Nepomorpha (benthic or nektonic) and Gerromorpha (pleustonic), the statistical analysis was conducted separately for these two infra-orders.

Subsequently, multiple regressions were used to examine the relationship between species richness and certain the physical-chemical variables. Before analyses, all data, except pH, were log transformed to stabilize the variance, and were used in the correlation matrix among the explanatory variables. The variables nitrite, phosphate, calcium and magnesium were excluded from the analyses because they have a correlation equal to or greater than seven ($r >$ or $= 0.7$) with another variable used.

We used the ANOSIM analysis (Bi-factorial Similarity Analysis) to test for differences in species composition in the preserved and degraded areas. This test is applied in order to detect differences in species structure across areas (MELO & HEPP 2008). The Canonical Correlation Analysis (CCA) was employed to verify relationships between environmental characteristics and species distribution. This analysis ranks sample units using the smallest possible number of axes, enabling the calculation of variable scores which may belong to the same graphic representation. The scores from these sites are obtained with the aim of maximizing species dispersion scores (BINI 2004, KARAOUZAS & GRITZALIS 2006). The significance value was obtained through the Monte Carlo randomization test using 10,000 randomizations.

In order to verify the presence of species that might be indicative of environmental quality, we used the Indicator Value (IndVal,), which measures the level of specificity (occurrence of the species related with a specific variable) and the level of fidelity of species (every time the variable occurs, the species will be present) to an environmental category. By multiplying these two values by 100, we generated an index ranging from 0 to 100 (the higher the value, the more significant the level of species indication – only the ones over 40% were considered), and the significance value was obtained through the Monte Carlo randomization test using 10,000 randomizations (DUFRÊNE & LEGENDRE 1997).

RESULTS

A total of 1,425 individuals distributed into 10 families, 30 genera and 67 morphospecies were collected. Of these, 880 individuals belonged in the Gerromorpha (62%), which was represented by four families, 16 genera, and 29 morphospecies/species. The Nepomorpha was represented by 545 specimens (38%), six families, 14 genera, and 38 morphospecies/species (Tab. I). The dominance of Gerromorpha in our samples may be the result of a sampling bias: as a water surface-dwelling and gregarious group, they are easily observed, increasing their presence in the samples.

Gerromorpha was represented by the families Gerridae (number of individuals, n = 224), Hydrometridae (n = 12), Mesoveliidae (n = 3), and Veliidae (n = 640); whereas Nepomorpha was represented by Belostomatidae (n = 16), Corixidae (n = 11), Gelastocoridae (n = 15), Naucoridae (n = 224), Nepidae (n = 19), and Notonectidae (n = 261).

Abundance and species composition in preserved and degraded areas

Total abundance was higher in preserved streams (MS HII (0,87 ± 0,06) (mean ± standards deviation), TS (0,79 ± 0,16) and PS (0,79 ± 0,08)) than in degraded ones (CS (0,67 ± 0,05) and CVS (0,59 ± 0,06), with a total of 43 more individuals in the former (t-value = 2.314, Df = 36, p = 0.026). Based on estimated species richness, altered areas had nine species less than preserved areas. This difference was statistically significant (t-value = 2.49, Df = 18, p = 0.022).

Species composition also proved to be different between degraded and preserved areas (ANOSIM R = 0.307, p = 0.004). The same result was observed when the analysis was carried out after separating the infra-orders Gerromorpha (ANOSIM R = 0.309, p = 0.002) and Nepomorpha (ANOSIM R = 0.224, p = 0.012).

Physical-chemical variables and HII on the Heteroptera community

Species richness was related with the Habitat Integrity Index (HII), showing a positive relationship for Gerromorpha ($r^2 = 0.23$, $p = 0.03$) (Fig. 2), but not for Nepomorpha ($r^2 = 0.06$, $p = 0.304$) or Heteroptera overall ($r^2 = 0.138$, $p = 0.105$).

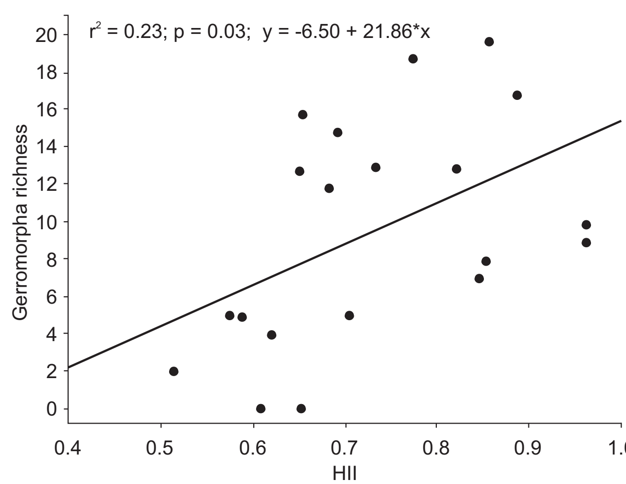

Figure 2. Relationship between the estimated richness of Gerromorpha morphospecies and the Habitat Integrity Index (HII), Pindaíba River Basin, Mato Grosso, 2008.

Table I. Nepomorpha and Gerromorpha abundance, based on samples carried out in the Pindaíba River Basin, Mato Grosso, 2008. (CS) Cachoeirinha Stream, (CVS) Caveira Stream, (MS) Da Mata Stream, (PS) Papagaio Stream, (TS) Taquaral Stream.

Species	Sites					Total
	Degraded		Preserved			
	CS	CVS	MS	PS	TS	
Nepomorpha						
Belostomatidade						
Belostoma bifoveolatum (Spinola, 1852)	0	1	0	1	0	2
B. costalimai (De Carlo, 1938)	1	0	0	0	0	1
B. foveolatum (Mayr, 1863)	0	0	1	0	0	1
B. ribeiroi (De Carlo, 1933)	0	0	3	1	1	5
Belostoma sp. 1	2	0	0	0	2	4
Belostoma sp. 2	0	0	0	0	2	2
Belostoma sp. 3	0	0	0	0	1	1
Corixidae						
Tenagobia incerta Lundblad, 1928	1	0	0	8	2	11
Gelastocoridae						
Gelastocoris flavus flavus (Guérim-Méneville, 1835)	0	0	1	6	0	7
Gelastocoris sp. 2	0	0	0	0	2	2
Montandonius sp. 1	0	0	0	4	2	6
Naucoridae						
Ambrysus sp. 1	3	5	13	6	4	31
Ambrysus sp. 2	0	1	4	8	2	15
Ambrysus sp. 3	4	0	3	8	18	33
Ambrysus sp. 4	0	0	1	0	1	2
Cryphocricos cf. *vianai* De Carlo, 1951	0	0	1	0	0	1
Limnocoris sp. 1	0	6	9	0	0	15
Limnocoris maculiceps Montandon, 1898	1	3	30	1	7	42
Limnocoris illiesi De Carlo,1967	6	0	8	1	3	18
Limnocoris sp. 4	0	0	0	4	0	4
Limnocoris sp. 5	7	3	10	6	29	55
Limnocoris sp. 6	0	0	0	1	0	1
Limnocoris sp. 7	0	0	1	0	0	1
Limnocoris sp. 8	0	0	0	0	1	1
Pelocoris sp. 1	0	0	1	2	0	3
Placomerus sp. 1	1	0	0	0	1	2
Nepidae						
Curicta sp. 1	0	1	0	0	1	2
Curicta sp. 2	1	1	0	0	0	2
Ranatra *sattleri* (De Carlo, 1967)	0	0	1	0	0	1
Ranatra sp. 1	1	0	1	0	0	2
Ranatra sp. 2	1	0	0	0	1	2
Ranatra sp. 3	4	1	0	2	1	8
Ranatra sp. 4	1	0	1	0	0	2

Continue

Table I. Continued.

Species	Sites					Total
	Degraded		Preserved			
	CS	CVS	MS	PS	TS	
Notonectidae						
Buenoa sp. 1	23	0	0	0	2	25
Martarega sp. 1	28	19	11	12	17	87
Martarega sp. 2	0	0	115	13	9	137
Martarega sp. 3	1	0	0	0	0	1
Notonecta sp. 1	11	0	0	0	0	11
Gerromorpha						
Gerridae						
Brachymetra sp. 1	5	0	16	22	23	66
Brachymetra sp. 2	0	0	7	8	11	26
Charmatrometra sp. 1	1	4	11	4	0	20
Cylindrostethus sp. 1	0	0	1	2	2	5
Cylindrostethus sp. 2	0	0	0	2	0	2
Limnogonus sp. 1	5	0	0	1	0	6
Limnogonus sp. 2	6	0	0	0	0	6
Neogerris sp. 1	0	0	0	1	0	1
Neogerris sp. 2	21	0	2	1	0	25
Neogerris sp. 3	3	0	0	0	0	3
Ovametra sp. 1	8	15	3	4	1	31
Tachygerris sp. 1	1	0	0	0	14	15
Trepobates sp. 1	4	0	11	1	2	18
Hydrometridae						
Hydrometra argentina Berg, 1879	9	0	0	0	0	9
Hydrometra sp. 1	2	0	0	0	1	3
Mesoveliidae						
Mesovelia sp. 1	1	0	1	0	1	3
Veliidae						
Euvelia sp. 1	0	3	0	0	0	3
Microvelia sp. 1	6	4	0	0	4	14
Paravelia sp. 1	0	2	2	0	0	4
Platyvelia sp. 1	1	1	1	0	0	3
Rhagovelia sp. 1	4	0	8	45	2	59
Rhagovelia sp. 2	2	0	4	8	2	16
Rhagovelia trailli (White, 1879)	2	0	93	115	18	228
Rhagovelia sp. 4	0	0	0	7	2	9
Rhagovelia sp. 5	24	22	112	32	64	254
Rhagovelia sp. 6	0	0	9	3	4	16
Stridulivelia sp. 1	19	0	4	3	1	27
Stridulivelia sp. 4	0	0	0	1	0	1
Stridulivelia sp. 5	0	0	0	0	1	1
Total of individuals						1425
Taxa total	37	16	35	35	39	

Water physical-chemical variables (Appendix 2) showed no effect on the heteropteran community ($r^2 = 0.472$, $p = 0.925$) (Tab. II). The same was observed for Gerromorpha ($r^2 = 0.378$, $p = 0.255$) and Nepomorpha ($r^2 = 0.105$, $p = 0.464$) (Tab. II).

Based on 10,000 randomizations of Monte Carlo test, there was no significant association between the environmental variables and species distribution (eingenvalue of first canonical axis = 0.717, p = 0.140) (Tab. III). Although correlations between the two matrixes were significantly high (Tab. IV), none has shown substantial relationship with each other (Tab. IV).

In accordance with the results of the IndVal analysis, three species out of 78 morphospecies are indicative of preserved areas: *Rhagovelia trailli* (White, 1879) (mean ± standard deviation) (26.2 ± 5.87, p = 0.006), and morphospecies *Rhagovelia* sp.4 (24.5 ± 5.80, p = 0.007) (Gerromorpha: Veliidae) and *Tenagobia incerta* Lundblad, 1928 (27.5 ± 6.33, p = 0.021) (Nepomorpha: Corixidae). For degraded areas, some species had significant values ($p < 0.05$), but with IndVal lower than 40% they were not taken into account due to their low recurrence in the sites.

DISCUSSION

Influence of Habitat Integrity Index on the Heteroptera fauna

We have not found any relationship between the values of the HII for the Heteroptera community and the environmental variables measured. However, we believe that the analyses conducted taking all Heteroptera into consideration have revealed no clear pattern and provide no revelant information because this group is composed of two infra-orders that have highly distinctive ecological requirements. According to the observations of Karaouzas & Gritzalis (2006), heteropteran families differ considerably in morphology and ecological preferences from one another and many species display specific habitat preferences (Corixidae) (Savage 1994). In rivers, heteropterans are found along the margins of shallow water (Corixidae) (Macan 1938, 1954), on the water surface of lentic (pool) (Gerridae and Veliidae) and lotic (riffle) stream zones (some Veliidae), and among aquatic vegetation (Notonectidae, Nepidae and Naucoridae). They may also be found under rocks in fast waters (some Naucoridae). These differences in ecological requirements may have confused or masked the effects of environmental integrity on species richness for the order.

Nepomorphan richness showed no response to environmental alterations as measured by the HII. Changes in environment are frequent, especially those caused by natural seasonal variations. They increase the typical flow of the Cerrado rivers, which is associated with group plasticity, causing an intermediate disturbance response such as the one predicted by Connell (1978). Furthermore, communities are also subject to local processes, which may determine whether or not species are fit to settle and keep their population once they have found a habitat (McCauley 2006).

Table II. Results of the multiple regression analysis assessing the effect physical-chemical parameters on estimated richness of general Heteroptera, Nepomorpha and Gerromorpha morphospecies. (Beta) Standardized coefficients, (CO) coefficients, (SE) coefficient standard errors, (t) Test t to assess the coefficient significances.

Estimated richness	Total					Gerromorpha					Nepomorpha				
	Beta	CO	SE	t	p	Beta	CO	SE	t	p	Beta	CO	SE	t	p
Intercept		351.037	280.937	1.250	0.267		207.440	114.241	1.816	0.129		307.971	120.837	2.549	0.061
Water temperature (°C)	-0.559	-85.540	95.435	-0.896	0.411	-0.875	-92.545	38.808	-2.385	0.063	-0.539	-50.226	41.049	-1.224	0.276
Air temperature (°C)	0.472	73.455	106.403	0.690	0.521	0.000	-0.005	43.268	0.000	1.000	0.090	8.546	45.766	0.187	0.859
pH	-0.479	-11.644	16.192	-0.719	0.504	-0.191	-3.207	6.585	-0.487	0.647	-0.545	-8.078	6.965	-1.160	0.298
Electric current (µs)	-0.294	-8.801	16.202	-0.543	0.610	0.109	2.254	6.588	0.342	0.746	-0.244	-4.459	6.969	-0.640	0.550
Turbidity (NTU)	0.551	10.076	10.641	0.947	0.387	0.194	2.447	4.327	0.565	0.596	-0.193	-2.146	4.577	-0.469	0.659
Dissolved oxygen (mg/l)	-0.245	-30.204	60.863	-0.496	0.641	-0.035	-2.942	24.750	-0.119	0.910	-0.352	-26.453	26.179	-1.010	0.359
ORP	-0.906	-60.615	56.174	-1.079	0.330	-0.236	-10.892	22.843	-0.477	0.654	-1.202	-48.976	24.161	-2.027	0.098
Hardness total (mg/l)	-0.852	-37.034	24.880	-1.488	0.197	-0.302	-9.069	10.117	-0.896	0.411	-0.693	-18.350	10.701	-1.715	0.147
Nitrate (mg/l)	-1.300	-102.682	72.719	-1.412	0.217	-0.498	-27.207	29.571	-0.920	0.400	-1.352	-65.109	31.278	-2.082	0.092
Flow (m3/s)	-0.155	-22.265	64.279	-0.346	0.743	-0.247	-24.489	26.138	-0.937	0.392	0.160	14.030	27.648	0.507	0.633
Mean width	0.506	12.169	14.489	0.840	0.439	0.060	1.000	5.892	0.170	0.872	0.087	1.274	6.232	0.204	0.846
Mean depth	-0.613	-41.130	47.272	-0.870	0.424	-0.063	-2.919	19.223	-0.152	0.885	-0.270	-11.043	20.333	-0.543	0.610

Table III. Self-values (eingenvalue) of the Canonical Correspondence Analysis (CCA) of the matrix of environmental characteristics in respect to species distribution, and significance level obtained through the Monte Carlo test.

Axes	Eingenvalue	Mean	Minimum	Maximum	p
1	0.717	0.873	0.514	8.702	0.140
2	0.621	0.529	0.412	0.666	0.040
3	0.593	0.468	0.376	0.602	0.020

Table IV. Species correlation with the matrix of environmental variables in the Canonical Correspondence Analysis with the significance level obtained through the Monte Carlo test. (spp-envt Corr) Species correlation with environmental variables.

Axis	spp-envt Corr	Mean	Minimum	Maximum	p
1	0.972	0.922	0.873	0.999	0.730
2	0.983	0.986	0.916	1.000	0.740
3	0.983	0.981	0.981	0.999	0.630

Nevertheless, the HII has shown a mild, yet positive relationship with the estimated richness of Gerromorpha species. The shady nature of the sampled sites has rendered more shelters, and increased the supply of food, resulting in higher habitat heterogeneity, which leads to higher species richness. This relationship is observed with most species of the infra-order which favor shady sites with nearby marginal vegetation, where they can find prey and shelter and lay their eggs (Nieser & Melo 1997). Such behavior makes these species more sensitive to alterations in the physical structure of rivers.

The Habitat Integrity Index (Nessimian *et al.* 2008) was a major tool for the assessment of the structure of the streams studied. However, because it was developed specifically for Amazonian streams, it had to be adjusted to be used in Cerrado streams. These adjustments included adapting patterns and including new parameters (such as incidence of light), to better fit and respond to observed alterations. Nevertheless, we must take into consideration that while some insects can tolerate environmental conditions that would be lethal to other invertebrate species, others show less tolerance (Karaouzas & Gritzalis 2006). For example, some Corixidae species were found in acidic (pH < 3) mining lakes of Lusatia, Germany, (Wollmann 2000), whereas the quality of the environment (i.e. water pollution and hydromorphological degradation) influences the successful colonization and populations of the water strider *Aquarius najas* (De Geer, 1773) (Ahlroth *et al.* 2003).

Species abundance and composition in preserved and degraded areas

In a complementary analysis carried out in sampling sites in bodies of water which had undergone straightening, damming (CVS), and/or loss of riparian vegetation (CVS and CS) in the 70's due to agricultural colonization (Brannstrom 2008), a significant loss in morphospecies abundance and richness was observed. Significant differences in the composition of Heteroptera and other studied infra-orders were also observed, which suggests that anthropic disturbances in these sites have changed their insect communities, especially in the CVS, where the impact on the river flow has been significantly more intense. Several authors have correlated the influence of the presence of plant coverage with the structure of the macroinvertebrate community (Kikuchi & Uieda 2005, Couceiro *et al.* 2007), as well as the changes in structure caused by straightening and damming (Houghton 2004).

The greater species richness in heterogeneous areas (variance of biotic and abiotic factors over space) is due to the greater amount of resources and habitat availability within these areas. Species become more diverse with increasing environmental heterogeneity, resulting in increased niche partitioning, which optimizes specialization and decreases the effects of inter-specific competition (O'Connor 1991, Cramer & Willig 2005). Because species adjust to certain environmental conditions, disturbances decrease the richness of several specialist groups, modifying species distribution and abundance, which can ultimately lead to changes in the ecological processes of the system (Resh *et al.* 1988, Covich *et al.* 1999). Under conditions of intermediate perturbation, species diversity is maximum because a variety of taxa can tolerate the conditions, but none can completely dominate the community (Death & Winterbourn 1995). On the other hand, Naiman *et al.* (1988) developed a derived general model that predicts that biodiversity is constrained at low levels of ecotone frequency because large homogeneous patches provide little habitat for edge species. At high ecotone frequencies, substantial edge habitat is provided, but small patch sizes exclude interior species. Maximum biodiversity occurs where there is an optimal mix of patch and edge habitats (Ward *et al* 1999).

At the same time, our results suggest that the alteration in riparian areas can lead to significant changes in Heteroptera community composition even though species richness was not affected. This can be explained using the subsidy-stress model of Odum *et al.* (1979) that describes the ecological changes that occur when a tree canopy is removed from the banks of small native forest streams. Macroinvertebrate biomass and production increase and diversity is not adversely affected, or may increase only initially, reflecting a mix of sensitive and more tolerant taxa that colonize the area. Once deforestation in the catchments exceeds some critical threshold these measures start to decline well below those in forest streams (Death & Collier 2009).

Species environment relationships

The Canonical Correlation Analysis used to assess species correlation with environmental characteristics, as well as the result of multiple regressions showed no relationship between the matrix studied and the species community, failing to corroborate the hypothesis that richness responds to changes in chemical variables of the water. Such a result leads us to believe that there were insufficient alterations in the environment to cause changes in the community investigated. This suggests that factors other than those analyzed here may be responsible for such variation. It may also indicate that the space and interactions between organisms may be responsible for the structuring of the community.

The prevalence of livestock in the vicinity of the investigated areas may have contributed to the presence of tolerable ionic patterns found at the sites, since there is extensive livestock production in these areas. As far as chemical patterns are concerned, the conversion of native forests into pastures is relatively less disturbing to the aquatic environment than plantation areas, since most pasture areas are not subjected to composting or pesticide utilization (FERREIRA & CASATTI 2006), which was verified in the areas studied.

Consideration should also be given to the fact that the insects may be adjusted to broad variations in physical-chemical parameters, since the Cerrado streams experience prolonged dry and rainy seasons, with several natural disturbances occurring in the rainy season (multiple pulses of rapid flooding), which change these parameters.

Species indicative of preserved and degraded areas

Ecologists studying Heteroptera have long tried to use freshwater insects for biomonitoring and classification purposes. Prior to the development of monitoring models, many studies were conducted to ascertain whether there is an association between insect species and environmental parameters (KARAOUZAS & GRITZALIS 2006). In our data, the Index of Indicator Species (IndVal) indicates that *Rhagovellia trailli*, *Rhagovellia* sp.4 and *T. incerta* are specific and recurrent in preserved sites. The first two species belong to Veliidae (Gerromorpha), known to inhabit shady sites, can be found both in running and stagnant water (ROLDÁN-PÉREZ 1988). UIEDA & GAJARDO (1996) when verifying the composition of periphytic macroinvertebrates in a stream in the state of São Paulo, found individuals of Veliidae in lake portions of the stream, in areas enclosed by riparian vegetation or well-shaded by marginal riverine vegetation.

Species of *Tenagobia* Bergroth, 1899 (Nepomorpha: Corixidae), are known to inhabit sites where vegetation is present, and are found in shallow places with low current (NIESER & MELO 1997, ROLDÁN-PÉREZ 1988). According to the IndVal, one species of this genus was more sensitive to environmental changes than other species collected. This indicates that broader studies are required on their trophic and behavioral relationships. Land use/cover, aquatic and riparian vegetation, stream size and water chemistry were the most important factors structuring heteropteran assemblages (KARAOUZAS & GRITZALIS 2006).

On average, our results corroborate the findings of several other authors who have stated that macroinvertebrates are more useful as indicators of environmental quality in water bodies (YODER & RANKIN 1998, CAPÍTULO *et al.* 2001, HOUGHTON 2004, SHARTAU *et al.* 2008, ARIMORO & IKOMI 2009, TESTI *et al.* 2009) than physical-chemical parameters. Additionally, our results clearly point to the need to conduct more studies, giving special attention to the behavior, as well as the inter-specific relationships among this group.

Based on our results, we conclude that the Habitat Integrity Index (HII) showed a positive relationship with gerromorphan richness, but not with the richness of Nepomorpha and the heteropteran community as a whole. Therefore, our results have failed to corroborate the hypothesis that heteropteran richness decreases with decreasing HII values. However, it is crucial to highlight that a significant loss of species richness was found in the Heteroptera and in the two included infra-orders (when analyzed separately) in the degraded areas when the analysis was based on the environmental quality of the streams and not on the sampling sites, showing that the HII must be adjusted in order to be informative for the Cerrado streams.

The preference heteropterans have for small streams suggests the existence of microhabitat heterogeneity along them, which may be sufficient to maintain species richness in these areas. The hypothesis that richness would correlate with changes in physical-chemical variables not was corroborated. Future monitoring of Heteroptera in other basins would benefit from a separate analysis of infra-orders, since they respond distinctively to both physical-chemical parameters and the HII.

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Appendix 1. Sites of samples, orders, abbreviations dos streams, geographic coordinates, values of HII, mean width and mean depth.

Sites	Order	Abbreviations	Geographic Coordinates	HII	Mean width (m)	Mean depth(m)
Cachoeirinha Stream	1	CS	S 14° 50' 30" e W 52° 24' 54"	0.61	2.00	0.30
	2	CS	S 14° 50' 50" e W 52° 24' 22"	0.69	2.15	0.80
	3	CS	S 14° 50' 33" e W 52° 21' 34"	0.73	2.45	0.85
	4	CS	S 14° 49' 44,7" e W 52° 12' 56,3"	0.65	7.12	1.20
Caveira Stream	1	CVS	S 14° 55,9' 06" e W 52° 20' 29"	0.59	1.40	0.13
	2	CVS	S 14° 59' 53,4" e W 52° 18 '17,5"	0.52	3.17	0.73

Continue

Appendix 1. Continued.

Sites	Order	Abbreviations	Geographic Coordinates	HII	Mean width (m)	Mean depth(m)
	3	CVS	S 14º 57' 28,7" e W 52º 13' 43,9"	0.65	3.20	0.60
	4	CVS	S 14º 42' 47,7" e W 52º 03' 16,4"	0.58	17.20	1.63
Da Mata Stream	1	DMS	S 14º 29' 51,7" e W 52º 28 '42,6"	0.96	3.20	0.33
	2	DMS	S 14º 59 '25,2" e W 52º 27' 57,7"	0.86	2.63	0.30
	3	DMS	S 14º 59' 59" e W 52º 26' 29"	0.82	6.16	0.40
	4	DMS	S 14º 01' 37" e W 52º 26' 29"	0.85	4.86	0.40
Papagaio Stream	1	PS	S 15º 27' 01" e W 52º 24' 30"	0.85	1.06	0.10
	2	PS	S 15º 27' 32" e W 52º 24' 42"	0.66	1.10	0.17
	3	PS	S 15º 28' 11" e W 52º 24' 32"	0.78	4.77	0.23
	4	PS	S 15º 28' 56" e W 52º 21' 47"	0.71	10.96	0.53
Taquaral Stream	1	TS	S 15º 41' 54" e W 52º 20' 03"	0.96	1.17	0.10
	2	TS	S 15º 41' 57" e W 52º 19' 56"	0.89	4.43	0.46
	3	TS	S 15º 39' 35" e W 52º 13' 52"	0.68	4.67	0.97
	4	TS	S 15º 38' 53" e W 52º 12' 53"	0.62	9.30	1.03

Appendix 2. Variables physical-chemical in streams in the collections of 2008. Mata Stream (MS), Cachoeirinha Stream (CS), Taquaral Stream (TS), Papagaio Stream (PS) and Caveira Stream (CVS). Temperature of water (T.W.), temperature of air (T. Air), pH, conductivity eletrical (C. eletrical), turbidity (T), oxygen dissolved (OD), hardness total (H), calcium (C), magnesium (Mg), phosphate (P), nitrate (N), nitrite (Ni) and flow (F).

Sites	Order	T. W (°C)	T. Air (°C)	pH	C. eletrical (µs)	T (NTU)	OD (mg/l)	H (mg/l)	C (mg/l)	Mg (mg/l)	P (mg/l)	N (mg/l)	Ni (mg/l)	F (m^3/s)
MS	1	25.25	29.95	6.56	2.52	1.000	7.95	2.80	0.17	2.66	0.16	1.71	1	0.05
	2	19.00	21.10	6.20	3.05	0.370	8.90	5.60	2.39	3.18	0.06	1.03	1	0.22
	3	25.50	29.50	6.44	5.50	9.000	7.72	11.50	5.33	6.20	0.11	1.43	7	0.12
	4	26.85	30.90	6.41	16.70	14.000	6.58	13.00	5.91	7.13	0.27	2.20	2	0.11
CS	1	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	2	25.70	28.20	6.58	13.50	169.250	6.80	10.50	4.21	6.28	0.49	2.53	120	0.04
	3	24.45	28.75	6.29	4.57	7.050	4.15	10.62	4.08	6.53	0.18	1.35	4	0.02
	4	26.45	31.80	6.61	7.55	12.700	6.67	11.57	5.77	5.81	0.15	0.89	1	0.29
TS	1	24.25	25.00	6.60	0.21	22.050	5.89	32.40	16.8	15.59	0.28	1.04	1	0.30
	2	20.55	30.55	6.80	12.4	0.155	8.07	13.20	7.77	5.43	0.09	1.53	1	0.11
	3	26.15	30.60	6.53	4.17	5.850	6.84	9.70	3.14	6.57	0.14	1.56	4	0.04
	4	30.40	31.30	6.49	4.71	5.700	7.11	9.05	3.48	5.57	0.14	1.97	1	0.04
PS	1	24.10	29.75	6.73	4.76	7.400	7.99	8.52	3.62	4.91	0.14	2.73	1	0.01
	2	22.35	31.05	7.10	7.90	0.300	9.01	7.44	3.27	4.17	0.09	0.93	1	0.03
	3	24.95	26.65	6.73	7.41	6.650	7.93	7.57	2.78	4.79	0.12	1.70	1	0.12
	4	27.95	25.95	6.67	6.99	7.850	7.28	6.61	2.08	4.52	0.10	1.31	1	0.71
CVS	1	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	2	30.00	31.40	6.44	5.50	9.00	7.73	11.53	5.33	6.20	0.11	1.43	7	0.12
	3	29.40	35.50	5.35	1.50	0.700	6.29	5.84	1.00	4.84	0.05	3.90	2	0.19
	4	28.20	33.30	6.38	12.70	1.100	7.06	7.34	1.57	5.77	0.07	1.80	2	–