

Does the damming of streams in the southern Amazon basin affect dragonfly and damselfly assemblages (Odonata: Insecta)? A preliminary study

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Our goal was to investigate whether the loss of riparian forests alters the structure of assemblages and populations of dragonflies and damselflies. We tested the hypothesis that the composition of the odonate assemblages found upstream from dams are significantly different from those found downstream of these barriers. To test the hypothesis, we investigated stream sectors upstream and downstream of three dams located at the extreme of the southern Amazon basin, in the Brazilian state of Mato Grosso. We collected 111 adult odonates, 45 upstream and 69 downstream, representing 18 species, 12 upstream and 10 downstream. The most abundant species was *Epipleoneura williamsoni* Santos, 1957 ($n = 41$, 36.9%), followed by *Epipleoneura metallica* Rácenis, 1955 ($n = 20$, 18%) and *Hetaerina curvicauda* Garrison, 1990 ($n = 17$, 15.3%). Statistical ordination separated the different sectors, with the greatest dissimilarity being found between the upstream and downstream I (DS I), and our hypothesis was further supported by the fact that six of the 18 species recorded in the study did not occur in the upstream sector. As this process may lead to the local extinction of part of the biodiversity of the Amazon–Cerrado transition, even before it is fully understood, we would recommend that the observed pattern be verified through the analysis of other taxonomic groups and on a more ample spatial scale.

Keywords: conservation; biodiversity; environmental change; removal of riparian vegetation; agricultural frontier

Introduction

The process of colonization in the Amazon basin typically begins with the construction of roads, which enable the illegal occupation of land, the predatory exploitation of hardwoods, and eventually, the conversion of forest habitats into plantations and cattle pasture (Fearnside, 2005; Ferreira, Venticinque, & Almeida, 2005). In the case of watercourses, impacts may be caused by the construction of dams, whether for the generation of electricity (Wolfgang & Mello, 1990)

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or supplying water for agricultural activities (Teyssier, 2002); or road-building (Nimer, 1977). Impoundment transforms a naturally lotic or semi-lotic environment into a lentic one, altering the physical and chemical parameters of the water, and the availability of different microhabitats (Allan & Castillo, 2007; Esteves, 1998). The construction of dams may also result in discontinuities of the riparian vegetation due to deforestation (Lampert & Sommer, 2007; Naiman, Décamps, & McClain, 2005). These problems may be compounded by the loss of connectivity, which may affect population dynamics (Naiman et al., 2005).

The preservation of large areas of natural habitat is essential for the conservation of biodiversity, even in apparently 'healthy' environments, where habitat fragmentation and discontinuities may put diversity at risk (Watts, Saccheri, Kemp, & Thompsom, 2006). The Odonata (dragonflies and damselflies) are often used in studies that assess environmental integrity (Hornung & Rice, 2003; Monteiro-Júnior, Couceiro, Hamada, & Juen, 2013) because different groups of species are more or less sensitive to anthropogenic stresses (Clark & Samways, 1996). In particular, damselflies tend to require shaded habitats, whereas dragonflies are less selective (Monteiro-Junior et al., 2013). Many zygopteran species thus become rare or absent following deforestation for road building (Monteiro-Júnior et al., 2013) or agricultural activities (Ferreira-Peruquetti & Fonseca-Gessner, 2003), as well as the inadequate preservation of riparian vegetation (Carvalho, Pinto, Oliveira-Júnior, & Juen, 2013).

The use of adult odonates as bioindicators is based on the intimate relationship found between many species and the characteristics of the riparian vegetation. The removal of this vegetation may in fact favor some of the larger-bodied, heliothermic, generalist species (Ferreira-Peruquetti & Fonseca-Gessner, 2003). A predominance of these generalist species may contribute to a reduction in the occurrence of specialist species due to increased competition or predation (Okuyama, Samejimaa, & Yoshitaka, 2013). Changes in the riparian vegetation may also modify the distribution of microhabitats for oviposition (Baird & May, 1997; Waage, 1987). All these questions reinforce the need for further research on both communities and populations for more comprehensive diagnosis of the effects of environmental changes on the biota (Ferreira-Peruquetti & Fonseca-Gessner, 2003; Samways, 1991).

Given these considerations, the present study investigated whether the loss of riparian vegetation following the construction of dams on streams has a significant impact on the structure of odonate assemblages in an area of transition between the Amazon rainforest and the Cerrado savanna of central Brazil, in the Xingu River basin. We tested the hypothesis that the composition of odonate assemblages in areas upstream and downstream from the dams was significantly different.

Methods

Study area

We conducted this study in three streams located in the Xingu River basin in southern Amazonia, in an area considered to represent the transition between the Cerrado savanna of central Brazil and the Amazon rainforest biome, which covers most of the north of the country (Balch, Nepstad, & Brando, 2008; Ivanauskas, Monteiro, & Rodrigues, 2008). Canopy height (approximately 20 m) and biomass ($191 \pm 6 \text{ Mg ha}^{-1}$) are lower than those found in the Amazon rainforest (Balch et al., 2008). The vegetation is composed of at least 97 species of tree and liana, although nine of these predominate (IVI = 50%), and the Lauraceae and Burseraceae families are the most frequently observed (Balch et al., 2008). This area is of special interest due to its proximity to the "Arc of Deforestation" agricultural frontier of the southern Amazon basin (Nogueira, Fearnside, Nelson, & França, 2007; Nogueira, Nelson, Fearnside, França, & Oliveira, 2008). Specimens

were collected in October 2012 at three streams: stream 1 (13°03'23.13" S, 52°23'13.86" W, elevation: 339 m); stream 2 (13°01'45.14" S, 52°24'29.77" W, elevation: 345 m), and stream 3 (13°01'01.42" S, 52°21'40.36" W, elevation: 355 m). All the sites were first-order streams according to Strahler (1957) with widths of 1–2 m and depths of 0.3–0.8 m. The predominant substrates were roots and leaf litter.

We collected adult odonates at nine points upstream (US) and downstream (DS I and DS II) of areas of deforestation created by the construction of dams on each stream. The riparian vegetation between the US and DS I environments was discontinuous, with gaps of approximately 800 m, while the DS I and II habitats were separated by a similar distance of around 800 m, but this time, the riparian vegetation was continuous (Figure 1). Using gvSIG software, we determined that the fragments were formed, through dam construction, approximately 26 years ago. Initially the adjacent land was converted to cattle pasture, grass (*Brachiaria* sp.), but in 2005, the pasture was replaced by soybean plantations. The Landsat 5 images used to generate the map of the study area (Figure 1) were obtained from INPE (www.inpe.br).

Collection of odonate specimens

We collected adult odonates at each of the nine sampling points by capturing all the individuals observed (when possible) during one hour along a 100 m linear transect, divided into 20 sectors of 5 m. This approach was adapted from De Marco (1998), Ferreira-Peruquetti & De Marco (2002), and Ferreira-Peruquetti & Fonseca-Gessner (2003). The specimens were captured by an experienced collector using an entomological hand net of approximately 40 cm in diameter with a 140 cm shaft.

The vast majority of odonates are ectothermic, relying on sunlight or ambient heat to warm their bodies (Corbet, 1999; Heinrich & Casey, 1978), although the period of flying activity may vary considerably among species (De Marco, Latini, & Resende, 2005; De Marco & Resende, 2002). To minimize the potential effects of the time of day on the data, then, all three points (US, DS I and DS II) of a given stream were sampled consecutively between 10:00 h and 11:00 h, 11:30 h and 12:30 h, and 13:00 h and 14:00 h, with the schedule alternating among streams (Table 1). We identified specimens to the species level using the relevant taxonomic references (Garrison, Ellenrieder, & Louton, 2010; Lencioni, 2005, 2006), and when identification was uncertain, the specimens were classified as morphospecies. All the specimens were deposited in the James Alexander Ratter zoobotanical collection at the State University of Mato Grosso in Nova Xavantina, Mato Grosso, Brazil.

Statistical analysis

In order to test the hypothesis that the composition of odonate species varies between the upstream and downstream sampling points, we considered downstream points I and II as a single sample unit, given that they were located in continuous tracts of forest. These points were considered to be the control for the analysis of the effects of the fragmentation of riparian habitats upstream from the dams.

The distribution of the communities was visualized using a principal coordinates analysis (PCoA). The three replicates of the habitat types (upstream and downstream I and II) in the three streams corresponded to a total of nine sample units. The same sample units were used for an analysis of percentage similarity, or SIMPER (Clarke, 1993) to verify the degree of similarity in the species composition of each sample unit, providing a quantitative complement of the results visualized in the PCoA ordination.

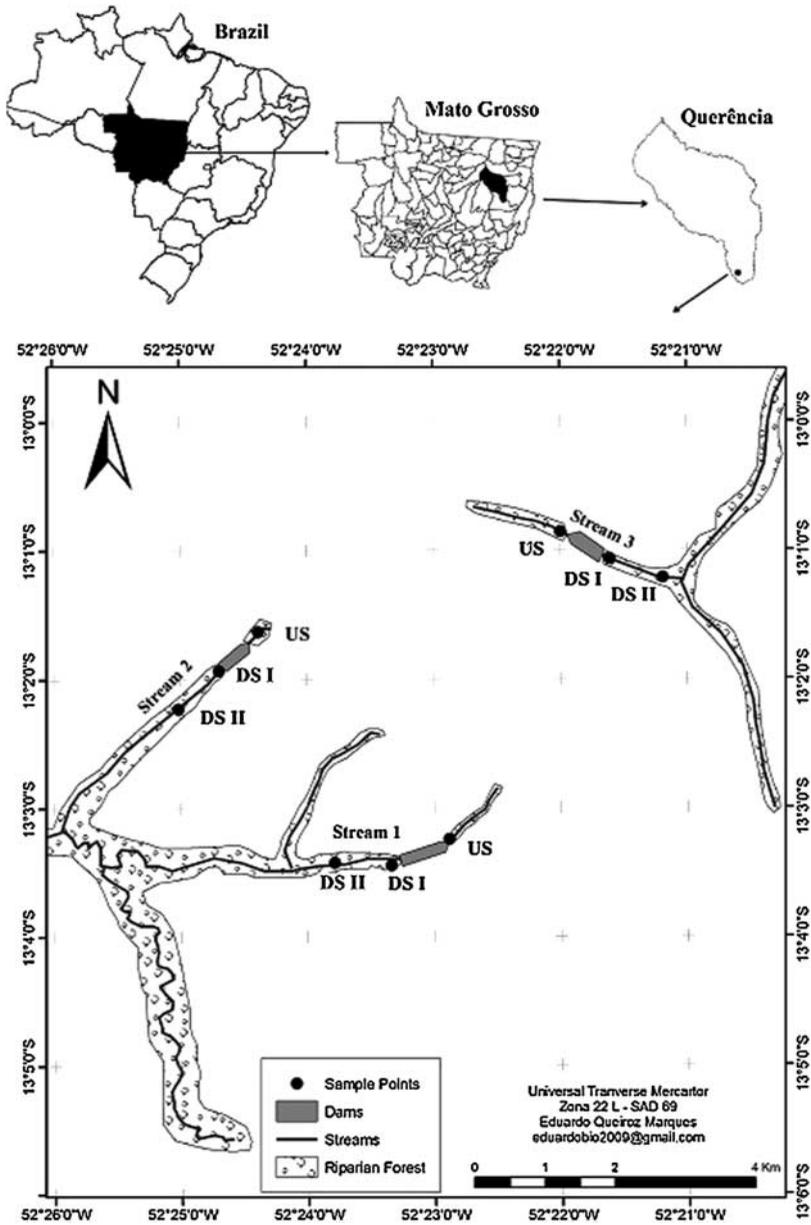


Figure 1. Spatial distribution of sampling points in three streams of the southern Amazon basin, Brazil, in environments upstream (US) and downstream (DS I and DS II) from impoundments.

To assess the percentage of occurrence of community and species in the three environments (US, DS I and DS II) we used a chi-square test, based on the assumptions that no expected frequency could be less than one, and only 25% could be less than five (Zar, 2010).

We made a generalized linear model (GLM) in R software (R Development Core Team, 2009) with Gaussian errors, taking into account the nine sampling units (three environments \times three streams). We used the abundance of each species as response and environments (US, DS I and DS II) as predictor variables. The GLM uses *t*-test statistics to check significant differences, by using

Table 1. Dates and times of collections of Odonata in streams of southern Amazon, Brazil.

Site	Environment			Date
	Upstream	Downstream I	Downstream II	
Stream 1	10:00–11:00	11:30–12:30	13:00–14:00	1 October 2012
Stream 2	13:00–14:00	10:00–11:00	11:30–12:30	2 October 2012
Stream 3	11:30–12:30	13:00–14:00	10:00–11:00	3 October 2012

each environment as a categorical predictor, and allows comparisons between the abundance of each species of one factor (environment) with the others.

Results

We collected 111 adult odonate specimens, 45 from upstream points and 66 downstream (24 in DS I and 42 in DS II). The most abundant species were *Epipleoneura williamsoni* Santos, 1957 ($n = 41$, 36.9%), followed by *Epipleoneura metallica* Rácenis, 1955 ($n = 20$, 18%) and *Hetaerina curvicauda* Garrison, 1990 ($n = 17$, 15.3%). All these three species were collected in the three habitat types (Table 2).

The first two axes of the ordination of the communities explained 60% of the distribution of the odonate species in the different habitat types, and separated the upstream points from all the others, whereas downstream points I and II were clearly grouped together (Figure 2). The SIMPER results reinforce these findings, given that DS I and II were most similar to one another, while US and DS I were the least similar (Table 3). However, DS II of stream II separated from all others (outlier); we believe this occurred mainly due to *Hetaerina curvicauda*, which occurred at all points except DS II of stream II, and *Argia tinctipennis*, which occurred only at this point. These were probably responsible for the difference in the structure of this community compared to all other US and DS sectors.

Table 2. Abundance of odonates in three streams of the southern Amazon, representing environments upstream and downstream (I and II) of impoundments. Species that occurred in at least one downstream site, but no upstream site are represented by an asterisk (*), while those that occurred in at least one upstream site, but no downstream site are represented by a double asterisk (**).

Taxon	Upstream	Downstream I	Downstream II	Total
<i>Acanthagrion apicale</i> Selys, 1876 **	0	1	2	3
<i>Acanthagrion gracile</i> (Rambur, 1846)	1	1	0	2
<i>Acanthagrion</i> sp. *	2	0	0	2
<i>Argia lilacina</i> Selys, 1865	2	1	0	3
<i>Argia reclusa</i> Selys, 1865 *	0	0	2	2
<i>Argia</i> sp.**	0	1	2	3
<i>Argia tinctipennis</i> Selys, 1865 **	0	0	1	1
<i>Elga</i> sp.	3	3	1	7
<i>Epipleoneura metallica</i> Rácenis, 1955	8	3	9	20
<i>Epipleoneura williamsoni</i> Santos, 1957	16	7	18	41
<i>Hetaerina curvicauda</i> Garrison, 1990	7	5	5	17
<i>Hetaerina</i> sp. *	2	0	0	2
<i>Phasmoneura janirae</i> Lencioni, 1999	1	1	1	3
<i>Telebasis</i> sp. *	1	0	0	1
<i>Telebasis coccinea</i> (Selys, 1876) *	1	0	0	1
<i>Telebasis gigantea</i> Daigle, 2002 *	1	0	0	1
<i>Telebasis racenisi</i> Bick & Bick, 1995 **	0	0	1	1
<i>Tuberculobasis inversa</i> (Selys, 1876) **	0	1	0	1
Total individuals (species)	45 (12)	24 (10)	42 (10)	111 (18)

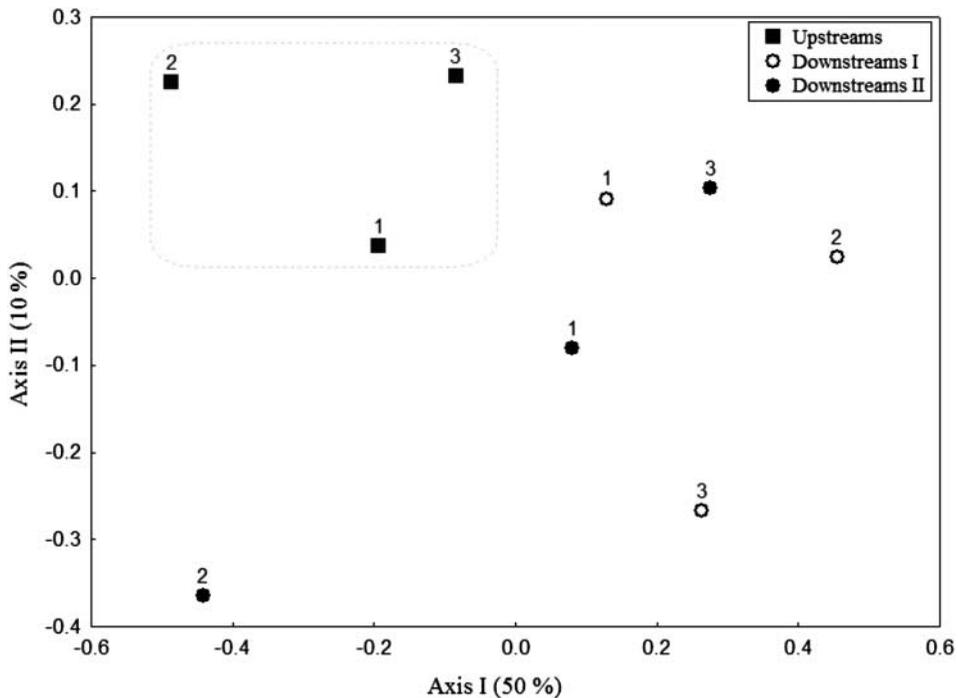


Figure 2. Ordination of the odonate communities from upstream and downstream environments. The numbers represent the streams of southern Amazon, Brazil.

Table 3. Dissimilarity of the species composition upstream and downstream assemblages.

Environment	Dissimilarity (%)
Upstream × Downstream I	77.04
Upstream × Downstream II	65.11
Downstream I × Downstream II	61.66

The distinct position of the DS I samples was further reinforced by the nonparametric test ($\chi^2 = 7.74$, $df = 2$, $p < 0.025$). Once again, this pattern was strongly influenced by the *Epipleoneura* populations, which represented 54% of the total abundance and had significantly different distribution in the DS I sectors, in comparison with the others ($\chi^2 = 8.22$, $df = 2$, $p < 0.02$).

The species *Acanthagrion apicale*, *Telebasis racenisi*, *Argia reclusa*, *Argia* sp., *Argia tinclipennis*, and *Tuberculobasis inversa* occurred exclusively in the downstream sector. *Acanthagrion* sp. and *Hetaerina* sp. were significantly more abundant in upstream sites ($p = 0.049$, $df = 7$, $t = 2.44$; and $p = 0.048$, $df = 7$, $t = 2.44$ respectively), while *Argia reclusa* was found predominantly in downstream sites ($p = 0.049$, $df = 7$, $t = 2.44$).

Discussion

Ecological processes and factors such as variation in the physical environment, competition, and the availability of resources all contribute to the distribution and abundance of odonate species

(Córdoba-Aguilar, 2008). Communities can often be divided into two groups, one with a few, relatively abundant species, and the other with a large number of comparatively rare species (Magurran, 2012). Consistent with this, *Epipleoneura williamsoni*, *E. metallica*, and *Hetaerina curvicauda* together contributed 70% of the total odonate abundance recorded in the present study, and occurred in all environments. While this pattern may have been expected, it should be treated with caution here, given the small number of sites surveyed, and the fact that the distribution of the *Epipleoneura* species of the DS I sites was significantly different from that of the others.

The data indicate a significant effect of anthropogenic impacts on the composition of the odonate communities, as proposed in our hypothesis, although it is also possible that random sampling factors may apply, impeding more definitive conclusions on this process. The pattern may be related to the isolation of the upstream and downstream communities, due to the removal of the riparian vegetation along the reservoir, and the resulting changes in microclimates (Didham & Lawton, 1999). Changes in the composition of the odonate assemblages are thus related to the ecophysiological characteristics of each species, such as thermoregulatory potential, as well as dispersal ability and body size (May, 1979). However, odonate species tend to have good dispersal potential, and the patterns we found in the present study may be caused by other variables that were not contemplated in this study, as well as random effects. Some species may be naturally absent from some areas, despite the relatively short distances that separate them.

Flying organisms may be affected by the fragmentation of the landscape, even on a small spatial scale. In a study of damselflies in England, Watts et al. (2007) demonstrated that some species are unable to disperse freely among fragments separated by an open matrix. These authors emphasized the importance of habitat continuity, given that even small-scale habitat fragmentation may lead to a loss of genetic diversity.

The loss and fragmentation of riparian vegetation eliminates natural gradients (Wiens, Stenseth, Vanhorne, & Ims, 1993), alters microclimatic conditions and nutrient cycles, and may modify species composition, dispersal, and interactions, leading to a decrease in species richness (Ferreira-Peruquetti & Fonseca-Gessner, 2003), and changes in the composition of the odonate community due primarily to environmental homogenization (Monteiro-Júnior et al., 2013).

Hydrographic connectivity and vegetation characteristics are determinants of the occurrence of odonate species on local and regional scales (Chovanec & Waringer, 2001). Gallery forests may play an important role in the maintenance of biodiversity by forming corridors for dispersal (Allan & Castillo, 2007), and are crucial to the occurrence of groups, such as odonates, which depend on specific habitat characteristics for their foraging behavior (Ferreira-Peruquetti & Fonseca-Gessner, 2003; Samways, 1991). Dispersal is a critical process in the life cycle of odonate species (Corbet, 1983), and is related primarily to body size (Conrad, Wilson, Harvey, Thomas, & Sherratt, 1999). The Zygoptera, which contributed 95% of the specimens collected in our study, have limited flight capacity. We believe them to be similar the species studied by Watts, Rouquette, Saccheri, Kemp, and Thompson (2004) and they are especially sensitive to modifications of the riparian vegetation (Samways & Steytler, 1996).

When impacts such as deforestation or damming occur in the upper reaches of streams, the species found in the lower stretches, which tend to have more open natural habitats, migrate upstream, resulting in changes in the composition of species (Dijkstra & Lempert, 2003). The odonate species typically found in open areas are more agile and aggressive than forest species, which tend to be slower and more fragile. These natural differences contribute to niche partitioning between the forest-dwelling species and those that occupy more open habitats (Dijkstra & Clausnitzer, 2006), and when forest habitats are altered, the forest-dwelling odonates tend to lose ecological space.

The occurrence or absence of a species in a given system may reflect its biological integrity (Moulton, 1998), and the potential of an ecosystem to support a well-balanced, integrated,

and functional community, with a species composition comparable to that of natural habitats, reflects the health of the system (Ferreira-Peruquetti & De Marco, 2002). Anthropogenic impacts, such as the modification of stream flow by damming, and the fragmentation of riparian vegetation with the resulting disruption in natural environmental gradients (Ferreira-Peruquetti & Fonseca-Gessner, 2003), are likely to extirpate the species most sensitive to environmental changes (Harabis & Dolny, 2012).

The observed abundance values in our study are smaller than those observed in other studies in neighboring regions (e.g. Carvalho et al., 2013; Juen, Oliveira-Junior, Shimano, Mendes, & Cabette, 2014) or in more northern regions of the Brazilian Amazon (e.g. Monteiro-Junior et al., 2013; Monteiro-Junior, Juen, & Hamada, 2014). However, in those studies samples were made in second and third order streams (Stralher, 1957). These environments have greater light input, which provides a significant increase in richness and abundance associated with greater environmental heterogeneity. These larger streams can provide greater variety of resources (autochthonous and allochthonous energy; Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). Other drivers that could affect Odonata abundance are air temperature (De Marco & Vital, 2008; Hilfert-Ruppell, 1998; May, 1991) and luminosity (De Marco & Peixoto, 2004; Shelly, 1982).

The temperature of the water increases considerably in both the reservoir and the downstream sector. However, temperatures may be more stable further upstream and downstream, due to the presence of riparian forests (Vinson, 2001). Little is known of the biology or ecology of *Epipleoneura* species, although individuals of this genus are typically found in riparian forests, on the margins of streams, flying close to the water or perched on bushes (Lencioni, 2005). These odonates have a high surface/volume ratio, and are thus probably thermal conformers, which makes them more sensitive to fluctuations in temperature (May, 1976, 1981). Given this, abundance would be expected to be affected directly by the removal of the forest, and the subsequent increase in air and water temperatures, as observed in the DS I sector, just down from the reservoir. These variables may thus act as environmental filters.

The species *Acanthagrion* sp. and *Hetaerina* sp. were related significantly to the upstream environments, and were not observed at any of the downstream points. These two genera are widely distributed in tropical regions, although *Acanthagrion* Selys (1876) is found typically in lentic habitats (Lencioni, 2006). Species of the genus *Hetaerina* Rambur (1842) have been found in higher numbers in more open habitat with greater incidence of sunlight (De Marco & Peixoto, 2004), which would account for their presence in the upstream fragments, where the lower proportion of forest is reflected in an increased input of sunlight.

All these odonates, especially *Hetaerina*, are heliothermic, and are thus dependent on the direct incidence of solar radiation for thermoregulation (De Marco & Peixoto, 2004). These authors concluded that heliotherms may be favored by the removal of the forest, as well as interspecific competition, which excludes the most specialist species. This reinforces the importance of the role of the availability of sunlight as an environmental filter in these habitats. The removal of the forest has a direct effect on the characteristics of the body of water and the stream bed, reducing current velocity and causing siltation. The species adapted to lentic habitats will be favored by these changes and would tend to replace the more sensitive species and those more adapted to lotic habitats (Ferreira-Peruquetti & De Marco, 2002). In more open habitats, in addition, the availability of perches will decrease, and have a negative effect on the abundance of adult odonates (Remsburg, Olson, & Samways, 2008).

While the present study did not cover a large spatial scale, it did demonstrate important alterations in the composition of odonate communities related to the damming of streams and the fragmentation of riparian forests due to the development of agricultural activities. We recognize that the patterns identified in the present study are preliminary, and thus recommend that they

should be investigated in additional taxonomic groups and on a wider spatial scale, given the potential for the local extinction of part of the biodiversity of the Amazon/Cerrado even before this biological resource has been fully documented.

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