



Idiosyncratic responses of aquatic and terrestrial insects to different levels of environmental integrity in riparian zones in a karst tropical dry forest region

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Abstract

Decisions about biodiversity conservation depend on how different taxonomic groups respond to human-influenced environmental change. Here, we ask whether richness and composition of terrestrial (frugivorous butterflies and dung beetles) and aquatic insects (Plecoptera, Trichoptera, Ephemeroptera, Odonata and Coleoptera) change in a congruent manner across a gradient of riparian habitat degradation in a karst tropical dry forest region of Brazil, the Bodoquena Plateau. Our results showed incongruent ordination patterns based on the different taxa analysed. We found no correlation between richness and composition of the groups and environmental integrity. Incongruent responses among the taxonomic groups may be a consequence of high variability in ecological requirements among different taxa. Additionally, the effect of human disturbance on these taxonomic groups can be masked by the predominant presence of generalist species in tropical dry forests and by historical factors related to the adaptability of several species to changing ecosystems.

Key words human impact, macroinvertebrate, multi-taxa.

INTRODUCTION

Species extinction constitutes one of the most drastic consequences of human influence on nature. Some authors suggest that we are living in the Anthropocene where the sixth mass extinction is well under way (Barnosky *et al.* 2011). Consequently, a major challenge is to reduce the current rate of biodiversity loss (CBD 1992 - Aichi Target 2010, Strategic Plan for Biodiversity 2011–2020). So, biological monitoring is critical to increase our knowledge about consequences of anthropogenic impacts on biodiversity, with the goal of ultimately improving the efficacy of biodiversity conservation management strategies (Braby & Williams 2016). One of the most important aspects to monitor biodiversity is identifying cost-effective surrogates or indicators that can be widely used and easily understood and that truly represent functions and environmental services they render (Balmford *et al.* 2005; Lindenmayer *et al.* 2015). This subject has been suggested as a priority for conservation initiatives in tropical regions (Barlow *et al.* 2010).

In this context, multi-taxa studies are important as they may potentially optimise the resources of biological monitoring

(Lawton *et al.* 1998; Basset *et al.* 2004; Gardner *et al.* 2008; Uehara-Prado *et al.* 2009). Such investigations studies can be conducted in terrestrial (e.g. Lawton *et al.* 1998; Janzen 2000; Basset *et al.* 2004; Andrade *et al.* 2011) and aquatic (e.g. Heino *et al.* 2009; Heino 2010; Padial *et al.* 2012) ecosystems. Nonetheless, few studies have evaluated the responses of both terrestrial and aquatic environments simultaneously, limiting the use of the generated information across-ecosystems or complex terrestrial–aquatic systems, such as riparian zones (Soininen *et al.* 2015).

Riparian zones are considered the direct link between aquatic and terrestrial systems and are highly sensitive to human induced environmental change and biodiversity loss. Furthermore, riparian areas across the world tend to harbour many taxa and are important for maintaining biodiversity because they perform multiple environmental functions, such as providing physical corridors for dispersal (Décamps 1993; Naiman & Décamps 1997). All these reasons support the importance of protecting and defining appropriate and efficient environmental indicators to preserve them (Sabino & Andrade 2003).

In this study, we asked (i) whether composition and richness of different insect groups are affected by a gradient of riparian degradation in a karst tropical dry forest region in

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Brazil (Bodoquena Plateau) and (ii) whether the composition and richness of terrestrial and aquatic insect groups changes in a congruent way to that environmental gradient. To address these questions we compared assemblages of terrestrial (dung beetles and frugivorous butterflies) and aquatic (Plecoptera, Trichoptera, Ephemeroptera, Odonata and Coleoptera) insects as focal groups. We considered these assemblages because they are speciose groups, represent key components to various natural processes and serve as successful indicators of environmental impacts (Kremen 1993; McGeoch 1998). Considering that (i) many stream-dwelling insects are strongly associated to microhabitats in riparian zones (Vinson & Hawkins 1998); (ii) some species that live in riparian microhabitats have co-evolved to possess similar morphological, behavioural and physiological adaptations that correspond to an often narrow range of environmental conditions; and (iii) small functional niches render many species intolerant of conditions that fall outside those experienced in evolutionary time (King & Baker 2011), we expected that riparian zone condition would determine taxonomic diversity patterns resulting in high level of cross-taxon congruence. We did not assume that terrestrial and aquatic insects respond mechanistically to the same variables, but only that the gradient of riparian zone integrity we studied would be strong enough to imprint a similar spatial distribution pattern among different groups based on richness and composition. In other words, as the loss of native vegetation and fragmentation of riparian zone can affect key drivers of terrestrial and aquatic biodiversity (e.g. luminosity, amount of vegetation and resource availability), we expected that the communities would show similar trends in discriminating the sites across the gradient.

MATERIALS AND METHODS

Study area

The study was conducted in riparian sites across the Bodoquena Plateau, Mato Grosso do Sul, Brazil (Fig. 1). The vegetation of this region is a mosaic of Cerrado (savannahs) and semi-deciduous Atlantic Forest (dry forest). The hydrography is characterised by calcareous watersheds (Boggiani *et al.* 1993) and is considered the most extensive karst aquatic system in Brazil (Sallun Filho & Karmann 2007). The climate is temperate-humid, with average temperatures ranging from 20°C to 22°C and annual rainfall ranging from 1300 to 1700 mm (Françoso *et al.* 2011).

A portion of the plateau was designated as the Serra de Bodoquena National Park in 2000 due to the ecological importance of this region, while extensive surrounding areas were converted into agricultural lands (soy and corn) and pasture since the same period. Much of this conversion occurred on lands adjacent to streams and created riparian habitats with different levels of environmental integrity. These areas provide a good opportunity to study how insect communities respond to the degradation of riparian zones.

Environmental integrity

We used Channel and Environmental Integrity (RCE) index based on Petersen (1992) and adapted by Nessimian *et al.* (2008) to measure environmental integrity of each riparian zone (Appendix S1). This index is composed of multiple metrics, each one with four conditions given a particular score. We used 12 metrics of the RCE index: (i) land-use pattern beyond the immediate riparian zone; (ii) width of riparian zone from stream

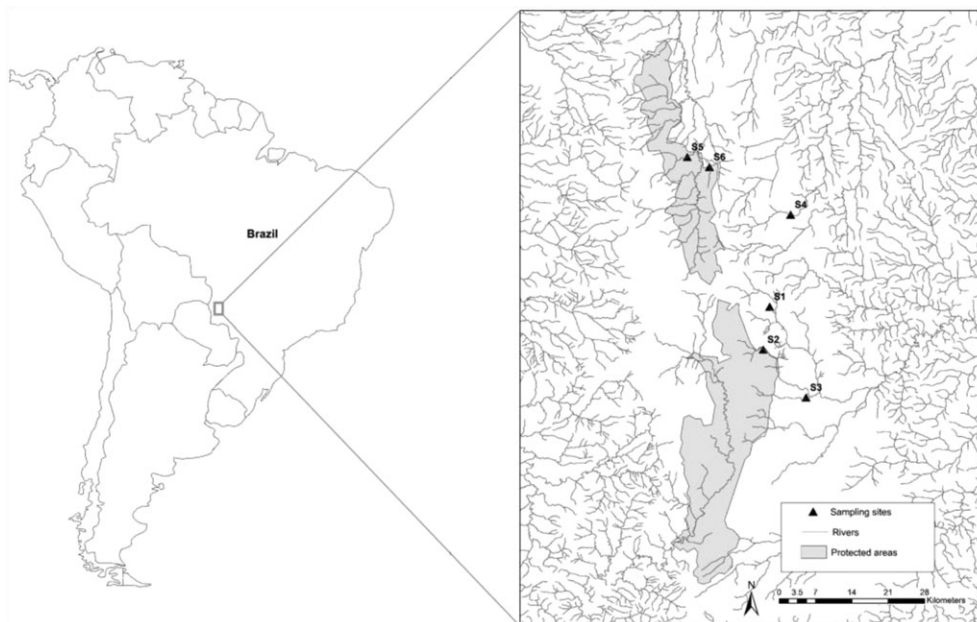


Fig. 1. Indication of the sampling sites (S1–S6) and contour Parque Nacional da Serra da Bodoquena, Mato Grosso do Sul, Brazil, location Bodoquena Plateau.

edge to field; (iii) completeness of riparian zone; (iv) vegetation of riparian zone within 10 m of channel; (v) retention devices, i.e. the degree of channel set in place large substrates, such as wood; (vi) channel sediments; (vii) stream-bank structure; (viii) bank undercutting; (ix) stream bottom; (x) riffles and pools/meanders; (xi) aquatic vegetation; and (xii) detritus. The sum of all scores of the metrics used in this study corresponds to RCE index (Table 1). Other metrics were not considered as they are generally related to the formation of the riverbed, especially a rocky bed, and the streams analyzed here have naturally sandy beds. The RCE index has larger values for preserved riparian vegetation and streams and low values for degraded ones.

Sampling and identification

The study was conducted during 13–24 of November 2009, during a Post Graduate Entomology Field Course organised by the Universidade Federal da Grande Dourados, Mato Grosso do

Table 1 Environmental Integrity Index score, according to the environmental characteristics of each sampling site

Site	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Total score
S1	3	3	1	1	1	1	3	2	1	1	0	1	18
S2	3	3	1	3	2	2	3	3	3	3	0	4	30
S3	3	4	2	2	3	2	3	3	3	2	0	4	31
S4	3	4	4	3	3	4	4	4	3	4	0	4	40
S5	6	6	4	4	4	4	4	4	4	4	0	5	49
S6	6	6	4	4	4	4	4	4	4	4	4	4	52

Sul, Brazil. We selected six riparian zones of independent streams in the Bodoquena Plateau, ranging from conserved (native vegetation) to non-conserved (pasture and monoculture) (Fig. 1). In each riparian zone, we collected insects along a transect of 500 m × 30 m, located alongside the stream (Fig. 2).

Three teams of seven entomologists each worked concomitantly in the field to conduct a condensed sampling design. All taxonomic groups were collected with specific protocols of rapid survey which provided a snapshot of the biodiversity in each location. We recognise that snapshots surveys do not result in complete species inventories, but we used standardised methods that allow comparisons of community composition among these areas. At each point, we collected terrestrial and aquatic insects at spatial locations outlined in Fig. 2 and using the methodology described below.

Frugivorous butterflies

Frugivorous butterflies were collected using four Van Someren-Rydon traps, suspended 1 m above the soil with 100 m between each trap as outlined by Brown and Freitas (1999). This method is independent of a collector's ability to capture individuals and therefore provides unbiased comparisons of frugivorous butterfly assemblages (Freitas & Marini-Filho 2011). We baited traps with the traditional mix of banana and fermented sugar cane juice (250 g/trap) and left them open in the field during three consecutive days. Butterflies were identified to the species level following D'Abreu (D'Arera 1987, 1988), Uehara-Prado *et al.* (2004) and Penz *et al.* (2007).

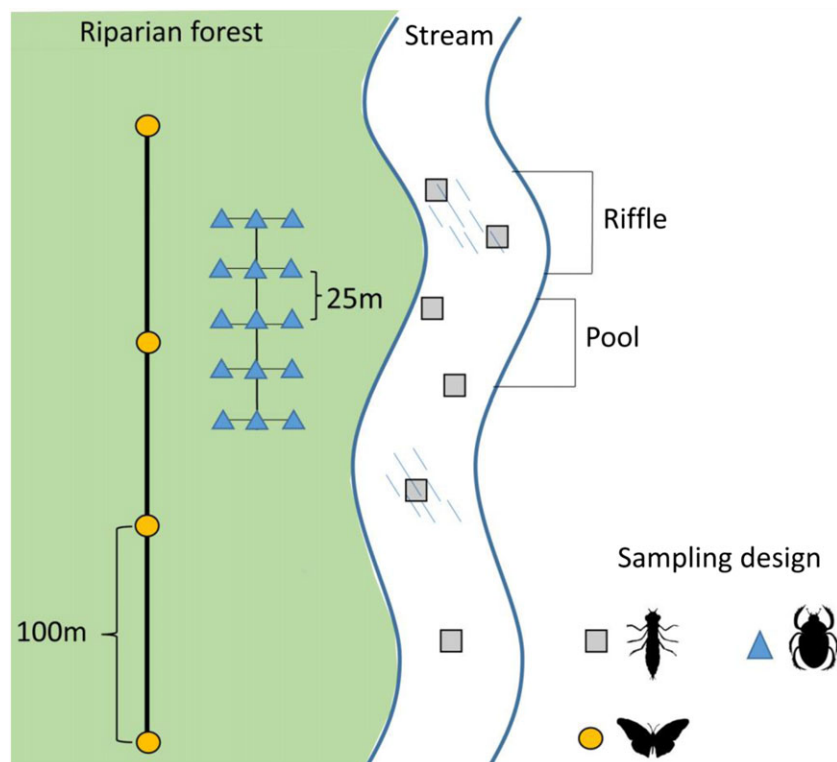


Fig. 2. Schematic illustration of distribution of collection traps for aquatic insects, dung beetles and frugivorous butterflies at the study sites in the Bodoquena Plateau, Mato Grosso do Sul, Brazil. [Colour figure can be viewed at wileyonlinelibrary.com]

Dung beetles

Dung beetles were sampled using baited pitfall traps, a method extensively applied in dung beetle surveys, by exploiting their tendency to actively search for food by odour plumes and strong flight capabilities (Peck & Howden 1984). Each pitfall trap consisted of a 15 cm × 9.5 cm plastic container buried in the ground flush with the surface. A total of 15 pitfall traps were baited with beef liver (100 g), human excrement (50 g) and banana (50 g) (Andrade *et al.* 2011). All insects captured in pitfalls were collected after 2 days and were identified to the species level using the key of Vaz-de-Mello *et al.* (2011).

Aquatic insects

Aquatic insects were collected using Surber samplers with mesh size of 0.250 mm. All collections in each point were made in one day; six samples (three samples in pools and three in riffle sites) were randomly collected along a 500 m segment of each stream. We counted and identified all specimens up to genus level, using the following taxonomic keys: Hamada *et al.* (2014) and Domínguez and Fernández (2009).

We sorted all insect material into order in the field and sent material to experts for further identification (see acknowledgments). Specimens were deposited in the Museu de Biodiversidade (MuBio) at the Universidade Federal da Grande Dourados, Mato Grosso do Sul, Brazil, and a synoptic collection of dung beetles in the entomology collection at the Universidade Federal de Mato Grosso, Cuiabá, Brazil.

Analysis

Considering that insect inventories, especially those of very species-rich taxa, are often incomplete (Gotelli & Colwell 2001), we calculated individual-based rarefied richness, using the lowest number of individuals as the cut-off threshold values. We carried out this procedure for all groups. For rarefied richness cross-taxon congruence, we calculated Pearson correlations between dung beetles, frugivorous butterflies and aquatic insects. To test whether rarefied richness of the different groups were affected by environmental integrity, we used a simple regression with the RCE total score as a predictor. To order community composition, we used Principal Coordinates Analysis (PCoA) and Bray-Curtis index to calculate pairwise dissimilarity of abundance data between sampling sites. We used the scores of the first three PCoA axes of each group as a measure of community composition, because they captured at least 75% of variation of the original dataset. To test whether community composition was affected by environmental integrity, we used a multivariate regression with the RCE total score as a predictor and the three PCoA axes as response variables. We used Pillai trace for statistical analysis, which was then transformed into approximated F statistics to test our null hypothesis (no relationship). Significance ($P \leq 0.05$) was checked by comparing F values with parametric F distribution. Considering that common species in communities generally show congruent patterns, but rare species do not (Reddin *et al.* 2015), and insect communities in tropical regions have a

disproportionately large number of rare species, which may influence the detection of general patterns of congruence, we also assessed the cross-taxon congruence in composition with and without singletons. Since the results were the same, we only reported those with singletons.

We used Procrustes analysis to assess the degree of pairwise association between the different biological compositional matrices. Procrustes is similar to Mantel analysis but instead of comparing distance matrices directly the ordination solution of the raw data matrices are scaled and rotated to find an optimal superimposition that maximises fit (see Peres-Neto & Jackson 2001). The significance of each pairwise comparison of groups was tested through permutation using Procrustean randomisation test permutations – PROTEST (Jackson 1995; Peres-Neto & Jackson 2001). We used the Procrustes correlation as statistical analysis, derived from the symmetric Procrustes residual m^2 . We also used Mantel tests to compare distance matrices, but, since both analyses provide similar results, we only reported Procrustes analyses. Analyses were done using the vegan package (Oksanen *et al.* 2013) in the program R (R Development Core Team 2011).

RESULTS

We collected 132 individuals of 64 species of butterflies, 3510 individuals of 88 species of dung beetles and 2667 individuals of 164 morphospecies of aquatic insects (Appendix S2). RCE scores varied from 18 (S1) to 52 (S6) (Table 1). Richness and abundance for each group were not related to the RCE scores. That is, more preserved sites did not have more species or individuals, except richness of dung beetles. Moreover, there was no association between the number of exclusive species and RCE scores (Appendix S2).

We were unable to detect a clear pattern between rarefied richness and RCE index. Thus, RCE index did not explain rarefied richness (frugivorous butterflies Adjusted $R^2 = -0.24$, $P = 0.88$; dung beetles Adjusted $R^2 = 0.09$, $P = 0.28$; aquatic insects Adjusted $R^2 = -0.06$, $P = 0.44$). Rarefied richness cross-taxon analysis showed no congruence between groups: correlation values varied from -0.37 to 0.16 (P -values > 0.05).

There was no correlation between RCE and community composition (frugivorous butterflies $F_{1,4} = 0.69$, $P = 0.63$; dung beetles $F_{1,4} = 0.84$, $P = 0.21$; aquatic insects $F_{1,4} = 0.21$, $P = 0.88$). Each group showed distinct ordination patterns (Fig. 3), but there was no clear correspondence between the values of RCE and the position of the sites in the PCoA or in Procrustes analysis (Fig. 3). Pairwise Procrustes analysis indicated low congruence between all groups, as demonstrated by the values of r , ranging from 0.61 to 0.66 (P -values > 0.05).

DISCUSSION

Studies involving multi-taxa analysis showed different degrees of congruence among taxa in relation to environmental gradients (Barlow *et al.* 2007; Barlow *et al.* 2014; Westgate *et al.* 2014). We found incongruence between terrestrial and aquatic insects,

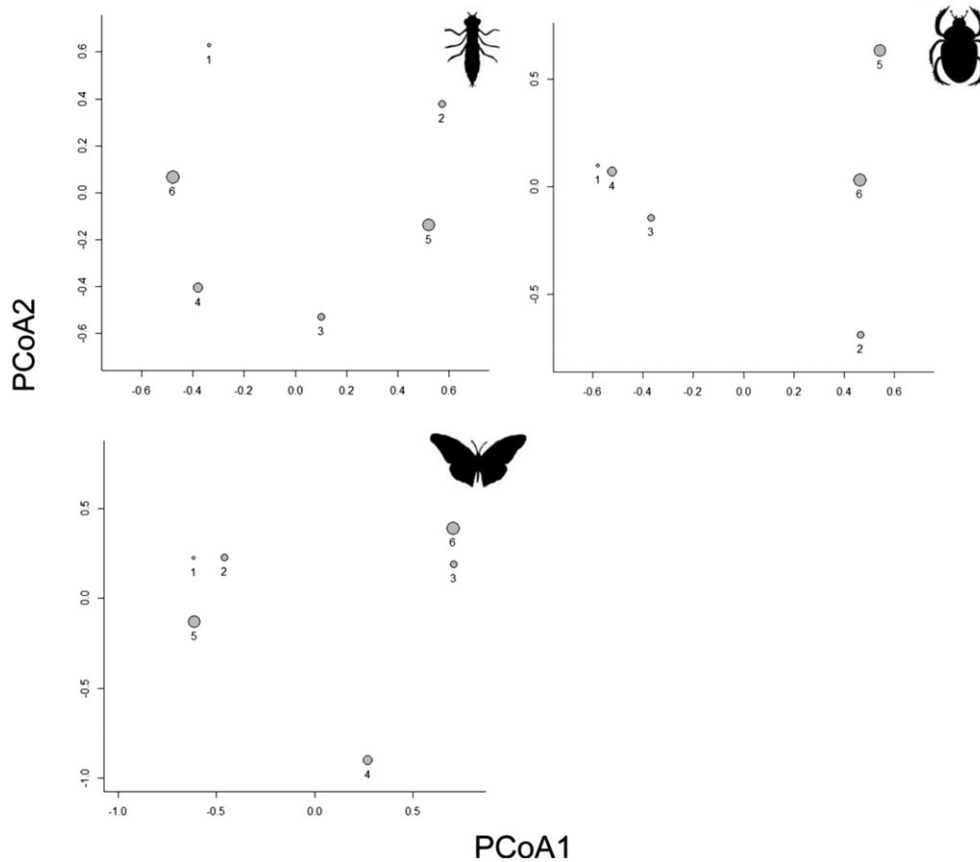


Fig. 3. Ordination of insect communities (aquatic insects, dung-beetles and frugivorous butterflies) along a deforestation gradient, using two-dimensions. Codes (S1–S6) represent sites that ranged from deforested (small circles) to well preserved (large circles).

which is not in line with our initial expectation that all groups would respond similarly to the level of environmental integrity of each riparian zone. Our results add evidence to the weak congruence among different taxa found in other studies (e.g. Weaver 1995; Niemelä & Baur 1998; Oliver *et al.* 1998; Vessby *et al.* 2002; Perfecto *et al.* 2003; Su *et al.* 2004; Louzada *et al.* 2010; Andrade *et al.* 2011).

The lack of congruence in biodiversity patterns has been attributed to the high variability in ecological requirements of various taxa (Lawton *et al.* 1998). Moreover, these responses may vary depending on the degree of taxon dependence on riparian conditions and functional significance of the landscape in relation to the perception of the taxonomic group. Although it is expected that all groups have some dependence on the riparian zone, the ecological requirements of the observed assemblages in our study may differ in important niche dimensions. For example, frugivorous butterflies communities are more dependent on floristic composition for feeding than aquatic insects or dung beetles. As the groups did not respond to the RCE gradient, we hypothesise that they are more associated with specific characteristics of the landscapes, such as resource availability, rather than on riparian zone condition in general.

Another possible explanation for low congruence could be related to the intensity of the anthropogenic environmental gradient. Some environmental gradients may not be strong enough to elicit similar responses from different groups (Heino

et al. 2007). This probably explains part of the variation in our data, especially because most landscapes in the Bodoquena Plateau are characterised by connected mosaics of native vegetation embedded in pasture areas which may maintain functional connectivity avoiding biodiversity loss.

Historical factors can also account for the lack of clear links between anthropogenic environmental gradients and the responses of multiple invertebrate groups (Uehara-Prado & Garófalo 2006). Brown (1997) suggested that some groups do not respond to the processes of forest fragmentation in the Atlantic Forest because the group has experienced processes of forest contraction and expansion generating a most resilient community, which in consequence is less sensitive to habitat fragmentation. In our case, considering that (i) the Bodoquena Plateau has suffered severe climate fluctuations (Boggiani *et al.* 1993) and that (ii) the region is considered a landscape mosaic, which includes different types of vegetation such as savannah and semi-deciduous forests, we hypothesise that the insect community of these riparian zones is composed of various groups with medium to low sensitivity to forest loss and fragmentation.

We expected that different invertebrate species living in riparian zones would have similar (narrow) environmental preferences, which would result in similar responses to anthropogenic environmental gradients. However, it is possible that our premise was flawed for species groups in mosaic landscapes such as those studied here. Consequently, when analysing

all species together, their overall response to the environmental gradient was weak, likely due to opposing responses that weaken the main sign of the community. This reinforces the view that the combination of certain taxa from a multiple taxa perspective, independent of their taxonomic group, should be considered in the selection of indicator groups in biomonitoring (Siqueira *et al.* 2012). This topic requires further investigation prior to suggesting any set of insect taxa as a useful group for monitoring riparian zones. However, considering the aquatic–terrestrial variability of such zones and the idiosyncratic responses of aquatic and terrestrial insects to different levels of environmental integrity that we found, we believe that both terrestrial and aquatic insects should be considered to effectively monitor trends in the integrity of these systems as the optimal ‘surrogate sets’ to describe the complexity of environmental gradients should include those groups that display incongruent patterns (Westgate 2015).

Perhaps, the greatest strength of our sampling design is the assessment of terrestrial and aquatic groups using specific sampling methods for each taxon. However, logistic difficulties in terms of carrying out multiple taxa sampling *in situ* and insect identification (mostly related to time requirements) constrained our work to few riparian zones. In this way, one could say that our power of generalisation is low. We recognised this caveat in our sampling design, but we believe that if the anthropogenic impacts in the riparian zones were strong, they would imprint clear biological responses, even if only a small number of samples were considered. In conclusion, our results indicated that there is not a simple common response of different insect groups to anthropogenic environmental gradients in riparian zones and a better understanding of the factors that shape their distributions is necessary before using complementary information from different groups in biomonitoring.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web site.

Appendix S1 Habitat characteristics used in the protocol for evaluation of the sampling sites and calculating the Environmental Integrity Index (RCE).

Appendix S2 List of the morphospecies collected in six riparian sites in Bodoquena Plateau, Mato Grosso do Sul, Brazil.