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DRAGONFLIES AS INDICATORS OF THE ENVIRONMENTAL CONDITIONS OF VEREDAS IN A REGION OF CENTRAL-WESTERN BRAZIL

Marciel Elio Rodrigues[1], Emanuelle Batista Moura[2] & Fabio de Oliveira Roque[3]*

[1] Universidade Estadual de Santa Cruz, Departamento de Ciências Biológicas, Programa de Pós-graduação em Sistemas Aquáticos Tropicais, Laboratório de Organismos Aquáticos, Rod. Jorge Amado, Km 16, CEP 45662-900, Ilhéus, BA, Brazil.

[2] Universidade Federal de Mato Grosso do Sul, Departamento de Ciências Biológicas, Cidade Universitária, s/n, CEP 79060-300, Campo Grande, MS, Brazil.

[3] Universidade Federal de Mato Grosso do Sul, Departamento de Ciências Biológicas, Programa de Pós-graduação em Ecologia e Conservação, Laboratório de Ecologia, Cidade Universitária, s/n, CEP 79060-300, Campo Grande, MS, Brazil.

Emails: rodrigues.mbio@gmail.com (*corresponding author); emanuelle.bdm@gmail.com; roque.eco@gmail.com

Abstract: Veredas (palm swamps) play a critical role in maintaining the hydrological system and they are considered the cradle of the waters of the Brazilian Cerrado. Currently, veredas are suffering intense human pressure due to the conversion of native landscapes for other land uses as agriculture, pasture and urban environments. Few studies have evaluated the biodiversity of veredas and the current effects of human impact, especially on aquatic communities. Dragonflies and damselflies (Odonata) have excelled as bioindicators of environmental quality and they are increasingly used in environmental monitoring programs. In this study, we evaluate whether loss of riparian vegetation around the vereda areas alters the communities of Odonata and whether the species can be considered bioindicators of these environmental conditions. Our hypothesis is that eco-physiological and behavioral characteristics, such as thermoregulation capacity and oviposition behavior, influence the persistence of species in communities in natural or altered environments. We sampled 25 veredas and classified them into two groups, namely “preserved riparian vegetation” (VRP), when the riparian vegetation surrounding the sampled stretch was 30 meters or more, and “altered riparian vegetation” (VRA), when the vegetation extended for less than 30 meters from at least one of the banks. Our results showed that the composition of the communities in areas classified as VRP was more similar to each other and different from the communities found in the areas classified as VRA. Of the 52 species observed, 11 species responded as indicators for preserved or altered riparian vegetation. Of these species, four were indicative of areas with preserved riparian vegetation and seven were indicative of veredas with altered riparian vegetation. Our results show that the composition of dragonflies and damselflies, and some taxa in particular may be potential indicators of the condition of veredas, and may, therefore, be included in vereda monitoring programs in Central-Western Brazil.

Keywords: aquatic insects; bioindicators; Odonata; palm swamps; riparian vegetation.

INTRODUCTION

The conversion of native areas into areas with other land uses, such as agriculture, pasture and urban areas, has a significant impact on aquatic ecosystems and, consequently, on biodiversity (Vörösmarty *et al.* 2010, Junk *et al.* 2013). The consequences of such disruptions to the physical environment and chemical alterations in the dynamics of biological communities entail a significant drop in the quality of aquatic ecosystems and the loss of biodiversity (Allan 2004, Millennium Ecosystem Assessment 2005).

The Cerrado is one of the tropical areas that is suffering alarming land conversion rates (Overbeck *et al.* 2015, Strassburg *et al.* 2017). One of the most important physiognomies at risk of conversion in the Cerrado are the veredas. They form and maintaining the hydrological system and function as areas for feeding, procreation, and refuge of flora and fauna during the drier seasons of the Cerrado (Bastos & Ferreira 2010). The veredas are also critical to humans. They serve to extract natural resources, such as water for human consumption, irrigation, and livestock watering. Moreover, the surrounding areas are used for agriculture and pasture, which cause extreme anthropogenic modifications in these areas (Oliveira-Filho & Ratter 2002, Meirelles *et al.* 2006, Côrtes *et al.* 2011). Given the importance of veredas for the Cerrado and for humans, they are considered permanent preservation areas by the Brazilian Forest Code - Law No. 12.651 (Brazil 2012).

Few studies have assessed and monitored environmental impact in vereda areas (Cortês *et al.* 2011). Most of the available studies do not use bioindicators to assess the effects of human-induced impacts on biodiversity. Of the different groups used as bioindicators, aquatic insects have been particularly effective for assessing changes in riverine ecosystems and their surroundings (Rosenberg & Resh 1993, Simaika & Samways 2010, Gerlach *et al.* 2013, Valente-Neto *et al.* 2016, Calvão *et al.* 2018). Furthermore, aquatic insects can be used as indicators of the environmental conditions of veredas.

The communities of aquatic insects in veredas include dragonflies and damselflies (Insecta: Odonata), which can be sensitive and reflect environmental conditions. Due to the ecological and behavioral characteristics of the species, they can positively or negatively select such environments (Corbet 2004, Simaika & Samways 2009, 2010, De Marco *et al.* 2015). The characteristics of the species that can reflect the conditions of vereda areas include the ability to thermoregulate, disperse, oviposition behavior, and environmental requirements for developing larvae and maintaining adults (De Marco *et al.* 2015, Monteiro-Junior *et al.* 2014, Monteiro-Junior *et al.* 2015, Rodrigues *et al.* 2018a, Calvão *et al.* 2018).

In this paper, we assessed the influence of riparian vegetation in the areas surrounding veredas on the composition of Odonata communities and selected potential indicator species for areas considered to be "preserved riparian vegetation" (VRP) and "altered or absent riparian vegetation" (VRA) surrounding the sampled points. Our prediction was that areas with riparian vegetation surrounding the water bodies would maintain a different community than that of areas with altered or absent riparian vegetation. In addition, we expected the communities of the areas with riparian vegetation to be made up of species with thermoregulatory characteristics adapted to environments with limited light, low temperature variation (conformers) (De Marco *et al.* 2015) and epiphytic oviposition behaviors (laying of eggs on roots, leaves and trunks at the oviposition sites) (Rodrigues *et al.* 2018). Areas surrounded by riparian vegetation maintain a more stable temperature and offer more sites for oviposition and habitats for larval development (Monteiro-Junior *et al.* 2014, De Marco *et al.* 2015, Monteiro-Junior *et al.* 2015, Calvão *et al.* 2018, Rodrigues *et al.* 2018a). In the communities of the areas considered to have altered or absent riparian vegetation, we expected to find species adapted to environments with a high availability of light and high temperatures (heliothermic or endothermic) (De Marco *et al.* 2015) and displaying endophytic or exophytic oviposition behaviors (species that lay eggs inside plants or directly into the water column, respectively) (Calvão *et al.* 2018, Rodrigues *et al.* 2018a). These ecological and behavioral characteristics of the group act as filters and select species of communities that can be considered as bioindicators of the environmental conditions of aquatic ecosystems and their surroundings (Carvalho *et al.* 2013, Monteiro-Junior *et al.* 2014, De Marco *et al.* 2015, Monteiro-Junior *et al.* 2015, Calvão *et al.* 2018, Rodrigues *et al.* 2018a).

MATERIAL AND METHODS

Study area

The sampled points are located in a region of the Cerrado biome, considered to be one of the world's biodiversity hotspots (Myers *et al.* 2000).

The climate of the region is classified as humid tropical, with clearly defined dry and rainy seasons. Twenty-five areas of veredas were sampled in the urban and rural perimeters of the municipalities of Campo Grande and Terenos, state of Mato Grosso do Sul, Brazil (Figure 1). This region is dominated by matrixes of pastures and urban environments. The veredas differed in their phytophysiognomy (vegetation types), since they included areas with preserved riparian vegetation, including tree species and a closed canopy, and with absent or altered riparian vegetation on one or both banks resulting from agriculture and urbanization.

Sampling and identification

The dragonflies were collected between November 2014 and January 2015. A standardized collection effort was adopted in each sampled stretch, as used in other studies (Rodrigues *et al.* 2016, Calvão *et al.* 2018, Rodrigues *et al.* 2018a). The sweeping method was used to collect the samples, with a 1-hour sampling effort performed by two collectors (total of two hours per point) on a 100-meter stretch. The specimens were captured with an entomological net during the hottest hours of the day (between 10:00 and 15:00 h), because the adults are most active at these times (Corbet 2004).

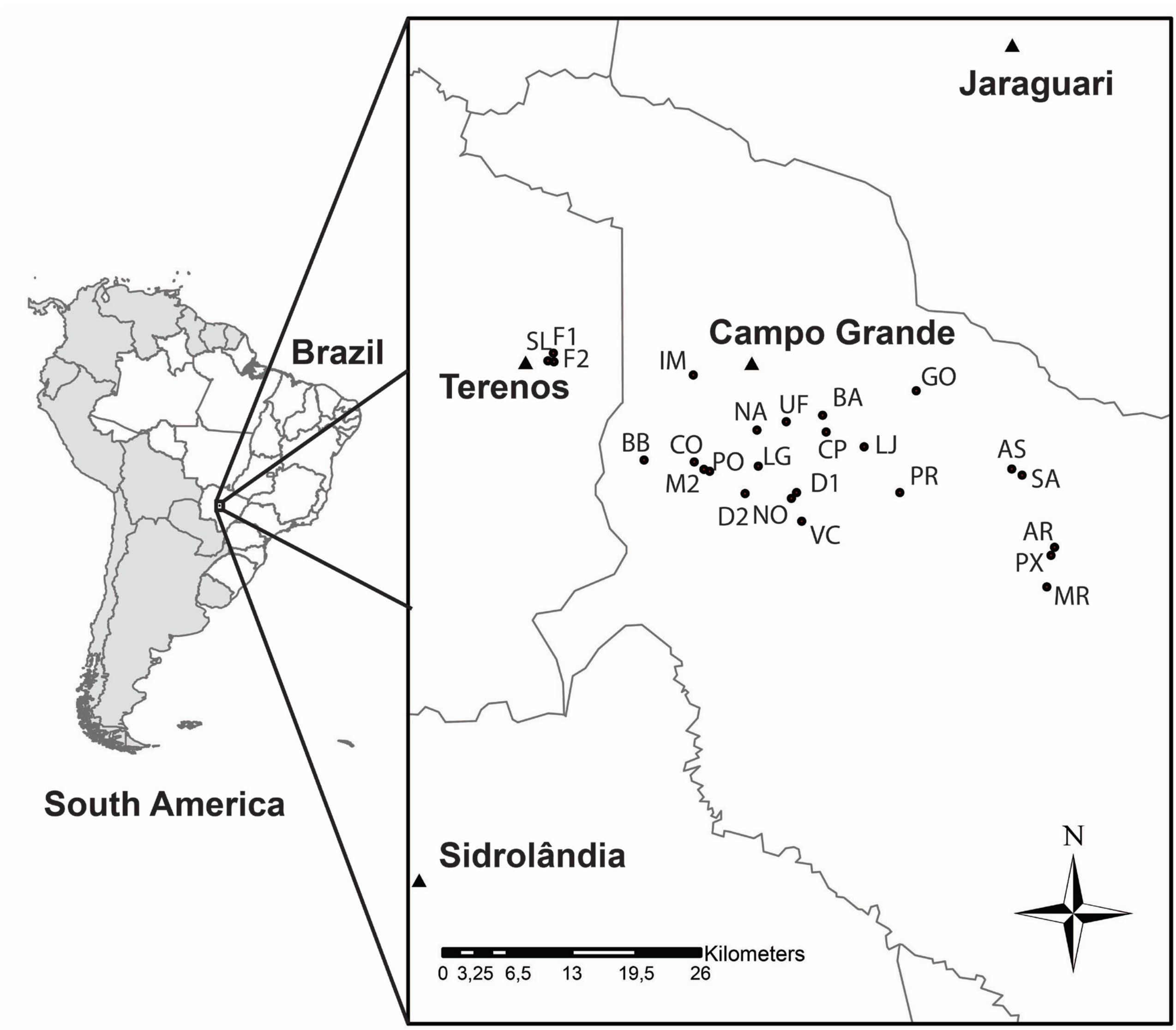

Figure 1. Map with the 25 sampled veredas in the Cerrado region of two municipalities in the state of Mato Grosso do Sul, Brazil. The triangles indicate the names of the municipalities and the circles are the sampling points.

The specimens were identified according to the work of Garrison *et al.* (2006, 2010), Lencioni (2005, 2006), and specialists from the Universidad Nacional de Avellaneda in Argentina. The material was deposited in the zoological collection of the Federal University of Mato Grosso do Sul - UFMS in Campo Grande and Santa Cruz State University - UESC, in Ilhéus, Bahia.

Environmental profiling

The sampling points were georeferenced using a GPS (Geographic Position System). The vereda areas were classified as "preserved riparian vegetation" (VRP) and "altered or absent riparian vegetation" (VRA), based on two methods of evaluation. In the field, we recorded the width of vegetation along both banks, the composition of the dominant vegetation and observed whether the canopy cover was characterized as open or closed. In the laboratory, Google Earth Pro was used to calculate the average width of the riparian vegetation, using five measurements for each area and confirm the measurements made in the field.

When the riparian vegetation surrounding the sampled stretch averaged 30 m or more on both banks and when the surroundings consisted of large arboreal vegetation with a closed canopy, the area was considered to be VRP. When the riparian vegetation averaged less than 30 m on at least one of the margins, with frequent interruptions of the vegetation surrounding the sampled stretch, dominant vegetation consisting of grasses (native or planted) or shrubs and few trees, and a partial or a fully open canopy, the area was classified as VRA.

The choice of 30 m was primarily based on two factors. The first factor is related to the Brazilian Forest Code, which establishes a mandatory minimum of 30 m for lotic environments less than 10 m wide (Law No. 12.651/2012). For the vereda areas, the law establishes a mandatory minimum of 50 m. However, when selecting the points, only four areas met this requirement. The second factor was related to observations of the authors in the field. The veredas with strips of riparian vegetation wider than 30 m on both banks consisted of large trees with a closed canopy that protected the physical integrity of channel and of the banks, so they were considered to be preserved.

Statistical analyses

To verify whether the composition of the Odonata communities differed between the areas with preserved and altered riparian vegetation, we analyzed the similarity of community composition for each sampled area using the Jaccard index. Subsequently, ordination analysis - non-metric multidimensional scaling (NMDS) - was performed to check the arrangement of the communities in the sampled areas classified as having preserved or altered riparian vegetation. So, we performed a similarity analysis (ANOSIM), to verify if the structuring of the communities between the areas was different from the one expected at random.

A species indicator value (IndVal) was calculated to assess which species of the community could be considered indicators of areas considered VRP and VRA. The IndVal was calculated as proposed by Cáceres *et al.* (2010). This analysis creates combinations for each species according to the selected groups and issues association values that are subsequently tested statistically. The statistical analyses were carried out using the R environment version 3.4.2 (R Development Core Team 2009) with the indicspecies package (Cáceres *et al.* 2010). This analysis also shows two new components for species that are considered to be indicators. Component A, also called specificity, is the probability of an indicator species belonging to one of the selected target groups. Component B, also called fidelity, determines to what extent a species is related to the sampled target sites belonging to the same group (Cáceres *et al.* 2010).

RESULTS

Of the 25 areas sampled, nine were classified retrospectively as VRP and 16 as VRA, based on the environmental profiling information mentioned in the methodology. A total of 52 species were collected across all of the sampled points, of which 31 were species of Zygoptera and 21 were species of Anisoptera.

Cluster analysis (NMDS) showed that the communities in the areas VRP are different from the communities observed in the areas VRA. The communities found in the areas classified as VRP were more similar to each other, while the communities found in the areas classified as VRA were less similar to each other (Figure 2).

The ANOSIM showed a significant difference in composition similarity between the areas VRP and VRA ($R^2 = 0.36$, $p = 0.002$).

Of the 52 species collected, 11 responded as indicators of areas VRP and VRA. Four of these species were considered indicators of areas VRP and seven were considered indicators of areas VRP (Table 1). One species, *Protoneura tenuis*, was only recorded in the vereda areas with riparian vegetation over 50 meters wide on both banks.

With regard to specificity (component A). A slight variation from 0.81 to 1.00 was observed for the indicator species of areas VRP (mean = 0.945) and between 0.94 and 1.00 for indicator species of areas VRA (mean = 0.99). All the species considered to be indicators had a high specificity value. In other words, these species mostly occurred only in locations belonging to one of the groups (preserved or altered riparian vegetation), and these, eight species were found only in the locations classified with the same category (Table 1).

In relation to fidelity (component B), which is the occurrence of the species in all of the locations of a particular group, the values were moderate, with a variation between 0.33 and 0.89 for indicator species of VRP and between 0.43 and 0.69 for indicator species of areas VRA. In other words, these species were not found in all the areas sampled within each category. The average for the species in areas VRP was 0.66 and the average for the species in areas VRA was 0.53 (Table 1).

DISCUSSION

Changes in the composition of Odonata communities may indicate alterations in aquatic ecosystems or their surroundings and provide valuable insights into anthropogenic changes to these ecosystems (Simaika & Samways 2010, Carvalho *et al.* 2013, Monteiro-Junior *et al.* 2014,

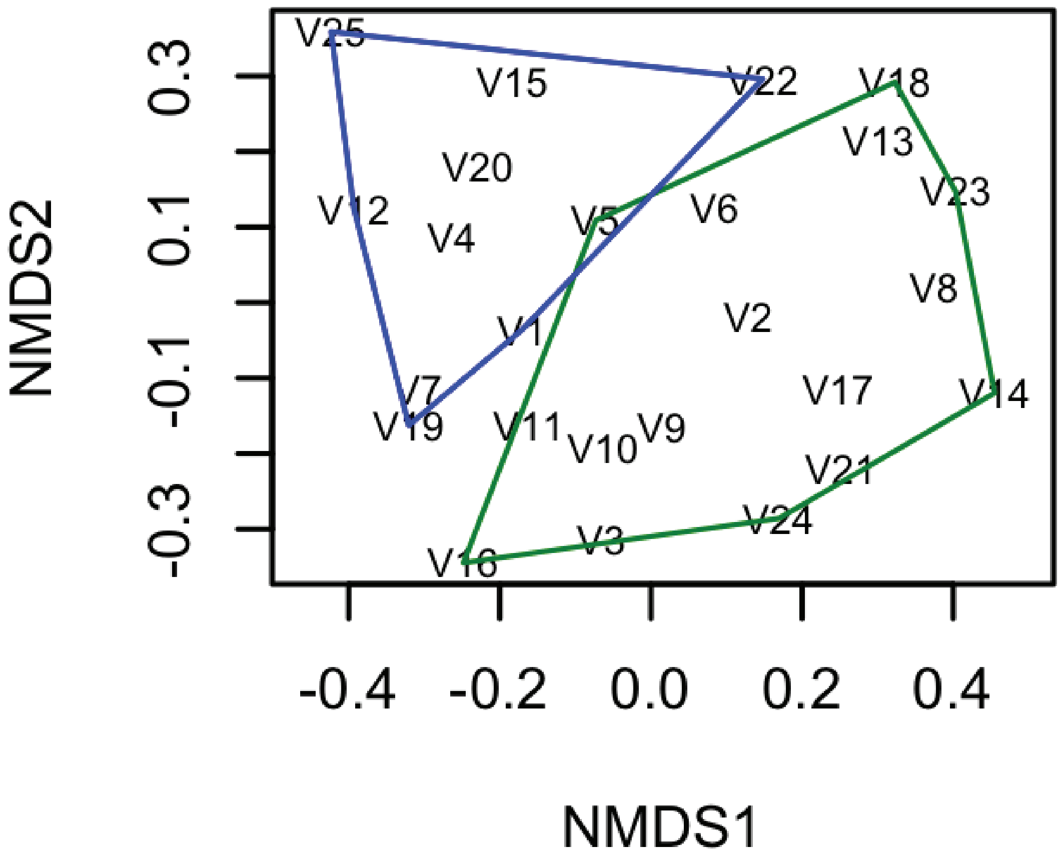

Figure 2. Cluster analysis using NMDS. The communities of the areas classified as VRP are the points connected by the blue line. The communities of the areas classified as VRA are the points around the green line (Stress = 0.1842).

Table 1. List of the species that responded to the IndVal analyses for the categories "preserved riparian vegetation" (VRP) and "altered riparian vegetation" (VRA). Stat = bioindicator value of species, the closer to one, the better the response of the species as a bioindicator for the given category, p-value, with *p < 0.05, **p < 0.01, ***p < 0.001. Components A and B are the specificity and fidelity values, respectively, of each species considered indicators. **** Species found only in areas with riparian vegetation of over 50 m in width.

Species	Preserved riparian vegetation	Altered riparian vegetation	stat	p value	Specificity	Fidelity
Acanthagrion marinae	X		0.94	0.001***	1.00	0.89
Argia mollis	X		0.97	0.003**	0.97	0.66
Argia reclusa	X		0.79	0.014*	0.81	0.78
*Protoneura tenuis*****	X		0.57	0.043*	1.00	0.33
Acanthagrion aeopilum		X	0.70	0.030*	1.00	0.50
Acanthagrion cuyabae		X	0.75	0.005**	1.00	0.56
Acanthagrion gracile		X	0.70	0.025*	1.00	0.50
Argia lilacinia		X	0.66	0.05*	1.00	0.43
Erythrodiplax fusca		X	0.80	0.005**	0.94	0.69
Perithemis thais		X	0.70	0.024*	1.00	0.50
Zenithoptera viola		X	0.75	0.013*	1.00	0.56

Monteiro-Junior *et al.* 2015, Dutra & De Marco 2015, Rodrigues *et al.* 2016, Rodrigues *et al.* 2018a, Calvão *et al.* 2018). Our results showed that areas of veredas classified as VRP have different Odonata communities to those found in areas classified as VRA. Our findings add more evidence to the growing number of studies in Neotropical regions that show clear changes in the composition of Odonata communities when comparing preserved and altered lotic environments in Cerrado and in the Amazon (Carvalho *et al.* 2013, Monteiro-Junior *et al.* 2014, Monteiro-Junior *et al.* 2015, Calvão *et al.* 2018).

The species that proved to be potential indicators for vereda areas VRP belong to the suborder Zygoptera. The riparian vegetation surrounding the aquatic ecosystems reduces the incidence of sunlight, which diminishes the temperature variation during the day (Cabette *et al.* 2017, Calvão *et al.* 2018). Therefore, the species that are expected to be found in these areas are smaller, with the ability to thermoregulate through convection (Corbet 2004, De Marco *et al.* 2015). These species are more dependent of air temperature to initiate their activities and they are especially affected by high temperatures in the middle of the day, which can overheat their thoracic muscles (May 1991, De Marco *et al.* 2005, 2015). Of these species, it is worth mentioning that *P. tenuis* only occurred in veredas with vegetation > 50 m. Although our sampling effort does not allow generalizations for such a pattern, this species supports the idea that the vegetation around of the vereda areas need to be preserved, as established in the forest code.

As we predicted, epiphytic oviposition behavior also dominates in the indicator species for areas with riparian vegetation. Areas with larger amounts of surrounding riparian vegetation can provide more sites for oviposition and contribute to a greater diversity of habitats for the development of species in the immature stages (Rodrigues *et al.* 2018a). The species *Argia mollis, Argia reclusa,* and *Acanthagrion marinae* depend on roots, leaves, and trunks in the water to lay their eggs (Vilela *et al.* 2016, Rodrigues *et al.* 2018a). Moreover, species such as *A. mollis, A. marinae,* and *P. tenuis* are always associated with preserved environments and with surrounding riparian vegetation (von Ellenrieder 2009a, Garisson *et al.* 2010, Calvão *et al.* 2018, Lozano & Rodrigues 2018). These species also exhibited high specificity for the areas surrounded by riparian vegetation, i.e. they were only found in these environments.

Of the species that were selected as bioindicators of veredas with altered or absent riparian vegetation, three belong to the suborder Anisoptera and four belong to the suborder Zygoptera. Areas with altered or absent riparian vegetation have a higher incidence of sunlight and temperature variations throughout the day (Calvão *et al.* 2018). In general, species of Anisoptera are better adapted to open areas with a higher incidence of sunlight. Species such as *Erythrodiplax fusca* and *Zenithoptera viola* that responded to veredas with altered riparian vegetation are adapted to open environments and tolerate temperature variations throughout the day (von Ellenrieder 2009b, Monteiro-Junior *et al.* 2014, Monteiro-Junior *et al.* 2015, Calvão *et al.* 2018). Such species have the ability to thermoregulate more efficiently in places with high solar irradiation and in a more temperature-independent manner because the capacity to transfer heat through irradiation increases with body size (May 1991, Corbet 2004, De Marco *et al.* 2015).

Another feature that may help explain the presence of Anisoptera in more open areas is the exophytic oviposition behavior, which is dominant in the species of the group. Species with such behavior can use the reflection of sunlight on water to select oviposition sites or choose environments with more lentic formations for oviposition (Stevani *et al.* 2000, Van de Koken *et al.* 2007, Rodrigues *et al.* 2018a). The loss of vegetation surrounding bodies of water physically alters the environments and forms regions with large areas of backwaters and a higher incidence of sunlight. These factors facilitate the occupation and development of species that characteristically adapt to lentic environments and to a higher incidence of sunlight (May 1991, Corbet 2004, Monteiro-Junior *et al.* 2014, De Marco *et al.* 2015, Monteiro-Junior *et al.* 2015, Rodrigues *et al.* 2018a).

The species of Zygopteras (*A. aepiolium*, *A. cuyabae,* and *A. gracile*) associated with the vereda areas without riparian vegetation exhibit epiphytic oviposition behavior, but lay their eggs on macrophytes (Kompier *et al.* 2015, Rodrigues *et al.* 2018a). Areas of veredas without riparian vegetation can maintain greater development of aquatic macrophytes and, consequently, the species of Odonata with this ecological and behavioral characteristic of oviposition (Vilela *et al.* 2016, Rodrigues *et al.* 2018a).

The distribution of many species is restricted by a specific ecological traits and/or behavior, and such species can be used as environmental quality indicators (Oertli 2008, De Marco *et al.* 2015). The use of species of Odonata as bioindicators of changes in the vereda areas and in other aquatic ecosystems can be a fast, efficient, and low-cost way of assessing the quality of aquatic ecosystems (Valente-Neto *et al.* 2018) and the impacts to their surroundings (Rodrigues *et al.* 2016, Calvão *et al.* 2018, Rodrigues *et al.* 2018a). In relation to the presence or alteration of riparian vegetation in the areas surrounding vereda environments, we conclude that the composition of Odonata communities differs in areas with preserved riparian vegetation and areas with altered or absent riparian vegetation. Moreover, we emphasize that some species can be considered indicators of such conditions. However, our study evaluated veredas in a dichotomous manner, which hinders the identification of the level of landscape alteration that leads to abrupt changes in the communities (Rodrigues *et al.* 2016). Veredas are not homogeneous systems, so this study should be viewed as a first step toward selecting potential bioindicators. One of the remaining bottlenecks is how to differentiate the patterns of naturally open veredas from veredas that suffer land use changes that also create open areas. Bioindicator species are one way to support the monitoring, conservation, and restoration of the conditions of these environments.

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