

Effect of vegetation removal for road building on richness and composition of Odonata communities in Amazonia, Brazil

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This study showed that the main impact on Odonata species of removal of riparian vegetation for road building was on community composition, since species richness remained unaltered. This result, most evident in damselflies, was probably driven by the entry of generalist species that replaced specialist species after the impact. We collected adult odonates in forested and deforested streams in the surroundings of Manaus, Amazonas, northern Brazil. We collected 380 specimens belonging to 32 odonate species. *Erythrodiplax fusca* and *Argia* sp. 1 could be used in biomonitoring programs, since they were significantly associated with deforested streams. Using odonate community composition and key species appears to be more efficient in biomonitoring programs than simply using species richness.

Em nosso estudo mostramos que o principal impacto sobre as espécies de Odonata causado pela retirada da vegetação ciliar para a construção de estradas é a modificação na composição da comunidade, uma vez que a riqueza de espécies continua praticamente constante. Possivelmente, devido à entrada de espécies mais generalistas em detrimento das especialistas, que são extintas localmente após o impacto, e isso é mais evidente em Zygoptera. Coletamos em 100 m de igarapés localizados em áreas sem vegetação e em fragmentos florestais na região de Manaus-AM. Foram coletados 380 espécimes, distribuídos em 32 espécies. Dessas, *Erythrodiplax fusca* e *Argia* sp. 1 podem ser utilizadas em programas de biomonitoramento pois mostraram uma associação com ambientes sem vegetação marginal. Nossos resultados indicam que a composição da comunidade de Odonata e o uso de espécies chaves são mais eficientes que a simples medida de riqueza para avaliar os impactos causados a esse grupo.

Keywords: Amazonia; dragonfly; aquatic insects; anthropogenic impact; streams; bioindicators

Introduction

Road building may have serious impacts on streams (Brandão et al., 2007; Soares-Filho et al., 2005), either directly by the removal of riparian vegetation, or indirectly by increasing sediment input (eg Couceiro et al., 2010). Consequently, streams overflow during rainfall, flooding the

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riparian vegetation and creating clearings, which increases deforestation even more. Road building may also change abiotic features of streams depending on the physical characteristics of the watershed (Forman & Alexander, 1998).

Removal or replacement of riparian vegetation directly affects stream communities mainly by changing environmental conditions (eg light and nutrient input and leaf litter deposition). Additionally, riparian vegetation also regulates thermal stability in small streams (Steinblums et al., 1984). Removal of this vegetation therefore represents a major threat to stream functioning and structure (Couceiro et al., 2007), since it may potentially raise temperature and decrease humidity. Deforestation is known to change macroinvertebrate communities in temperate rivers by changing light input, temperature variation, nutrient levels, substrate particle size, and the distribution and availability of food resources (Bojsen & Jacobsen, 2003). Riparian vegetation is thus a key factor structuring larval odonate assemblages owing to its role in dictating the quality of the aquatic habitat.

Removal of riparian vegetation may also influence adult odonate community structure, since temperature influences the occurrence of species and their reproductive cycles (Samways & Steytler, 1996). Riparian vegetation can affect mate choice, since females choose males that guard the best oviposition sites in the riparian vegetation (De Marco & Resende, 2004), and nearby vegetation may affect the availability and nature of both perches and oviposition substrates. Oviposition is endophytic (eggs laid in plants, usually underwater) and/or exophytic (eggs laid into open water, often with submerged vegetation, or moist sediments) (Corbet, 1999).

Adult Odonata can be classified into two groups according to their ecophysiological requirements and flight abilities: perchers and flyers (Corbet, 1999). Perchers are typically ectothermic and use sunlight as their main heat source. They can be either thermal conformers or heliotherms. Thermal conformers are small-sized zygopterans with high conductance, in which body temperature tracks environmental temperature (Heinrich & Casey, 1978). Heliotherms usually have larger bodies (some zygopterans and anisopterans), and consequently lower thermal conductance. Activity patterns of heliotherms are mainly determined by solar irradiation (May, 1976). Endotherms, including many of the largest species of Anisoptera and even some medium-sized flyers, produce large amounts of heat during activity of the flight muscles, and regulate thoracic temperature endothermically by controlling hemolymph flow, and thus heat transfer, to the abdomen (Corbet, 1962; May, 1976). Thus, ecophysiological patterns of odonates are associated not only with thermoregulatory ability but also with their body size. These different requirements have an important role in species' dispersal abilities (Corbet, 1999).

Odonates have been increasingly used as bioindicators to assess the quality of the environment and how it changes over time (Butler & deMaynadier, 2007; Carle, 1979; Castella, 1987; Samways & Sharratt, 2010; Samways & Steytler, 1996), since they are strongly affected by anthropogenic changes in freshwater environments (Ferreira-Peruquetti & De Marco, 2002; Ferreira-Peruquetti & Fonseca-Gessner, 2003; Pinto et al., 2012; Samways & Steytler, 1996; Silva et al., 2010). However, little is known about the effects of deforestation on odonates in Amazonia. Similarly, basic natural history information of Amazonian odonates is scarce, since previous studies have been mainly conducted on the Amazon River floodplain (Juen & De Marco, 2012).

Our main goals were: (1) to evaluate the effects of riparian vegetation removal for road building on adult odonates; and (2) to identify species as potential indicators of environmental quality (environments without human changes), thereby increasing knowledge of this group in Central Amazonia. Our hypothesis is that deforested streams with high sunlight input would provide a suitable habitat for anisopterans, especially heliotherms. Meanwhile, forested streams with low sunlight input would be a more suitable habitat for many zygopterans, mainly due to the greater stability of these habitats.

Material and methods

Study area

This study was conducted in eight black-water streams in Manaus municipality, Amazonas, Brazil (Table 1). Three of them had preserved riparian vegetation while in the other five the vegetation was removed due to road building. The riparian vegetation is composed of *terra firme* rain forest. Forested streams had an average air temperature of 27°C (± 0.584) (measured at the time of sampling with a portable hygro-thermometer, Cole-Parmer, USA), sandy bottom, and many available substrates (eg roots, tree trunks and stems, leaf litter). The other five streams had high sunlight input, temperature averaging 31°C (± 1.151), standing water in their surroundings, and fine sediments on the stream bed, with almost no other substrates. Furthermore, these deforested streams were affected by siltation due to erosion caused by roads crossing the streams.

Sampling

We collected adult odonates with a hand net along a 100-m transect parallel to the stream banks. This methodology has been effectively used in other studies (eg Juen & De Marco, 2011; Pinto et al., 2012; Silva et al., 2010). Samplings were conducted twice at each site in the eight locations, totaling 16 samples, on sunny days between 10:00 and 13:00 h from September 2007 to April 2008. After collection, specimens were placed in plastic envelopes. The identification of specimens to species or morphotype followed taxonomic keys and original descriptions (eg Garrison et al., 2006, 2010; Lencioni, 2005, 2006), or by comparison with material housed in the invertebrate collection at INPA (the Brazilian Instituto Nacional de Pesquisas da Amazônia), and confirmation by experts (G. Fleck and F.A.A. Lencioni). Voucher specimens are deposited in INPA's invertebrate collection.

Data analysis

Richness data were analyzed with and without rarefaction because the difficulties in estimating and comparing species richness from sampling data made it necessary to adjust for differences in sampling effort (Magurran, 1988). The rarefaction method was used to establish the number of individuals to be used to compare the observed richness between forested and deforested streams. Differences in species richness between deforested and forest streams were analyzed by the Mann–Whitney test due to the non-normal nature of the data; separate tests were conducted for the total species and for zygopterans and anisopterans. The same test was used to compare the temperature between forested and deforested streams.

We used non-metric multidimensional scaling (nMDS) with the Bray–Curtis index on $\log(x + 1)$ transformed samples to compare odonate species composition between forested and deforested

Table 1. Odonata sampling sites in Manaus municipality, Amazonas, Brazil.

Stream number and type	Location	Latitude (S)	Longitude (W)
1. Deforested	BR 174 – Km 47	02°33'44.8"	60°01'43.1"
2. Deforested	AM 010 Km 37 – Ramal Toca do Leão	02°50'33.8"	59°58'25.5"
3. Deforested	AM 010 Km 32 – Ramal Água Branca	02°54'06.2"	59°54'23.6"
4. Deforested	Ramal da Praia Dourada	03°01'25.2"	60°04'45.1"
5. Deforested	BR 174 – Km 41	02°36'36.7"	60°02'20.6"
6. Forested	Universidade Federal do Amazonas	03°05'55.2"	59°58'07.7"
7. Forested	Reserva Ducke – Bacia do ig. Bolívia	02°58'43.0"	59°56'36.9"
8. Forested	Reserva Ducke – Bacia do ig. Acará	02°55'50.0"	59°58'27.7"

streams using PC Ord for Windows v. 5.15 (McCune & Mefford, 2006). We also used an analysis of similarity with 999 permutations (ANOSIM; McCune & Grace, 2002; Melo & Hepp, 2008) to test for a difference in species composition between forested and deforested streams.

We used the indicator value (Indval; Cáceres & Legendre, 2009; Dufrière & Legendre, 1997) to evaluate the association of each species with the two types of environment and to evaluate the potential of species to be used as indicators of environmental quality. According to Niemi

Table 2. Abundance of odonates in deforested and forested streams in Manaus municipality, Amazonas, Brazil; streams numbered as in Table 1.

Family/species	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7	Stream 8	Total
Libellulidae									178
<i>Erythrodiplax basalis</i> (Kirby, 1897)	0	1	7	1	0	0	0	0	9
<i>Erythrodiplax castanea</i> (Burmeister, 1839)	2	12	8	0	1	0	0	0	23
<i>Erythrodiplax famula</i> (Erichson, 1848)	6	13	0	1	0	1	0	0	21
<i>Erythrodiplax fusca</i> (Rambur, 1842)	23	35	6	5	5	1	0	0	75
<i>Erythrodiplax venusta</i> (Kirby, 1897)	0	0	0	1	0	0	0	0	1
<i>Dasythemis esmeralda</i> Ris, 1910	3	3	0	0	1	0	0	0	7
<i>Gynothemis pumila</i> (Karsch, 1890)	0	1	2	0	0	1	0	0	4
<i>Macrothemis</i> sp. 1	0	1	0	0	0	0	0	0	1
<i>Orthemis biolleyi</i> Calvert, 1906	0	1	0	0	1	0	0	0	2
<i>Orthemis ferruginea</i> (Fabricius, 1775)	0	2	0	0	0	0	0	0	2
<i>Pantala flavescens</i> (Fabricius, 1798)	0	0	1	0	0	0	0	0	1
<i>Uracis imbuta</i> (Burmeister, 1839)	0	0	0	2	0	0	0	0	2
<i>Zenithoptera fasciata</i> (Linnaeus, 1758)	0	23	0	4	3	0	0	0	30
Gomphidae									1
<i>Diaphlebia angustipennis</i> Selys, 1854	0	0	0	0	0	1	0	0	1
Megapodagrionidae									5
<i>Heteragrion ictericum</i> Williamson, 1919	0	0	0	0	0	0	1	0	1
<i>Oxystigma petiolatum</i> (Selys, 1862)	0	0	0	0	0	2	1	0	3
<i>Oxystigma williansoni</i> Geijskes, 1976	0	0	0	0	0	1	0	0	1
Calopterygidae									66
<i>Hetaerina amazonica</i> Sjöstedt, 1918	2	0	40	2	0	0	0	8	52
<i>Hetaerina moribunda</i> Hagen in Selys, 1853	0	0	1	0	1	2	0	0	4
<i>Hetaerina sanguinea</i> Selys, 1853	4	6	0	0	0	0	0	0	10
Coenagrionidae									81
<i>Aeolagrion dorsale</i> (Burmeister, 1839)	0	0	0	0	2	0	0	0	2
<i>Acanthagrion adustum</i> Williamson, 1916	2	2	0	0	2	0	0	0	6
<i>Argia bicellulata</i> (Calvert, 1909)	1	0	1	0	0	0	0	0	2
<i>Argia indicatrix</i> Calvert, 1902	3	1	3	0	0	0	3	6	16
<i>Argia</i> sp. 1	3	15	3	2	11	2	0	0	36
<i>Argia</i> spp females	0	7	4	3	2	1	0	0	17
<i>Ischnura capreolus</i> (Hagen, 1861)	0	1	1	0	0	0	0	0	2
Perislestidae									3
<i>Perilestes attenuatus</i> Selys, 1886	0	0	0	0	0	0	3	0	3
Protoneuridae									6
<i>Epipleoneura capilliformis</i> (Selys, 1886)	0	0	0	0	0	1	0	0	1
<i>Epipleoneura manauensis</i> Santos, 1964	0	0	0	0	0	0	1	0	1
<i>Phasmoneura exigua</i> (Selys, 1886)	0	1	1	0	1	1	0	0	4
Dicteriadidae									1
<i>Dicteria atrosanguinea</i> Selys, 1853	0	0	0	0	0	0	1	0	1
Polythoridae									39
<i>Chalcopteryx scintillans</i> McLachlan, 1870	0	0	0	0	0	0	25	14	39
Total	49	127	79	20	31	14	35	28	380

& McDonald (2004) a good indicator primarily reflects environmental conditions and may be assessed by presence, abundance and behavior of biota in response to the stressor. This analysis takes into account two criteria: specificity and fidelity. A perfect indicator species should occur only in sampling units from a given category (specificity) and also in all sampling units of that given category (fidelity). The significance of the indicator value was tested by a Monte Carlo method using 10,000 randomizations in the *indicspecies* package (Cáceres & Legendre, 2009) of the R program (R Development Core Team, 2011).

Results

We collected 380 specimens from 21 genera and 32 species; nine genera and 14 species were Anisoptera, while 12 genera and 18 species belonged to Zygoptera (Table 2). We collected nine species only at forested streams, eight belonging to Zygoptera, and 15 species only at deforested streams, 10 belonging to Anisoptera. Only eight of the 32 species (five species of Zygoptera and three of Anisoptera) occurred at both forested and deforested streams (Figure 1).

Despite the significant differences ($Z = -2.09$; $p = 0.03$) in temperature between deforested ($31^{\circ}\text{C} \pm 1.15$) and forested streams ($27^{\circ}\text{C} \pm 0.58$), the species richness was similar between the two environments (without rarefaction $Z = -1.49$; $p = 0.134$; after rarefaction $Z = -0.60$; $p = 0.55$; Figure 2). Species richness of Zygoptera was similar in both environments ($Z = 0.15$; $p = 0.87$), but not that of Anisoptera ($Z = -1.97$; $p = 0.04$). Species composition clearly formed two groups of species related to the two environments (NMDS stress: 0.17; Figure 3). This result proved to be significant (ANOSIM $R = 0.646$; $p = 0.033$), demonstrating that there are differences in odonate species composition between forested and deforested streams. Species occurring in deforested streams appeared more clustered in the ordination diagram, suggesting the homogenization of species composition in these areas, while species of forested streams were more dispersed in the diagram, suggesting greater variation in composition (Figure 3); this apparent trend requires additional data for confirmation, however.

When we compared the composition of each suborder separately using the similarity analysis ANOSIM, we did not find differences in species composition of Anisoptera between sites ($R = 0.92$; $p = 0.159$), perhaps because only one anisopteran was restricted to forested streams. However, zygopterans seem to be more affected by differences in forest cover since

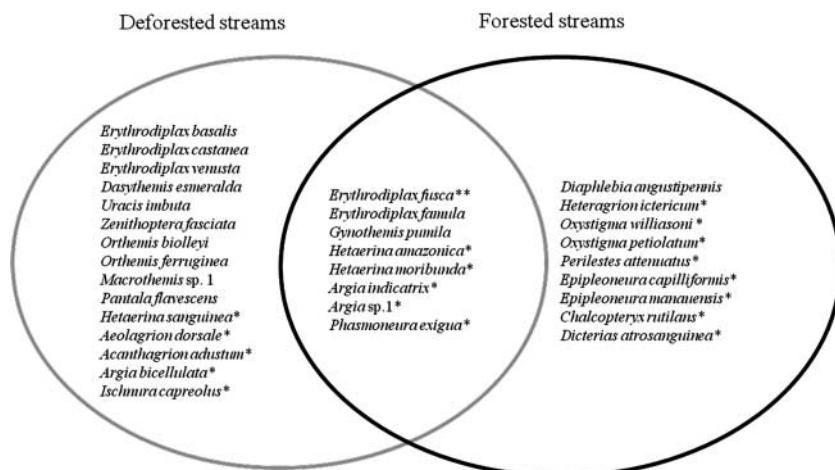


Figure 1. Venn diagram with species and morphotypes occurring in the studied streams in Manaus municipality, Amazonas, Brazil. Asterisk represents species/morphotypes of Zygoptera.

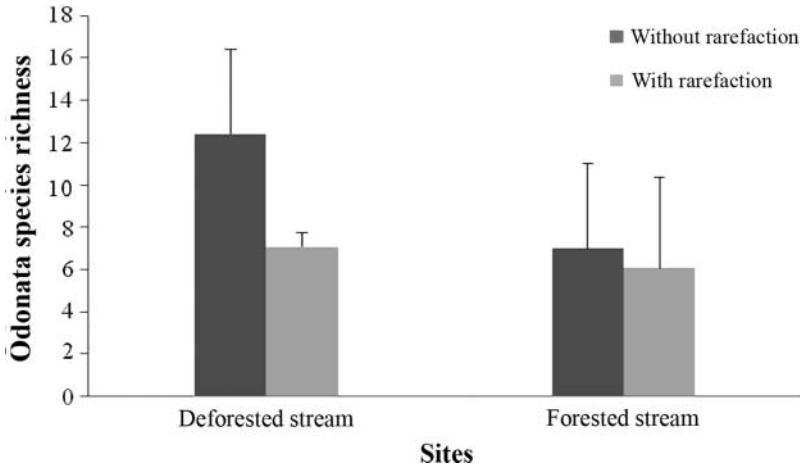


Figure 2. Means of Odonata species richness in deforested and forested streams in Manaus municipality, Amazonas, Brazil, with and without rarefaction. The bars represent 95% confidence intervals.

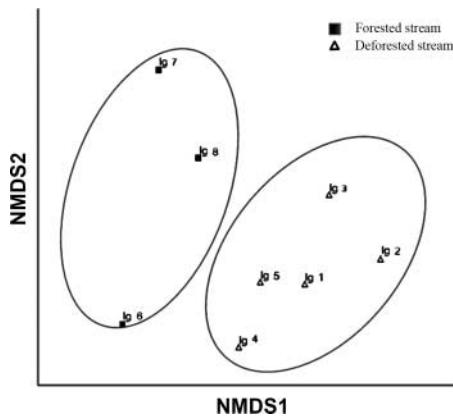


Figure 3. Odonate composition in forested and deforested streams (Ig.) based on the Bray–Curtis index, Manaus municipality, Amazonas, Brazil.

the composition of species is different after changes occur in the environment ($R = 0.533$; $p = 0.03$). Only *Erythrodiplax fusca* Rambur, 1842 ($Indval = 98.90$; $p = 0.025$) and *Argia* sp. 1 (new species under description by RW Garrison, California Department of Food and Agriculture) ($Indval = 95.40$; $p = 0.041$) were significantly associated with deforested streams according to the indicator species analysis (Table 3).

Discussion

Odonate species richness was similar between forested and deforested streams, except when we analyzed the suborders separately and then only for Anisoptera. This difference in anisopteran richness was probably due to increased sunlight input and temperature in open water. This result shows that odonate richness per se is a potentially misleading parameter in environmental studies due to the increased richness in degraded habitats caused by opportunistic species. Previous studies in Brazil also observed an increase in odonate species richness in deforested areas (Ferreira-Peruquetti & De Marco, 2002), or in an agriculture area (Ferreira-Peruquetti &

Table 3. Results of odonate indicator species analysis in deforested and forested streams, Manaus municipality, Amazonas, Brazil.

Species	Environment	Indval	Mean	SD	<i>p</i>
<i>Erythrodiplax basalis</i>	Deforested streams	60.00	42.20	16.75	0.376
<i>Erythrodiplax castanea</i>	Deforested streams	80.00	47.00	18.11	0.101
<i>Erythrodiplax famula</i>	Deforested streams	55.40	48.70	18.65	0.417
<i>Erythrodiplax fusca</i>	Deforested streams	98.90	59.30	16.68	0.025
<i>Erythrodiplax venusta</i>	Deforested streams	20.00	25.00	6.46	1.000
<i>Dasythemis esmeralda</i>	Deforested streams	60.00	38.30	19.07	0.285
<i>Gynothemis pumila</i>	Deforested streams	25.70	38.60	17.91	0.807
<i>Macrothemis</i> sp. 1	Deforested streams	20.00	25.00	6.46	1.000
<i>Orthemis biolleyi</i>	Deforested streams	40.00	32.70	14.77	0.468
<i>Orthemis ferruginea</i>	Deforested streams	20.00	25.00	6.46	1.000
<i>Pantala flavescens</i>	Deforested streams	20.00	25.00	6.48	1.000
<i>Uracis imbuta</i>	Deforested streams	20.00	25.00	6.46	1.000
<i>Zenithoptera fasciata</i>	Deforested streams	60.00	42.50	16.92	0.383
<i>Diaplebia angustipennis</i>	Forested streams	33.30	24.80	6.41	0.362
<i>Heteragrion ictericum</i>	Forested streams	33.30	25.10	6.48	0.381
<i>Oxystigma petiolatum</i>	Forested streams	66.70	32.30	15.45	0.106
<i>Oxystigma williansoni</i>	Forested streams	33.30	24.80	6.41	0.362
<i>Hetaerina amazonica</i>	Deforested streams	46.00	51.10	18.72	0.660
<i>Hetaerina moribunda</i>	Forested streams	20.80	38.90	17.71	1.000
<i>Hetaerina sanguinea</i>	Deforested streams	40.00	32.50	15.19	0.462
<i>Aeolagrion dorsale</i>	Deforested streams	20.00	25.00	6.46	1.000
<i>Acanthagrion adustum</i>	Deforested streams	60.00	37.90	18.68	0.194
<i>Argia bicellulata</i>	Deforested streams	40.00	32.60	14.98	0.460
<i>Argia indicatrix</i>	Forested streams	45.50	50.50	16.19	0.569
<i>Argia</i> sp. 1	Deforested streams	95.40	57.70	16.08	0.041
<i>Ischnura capreolus</i>	Deforested streams	40.00	32.20	14.61	0.452
<i>Perilestes attenuatus</i>	Forested streams	33.30	25.10	6.48	0.381
<i>Epipleoneura capilliformis</i>	Forested streams	33.30	24.80	6.41	0.362
<i>Epipleoneura manauensis</i>	Forested streams	33.30	25.10	6.48	0.381
<i>Phasmeoneura exigua</i>	Deforested streams	38.60	45.90	14.61	1.000
<i>Dictierias atosanguinea</i>	Forested streams	33.30	25.10	6.48	0.381
<i>Chalcopteryx scintillans</i>	Forested streams	66.70	32.60	15.33	0.110

Note: *p*-values in bold are statistically significant ($p < 0.05$).

Fonseca-Gessner, 2003), probably due to the increased primary productivity and occurrence of generalist species in open, lentic habitats (Ferreira-Peruquetti & De Marco, 2002).

Species composition was a more efficient parameter for the characterization of environmental changes. Species colonization–extinction dynamics might change the entire community due to interspecific interactions, including habitat selection, being gained or lost. The colonization of new species (usually generalists with high competitive ability) may promote the extinction of local species (eg De Marco & Resende, 2004). Our results indicate that odonate composition in deforested streams differs from that in forested streams, with the appearance of species such as *Pantala flavescens* (Fabricius, 1798) in open water and loss of forest species such as *Chalcopteryx scintillans* McLachlan, 1870, and with few species occurring in both areas.

The scarcity of studies on adult odonates in anthropogenic habitats in the Amazon prevents further comparisons. However, there is a general distribution pattern determined by thermoregulation in tropical regions (De Marco et al., 2005). Large species of Anisoptera are expected to occur in open, sunny areas, due to their high thermoregulatory efficiency, compared to Zygoptera, which are restricted to shaded areas (eg De Marco et al., 2005). Therefore, our results corroborate those of Delgado (2002) for larvae and Juen & De Marco (2011) for adult odonates in forested areas in Central Amazonia. Odonate communities in both studies were dominated by zygopterans. Additionally, a previous study (Stewart & Samways, 1998) found a strong correlation with zygopterans and riparian vegetation in African streams. Furthermore, Samways & Sharratt (2010)

found that quality as well as quantity of riparian vegetation affected Zygoptera and Anisoptera, but the natural habitat was not densely forested as the Amazonian rainforest.

Environmental conditions (eg presence of riparian vegetation, stream bed sediment, and sunlight input) represent a strong filter for species. Thus, species can be divided into two groups regarding their tolerance: eurytopic (wide tolerance to environmental quality) and stenotopic (narrow tolerance; Kinvig & Samways, 2000). Accordingly, deforested streams have few stenotopic species (Stewart & Samways, 1998), and as recorded in our study notably more Anisoptera, such as *Erythrodiplax castanea* (Burmeister, 1839), *Dasythemis esmeralda* Ris, 1910, *Uracis imbuta* (Burmeister, 1839), and *Zenithoptera fasciata* (Linnaeus, 1758) than Zygoptera.

Erythrodiplax fusca and *Argia* sp. 1 were recovered as potential bioindicator species of environmental quality. *Erythrodiplax* is a genus that is typical of lentic habitats (Nessimian, 1995; Santos, 1967). A previous study (Ferreira-Peruquetti & De Marco, 2002) in Minas Gerais showed that *E. fusca* occurs in both forested streams and farm dams. In this study, *E. fusca* occurred in all deforested streams, with only one individual in the forested stream, probably due to the open water habitat nearby. Although zygopterans are more characteristic of forested areas, *Argia* sp. 1 was recorded in all deforested streams, with high sunlight input, and little or no riparian vegetation. These are the first ecological data about this species.

Environmental disturbance may eliminate the breeding sites of odonate prey, driving many species to extinction (Pyle et al., 1981). Alterations in water flow by damming, canalization, and fragmentation, and isolation of water bodies in relation to riparian forests and wetlands, interrupt the regime of natural perturbation and eliminate environmental gradients. Here, however, we demonstrated that the simple loss of vegetation, which is an indirect effect of road building, may also change odonate species composition, favoring open water anisopterans.

Thus, deforestation has a strong effect on odonate species composition, with the loss of species such as *Dicterias atosanguinea* Selys, 1853 and *C. scintillans* that inhabit the interior of forests in Amazonia. Moreover, species composition seems to be a better measure than species richness per se for detecting environmental change, since colonization by generalist species (eg *Pantala* and *Orthemis*) may obscure actual changes.

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